Phase 1 Concept of Operations (ConOps)

University of Washington ITS4US Deployment Project

www.its.dot.gov/index.htm

Final Report—June 28, 2021
FHWA-JPO-21-861

COMPLETE TRIP

ITS4US

U.S. Department of Transportation

Produced by University of Washington ITS4US Deployment Program, Phase 1
U.S. Department of Transportation
Intelligent Transportation Systems Joint Program Office
Federal Highway Administration
Office of the Assistant Secretary for Research and Technology
Federal Transit Administration

Notice

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-21-861	N/A	N/A

4. Title and Subtitle Phase 1 Concept of Operations (ConOps)—University of Washington ITS4US Deployment Project	**5. Report Date** June 28, 2021 **6. Performing Organization Code** N/A
7. Author(s) Mark Hallenbeck, Director of the Washington State Transportation Center at University of Washington; Anat Caspi, Director of the Taskar Center for Accessible Technology at University of Washington, Erin Flanigan, Cambridge Systematics; Mark Jensen, Cambridge Systematics; Alice Marecek, Cambridge Systematics; Adam Danczyk, Cambridge Systematics; Guilherme Leao, Cambridge Systematics	**8. Performing Organization Report No.**
9. Performing Organization Name and Address University of Washington 4333 Brooklyn Ave NE Box 359472 Seattle, WA 98195-9472	**10. Work Unit No. (TRAIS)** N/A **11. Contract or Grant No.** 693JJ321C000004
12. Sponsoring Agency Name and Address U.S. Department of Transportation ITS Joint Program Office 1200 New Jersey Avenue, SE Washington, DC 20590	**13. Type of Report and Period Covered** N/A **14. Sponsoring Agency Code** HOIT-1

15. Supplementary Notes

Kate Hartman, COR

16. Abstract

This report is the Concept of Operations (ConOps) document for the Transportation Data Equity Initiative (TDEI) project, an effort funded by the Federal Highway Administration's ITS4US Program. The project, led by the University of Washington's (UW) Taskar Center for Accessible Technology and the Washington State Transportation Center, will develop a national pipeline to create, disseminate, and share standardized data about pedestrian environments, transportation environments, and on-demand transportation services to enable better use, discoverability, and data analytics of these assets and services. Specifically, the project will release nationally the OpenSidewalks data standard for digitizing pedestrian ways and will extend the national data standards for on-demand transit services (GTFS-Flex) and for mapping of multilevel transit stations (GTFS-Pathways). Additionally, the project will demonstrate the use of those data and standards in three applications: a multimodal, accessible travel planner (an extension of Access Map), an expansion of Microsoft's Soundscape application, which helps blind and low-vision people navigate and explore the environment, and a simulation tool to be built by Unity Technologies that allows travelers to explore the layout of transit stations prior to using those facilities.

The ConOps, based on the format and guidelines of ISO/IEC/IEEE 29148:2011 ConOps Standard, is a user-oriented document that describes system characteristics for the proposed UW ITS4US Deployment Project system from the users' perspective. The ConOps has been drafted to communicate the users' needs for and expectations of the proposed system to greatly increase the availability of pedestrian pathway data and flexible transit information available to underserved travelers. The ConOps will be the guiding document for subsequent planning activities in Phase 1.

17. Keywords	18. Distribution Statement
ITS4US; Complete Trip; Deployment; ITS; Intelligent Transportation Systems; Concept of Operations; Accessibility; Sidewalks; Navigation software; Data Standards	N/A

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
N/A	N/A	180	N/A

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

Revision History

Name	Date	Version	Summary of Changes	Approver
Mark Hallenbeck, University of Washington; Mark Jensen, Cambridge Systematics	24 May 2021	1	Initial Draft	
Mark Hallenbeck, University of Washington; Mark Jensen, Cambridge Systematics	28 June 2021	2	Final	
Mark Hallenbeck, University of Washington; Mark Jensen, Cambridge Systematics	8 July 2021	2.1	Minor revisions made in response to three USDOT comments.	

Table of Contents

1. Scope 1

1.1. Complete Trip—ITS4US Deployment Program 1

1.2. Project Aims 2

1.3. Motivating Factors 4

1.3.1. Transportation and Mobility Undergoing Transformation 5

1.3.2. Accessible and Inclusive Design in Data Systems Cannot Be Retrofitted 5

1.3.3. Civic Technologies Are Integrally Driven by Equitable, Interoperable Data-Sharing Infrastructure 6

1.4. Project Background 7

1.5. System Overview 10

1.6. Systems Engineering Approach 14

1.7. Acronyms and Glossary 16

1.8. Document Overview 18

2. Referenced Documents 21

3. Current Systems and Situation 25

3.1. Background and Scope 25

3.2. Description of the Current System and Situation 28

3.2.1. Mapping Technology Company Sidewalk Data Systems 30

3.2.2. Infrastructure Owner-Operator Sidewalk Data Provider Subsystems 30

3.2.3. Crowdsourced Sidewalk Data Systems 30

3.2.4. Transit Station and Service Data 31

3.2.5. Wayfinding Applications 32

3.2.6. Auditory Orientation Applications 32

3.2.7. Third-Party Applications 32

3.2.8. Environmental Simulation Applications 33

3.3. Current System Stakeholders and Actors 33

3.3.1. Stakeholders 34

3.3.2. Actors 36

3.4. Support Environment 39

3.4.1. Data Producers, Contributors, and Aggregators 39

3.4.2. Navigation Applications 39

3.5. Modes of Operation for Current System 39
3.6. Operational Policies and Constraints 40

4. Justification for and Nature of Changes 43

4.1. Justification of Changes 44
4.1.1. Lack of Widely Available Data Objectively Describing the Pedestrian Built Environment 44
4.1.2. Lack of Widely Available On-Demand Transportation Service Data 46
4.1.3. Lack of Widely Available Transit Station Data 46
4.1.4. Lack of Scalable Solutions to Easily Facilitate New Services to Be Available Across a Larger Geographic Region 47
4.1.5. Lack of Data Standards in Practice That Are Sustainable 47
4.1.6. Lack of Demonstrable Workspace for Proposed Standards 48
4.2. Description of Desired Changes 48
4.2.1. User Needs Breakdown 50
4.2.2. Priorities Among Changes 52
4.3. Changes Considered but Not Included 72
4.4. Assumptions and Constraints 73
4.4.1. Assumptions 73
4.4.2. Constraints 74

5. Concept for the Proposed System 77

5.1. Background and Scope 77
5.2. Description of the Proposed System 80
5.2.1. Subsystems 86
5.2.2. Performance Characteristics 93
5.2.3. Requirements 93
5.2.4. Quality Attributes 94
5.3. Stakeholders and Actors of the Proposed System 96
5.3.1. Stakeholders 96
5.3.2. Actors 100
5.4. Support Environment 104
5.4.1. Core Data Repository 104
5.4.2. Data Resource Systems 104
5.4.3. Third-Party Applications 104
5.4.4. Multimodal AccessMap 105
5.4.5. Soundscape 105
5.4.6. Digital Twin 105
5.5. Modes of Operation for the Proposed System 105
5.5.1. Normal Mode of Operation 106
5.5.2. Disrupted Mode of Operation 106
5.5.3. Degraded Mode of Operation 107
5.5.4. Failed Mode of Operation 108

5.6. Operational Policies and Constraints 109

6. Operational Scenarios 111

6.1. Sidewalk Data Generation, Collection and Vetting 115

6.2. Vetting of Sidewalk Data and Street Crossing Identification 118

6.3. Generation and Vetting of General Transit Feed Specification for Pathways Linking Together Locations within Stations Data 121

6.4. Generation and Vetting of General Transit Feed Specification for Demand-Responsive or Paratransit Service Data 123

6.5. Individual with Mobility Disability Uses Verified Sidewalk and Transit Data to Navigate Through Several Cities 126

6.6. Veteran with Mobility Disability Traveling from a Rural Home to the Veterans Affairs Hospital for a Medical Appointment 130

6.7. Blind, Vision Disabled, or Deafblind Individual Uses Verified Sidewalk and Transit Data 132

6.8. Multilingual Tourist Tries to Conduct Pre-Trip Planning for a Multilevel Transit Station 136

6.9. Low-Income Traveler Utilizes a Third-Party Application (One-Call/One-Click Service) to Reach a Destination 139

6.10. Travelers with Sidewalk Preferences Utilize Data Generated by a City Government 142

6.11. Travelers with Sidewalk Preferences Utilize Data Generated by a Civic Organization 144

6.12. Travelers with Sidewalk Preferences Utilize Data Generated by an Aerial Mapping Company’s Analytics Engine for Aerial Images 147

6.13. Transit Users Utilize General Transit Feed Specification for a Demand-Responsive or Paratransit Service and for Pathways Linking Together Locations within Stations Extensions Through a Navigation Application 149

7. Summary of Impacts 153

7.1. Operational Impacts 153

7.2. Organizational Impacts 153

7.3. Impacts During Development 154

8. Analysis of the Proposed System 157

8.1. Analysis of the Proposed System 157

- 8.1.1. Benefits 157
- 8.1.2. Limitations 159
- 8.1.3. Disadvantages 160

8.2. Alternatives and Tradeoffs Considered 161

- 8.2.1. Alternative 1: Do Nothing 161
- 8.2.2. Alternative 2: Focus the Proposed System on One Element (Sidewalks or Transit) but Not Both 162
- 8.2.3. Alternative 3: Build a New Application and Host All Services as a Primary Service 162
- 8.2.4. Alternative 4: Adopt Standards and Let the Market Develop the Proposed System 163
- 8.2.5. Alternative 5: Pull Data on Demand from Contributors to Reduce Data Repository Storage 164

List of Tables

Table 1. Complete Trip—ITS4US deployment program user groups. 9
Table 2. Actors of the current system. 36
Table 3. Examples of users in each user group category. 51
Table 4. Transportation Data Equity Initiative user needs. 53
Table 5. Summary of the subsystem components of the proposed system. 81
Table 6. Transportation Data Equity Initiative stakeholders and key roles. 96
Table 7. Transportation Data Equity Initiative actors and interaction with the proposed system. 101
Table 8. Summary of operational scenarios. 111
Table 9. Sidewalk data generation, collection, and vetting. 115
Table 10. Vetting of sidewalk data and street crossing identification. 118
Table 11. Generation and vetting of General Transit Feed Specification for pathways linking together locations within stations data. 121
Table 12. Generation and Vetting of General Transit Feed Specification for demand-responsive or paratransit service data. 124
Table 13. Individual with mobility disability uses verified sidewalk and transit data to navigate through several cities. 127
Table 14. Veteran with mobility disability traveling from a rural home to the Veterans Affairs Hospital for a medical appointment. 130
Table 15. Blind, vision disabled, or deafblind individual uses verified sidewalk and transit data. 133
Table 16. Multilingual tourist tries to conduct pre-trip planning for a multilevel transit station...... 137
Table 17. Low-income traveler utilizes a third-party application (one-call/one-click service) to reach a destination. 139
Table 18. Travelers with sidewalk preferences utilize data generated by a city government. 142
Table 19. Travelers with sidewalk preferences utilize data generated by a civic organization.....144
Table 20. Travelers with sidewalk preferences utilize data generated by an aerial mapping company's analytics engine for aerial images. 147
Table 21. Transit users utilize General Transit Feed Specification for a demand-responsive or paratransit service and for pathways linking together locations within stations extensions through a navigation application. 149
Table 22. High-level benefits of the proposed Transportation Data Equity Initiative system........157

List of Figures

Figure 1. Diagram. Complete Trip—ITS4US deployment program phases. 2
Figure 2: Diagram. UW ITS4US project's ecosystem. 4
Figure 3. Infographic. Segments of a complete trip....8
Figure 4. Map. Washington, Oregon, and Maryland counties. 11
Figure 5. Diagram. Concept framework for the proposed data services. 13
Figure 6. Diagram. Systems Engineering V-Model. 15
Figure 7. Infographic. What is a Concept of Operations? 15
Figure 8. Infographic. Segments of a complete trip....27
Figure 9. Diagram. Context diagram for the current situation. 29
Figure 10. Map. Sample walking paths. 45
Figure 11. Photos. Examples of street furniture. 73
Figure 12. Infographic. Interoperable data infrastructure that enables many downstream stakeholders. 80
Figure 13. Diagram. Context diagram for the proposed Transportation Data Equity Initiative system. 84
Figure 14. Diagram. Data flow diagram for the proposed Transportation Data Equity Initiative system. 85

1. Scope

1.1. Complete Trip—ITS4US Deployment Program

In late 2019, the United States Department of Transportation (USDOT) launched a new department-wide initiative. This initiative, referred to as Complete Trip, aimed to expand access to transportation for people with disabilities, older adults, and individuals of low income. This initiative recognized that all Americans need access to high-quality, affordable, safe, frequent, and accessible transportation options to access employment opportunities, educational opportunities, healthcare services, and other activities, but that some groups do not receive the same quality of service. To support these underrepresented groups, USDOT aimed to increase its investments in innovations that enhance access and mobility for all travelers, including, but not limited to, the following user groups: people with disabilities, older adults, low income earners, rural residents, veterans, and those with limited English proficiency (LEP) (henceforth referred to as "underserved travelers").

USDOT's Complete Trip portfolio identifies ways to provide more efficient, affordable, and accessible transportation options for underserved travelers who often face greater challenges in accessing essential services. The Complete Trip portfolio consists of several efforts that focus on these underserved groups, including the Federal Transit Administration's (FTA) Mobility for All Pilot Program, the Inclusive Design Challenge, and the Complete Trip—ITS4US Deployment Program.

This phase 1 Concept of Operations (ConOps) was developed as part of the University of Washington's (UW) ITS4US Deployment Project, referred to as the ***Transportation Data Equity Initiative*** (TDEI). It was developed as part of the Complete Trip—ITS4US Deployment Program, a multimodal effort led by the Intelligent Transportation Systems Joint Program Office (ITS JPO) and supported by the Office of the Secretary (OST), Federal Highway Administration (FHWA), and FTA to identify ways to provide more efficient, affordable, and accessible transportation options for underserved travelers. The ITS4US Program aims to develop and deploy integrated, replicable, and scalable data pipelines to serve a consistent, shared data resource for downstream mobility solutions to functionalize complete trips for all travelers. Its vision is to deploy innovative and integrated complete trip systems to support seamless travel for users across all modes, regardless of location, income, or disability.

The ITS4US Program, to be executed in three phases as shown in **Figure 1**, has procured and awarded five large-scale, replicable, real-world deployments of integrated innovative technologies to address the challenges of planning and executing complete trips:

- **Phase 1: Concept Development (Current Phase)—**In this phase, the preliminary idea is developed into a structured concept that is suitable for further design, building, testing, and operation. The structured concept includes identifying specific performance measures, targets, and capabilities associated with performance monitoring and performance management.

- **Phase 2: Design and Testing—**In this phase, the deployment concept is designed in detail, built, and tested prior to operation.
- **Phase 3: Operations and Evaluation—**In this phase, the tested deployment applications and technologies are placed into operational practice. The impacts of the deployment on a set of key performance measures will be monitored and reported on a daily, weekly, and monthly basis. Further, performance and other data supporting a comprehensive assessment of deployment impacts are to be shared with a USDOT-identified independent evaluator.

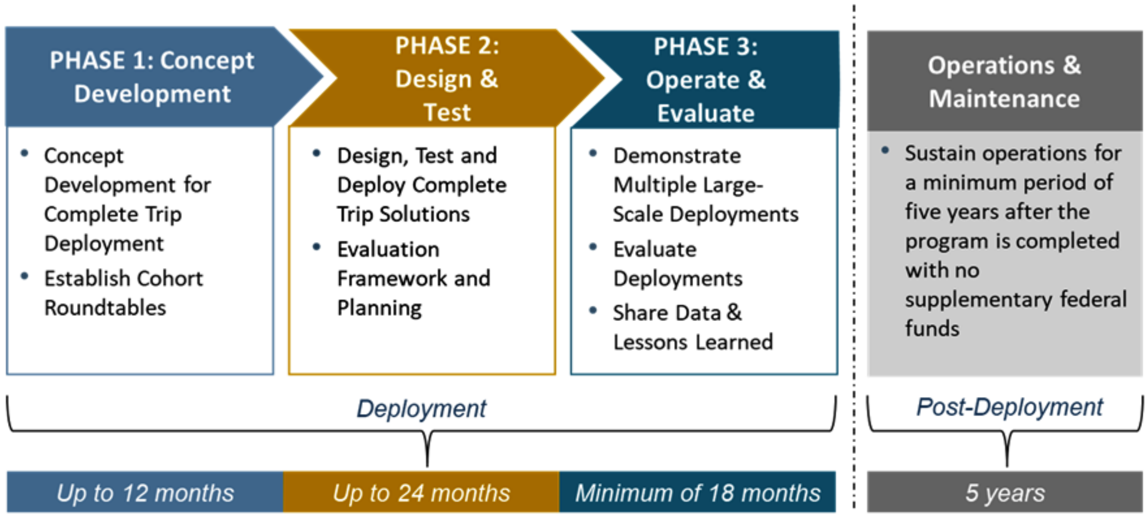


Figure 1. Diagram. Complete Trip—ITS4US deployment program phases.

Source: United States Department of Transportation.

1.2. Project Aims

The UW ITS4US Deployment Project aims to create the foundational data tools necessary for both public and private entities to collect, share, manage, and use transportation data that provide equitable outcomes to all travelers. At its core, the project is about creating the foundational requirements for interoperable transportation data sharing that fulfills the informational needs of all travelers. This requires a specific focus on the unmet needs of people with mobility disabilities and other historically travel-disadvantaged communities that are the focus of this project. Without implementing this type of project, the needs of these communities will continue to remain unmet or underserved, limiting the ability of citizens in these communities to access destinations, explore opportunities, and be aware of all services available to them.

The project itself consists of multiple parts.

First, it includes work with three existing standards committees to extend and update existing, early-stage international data standards: OpenSidewalks, GTFS-Flex, and GTFS-Pathways. These three data standards enable the consistent collection and reporting of data that provide the underlying information needed by the currently underserved target populations—people with disabilities, older adults, and individuals with low income—to efficiently travel.

The second part of the project is to develop a series of tools that help agencies, jurisdictions, and other stakeholders collect the data that can be stored with these refined data standards. These tools are needed to lower the cost and improve the quality and consistency of those data collection efforts to increase the availability of the data.

The third portion of the project is to develop tools, policies, and procedures that allow sharing and governance of the collected data. The tasks performed will enable effective and efficient vetting, aggregation, management and fusion of the data that participating agencies, jurisdictions, and other stakeholders collect. This portion of the project also includes tasks required to enable and manage the sharing of those data with application developers that write software to deliver requested travel information.

The fourth portion of this project is the development of a data repository to contain the data to be shared within the six counties that represent the geographic boundaries for this ITS4US project. The data repository will be developed to illustrate how these data can be collected, stored, governed, updated, and maintained over time and then served upon request to application developers.

Finally, the fifth portion of this project is the development of three example applications that use the collected data. The three applications are intended to demonstrate three very different uses of the data that are collected, maintained, and made available to application developers as a result of the other four aspects of this project. Those data can be used to fulfill a variety of information needs, and those needs can be met through an almost infinite number of applications. The three applications deployed as part of this project are meant to show other application developers how the newly available data can be obtained and delivered.

Figure 2 illustrates the overall “new mobility” ecosystem to which the UW’s ITS4US project is contributing. The outer circle consists of the variety of public transportation services that exist. Many of these services already generate data that can be readily obtained by applications via internet connections – the act which results in the discovery of “new mobility” options. These include fixed route transit services, micro-mobility services, and taxi services. The UW ITS4US project will help add the data sources that are particularly important to people with mobility disabilities, shown in purple at the bottom of the image. These are data that describe pedestrian pathways, transit station infrastructure. on-demand paratransit and community transit services, and other on-demand shared ride modes. The UW ITS4US project is also building the interoperable integrated transportation data sharing layer and APIs shown in the green inner circle. This is the functionality needed to collect, fuse, and aggregate the data from disparate transportation services. Finally, the UWITS4US project will demonstrate a small number of applications used by the travelers shown in the center of the diagram. The applications take requests for information from the travelers, extract the required data from the data sharing layer (green circle), perform any required tasks— such as computing navigation directions—and deliver information to users in formats (audio, text, tactile displays) designed to meet their needs.

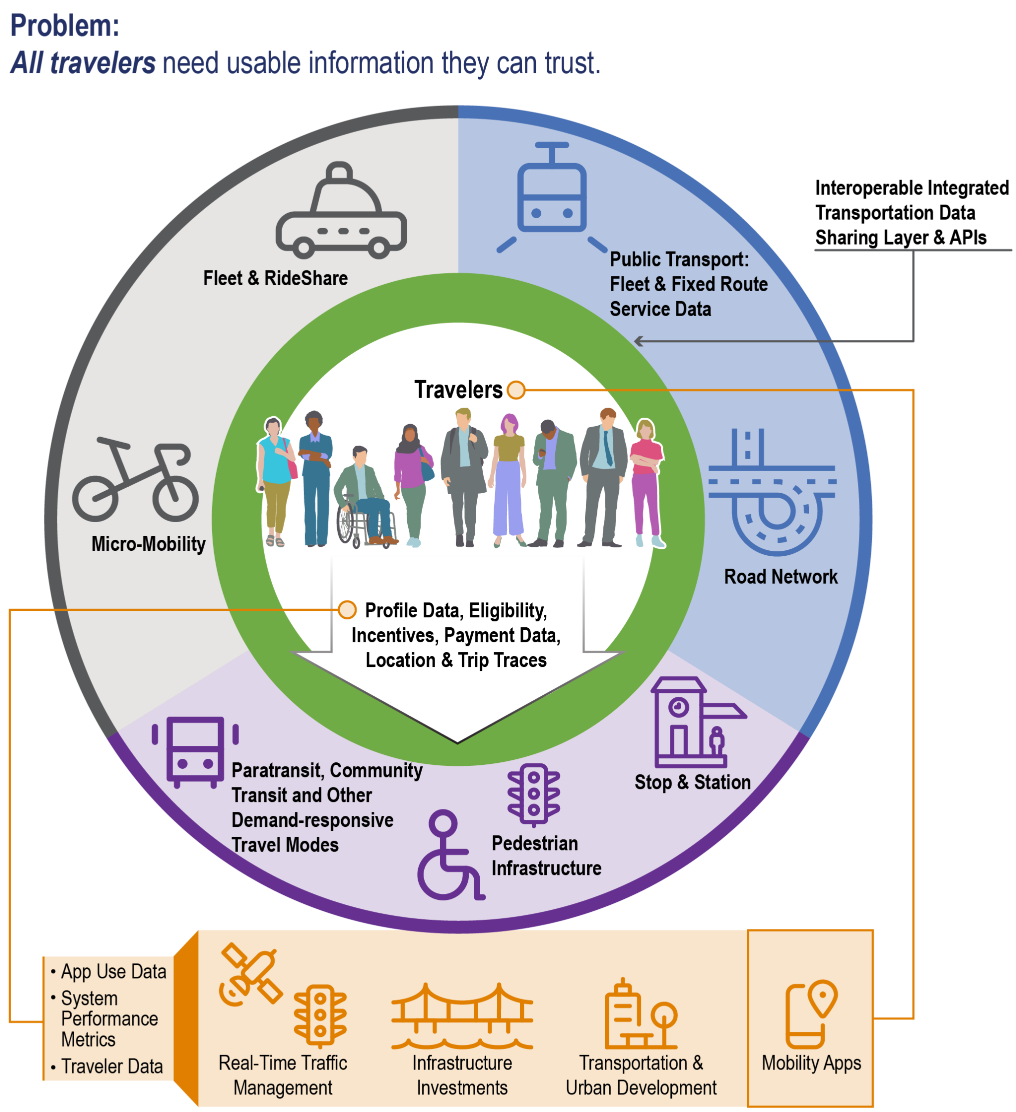


Figure 2: Diagram. UW ITS4US project's ecosystem.

Source: University of Washington.

1.3. Motivating Factors

The UW Team has categorized the factors that motivated and shaped the development of this project into three categories:

1) Transportation and mobility are undergoing transformational changes that take advantage of data;
2) Accessible and inclusive design in data systems cannot be retrofitted without great cost/complexity; and

3) Civic technologies must be integrally driven by equitable, interoperable data-sharing infrastructure.

These topic areas are discussed briefly below.

1.3.1. Transportation and Mobility Undergoing Transformation

Transportation and mobility are areas undergoing enormous transformation. Throughout most of the 20th century, transportation in the United States (U.S.) remained focused on ownership of a private vehicle, with additional modes offered as a collection of disconnected systems of separately financed public transit, influenced by political decision-making processes and supported through a variety of private providers (Michel, 2018). Importantly, this fragmentation of public transit systems in the U.S., combined with the projected growth in transport demand, is widely recognized as unsustainable, and it has generated a major shift towards innovative services that can support seamless mobility and away from car ownership. Specifically, three transformational trends are taking place in transportation:

1) Transportation agencies are adopting integrated data platforms in an effort to make mobility systems more seamless, sustainable, accessible, affordable, and safe (Fishman et al., 2020). Experts say this is driving the development of “integrated solutions that elevate collaboration and productivity among transit agencies, ultimately improving the quality-of-service agencies provide to their communities” (Trapeze, 2021);
2) To address first- and last-mile challenges, transit agencies and municipalities are introducing new mobility hubs, with a range of travel options tuned to local demand (Fishman et al., 2020); and
3) Transportation planning is focused on introducing flexible fleets of on-demand, shared, electric vehicles that connect to transit within a mobility hub, where the goal is to increase capacity, speed, and frequency of the transit network by including new modes of transit and improvements to existing services (San Diego Forward, 2021).

All three of these trends are expected to be heavily supported by the digitization of transportation made possible by mass access to smartphones and Internet connectivity, the proliferation of big data, and emergence of innovative and intelligent approaches to coordinating fleets and travelers using static and real-time data about the entire transport sector.

1.3.2. Accessible and Inclusive Design in Data Systems Cannot Be Retrofitted

For decades, transportation agencies have dealt with the significant expenses involved in retrofitting physical structures and fleets to address accessibility. For example, within the London subway system, while newer stations are designed with accessibility in mind, older stations that were not so designed are not yet all accessible because of the technical difficulties and costs involved. Another example is the Singapore metro system, for which a report in 2004 noted that the cost of incorporating accessibility into new construction was minimal in comparison to the astronomical costs associated with retrofitting the system years later. This has led to a worldwide best practice of designing accessibility features into the construction of new transportation systems.

For information technology, the pattern is similar. Ample examples exist of the extreme challenges and significant expenses involved in the process of retrofitting an existing information technology (like a website) for accessibility. By comparison, if a project starts with universal access in mind, the design can be achieved with less coding. Here again, the cost of accessibility retrofitting can be enormous, whereas the cost of accessibility when deliberately and intentionally planned is minimal.

The design of data pipelines and data schema involved in the creation of transportation databases (containing both static and real-time data) exhibit the same pattern. If data pipelines and their recipient databases contain data schemas that are not designed with accessibility and inclusivity in mind, then retrofitting those data schemas can be difficult, resource-intensive, and costly in comparison to the cost involved in creating accessible designs from the onset. Accessibility and usability have also been shown to add other value to products—as much as a hundred-fold return on investment, according to early research.

1.3.3. Civic Technologies Are Integrally Driven by Equitable, Interoperable Data-Sharing Infrastructure

Data-sharing infrastructures that are both open-source and interoperable represent a significant opportunity for all participants in technology that supports civic engagement, not just the mobility ecosystem. Social and demographic trends, as well as the popularity of various integrated mobile apps, suggest that civic consumers want access to public services, public assets, and information via citizen-centered, data-driven applications. Behind every such application lies a complicated data pipeline, potentially fed by multiple public data producers such as municipalities, utility companies, transportation agencies, and more. Moreover, federal guidelines and the public expect the data to be current, reliable, trustworthy, and accessible. The shared interest in foundational data infrastructure motivates public and private sector organizations to co-invest in trustworthy, equity-first data pipelines, interoperable standards, and shared repositories. Data infrastructure suppliers benefit from interoperable data sharing by using it to identify new civic market opportunities and hone their service offerings. Governments also benefit. The data platforms can be leveraged to plan the future of cities, help all civic services operate more efficiently, and avoid building expensive but unnecessary infrastructure for each civic sector by improving utilization of shared data infrastructures. The same infrastructure may also widen the potential for governments to participate in the delivery of new services.

For purposes of this work, data interoperability is defined as the ability to join and merge data without losing meaning (JUDS 2016). In practice, data are said to be interoperable when they can be easily reused and processed in different applications, allowing different information systems to work together. In today's world, people's expectations are for greater interconnectivity and seamless interoperability, so different systems can deliver data to those who need them and in the forms they need them. Data interoperability and integration are therefore crucial to data management strategies in every organization. However, teams and organizations are often overloaded with day-to-day operations and have little time left to introduce and adopt standards, technologies, tools, and practices for greater data interoperability. This is termed the "interoperability gap."

The following four contextual backdrops will peripherally inform the needs assessment for the UW ITS4US project, as they are influencing factors within the entities engaged in transportation data production and consumption. Namely,

1) There is significant pressure on the transportation industry to identify mechanisms for interoperable data sharing, underlying many efforts to systematize mobility data, whether called “mobility on demand,” “mobility-as-a-service,” or something else;
2) Where data creation and consumption happen in both public and private spaces, an equity-and-accessibility-first evaluation must take place during the design phase in order to conserve considerable retrofitting costs later;
3) Other civic and government players will be watching, and possibly consulting, this mobility data infrastructure development because it will likely inform data infrastructure in other civic domain; and
4) There is an “interoperability gap” between the data sharing needs of organizations and their capacity for building standards, technologies, and tools to support the creation, use, and sharing of those data. This UW ITS4US Deployment Project aims to follow and document a clear process for devising interoperable data strategies for transportation data, to help devise sustainable practices, organize quality data for accessibility, and set the scene for the development of more tailored, detailed, and interoperable approaches to data management.

In conclusion, the backdrop and focus of this project is the production of not just any transportation data, but the building of a transportation data sharing infrastructure that takes an intentional and directed approach to assuring inclusivity and accessibility

1.4. Project Background

To address the transportation needs of underserved travelers, the entire trip—from conception and planning to initiation, and then from origin to destination—must be considered. The USDOT has defined the Complete Trip concept to capture the idea that a trip can be composed of several parts or segments (refer to **Figure 3**), and any individual traveler must be able to execute every part of that trip regardless of location, income, or disability.

This program recognizes that underserved individuals have differing and unique travel needs, even among individuals within a specific stereotyped user group. In addition, the ITS4US Program recognizes that there is often overlap between these populations, so opportunities exist to implement a solution that serves individuals in a customizable manner, rather than categorizing travelers into user groups. For example, slope steepness is not a concern of only users with certain disabilities (e.g., wheelchair users) or older adults, and it would be inappropriate to exclude such concerns from mobility applications that offer nonvisual directions simply because the stereotype for travelers with visual disabilities tends to overlook such concerns.

Figure 3. Infographic. Segments of a complete trip.

Source: United States Department of Transportation, University of Washington, and Cambridge Systematics.

User groups such as those described in **Table 1** represent demographic groups that experience greater travel barriers than some others. Importantly, these descriptions steer clear of typifying functional limitations or prioritizing specific travel concerns because it would be impossible to comprehensively describe the specific informational gaps experienced by these groups. Rather, the table describes specific life experiences that increase the likelihood of experiencing challenges during travel.

The goal of the UW ITS4US Deployment project is to build a sustainable, inclusive data infrastructure to enable and accelerate the future of equitable mobility and access to transportation for the benefit of all travelers. Through community leadership, this proposed system (described in more detail in **Sections 1.5 and 5**), the associated standards development, and the adoption by users (including both data generators and data consumers) will help provide a means to offer appropriate travel services, automate routing, and map out the transportation network in ways appropriate for every traveler. With this in place, previously underrepresented individuals will have tools available to make informed, customized travel decisions under any situation.

Table 1. Complete Trip—ITS4US deployment program user groups.

User Groups	Population Description
People with Disabilities	People with disabilities experience a broad range of travel limitations and associated needs. For the purpose of the Complete Trip-ITS4US Deployment Program, four functional ability groups include individuals with mobility, vision, cognitive/developmental and hearing challenges. Each of these groups experiences different transportation needs and barriers that may also vary significantly within the group. Some individuals have multiple disabilities.
Older Adults	Older adults form a substantial demographic of U.S. residents. There are approximately 50 million U.S. residents above the age of 65. As individuals age, many develop mobility, vision, hearing, and cognitive disabilities that make it difficult to travel on their own and necessitate reliable transportation services to maintain their independence and mobility. Approximately 35 percent of older adults have some type of disability, while two out of three have some form of chronic medical condition. Many older adults choose not to drive or are unable to drive. Accordingly, they are often in particular need of flexible, reliable, and affordable transportation to access medical appointments, shopping, or other necessary services.
Low-Income Populations	Low-income Americans, defined by the USDOT as persons whose household income is at or below the Department of Health and Human Services poverty guidelines, require reliable and affordable transportation. They are less likely to own private vehicles and therefore have increased need for access to public transportation.
Rural Residents	Rural areas are located outside urban regions and are characterized by very low-development densities. Dwelling units are widely dispersed (typically less than one dwelling unit per acre). According to the U.S. census, approximately 60 million Americans (1 in 5) live in rural areas, including high populations of older adults and veterans. Transportation options can be especially limited in low-density rural communities for individuals who do not own or cannot use a personal vehicle.
Veterans	Nearly 19 million veterans live in the U.S., and about one-quarter of the population has a service-related disability. Veterans with disabilities face unique challenges, as they usually have a sudden change in lifestyle and have to adjust to their long-term disability as an adult. More than 40 percent of veterans live in areas considered rural.

User Groups	Population Description
LEP	People with limited English proficiency (LEP) are individuals whose primary language is not English and who have a limited ability to read, speak, write, or understand English. It includes people who reported to the U.S. Census that they speak English less than very well, not well, or not at all. According to the U.S. Census, nearly 26 million people were considered to have limited English proficiency in 2018, accounting for 8.5 percent of the population. Language for LEP persons can be a barrier for obtaining services and information relating to public transportation.

Source: United States Department of Transportation.

1.5. System Overview

The UW ITS4US Deployment project aims to greatly increase the availability of pedestrian and transit pathway data and flexible transit information available to all travelers. It will build sustainable data infrastructure to enable and accelerate the future of equitable mobility and access to transportation. Specifically, it will implement and demonstrate data collection and data standards that allow a variety of mobility applications to access the information they need to support a wide range of mobility services for travelers of all abilities.

The project will achieve three primary goals:

1. **Coordinate Collaborative Releases of Data Standards—**Through community leadership, this project will co-create, improve, and extend data formats that describe currently under- or un-represented, detailed travel network information about the following:
    a. The pedestrian-built environment (sidewalks and footpaths), through the OpenSidewalks data standard.
    b. Transportation stations and hubs, through the General Transit Feed Specification Pathways (GTFS-Pathways) data standard.
    c. Demand responsive travel services through the GTFS-Flex data standard (excluding real-time feeds).

    In phase 1, work in this topic area will include working with the various standards committees to ensure that changes made to those standards support the needs of travelers with disabilities and other mobility constraints, and specifically their need to identify paths and transit services that they can use. This includes the addition of new variables to the standards and the definitions for how those variables are coded.

2. **Publish and Maintain Interoperable Data Infrastructure—**During phase 2, the UW Team will build, refine, and use data collection and data vetting techniques to generate data for all three data standards, along with the development of data provisioning services that distribute those data for use in a variety of applications. Much of the Concept of Operations will be devoted to the needs associated with these tasks. By the end of phase 2, the UW Team will publish collected data for the six U.S. counties that are part of this project. Those data will be maintained for five years after the conclusion of

phase 3 of this project, thereby supporting the team's and any third-party applications' interests in consuming the data. The six counties, as shown in **Figure 4**, are King and Snohomish counties in Washington state, Multnomah and Columbia counties in Oregon, and Harford and Baltimore counties in Maryland.

Figure 4. Map. Washington, Oregon, and Maryland counties.

Source: United States Department of Transportation, University of Washington, and Cambridge Systematics.

Data availability will depend on the cooperation of multiple agencies in those counties. This will be part of the outreach effort of the UW ITS4US project, but the results of that outreach effort are unknown at this time. GTFS-Pathways data will be demonstrated at transit centers in the three states. The exact number and locations of the transit centers will be a function of the comfort level of the transit agencies that will ultimately be responsible for maintaining the data and the overall cost of the data collection process.

3. **Deploy and Sustain Three Accessible Mobility Applications—**This project will deploy three accessible mobility applications in the evaluation and testing of the usability and efficacy of the data standards developed in phase 1 and the supporting infrastructure developed in phase 2. The mobility applications will close information gaps for three very different populations and will address demonstrably different travel goals:
    a. Multimodal AccessMap (by Taskar Center for Accessible Technology)—a comprehensive, multimodal, personalized routing and trip planning web and mobile application addressing the needs of people with mobility limitations, particularly supporting travel and exploration through new environments.
    b. Soundscape (by Microsoft)—a specialized orientation and exploration mobility iOS application enabling blind, vision disabled, or deafblind travelers to perform

spontaneous travel and explore new pedestrian environments without having to specify a destination.

c. Digital Twin (by Unity Technologies)—a simulation tool that allows travelers (specifically sighted older adults and multilingual, multicultural travelers) to explore and visualize a trip path through a transit station that they need to use prior to taking a trip.

Figure 5 presents a conceptual framework for the project's vision. It illustrates the use of the data and data standards proposed for this project. It shows how data that need to be part of the transportation routing decision will come from multiple sources, including transit agencies, other governmental agencies, the private sector, and crowdsourcing. The data will be obtained in a consistent fashion by aggregators and supplied to applications that interact with end users. In this vision, the aggregators will contain non-personally identifiable information (PII) data, and the applications will maintain all the PII necessary to personalize the selection, presentation, and delivery of travel options. This framework represents the entire vision of a proposed system, including hardware, software, and services provided by both the UW team and the partnering application developers. In the context of the ITS4US Program, it can be subdivided into several different efforts, which are discussed in greater detail in **Section 5**. These include the following:

1) Components that the UW team will directly develop and test, which primarily include the data validation, storage, and services technologies that are the focal point of this project.
2) Components that the UW team will assist in developing, which include toolsets that support the collection and submission of data, to be used by data providers and data generators.
3) Software demonstrations that use the data generated in (2) and made available in (1). These demonstrations are designed to illustrate the success of the pipelines in (1) and comprise three applications that will provide services needed by underserved end users.
4) A co-Design effort with project stakeholders to develop and implement the policies and institutional relationships needed to scale and sustain the technology ecosystem being developed. The co-Design effort applies to all technical components being constructed by the project team or in which the UW team is assisting in the development.

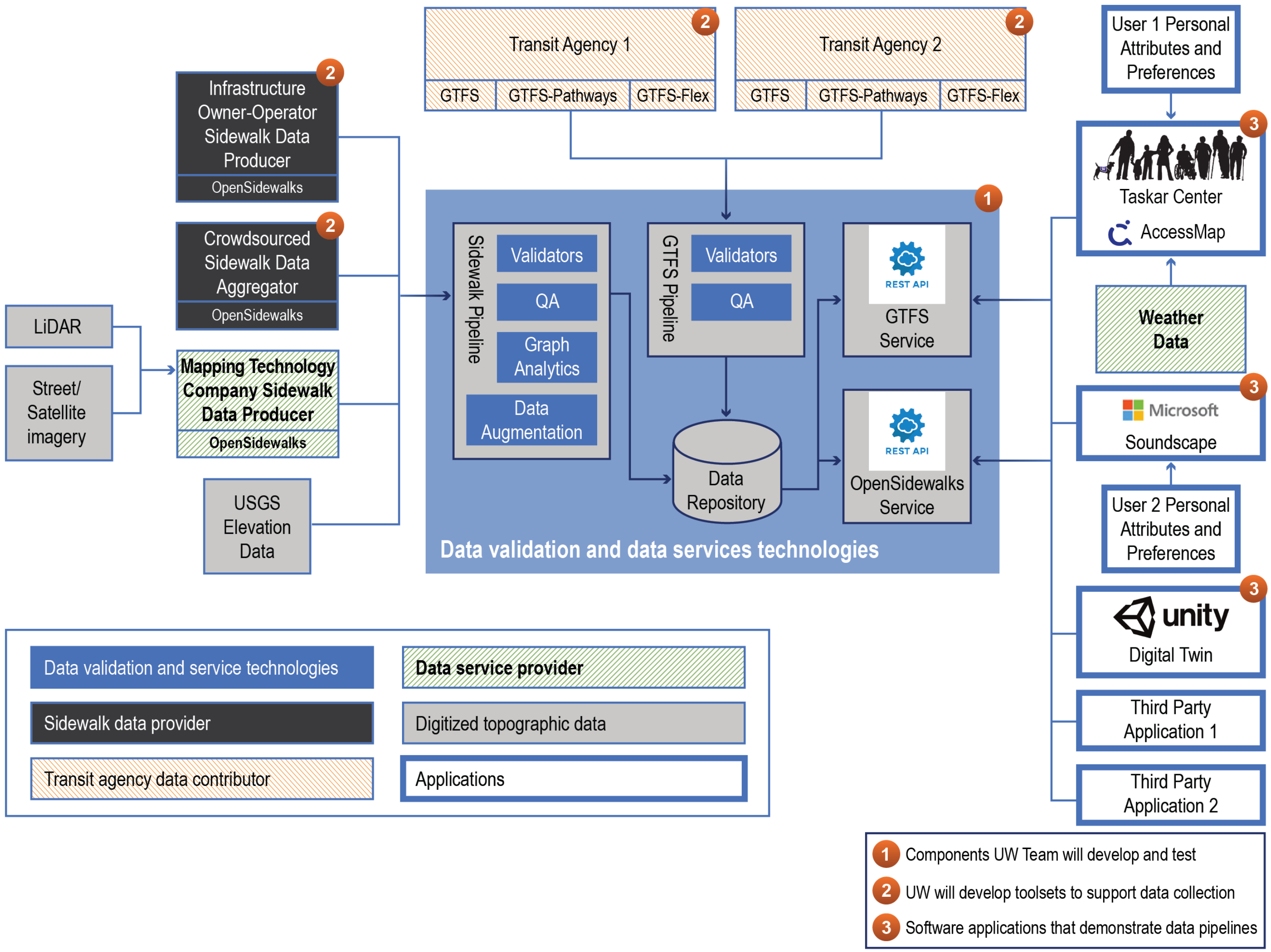


Figure 5. Diagram. Concept framework for the proposed data services.

Source: University of Washington and Cambridge Systematics.

The main stakeholders involved in the design, development, and operation of the proposed system include the UW, City of Bellevue, Unity Technologies, Google Inc., Microsoft Inc., Mapillary (now a subsidiary of Facebook Inc.), Washington State Department of Transportation (DOT), Oregon DOT, and Maryland DOT. The stakeholders' roles and responsibilities in the current system are described in more detail in **Section 3.2**, and their roles in the proposed system are documented in **Section 5.2**.

The main user groups that would interact with the proposed system include the following:

- Data providers (e.g., municipal infrastructure –owner/operators, private sector pedestrian-built-environment owner/operators, elevation data providers),
- Transportation service providers (e.g., transit agencies and the companies that support the delivery of transit services operated by or for those transit agencies),
- Data service providers (e.g., crowdsourced sidewalk reporters, mapping services, weather data providers),
- Application developers (e.g., AccessMap developers, Soundscape developers, Digital Twin developers, third-party application developers), and
- End users (e.g., travelers with sidewalk preferences, blind, vision disabled, or deafblind travelers, sighted older adults, multilingual or multicultural travelers, low-income transit users, rural transit users).

The anticipated interaction with the proposed system is documented for each user class within these five user groups in **Section 5.3**.

1.6. Systems Engineering Approach

The UW ITS4US Deployment Project ConOps, which will be based on the format and guidelines of the International Organization for Standardization (ISO)/Institute of Electrical and Electronics Engineers (IEC)/Institute of Electrical and Electronics Engineers (IEEE) 29148:2011 ConOps Standard (formerly IEEE Standard 1362-1998), is a foundational document for communicating the user needs and high-level operation and requirements of the system for TDEI stakeholders. The ConOps will be used to develop detailed system requirements and a design that will be traceable to the user needs defined herein. The end product will identify and describe the attributes of the proposed data system, the flow of data through the system, and the interaction with that system by downstream applications. The ConOps will serve as a model not only for phase 2 of the UW ITS4US Deployment Project but also for any future system developer that wishes to take advantage of this data framework to build applications that improve multimodal travel.

Developing a ConOps is a key step in developing a plan that results in a successful technology deployment. A ConOps provides a bridge between the needs that motivated the project and the specific technical requirements. By building support, gathering feedback, and refining the proposed concept, the ConOps document serves as a high-level guide for subsequent design efforts, as shown in the Systems Engineering V-Model in **Figure 6** (e.g., System Requirements, High-Level Design, Detailed Design). It helps advance the strategy into subsequent phases by reducing the risk of the strategy failing or being delayed because of a lack of agreement or understanding of the proposed concept.

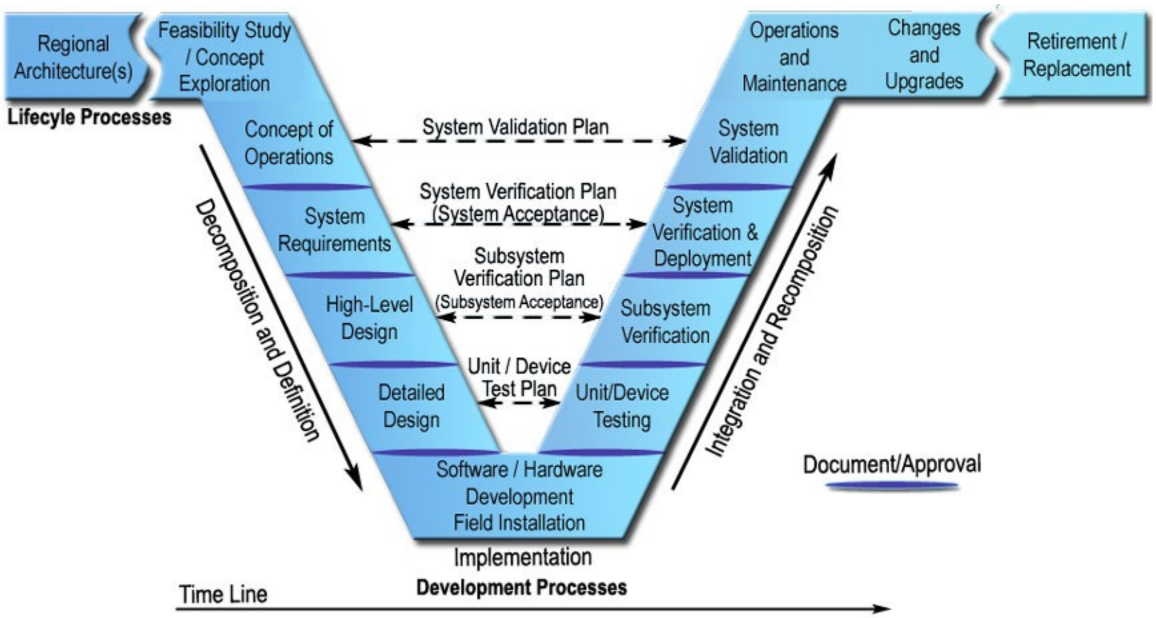


Figure 6. Diagram. Systems Engineering V-Model.

Source: Federal Highway Administration.

The development processes outlined in the Systems Engineering V-Model is based on systems engineering industry standards and is part of USDOT's best practices for ITS projects. It helps transportation agencies use common, consistent, and well-established systems engineering tools and processes to accomplish the following:

- Improve the quality of ITS.
- Reduce the risk of cost and schedule overruns.
- Gain wide stakeholder participation.
- Maintain, operate, and evolve ITS.
- Maintain consistency with the regional and state ITS architectures.
- Provide flexibility in procurement options for the agencies.
- Keep current with the rapid evolution of technology.

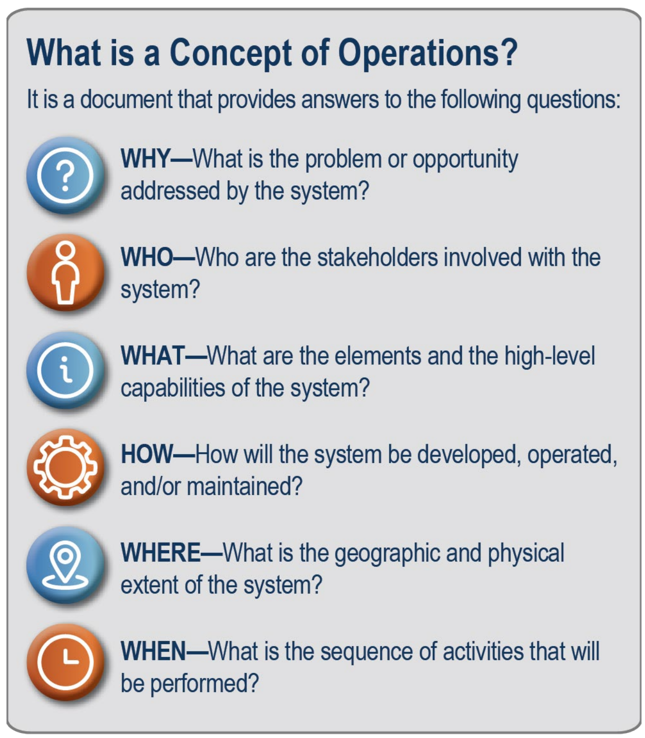


Figure 7. Infographic. What is a Concept of Operations?

Source: Federal Highway Administration.

For certain system development projects, an Agile Software Development practice can be used as an alternative approach to the standard Systems Engineering Waterfall progression between system requirements development and system deployment. Each approach has its own advantages. The traditional V-model approach reduces the risk of building the wrong product by prescribing sequential steps to refine the design and progressively detailing requirements before product implementation starts. In contrast, Agile Software Development processes reduce the risk of building the wrong product by demonstrating the product at incremental milestones to solicit user feedback and make incremental adjustments towards a final product.

Agile software development techniques work best for projects in which user groups are fully invested and committed and have existing expectations of the functionality that could be utilized to address their business and customer needs. Additionally, agile software development processes are commonly used in developing systems that create new applications through the integration of current systems and data. Agile software development processes provide substantial benefits in both improved responsiveness of a system to user needs and substantially accelerated software development.

It is anticipated that many aspects of agile software development will be incorporated into the development of the proposed UW ITS4US Deployment system. One core goal of this project is to implement user-focused data standards that are easily scalable, sustainably stored, and readily available. The scaled delivery of these outcomes will be a function of the software delivered, the business models of the participating institutions, and how those institutions react to the changing business environment (e.g., new opportunities for interaction with developers and end users) that these data make available.

Consequently, as new data collection systems are developed and demonstrated along with multiple use cases, the institutional partners that will help deploy these systems (transit agencies, technology firms, and government jurisdictions) will have considerable input into the final design and operation of those systems. Iterative feedback from these partners will result in changes to the systems as they are developed and deployed. The Systems Engineering Management Plan (SEMP) to be developed as part of Phase 1 will describe the agile software development processes that will be used and how they will be integrated with the traditional Systems Engineering processes.

1.7. Acronyms and Glossary

Acronym	Definition
2D	Two-dimensional
3D	Three-dimensional
AARP	American Association of Retired Persons
AD	Application developer
ADA	Americans with Disabilities Act
AI	Artificial intelligence
API	Application program interface
ATTRI	Accessible Transportation Technologies Research Initiative

Acronym	Definition
Civic Technology	Technology that enhances the relationship between people and government, such as software for communications, decision-making, service delivery, or that enables engagement in the political process.
ConOps	Concept of Operations
COVID	Corona virus disease
DG	Data generator
DOT	Department of transportation
DS	Data service provider
DU	Digital device end user experiencing travel barriers
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GIS	Geographic information systems
GOFS	General On-Demand Transit Feed Specification
GTFS	General Transit Feed Specification
GTFS-Flex	The Flex route extension to the General Transit Feed Specification, designed to describe demand-responsive or paratransit service
GTFS-Pathways	The Pathways extension to the General Transit Feed Specification which defines pathways linking together locations within stations
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
IT	Information technology
ITS	Intelligent transportation system
ITS JPO	Intelligent Transportation Systems Joint Programs Office
LEP	Limited English proficiency
LiDAR	Light detection and ranging
MARC	Mid-Atlantic Regional Council
MOOVEL	A software services provider to transit agencies
MVP	Minimum viable product
OGC	Open Geospatial Consortium
OST	Office of the Secretary
PII	Personally Identifiable Information
PPNA	Personalized pedestrian network analysis
REST API	Representational State Transfer Application Program Interface
ROI	Return on investment
SEMP	Systems Engineering Management Plan
Taskar Center or TCAT	Taskar Center for Accessible Technology at the University of Washington
TCRP	Transportation Cooperative Research Program
TDEI	Transportation Data Equity Initiative
TRAC	Washington State Transportation Center at the University of Washington
TSP	Transportation service provider

Acronym	Definition
U.S.	United States
USDOT	United State Department of Transportation
USGS	United States Geological Survey
UW	University of Washington
VA	Veterans Affairs
W3C	World Wide Web Consortium

1.8. Document Overview

This document is organized as follows:

- **Section 1—Scope.** This section provides background on the Complete Trip—ITS4US Deployment Program, high-level scope of the project, and summary of the systems engineering approach.
- **Section 2—Referenced Documents.** This section lists all references used in the creation of this document.
- **Section 3—Current System and Situation.** This section describes the current system and supporting systems utilized by stakeholders and how each is used. This section also identifies and describes current system stakeholders, support environments, modes of operation, and operational policies and constraints.
- **Section 4—Justification for and Nature of Changes.** This section identifies the deficiencies of the existing systems, desired changes to the systems, and motivation for the development of the new system. Changes considered but not included, as well as known assumptions and constraints, are also documented. This section provides a transition from Section 3, which describes the current system and supporting systems, to Section 5, which describes the proposed system concept.
- **Section 5—Concepts for the Proposed System.** This section describes the proposed system resulting from the features described in Section 4. It describes the proposed system and its subsystem components at a high level, indicating the operational features that are to be provided, without specifying design details. This section also documents the role each stakeholder will play in the proposed system and how each user group will interact with the system, in addition to the support environment, modes of operation, and operational policies and constraints.
- **Section 6—Operational Scenarios.** This section describes the use cases and operational scenarios which present how the project is envisioned to operate from various stakeholder perspectives. These are developed as “day-in-the-life” descriptions of how users would interface with, use, and benefit from the system. These have been developed through significant interaction with the previously defined user groups that the project team has involved in the co-Design process.

- **Section 7—Summary of Impacts.** This section describes the operational and organizational impacts the project is anticipated to have on stakeholders, user groups, and system owners/operators. Any impacts that stakeholders are anticipated to experience during development are also documented.
- **Section 8—Analysis of the Proposed System.** This section includes a summary of anticipated improvements, perceived limitations or disadvantages of the systems, and alternatives or tradeoffs considered during concept development.

2. Referenced Documents

- Accessible Transportation Technologies Research Initiative (ATTRI) Performance Metrics and Evaluation, Final Evaluation Framework Report, FHWA-JPO-20-784, https://rosap.ntl.bts.gov/view/dot/50748/.
- AccessMap GitHub site, https://github.com/AccessMap/accessmap.
- Bolten, Nicholas, Allie Deford, Reagan Middlebrook, Veronika Sipeeva, Alan Borning and Anat Caspi. AccessMap.io. Seattle, WA: N.p., 2015. Software. First Place Award at "Hack the Commute". Sponsored by Seattle Department of Transportation.
- Bolten, Nicholas, Amirhossein Amini, Yun Hao, Vaishnavi Ravichandran, Andre Stephens, and Anat Caspi. "Urban sidewalks: visualization and routing for individuals with limited mobility." First International Workshop on Smart Cities and Urban Analytics (UrbanGIS). Seattle, WA: 2015.
- Bolten, Nicholas, Sumit Mukherjee, and Anat Caspi. "Learning sidewalk path connectivity for accessible trip planning using crowdsourcing and open data." 2016. ArXiv
- Bolten, Nicholas, Veronika Sipeeva, Sumit Mukherjee, Anissa Tanweer and Anat Caspi. A pedestrian-centered routing approach for equitable access to the built environment. 2017. IBM J. RES. & DEV. VOL. 61 NO. 6:10 [November/December 2017] 10.1147/JRD.2017.2736279.
- Bolten, Nicholas and Anat Caspi. 2019. AccessMap Website Demonstration: Individualized, Accessible Pedestrian Trip Planning at Scale. In The 21st International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '19). Association for Computing Machinery, New York, NY, USA, 676–678. DOI: https://doi.org/10.1145/3308561.3354598.
- Bolten, Nicholas and Anat Caspi. "Towards routine, city-scale accessibility metrics: Graph theoretic interpretations of pedestrian access using personalized pedestrian network analysis." PLoS one 16.3 (2021): e0248399.
- Digital Twins website, https://create.unity3d.com/real-time-3d-and-digital-twins.
- FHWA. University of Washington ITS4US Deployment Project—Phase 1 Needs Summary. Final Report—May 3, 2021.
- FHWA. Accessible Transportation Technologies Research Initiative (ATTRI)—User Needs Assessment: Stakeholder Engagement Report. Final Report—May 2016. FHWA-JPO-16-354.
- FHWA. Accessible Transportation Technologies Research Initiative (ATTRI) Policy and Impacts Assessment—Policy Assessment, Gaps & Needs. Final Report—July 2019. FHWA-JPO-17-506.

- (Fishman et al., 2020) Fishman, Tiffany, Kelkar, Mahesh, and Schwartz, Avi (2020). Transportation Trends 2020, https://www2.deloitte.com/us/en/insights/industry/public-sector/transportation-trends.html. Deloitte Services (4/13/2020).
- GTFS-Flex document (ongoing), http://bit.ly/gtfs-flex-v2.
- GTFS-Flex GitHub site, https://github.com/MobilityData/gtfs-flex.
- GTFS-Pathways document (ongoing), http://bit.ly/gtfs-pathways.
- GTFS-Pathways GitHub site, https://github.com/google/transit/pulls?q=is%3Apr+pathways.
- (GTiO) Data Interoperability: A Practitioner's Guide to Joining Up Data in the Development Sector. https://www.data4sdgs.org/sites/default/files/services_files/Interoperability%20-%20A%20practitioner%E2%80%99s%20guide%20to%20joining-up%20data%20in%20the%20development%20sector.pdf, accessed 4/13/2021.
- (ISO) https://www.iso.org/home.html, accessed 3/15/21
- (JUDS, 2016) Joined-Up Data Standards project (2016). The frontiers of data interoperability for sustainable development. Available at: http://devinit.org/wp-content/uploads/2018/02/The-frontiers-of-data-interoperability-for-sustainable-development.pdf.
- (Michel, 2018) Michel, John E. (2018). Mobility-as-a-Service: Enabling the Transformation of Transportation through Digitalization. Mass Transit Magazine (2/19/2018).
- National Academies of Sciences, Engineering, and Medicine 2020. *Development of Transactional Data Specifications for Demand-Responsive Transportation*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25800.
- Needs expressed by MVTransit: How data science is driving digital transformation at MV Transportation. https://www.dxc.technology/workplace_and_mobility/insights/148131-how_data_science_is_driving_digital_transformation_at_mv_transportation.
- (ODW, 2018) Open Data Watch, 2018.
- (OGC) Open Geospatial Consortium.
- OpenSidewalks website, https://tcat.cs.washington.edu/opensidewalks-2/.
- OpenSidewalks GitHub site, https://github.com/OpenSidewalks/OpenSidewalks-Schema.
- (SDF, 2021) San Diego Forward, (2021) "A bold new transportation vision in 5 big moves," (https://www.sdforward.com/mobility-planning/5-big-moves) Accessed on 4/15/2021.
- Soundscape website, https://www.microsoft.com/en-us/research/product/soundscape/.
- Tanweer, Anissa, Margaret Drouhard, Brittany Fiore-Gartland, Nicholas Bolten, Jess Hamilton, Kaicheng Tan, and Anat Caspi. Mapping for Accessibility: A case study of ethics in data science for social good. Bloomberg Data for Good Exchange Conference. 24-Sep-2017, New York City, NY, USA.
- Transportation Data Equity Initiative website, https://transitequity.cs.washington.edu/.

- (Trapeze, 2021) Trapeze Group (2021). Esri and Trapeze collaborating on integrated data platform, https://www.masstransitmag.com/technology/press-release/21216834/trapeze-group-esri-and-trapeze-collaborating-on-integrated-data-platform. Mass Transit Magazine (4/1/2021).
- (W3C) https://www.w3.org, accessed 3/15/2021.
- Zhang, Yuxian and Anat Caspi. 2019. Stereo Imagery Based Depth Sensing in Diverse Outdoor Environments: Practical Considerations. In Proceedings of the 2nd ACM/EIGSCC Symposium on Smart Cities and Communities (SCC '19). Association for Computing Machinery, New York, NY, USA, Article 4, 1-9. DOI: https://doi.org/10.1145/3357492.3358627.

3. Current Systems and Situation

This section provides an overview of the current systems and situation, the users and stakeholders of these systems, the existing support environment, modes of operation for the current systems, and operational policies and constraints.

3.1. Background and Scope

For the USDOT's Complete Trip - ITS4US Deployment Program, a "Complete Trip" is defined as a traveler's ability to plan for and execute a trip from an origin to a destination without gaps in the segments of the trip (refer to **Figure 3** presented earlier). Historically, transportation planners and engineers across the United States have built a transportation system that aims to accommodate these goals, usually focusing on specific projects to provide or enhance a link of the trip. While the personal automobile remains one of the primary modes for transportation in the United States, it is not the only mode for trip-making. Many users rely on public transportation and pedestrian pathways as their primary travel mode, especially those in certain user groups who either lack access to a personal automobile or have a unique travel preference that is better accommodated by transit.

Unfortunately, the installation of many sidewalks and transit systems was often secondary to the road network. Sidewalks were often built next to roads in accordance with basic geometric standards, rather than as their own user-focused design. Many transit systems were designed to take advantage of existing roads, meaning that sometimes their routes were in response to the existing road network rather than to ridership needs. As a result, the user experience on these modes can vary widely, and it can be extremely difficult to navigate in these environments, especially for travelers with specific travel preferences.

Transportation agencies that provide transit service or sidewalk infrastructure have aimed to provide a travel experience that accommodates as many users as possible on these modes. The Americans with Disabilities Act (ADA) instituted many infrastructure requirements to better accommodate disabled users. Planners and engineers who implement projects on specific trip segments utilize these adopted standards to include more accessible infrastructure. However, deployment of ADA-compliant standards is rarely contiguous. For example, many cities looking to implement accessible pedestrian signals lack the funding to deploy them across their entire jurisdiction, causing their rollout to occur across a ten-year period or whenever an intersection improvement project can address it. Additionally, some ADA requirements and other accessibility standards cannot be met because of geography constraints. For example, accessibility standards may suggest a shallow grade for sidewalks, but those standards may be given exceptions in hilly communities where natural terrain prohibits reasonable cost-effective accommodation.

These gaps in coverage and definition remain a challenge for travelers who rely on accessible travel modes. The usefulness of a particular route is only as strong as its weakest link, and often an unimproved segment (e.g., a narrow sidewalk, an excessively steep grade) will limit a traveler's ability to navigate the route safely and comfortably. Compounding the challenge is the fact that limited advance information exists about the alternatives a traveler might consider, especially in unfamiliar areas. For some travelers, the lack of insight into a particular environment is enough to discourage taking the trip. As a result, millions of Americans remain underserved by the existing transportation system.

Fortunately, travel access in the United States has changed in the past 15 years. The rise of mobile cellular devices has created opportunities to provide immediate information to users. Traveler-focused tools, including mobility and wayfinding apps (such as MOOVEL, OneBusAway, Next Bus, Google's Directions™, OpenTripPlanner), have given travelers an ability to spontaneously find travel services, compare travel options, and streamline trip information through one application. Additionally, the creation and widespread adoption of certain descriptive standards—namely GTFS—have helped establish methodologies with which to describe part of the transportation system in the digital space.

GTFS is one of the more prominent standards and has demonstrated how a single data standard and associated data repository can describe fixed-route transit systems anywhere in the world, allowing a traveler with one mobile application to move from transit system to transit system without seeing changes in the way that information is conveyed. As a result, travelers feel more confident in their understanding of the transit system, which helps increase the number of users for that transit service.

Despite these advances, certain parts of the complete trip remain undocumented and are not digitized for travelers, which limits planning for travelers with specific preferences or who use specific services. Previous stakeholder outreach conducted by the UW reinforced the fact that underserved travelers want to travel more, know more about their travel options, and benefit from personalized traveler planners and tools that can describe their travel environments in the context of their needs and preferences. In particular,

- Accessible sidewalk routes remain largely unknown, particularly in the context of user-specific preferences. Some services (e.g., Google Maps) provide sidewalk routing for information purposes, but their guidance provides limited insight into whether the sidewalks truly accommodate specific accessibility preferences. Some cities have collected detailed accessibility information on their sidewalks, but these data have not found their way into mainstream mobile routing applications. Other cities that are interested in sharing accessibility data do not know what criteria to collect, making data collection either too costly (by collecting too much irrelevant data) or insufficient (by not collecting enough relevant data).
- Flexible paratransit service data are not shared in a standard format, even among agencies that utilize GTFS to describe their fixed-route transit service offerings. Travelers with limited fixed-route transit options rely on paratransit to provide service, but it can be difficult to identify what options are available without going to the agency's website. Transit agencies wishing to share these data on a widespread medium do not have an adopted standard with which to describe their information, nor a known data repository with which to share data with a wide audience.
- Transit station pathways and features are not currently available in digitized 3D formats. Even though most modern transit stations are designed to accommodate travelers with physical disabilities, insight into how to navigate those stations is important to travelers and helps boost their level of comfort with the trip. Guidance through a complex transit station can significantly improve the traveler experience of a user in an unfamiliar

environment, just as enhanced sidewalk information improves a traveler's experience through the pedestrian environment. Transit agencies that wish to share these data do not have an adopted standard with which to describe their physical environment, nor a known data repository with which to share data with a wide audience.

- Limited mobile applications exist to provide accessible Complete Trip information across multimodal links. Many applications are available for routing personal automobiles on the road network, but those applications are limited to just one mode. Some transit routing applications factor in the pedestrian pathway from the traveler's home to the fixed-route transit service bus stop or train station, but these pathways lack any information on accessibility. Additionally, travel insights at transfer points (e.g., a transit station) are extremely limited, often offering only instructions to "transfer at this station."

For a Complete Trip to be successful, no gaps can exist in the travel chain that make up that traveler's trip. For nonautomotive users, many pieces make up a trip chain. The links of this chain, shown in **Figure 8**, include trip planning, travel to a station, station/stop use, boarding vehicles, using vehicles, leaving vehicles, using the stop or transferring, and travel to a destination after leaving the station/stop. If one link is not accessible, then access to a subsequent link is unattainable and the trip cannot be completed. In such instances, the traveler will want a feasible alternative, thus necessitating enhanced information to help them make an informed routing decision.

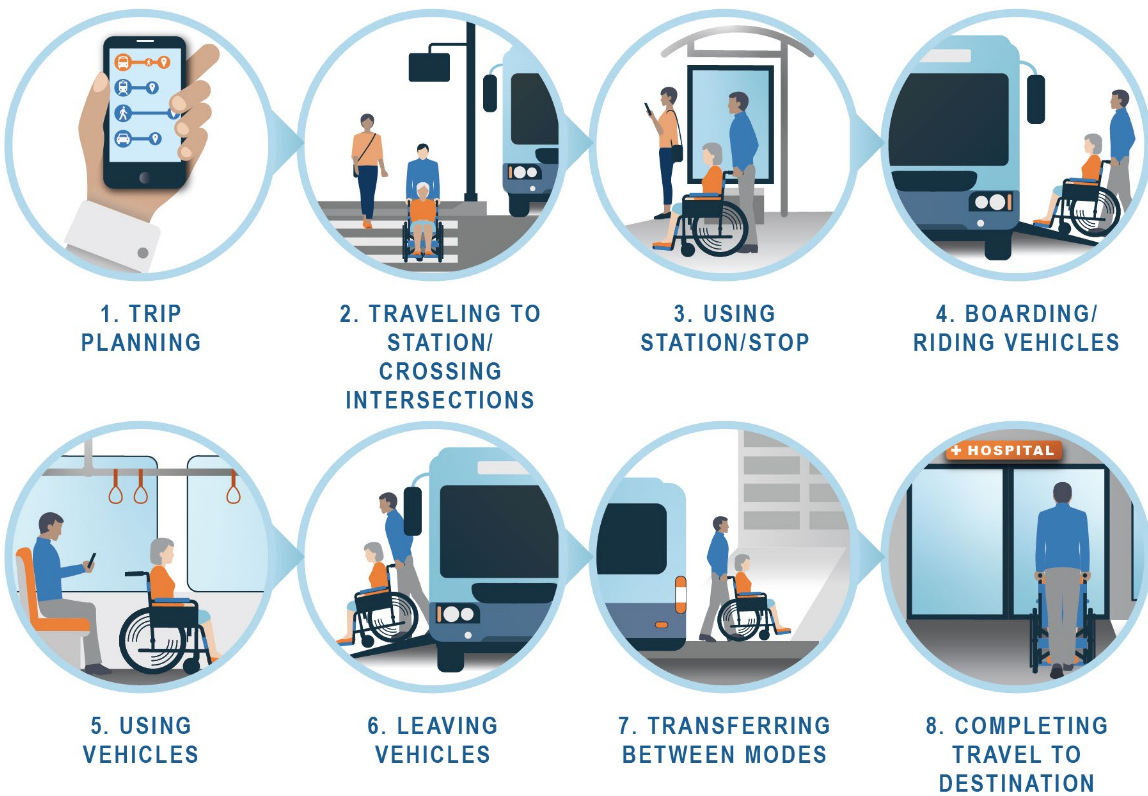


Figure 8. Infographic. Segments of a complete trip.

Source: Accessible Transportation Technologies Research Initiative.

3.2. Description of the Current System and Situation

Sidewalk and transit data exist in the current systems, but because of many challenges, the data are not widely used. At a high level, these challenges include the following:

1. **Siloed systems—**Public agencies and other organizations often collect data that describe the built environment or transit service in their own, decentralized standalone systems. It is not uncommon even within the same municipality to find multiple data repositories that are inconsistent among one another in digitizing information about the same built environments. As a result, application developers that wish to use these data must tie into each specific system, requiring a separate development pipeline to access the data of nearly each data system, which makes the level of effort complicated. Some data standards, namely the GTFS data standard, have helped consolidate these data into a single resource, which allows application developers to more easily access the data. At a high level, a digital device end user who experiences travel barriers is not accustomed to seeing sidewalk and transit-related data available in the same operating environment, which sets an expectation that he or she will need to use multiple application services to access any needed data, if those data are even available.
2. **Data are not standardized—**Data standardization provides many benefits to transit, as has been evidenced by the proliferation and adoption of GTFS Limited data standards for sidewalk and pedestrian path data. Agencies, departments, and organizations that collect data typically produce data describing infrastructure and services with their own data standards, if at all, based on their own internal business rules. As a result, application developers that wish to access different data sets have to translate the data using different data schema translation tools, which adds complexity to the level of effort required.
3. **Data differ in availability based on geography—**Some agencies have robust data collection programs, whereas others do not. Data may be available in one geographic area but not another. A complete trip pathway cannot be generated if that path goes through a geographic space for which there are limited data. Part of this challenge is that data contributors lack access to appropriate data standards.
4. **Data about infrastructure rarely describe connectivity of paths or the transportation network.**

Figure 9 illustrates the components that make up the current situation, and relevant components are discussed in greater detail in subsequent sections.

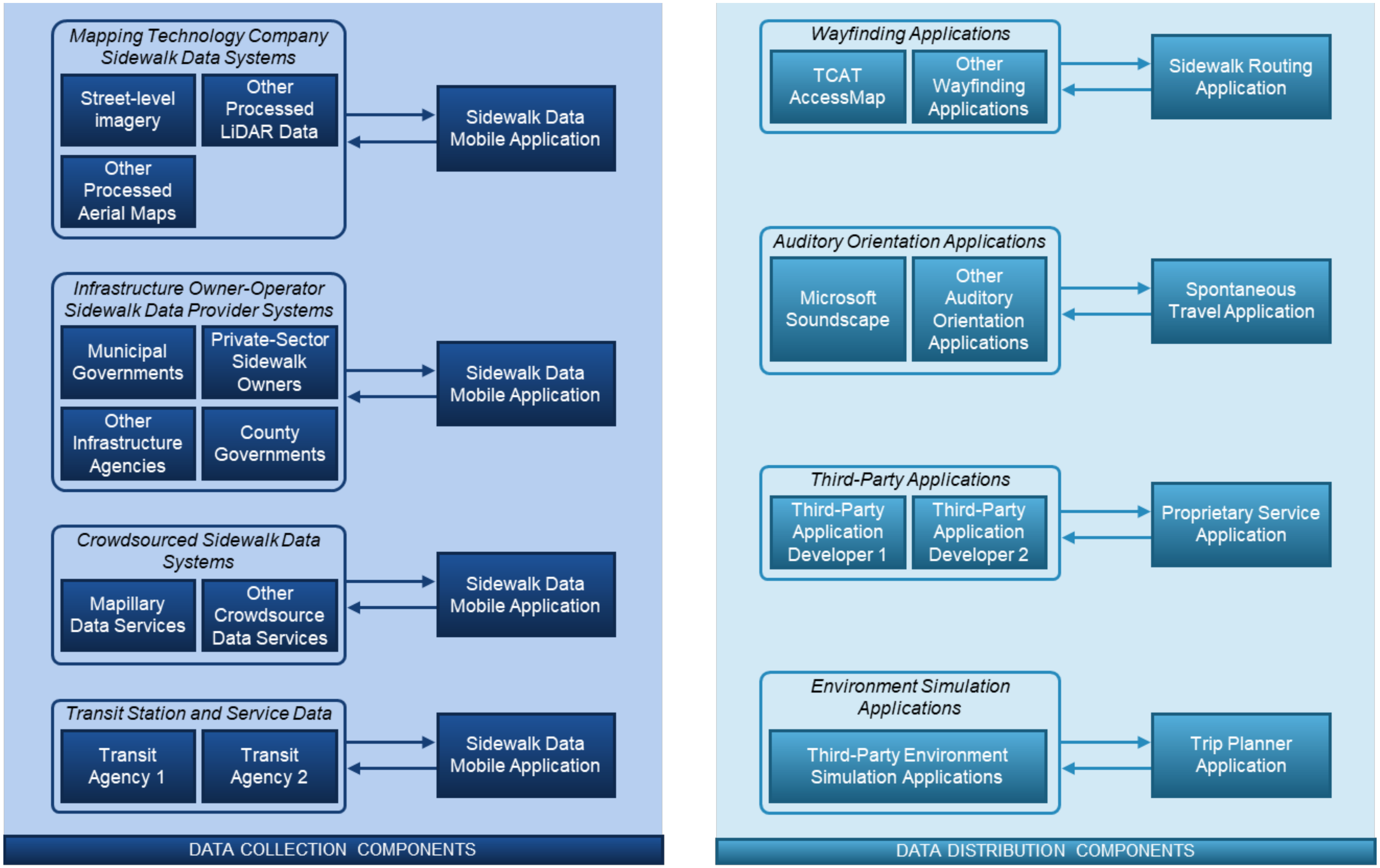


Figure 9. Diagram. Context diagram for the current situation.

Source: University of Washington and Cambridge Systematics.

3.2.1. Mapping Technology Company Sidewalk Data Systems

Various systems exist for converting light detection and ranging (LiDAR) and aerial mapping data (i.e., visual imagery, often converted to digitally rendered images) into useful applications. LiDAR is commonly used for land surveying, which is processed by software to create geographic workspaces from which civil, structural, or architectural designs are assembled. Digital versions of aerial maps are used by myriad planning and land-use applications. By utilizing advanced computer software techniques, it is possible to extract details from these maps that identify points of interest, such as road locations, buildings, coastlines, and other features. Sidewalk locations are one potential point of interest, but few applications exist to collect those types of data, or the attributes and features of the sidewalk that are key pieces of information needed by many people with mobility disabilities who want to determine whether they can successfully use a segment of sidewalk.

While sidewalk attribute data can sometimes be accessed in publicly available electronic formats, the available data are often of limited geographic scope and contain a limited number of important sidewalk attributes and features.

3.2.2. Infrastructure Owner-Operator Sidewalk Data Provider Subsystems

Infrastructure owner-operators—namely cities, counties, municipalities, and states—collect varying degrees of data about their pedestrian-built environments. Most agencies retain detailed design plans of sidewalks that are constructed within their jurisdictions, but these data often reside only in the electronic design files (e.g., MicroStation, AutoCAD) and are not readily available for use. Some agencies publish sidewalk attribute data as part of their geographic information system (GIS) mapping databases, which may or may not be publicly available, but these links are often standalone and are in a data format that does not allow for a route of multiple links to be logically mapped. Very few GIS databases capture all the pathway attributes that are valuable to travelers with disabilities, such as slope steepness, obstructions along the route, and other travel-related parameters.

While some of these data are publicly available, their use by external stakeholders tends to be by community planners or other citizen groups at the local level. Some agencies have provided initial data for sidewalks that are used by mobility-focused applications like AccessMap, which is discussed later, but those locations are geographically limited.

3.2.3. Crowdsourced Sidewalk Data Systems

Various systems exist to provide crowdsourced feedback data on the travel environment. Waze is one of the most common applications to deliver this service, in which individual drivers can contribute information about the road network (e.g., the presence of heavy traffic, a stalled vehicle, police activity, etc.) that benefits other users. In the context of sidewalks, the number of systems is quite limited. For example, a city services reporting system (e.g., “311”) may allow users to submit reports on sidewalk-related issues, such as sidewalk damage. Other mapping services groups—particularly Mapillary—focus on utilizing crowdsource contributors to build a mapped environment.

Crowdsourced sidewalk data unfortunately are very limited to the locations of an active base of crowdsourcing users. Additionally, these data are rarely captured or stored in a format that can be used to route pedestrians. The data that are collected in various jurisdictions are not stored in a consistent manner, and thus are difficult to use in applications that wish to provide navigational instructions to end users.

3.2.4. Transit Station and Service Data

Transit station and service data are currently created and disseminated through the GTFS standard. The GTFS was developed (co-designed) by a transit agency (Tri-Met in Portland, Oregon) and a major mapping-navigation service provider (Google Maps). Several business reasons existed for adopting GTFS. For Google, it allows transit agencies from around the world to supply fixed-route schedule data in a standard format that it can incorporate into its navigation software, dramatically increasing the market for those services. For transit agencies, by providing data in a standard format to Google—and to other major navigation service providers—they can dramatically increase the number of individuals who are aware of available transit options, increasing ridership and customer satisfaction at very little cost. For application developers, an application that uses GTFS can be deployed almost anywhere, as GTFS schedules are available almost anywhere. GTFS adoption skyrocketed very quickly, and other uses for this standard soon became apparent.

An extension of GTFS, referred to as GTFS-Pathways, uses a graph representation to describe a subway or train station, with nodes signifying specific feature locations inside the station and edges signifying the paths between those features to schematically describe paths within a transit station. Under this project, it is expected that GTFS-Pathways data will be published by a transit agency for facilities under its ownership. Currently, relatively little GTFS-Pathways data are generated by transit agencies because of the cost of producing those data and the lack of a national effort to aggregate and republish them.

One planned outcome from this project is to significantly lower the cost to transit agencies of developing GTFS-Pathways data. A second planned outcome is to help expand the features and attributes that GTFS-Pathways describes, so that this standard becomes even more useful for routing people with mobility disabilities through transit station environments. Other proposed GTFS extensions support GTFS-Pathways (e.g., levels within a station, planned closures of pathways for construction or routine entrance opening, unplanned closures like elevator outages) and are intended to become part of the transit services dataset routinely offered by transit agencies that operate transit stations. This will facilitate the navigation of those stations and increase the number of complete trips that people with mobility disabilities can perform.

Another extension of GTFS, referred to as GTFS-Flex, adds the capability to model demand-responsive transportation services. On-demand transit services cannot be accurately described by the current GTFS fixed-route data standard. The GTFS-Flex standard is applicable to transit services that offer dial-a-ride, route deviation, point-to-zone, or hail-and-ride services. As with GTFS-Pathways, currently little GTFS-Flex data are produced, partly because of a lack of software to easily produce these data and partly because the current version of the GTFS-Flex standard does not include some attributes needed to describe all on-demand services. The goal for the use of planned extensions to GTFS-Flex is to inform users of paratransit options in a standard way, increasing awareness of paratransit options.

3.2.5. Wayfinding Applications

A large number of wayfinding (or navigation) applications exist today. A number of these applications are specifically intended to help individuals with mobility disabilities identify routes they can use safely and conveniently. Wayfinding applications typically provide origin-to-destination routing; however, most wayfinding applications are not useful for people with mobility disabilities because the applications do not include details that allow individuals with specific travel needs ascertain whether suggested routes are accessible and safe for them.

For example, Google Maps is one of the widely recognized wayfinding applications that provide guidance for routing along fixed-route transit service and general sidewalk information as part of a Complete Trip. However, it has limited information available on whether the pathway satisfies many key accessibility requirements. For example, it does not include whether a sidewalk is wide enough for a user's wheelchair.

In contrast, the AccessMap application is designed to specifically address these mobility challenges, providing personalized routing (A to B trip planning) while specifically addressing the needs of people with mobility limitations. AccessMap was developed by the Taskar Center for Accessible Technology, which currently leads the OpenSidewalks initiative to help encourage widespread adoption of the OpenSidewalks data standard. OpenSidewalks provides insight on the locations and attributes of sidewalks, curb cuts, crossings, and street furniture in an effort to inform users of routing options and improve their quality of life. AccessMap is currently limited to specific geographic locations because of its reliance on the OpenSidewalks data standard, which has not been widely adopted because of a lack of collection of sidewalk connectivity and attribute data.

3.2.6. Auditory Orientation Applications

Auditory orientation applications assist blind, vision disabled, or deafblind individuals in navigating the environment around them. Soundscape by Microsoft is a specialized orientation and exploration mobility iOS application that enables blind, vision disabled, or deafblind travelers to spontaneously travel and explore new pedestrian environments without having to specify a destination. Soundscape uses audio cues to help the user build a mental map and make personal route choices while being more comfortable within unfamiliar spaces. It does this by using data from multiple sources, including OpenStreetMap, along with the user's current location, to provide the user with an audio description of landmarks and features of interest or importance. For example, the "Around Me" command will call out four points of interest in a 360-degree sweep, and the "Ahead of Me" command calls out five items in front of the user. This allows users to connect with their environment naturally and more intuitively without interfering with what they are doing or who they are with. Location and orientation are tracked with the device's location and activity sensors. Soundscape provides wayfinding assistance by using "audio beacons" set by users to guide them around the environment. Soundscape is available globally.

3.2.7. Third-Party Applications

Third-party mobility applications have also emerged. These apps provide a variety of traveler services, each designed to meet the needs of specific populations based on data to which the developer has access. An example of this type of application is Citymapper, which provides public transportation directions in major cities. Citymapper uses the same GTFS data as other applications, such as Google Maps. Some third-party applications, such as Citymapper, are aimed at the general public. Others are aimed at specific populations of travelers, such as Soundscape. Third-party applications are supported by a wide range of agencies, foundations, and private companies.

3.2.8. Environmental Simulation Applications

Environmental simulation applications, often referred to as "digital twins," create a digital representation of physical objects or places. Digital twin applications can be used to model physical places, processes, or people's behavior. These applications have generally been used for engineering solutions, and their use in simplified formats during the COVID pandemic have provided virtual tours of real estate being marketed for sale or rent. Some companies, including Unity Technologies, are exploring digital twin applications for modeling places in 3D, including transportation hubs.

3.3. Current System Stakeholders and Actors

The UW ITS4US Deployment project is led by the UW's Taskar Center for Accessible Technology, supported by the Washington State Transportation Center, with Cambridge Systematics leading the development of this Concept of Operations document. Studio Pacifica, UW's co-Design partner, will support this project by providing leadership for relevant stakeholder engagement (in the manner of community outreach, and the coordination, organization, and management of three co-design workshops). The project involves collaboration among all parties listed below in order to be successful. These parties include technology companies that can help scale data systems nationally, such as Google Inc., Microsoft Inc., and Facebook, which purchased the crowdsourcing data company Mapillary, as well as application developers that consume the data, such as Unity Technologies. Transportation service providers that supply data and services and wish to support their customers play an important role, with the City of Bellevue as a project partner. The project also includes three infrastructure owner-operators: the Washington State DOT, Oregon DOT, and Maryland DOT. The three state DOTs all support transit operations in their respective states and work with pedestrian-built environment data. The end users who experience travel barriers are actors within the current system.

Source: University of Washington, Cambridge Systematics, Studio Pacifica, Google, Microsoft, Mapillary, Unity Technologies, City of Bellevue, Oregon Department of Transportation, Washington State Department of Transportation, and Maryland Department of Transportation.

3.3.1. Stakeholders

The following stakeholders are involved in the operations and maintenance of the existing systems.

3.3.1.1 University of Washington

The UW is leading this project. The UW Team is led by the Taskar Center for Accessible Technology (TCAT) at the UW, whose mission is to develop and deploy open-source technologies that improve the quality of life and independence of people with disabilities. One of the Taskar Center's main focus areas is mobility and access to transportation. The Taskar Center has built and is operating functional versions of OpenSidewalks, which is a UW-initiated effort to define, collect, and disseminate open, routable, pedestrian transportation network data in a way that is scalable, extensible, and sustainable. The center also led the development of the AccessMap application (an open source, public, interactive, and individualized pedestrian accessibility map), which uses the OpenSidewalks data service, scaled to the city and county levels. The TCAT is also part of the open standards community developing GTFS-Pathways and GTFS-Flex extensions.

The Taskar Center is supported by the Washington State Transportation Center (TRAC), whose user role on campus is to connect UW faculty, researchers, and students with the state's publicly owned transportation service providers and facilitate research into improving the services they provide.

The Taskar Center has built a suite of tools for data management and maintenance, as well as a computer vision pipeline to reduce pedestrian-viewpoint videos to detailed mapping information. There currently is a prototype pipeline for a mapping application that is scalable and extensible, once the imagery data are available. The Center also is developing tools for data management and maintenance that provide the foundational data infrastructure to support publishing and maintaining data about the public right-of-way, GTFS-Pathways, and GTFS-Flex.

3.3.1.2 City of Bellevue

Bellevue is a city in the greater Seattle Metro Area with a forward-thinking approach to data and emerging technology implementation. In the past decade, Bellevue has made significant investments in ITS, such as the citywide adaptive signal control system and a high-speed fiber network, enabling productive technology partnerships. The City of Bellevue provides a local municipality context to deploying data standards that could be scaled up at large. Bellevue is part of the UW's project team and is an active supporter of the development of GTFS Pathways and GTFS Flex data standardization. With the arrival of six new Sound Transit Eastlink light rail stations in 2023, the City of Bellevue will be an ideal location in which to develop and implement the GTFS data standards undertaken by this project to ensure that these new facilities are highly accessible for the disabled population.

3.3.1.3 Google Inc.

Google operates one of the largest mapping companies in the world. Google Maps offers satellite imagery, aerial photography, street maps, 360-degree interactive panoramic views of streets (Street View), real-time traffic conditions, and route planning for traveling by foot, car, bicycle, and air (in beta), or public transportation. The company has a strong interest in navigation applications and the data standards and infrastructure supporting these applications, having helped develop GTFS. The adoption of the GTFS standard is largely due to the ease of use of the Google transit trip planning software and its ready availability through different electronic devices. Google Maps continues to look to ways to expand transportation navigation and is an active participant in the GTFS-Flex and GTFS-Pathways standards efforts, as well as in developing navigation applications for people with mobility disabilities.

3.3.1.4 Microsoft Inc.

Microsoft is a software development company that performs considerable research, development and testing in the areas of mapping, navigation, artificial intelligence, and cloud computing. The company has a strong commitment to accessible technology, having recently created a new center for research and education on Accessible Technology and Experiences at the UW. The UW and Microsoft have worked together in this area for more than a decade and share the same interests to work with the disability community to develop =innovations for accessibility. This partnership has created student internship and career opportunities, as well as ongoing research engagement with the Ability Team at Microsoft Research. Current projects include developing audio-first representations of websites for smart speakers; understanding how perceptions of software developer job candidates with autism may impact hiring decisions; AI-based sign language recognition and translation, as well as ongoing work on an ASL to English dictionary; and data-driven mental health apps. Another research project is Microsoft Soundscape, which explores the use of audio-based technology to enable blind, vision disabled, or deafblind travelers to receive detailed, step-by-step navigation, as well as thorough descriptions of the surrounding environment, all through a smartphone application.

3.3.1.5 Mapillary/Facebook Inc.

Mapillary is a street-level imagery platform that scales and automates mapping by using collaboration, cameras, and computer vision. Facebook recently acquired the company. The combined firms are committed to developing open, innovative technologies that extend the capabilities of all communities and enhance their quality of life. The mission of the World.AI team is to map the continuously changing world by leveraging AI and the OpenStreetMap community and to maintain the map information open and shared. The World.AI team's focus has been to help build tools and infrastructure to support underserved communities in their efforts to improve open-source map data for their regions. Expanding those data to contain support for individuals with disabilities is a natural extension of the team's work and aligns with the overall mission of Facebook's World.AI team. Facebook's recent acquisition of Mapillary allows for access to extensive, crowdsourced street-level imagery.

3.3.1.6 Unity Technologies

Unity is one of the leading platforms for creating and operating interactive 2D and 3D content. Unity is a key player in the development of software visualization tools and solving real-world problems using various types of available datasets, including GTFS. One of the company's primary areas of work is in the use of virtual reality and augmented reality systems. Unity's technology is the basis for most virtual reality and augmented reality experiences, according to

Fortune[1] magazine. For example, Unity software is used in the automotive industry to help design virtual world car testing simulations. Unity has been working with the City of Bellevue for several years to build tools for the efforts to reach the city's Target Zero goals with greater cost-efficiency. Specifically, Unity has been focused on pedestrian interactions at intersections and has worked on creating models of how pedestrians interact with vehicles.

3.3.1.7 State Departments of Transportation

A state DOT is the lead agency for planning and support of a U.S. state's land, air, and sea-based travel systems. Beyond their primary function of being an infrastructure owner-operator for the state-based highway system, state DOTs often oversee and financially support paratransit initiatives that occur in portions of the state, and often have influence with local transportation agencies and transit organizations. The three state DOTs that are participating in this project are Washington State DOT, Oregon DOT, and Maryland DOT.

3.3.2. Actors

Actors, as presented in **Table 2**, represent the stakeholders that interact with the existing system components in some way. Unlike other stakeholders, actors directly use the existing system components in some capacity as part of their operations.

Table 2. Actors of the current system.

Actor/User Class	Type	Short Description	Role Within the Current System
Municipal Infrastructure Owner-Operators	Data Generator	Governmental bodies that own, operate, and maintain pedestrian-built environments.	Operate and maintain sidewalk environments, and the data that describe them, that may be mapped through independent, standalone efforts.
Private-Sector Pedestrian-Built Environment Owner-Operators	Data Generator	Private-sector infrastructure owner-operators who own, operate, and maintain pedestrian-built environments.	Operate and maintain sidewalk environments that may be mapped through independent, standalone efforts.
Elevation Data Provider	Data Generator	Public- or private-sector organizations in the business of collecting topographic elevation data.	Collect and provide elevation data that can be used by application developers for development of navigation applications.

[1] Gaudiosi, John (19 March 2015). "This company dominates the virtual reality business, and it is not named Oculus." Fortune. Archived from the original on 5 December 2018. Retrieved 26 November 2018.

Actor/User Class	Type	Short Description	Role Within the Current System
Transit Agencies	Transportation Service Provider	Public- or private-sector transit agencies or transportation operators that offer fixed-route or on-demand transit service, and may own, operate, and maintain transit station facilities.	Provide regular GTFS feeds with transit scheduling information, which can be acquired by application developers.
Crowdsourced Sidewalk Reporters	Data Service Provider	Private citizens who utilize sidewalks and have the capability to report condition data.	Crowdsourced sidewalk reporters are currently used in standalone, independent efforts, such as OpenStreetmap and OpenSidewalks.
Mapping Services	Data Service Provider	Private-sector organizations in the business of mapping pedestrian-built environment data.	Mapping services generate data, which can be detailed infrastructure data. Currently, they are not producing scalable data on pedestrian environments.
Weather Data Provider	Data Service Provider	Public- or private-sector meteorological organizations in the business of collecting weather data.	Weather data providers generate up-to-date weather data, which can be accessed and used by application developers.
AccessMap Developers	Application Developer	Developers of the current service provider of sidewalk data.	AccessMap developers currently use the sidewalk data available to provide the existing AccessMap navigation application, which operates only in certain geographical areas.
Soundscape Developers	Application Developer	Developers of the current provider of audible cue information services.	Soundscape operates as a standalone system that functions based on available data, not yet incorporating detailed sidewalk information.
Digital Twin Developers	Application Developer	Developers of the current provider of visual 2D and 3D built environment data services.	Developers and operators of Digital Twin, which currently is used for applications such as modeling pedestrian-vehicle interactions and navigation through indoor spaces.
Third-Party Application Developers	Application Developers	New applications that aim to provide a service to end users.	Work with available data on pedestrian environments and transit service to develop navigation and other applications.

Actor/User Class	Type	Short Description	Role Within the Current System
Travelers With Sidewalk Preferences	End User	Travelers with routing and urban exploration preferences in sidewalk environments.	Utilize navigation services that currently are available, which may include a range of detail on transit service or pedestrian environment.
Blind or Vision Disabled Travelers	End User	Travelers who navigate spontaneously and wish to explore new, unfamiliar pedestrian environments.	Utilize navigation services that are currently available, which may include a range of detail on transit services or pedestrian environment.
Deafblind Travelers	End User	Travelers who benefit from additional navigation information when utilizing sidewalks, transit services, or unfamiliar pedestrian environments.	Utilize navigation services that are currently available, which may include a range of detail on transit services or pedestrian environment.
Travelers with Hearing Disabilities	End User	Travelers who benefit from additional navigation information when utilizing sidewalks or transit services.	Utilize navigation services that are currently available, which may include a range of detail on transit services or pedestrian environment.
Sighted Older Adults	End User	Travelers who seek to explore, assess, and visualize a trip path through a transit station in advance and that use on-demand transit services.	Utilize navigation services that are currently available, which may include a range of on-demand transit services as well as transfers at transit centers, or that require specific sidewalk attributes in the pedestrian environment in order to reach transit services.
Low-Income Transit Users	End User	Travelers who utilize public transportation in lieu of a more costly personal automobile.	Utilize navigation services that are currently available, which may include information on a range of transit services, transit facilities, or pedestrian environments.
Rural Transit Users	End User	Travelers in rural areas who utilize transit services, including on-demand services.	Utilize navigation services that are currently available, which may include a range of details about on-demand transit services or pedestrian environments.
Veterans	End User	Travelers who typically are in rural environments and need access to veterans' services.	Utilize navigation services that are currently available, which may include a range of details about on-demand transit services or pedestrian environments.

Actor/User Class	Type	Short Description	Role Within the Current System
Multilingual, Multicultural Travelers	End User	Travelers who seek to explore, assess, and visualize a trip path through a transit station in advance in a format that aligns with their native culture or language.	Utilize navigation services that are currently available, which may include a range of detail on transit services, transit facilities, or pedestrian environments.

Source: University of Washington and Cambridge Systematics.

3.4. Support Environment

This section describes the support concepts and environment that apply to the current systems. It also describes the additional equipment maintenance services necessary to keep the existing components active. The support environment in this project includes stakeholders that produce transit or sidewalk data or host the mobility applications that support the current system.

3.4.1. Data Producers, Contributors, and Aggregators

Systems exist among various stakeholders that house sidewalk or transit-related data. In the current situation, these systems are operated and maintained by their respective hosting agency or organization, regardless of whether that organization is in the public or private sector.

3.4.2. Navigation Applications

The two standalone applications of the current system include TCAT AccessMap and Microsoft Soundscape. Each system is supported by the maintenance efforts of its host agency and must comply with its information technology (IT) policies and procedures.

3.5. Modes of Operation for Current System

The current situation includes several different standalone systems that all serve different roles. As such, a degraded or failed mode of operation of one system should not affect the other systems. User experiences will vary dramatically depending on which part of the current situation experiences a degraded mode of operation. In addition, the full functionality of the systems to be delivered through this project do not exist, and therefore most of the target population are not aware of the transportation services currently available and do not use them.

Several modes of operation are envisioned for the current situation and its standalone systems: normal, degraded, and failure.

- **Normal Mode of Operation—**In this operational mode, all standalone systems are functioning properly. Data providers are able to showcase their data on their respective systems or websites. The AccessMap and Soundscape applications are fully operational and providing users with the latest information. For AccessMap, this involves three cities: Seattle, Bellingham, and Arlington, Wash. User satisfaction is at its best potential rating for the current situation so long as one is traveling in these cities. Soundscape works worldwide, but delivers audible cue information that includes only the map-based points of interest currently available to it. Cities, counties, and other agencies collect data about their sidewalks, including the locations of access ramps and other features, but those data are not accessible to the public for planning navigation routes. Similarly, transit agencies have data about on-demand transit operations and transit center layouts, such as in their printed service schedules, maps, or electronic records. However, those data are not in a standard format or readily accessible to the public, which often has difficulty learning about those services and facilities. The current standalone systems, discussed in the previous section, operate under the normal mode of operation.

- **Degraded Mode of Operation—**In this operational mode, some or all of the standalone systems are not operating at their full potential because of reductions in operational capabilities within that system. Examples include data providers with resources on a website that goes offline, or application services that become intermittently available.

  In this mode, users perceive data providers as having data and application services that are still functional, but the reliability and perceived availability of these resources are diminished. This impacts the AccessMap and Soundscape applications. The scale of impact depends highly on the extent of the outages. The reductions have little impact on other uses of sidewalk, transit center facility, or on-demand service information, as these data are not routinely accessed in the current condition.

- **Failed Mode of Operation—**In this operational mode, some or all of the standalone systems are not operating at all because of removal of that system. Examples include data providers that remove all resources from their websites, or application services that discontinue their services.

  In this mode, the users perceive that the item(s) in question is no longer available. With no expectation of it being restored, users may move to a different competing service or lose interest altogether in the benefits that were offered. This applies to both the AccessMap and Soundscape applications. For the public data sets to be expanded and included in this project, failure of those data systems would eliminate the use of those data for the agencies, which would be bad for those agencies. But since those data are not routinely used outside of those agencies, failure of one data system will not cause other systems to enter a degraded or failed mode of operation.

3.6. Operational Policies and Constraints

This section provides policies that may govern the current systems operation, as well as constraints that currently exist.

As discussed in **Section 3.2**, current systems stakeholders operate independently, with their own objectives, policies, and constraints. While AccessMap and OpenSidewalks seek to collect and provide detailed sidewalk infrastructure, other navigation applications are not collecting the same level of detail. Therefore, navigation applications across the U.S. and the world feature varying levels of detail on the pedestrian environment.

In regard to transit data, although GTFS Pathways and Flex extensions are being developed, there is a lack of coordination among application developers, transit agencies, and sidewalk data generators. Transit agencies generate GTFS data with certain fields that include basic attributes, such as routes, stops, and stop times. However, a major constraint is the lack of a rational business plan for transit agencies to generate and distribute data with important accessibility attributes, such as GTFS-Pathways and GTFS-Flex. Similarly, on-demand and paratransit services are not required to provide their service attributes.

Several major constraints exist related to the current operations of AccessMap. Although TCAT is involved in collecting detailed sidewalk data, the capabilities to collect scalable sidewalk data throughout the U.S. do not exist. With the data that are currently collected, another constraint exists, as TCAT does not have the ability to effectively validate all of the data used by AccessMap. The data that are collected are validated via crowdsourcing efforts. Another major constraint is the lack of both a cost-efficient method and well-defined process for validating sidewalk conditions and roadway crossing attributes. Digital Twin examples exist in the current system, but two major constraints exist. The first is the absence of a cost-effective data collection system for obtaining the digital data needed to create the simulated environment. The second constraint is the lack of applications that use the data and provide significant benefits to the agencies that collect the data.

4. Justification for and Nature of Changes

TCAT at the UW has dedicated the past six years to analyzing ways to improve access to mobility and transportation for people with mobility disabilities. In particular, it has prioritized the development of infrastructure to use interoperable shared data standards to extend and scale the data available for travelers of all abilities. TCAT has gathered valuable information about data availability, data pipelines, and informational needs from a large number of different stakeholders, including representatives from private data companies, transportation providers, community-based organizations, governments and municipalities, and riders with specific travel preferences (including people with disabilities, older adults, those with low income, rural residents, veterans, and those with LEP).

What began as TCAT's development of the OpenSidewalks data standard, whose usability was tested through the development of the AccessMap and Walksheds applications, has evolved into a more scalable and sustainable concept through this UW ITS4US Deployment project. As stated previously, the UW ITS4US Deployment project is intended to 1) coordinate collaborative releases of data standards, 2) publish and maintain interoperable data infrastructure, and 3) deploy and sustain three accessible mobility applications deployed in the evaluation and testing of the usability and efficacy of the data standards developed in phase (1) and the supporting infrastructure developed in phase (2). The focus of the project is to produce not just any transportation data, but to build a transportation data-sharing infrastructure that takes an intentional and directed approach to assuring inclusivity and accessibility.

This section outlines the challenges associated with the current situation and the desired capabilities of the proposed UW ITS4US Deployment system. Much of the work to understand the shortcomings of the current situation (outlined in **Section 4.1** and identify the user needs (outlined in **Section 4.2** has been done through the following set of collaborative research, standards development, and application development efforts:

- Previously published research by USDOT's Accessible Transportation Technologies Research Initiative (ATTRI) program.
- Previously published work by the Transportation Cooperative Research Program (TCRP), such as TCRP-210, Development of Transactional Data Specifications for Demand-Responsive Transportation.
- Research performed by the UW to develop the OpenSidewalks data schema.
- Research performed by the UW to develop the AccessMap and the personalized pedestrian network analysis, or Personalized Pedestrian Network Analysis (PPNA) software and the personalized routing process developed for that application to meet the needs of users with different abilities.
- Research performed by Microsoft Corporation for the development of Soundscape.

- Research performed by TriMet and Google for the development and deployment of the GTFS standard.
- Documented changes to both the GTFS standard and GTFS deployment guidelines over the period of use for that data standard.
- Documented activities for the acceptance review of the OpenSidewalks data standard within the OpenStreetMap community.
- Documented activity to develop formally adopted extensions to the original GTFS standard, including GTFS-Flex and GTFS-Pathways and other associated standards, such as GTFS-Stations, GTFS-Levels, GTFS-Vehicles, etc.
- Documented activities to implement and produce sidewalk data standards with the largest national paratransit operator, MVTransit, and the software consulting firm DXC.
- Various guides and standards published to define and support best practices in the development and deployment of software.

4.1. Justification of Changes

The following subsections discuss the shortcomings of the current situation that provide justification for the changes offered by the proposed system. As discussed earlier, the proliferation of new mobility and wayfinding apps has given travelers an unprecedented ability to plan trips from a single application, creating opportunities for more people to access destinations. However, the TDEI stakeholder population has not fully benefited from this new mobility ecosystem in the same way because most applications still lack relevant details about accessible pedestrian environments, transit station environments, and the on-demand transit services that some travelers use either exclusively (e.g., paratransit) or in conjunction with other modes. Stakeholder engagement efforts conducted as part of the ATTRI program indicated that travelers familiar with the needs and barriers related to disabilities ranked access to information before and during a trip higher than travel options, personal assistance, and even physical access to environments.

4.1.1. Lack of Widely Available Data Objectively Describing the Pedestrian Built Environment

Travelers with specific travel preferences need detailed information regarding travel environments to confirm whether routes will meet their accessibility needs (e.g., Will there be a sidewalk? Will there be auditory information? Will there be a tactile strip to guide me to the train platform? Will the path be wide enough for my wheelchair? Will the hill be too steep for me?). Data at this level of detail regarding the pedestrian-built environment currently are neither consistently collected nor shared.

While most cities and counties collect data on their sidewalks and have growing interest in the importance of their sidewalks and other pedestrian path data, the data are not collected consistently and do not utilize objective attribute criteria or use a standard approach. While many trip planning and navigation applications offer pedestrian pathway information, as shown in **Figure 10**, these data often do not include actual sidewalk information, nor do they include details that are critical to determining whether a path actually is usable by an individual with specific mobility preferences. For example, a manual wheelchair user needs ramps on and off each sidewalk, but that attribute is not discussed in current routing applications.

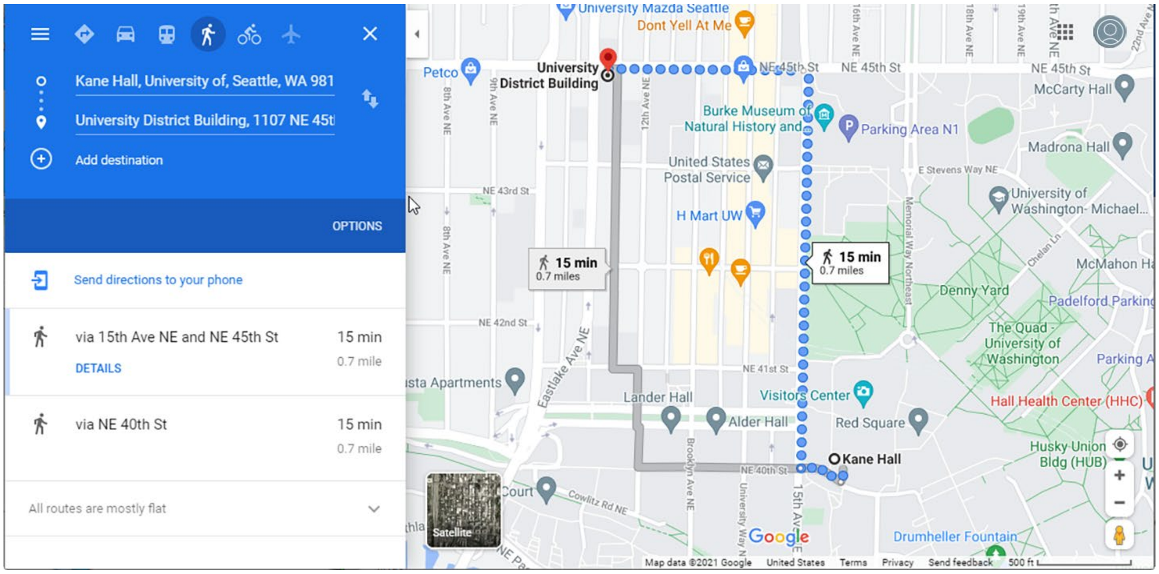


Figure 10. Map. Sample walking paths.

Source: Google Maps.

Multiple challenges exist with obtaining sidewalk data, including the following:

- Different agencies collect data attributes inconsistently and often collect them in different formats.
- Data often are not accessible to outside users because the data are retained within the agency’s design or asset management files and not published to the general public because of the cost of transcribing the level of detail required for certain attributes.
- Data are often not stored in link-node formats that describe the connections between sidewalk segments and allow for routing, meaning that routing algorithms do not recognize two adjacent sidewalks from two separate sources as a complete path.
- Sidewalk data often lack important attributes that are important to specific user groups. Common attributes include sidewalk width, surface type, grade, presence and detailed locations of ramps, and existence of discontinuities in the surface. These enable specific user groups to navigate the sidewalk successfully.
- Sidewalk features and attributes need to be reported using objective measures. That is, a feature cannot simply be labeled as “accessible” because what is accessible for one individual may not be accessible to another with different abilities. So, features need to be objectively measured (length, width, slope, etc.) and reported in consistent, verifiable ways so that individuals can use those metrics to determine whether a given feature is accessible to them.

4.1.2. Lack of Widely Available On-Demand Transportation Service Data

Many transit agencies and municipalities utilize flexible fleets of on-demand, shared vehicles that connect remote users to transit service. These on-demand paratransit services are extremely important for users in rural areas where fixed-route transit services are not available, as well as for disabled users who cannot utilize or easily access traditional transit. Despite being part of the transit agency, on-demand services are difficult to discover and integrate with other modes. The GTFS data standard that is widely used by transit agencies does not describe flex-route transit services, and therefore individuals who use these on-demand transit modes (e.g., Dial-a-ride, paratransit) do not have an equitable chance to discover the available services that meet their travel needs.

Because of the on-demand nature of these services, it is difficult for travelers to get a sense of the following:

- How riders request flexible services.
- The locations at which riders can request pick up or drop off.
- The times when services are available at on-demand locations, the expected pick-up wait time, and the expected travel times between origin and destination.
- Whether the vehicle dispatched for pickup can accommodate a rider’s specific travel preferences (e.g., wheelchair tie downs, driver assistance, bike rack availability).

4.1.3. Lack of Widely Available Transit Station Data

Currently, mobility apps consider the location of a transit station to be the entrance to the station. However, despite most modern transit stations being designed to accommodate individuals with disabilities, the complexity of their environment often makes for an unenjoyable travel experience. A lack of information creates barriers for people who have difficulty accessing transit stations or transit stops because of inappropriate infrastructure (e.g., broken elevators, only stairs). That can be particularly problematic in multilevel transit stations or for accessing infrastructure (e.g., using ticket machines). The GTFS data standard used by transit agencies to describe the fixed-route transit system does not describe transit station facilities.

People with specific travel preferences may need to know the following prior to their trip:

- The specific locations of amenities, such as elevators and escalators, and whether they currently are functioning.
- The specific locations of facilities such as fare gates, ticket vending machines, restrooms, etc.
- The specific locations of transit vehicle platforms and whether there are any barriers between the platform and the transit vehicle.

4.1.4. Lack of Scalable Solutions to Easily Facilitate New Services to Be Available Across a Larger Geographic Region

To plan a route in a neighborhood with which travelers are unfamiliar, most people use a navigation app like Google Directions to plan their route. Since Google Directions is limited in its pedestrian routing features, people need to access additional tools (typically, Google StreetView, Google Earth, or another street imagery app) to visually inspect the built environment at that location and ascertain whether it suits their needs. This visual inspection process can add a few extra minutes, to a few extra hours, to the trip planning process in order for some underserved travelers to feel comfortable taking a trip. An alternative to this process is to send a scout in advance to assess the route. Either of these processes may be preferred over attempting the trip with no additional information.

The lack of the data mentioned in the previous sections means that they cannot be conveniently aggregated or displayed in a single mobile application. Without a common data platform to publish these types of data, application developers face the challenge of having to locate multiple valid data sources to feed into mobility applications, many of which are often region specific, creating scalability issues for those applications. Entities with data to share with the public currently need to develop mobility applications for their data to be discoverable, or look for another entity to publish the data for them. For many data producers or contributors, application development is not part of their expertise. But without a common data platform, data sharing entities need to spend more resources establishing partnerships with trusted entities, reducing the probability that they will see value in generating those data in the first place.

4.1.5. Lack of Data Standards in Practice That Are Sustainable

Without adopted standards, data systems to publish and use sidewalk or transit information experience challenges. Data standards help encourage application developers to utilize the data by providing a framework from which to pull data at scale. They also help data contributors identify how to properly collect, format, and submit data to potential users, providing a similar framework as a guide for their efforts. Once data standards exist, economies of scale allow the development of far more cost-efficient approaches to data collection, storage, and access, and that access supports the scalability in application development required for widespread adoption of those applications.

There are two challenges with the adoption of standards. The first challenge is making sure that the standards have the right features. Without those features, the standards will not meet the needs of users and subsequently not be utilized.

The second challenge is ensuring the data standards are straightforward enough to encourage data contributors to collect and submit information. As noted earlier, attributes must be collected and described in objective ways, as subjective descriptors (e.g., “accessible”) are not universally applicable to all travelers. For example, a description such as “concrete ramp access, 2 percent slope, 5 feet wide” can be used by anyone to determine whether that entrance is accessible to them. Standards that are overly complex or costly to collect will reduce the number of interested data contributors, subsequently causing the standard to have a low rate of adoption. Since these two challenges are competitive, finding the right balance is critical, thus requiring constant coordination among stakeholder groups. If the data pipeline and the databases into which they push data contain data schemas that are not designed with accessibility and inclusivity in mind, retrofitting data schemas can be extremely difficult, resource intensive, and costly in comparison to the costs of creating accessible designs from the onset.

4.1.6. Lack of Demonstrable Workspace for Proposed Standards

No current working system has implemented the proposed data standards at a wide enough scale to significantly encourage data collectors to contribute. In addition, an "interoperability gap" exists between the data-sharing needs of organizations and their capacity for building standards, technologies, and tools to support creation, use, and sharing of these data. Data interoperability is defined as the ability to join and merge data without losing meaning (JUDS 2016). In practice, data are said to be interoperable when they can be easily reused and processed in different applications, allowing different information systems to work together. Interoperability is a key enabler for the development sector to become more data driven, which is necessary for different systems to deliver data to those who need then and in the form they need. Data interoperability and integration are, therefore, crucial to data management strategies in every organization. However, teams and organizations often are overloaded with day-to-day operations and have little time left to introduce and adopt standards, technologies, tools, and practices for greater data interoperability.

4.2. Description of Desired Changes

During TCAT's ongoing work on the development or enhancement of data standards, TCAT has identified user needs through comprehensive stakeholder engagement, in addition to an extensive review of previous research studies, including the USDOT's ATTRI program, and published work by TCRP, such as TCRP-210, Development of Transactional Data Specifications for Demand-Responsive Transportation.

TCAT has been engaged with the following five specific stakeholder involvement groups for the past four years as part of its co-Design process during the development of the OpenSidewalks data standard and AccessMap application. The following stakeholder involvement groups provided insight into the real-world usability of data to be incorporated into the OpenSidewalks data standard and the AccessMap accessible mobility application in development, on which much of the user needs for this project are based:

- People with disabilities and disability advocacy groups.
- Organizations involved in active transportation developments and audits.
- State and city DOTs.
- Paratransit operators.
- Commercial entities involved in producing urban map data and, in some cases, in consuming those data as well as in creating mobility applications and user experiences.

The five groups used to categorize stakeholders were developed to ensure that the perspectives and insights of not just end users but also organizations key to the collection and delivery of the data required to meet end user needs were well-represented in our work.

TCAT has gone one step further to demonstrate the usability of the OpenSidewalks data standard by developing the current AccessMap[2] routing application, which is fully functional in three Washington cities (Seattle, Bellingham, and Mount Vernon) and will soon expand to five international cities as part of a partnership with Microsoft. In addition, Microsoft has already developed and delivered the current version of the Soundscape application.[3] Soundscape accesses digital data that describe features in the geographic area surrounding an individual's location and provides synthesized binaural audio to the user (typically an individual who is blind or has low vision), creating the effect of 3D sound and providing contextual information. It can run in the background on a smartphone in conjunction with navigation applications to provide additional context to the user about the environment.

In the case of both of these applications, improvements in the scale and availability of data that can be accessed by the applications improves the ability of the application developers to serve user needs that their previous work has identified.

Finally, two of the unmet user needs identified in the AccessMap project were the ability to navigate multilevel transit stations and the ability to discover the availability of on-demand transit options. These user needs currently cannot be met because of a lack of available data that describe 1) station layouts and paths through those multilevel spaces, and 2) the availability and characteristics of on-demand transit services. These user needs have resulted in 1) the inclusion of the Digital Twin application, and 2) the extension of the AccessMap routing functionality to include on-demand transit services as part of this project (referred to as Multimodal AccessMap).

To continue to refine the existing understanding of needs for the UW ITS4US Deployment Project, TCAT formed six new TDEI stakeholder groups. Individual stakeholders may participate in more than one group. The categorization presented below separates stakeholders with respect to the nature of the work they will be involved in. Within each of these groups, individual stakeholders will be subdivided, as appropriate, into the five functional categories described in **Section 4.2.1**. Several of these groups are oriented towards data standards that have previously been proposed and are being extended. Those extensions are intended to meet many of the same unmet user needs identified as part of the AccessMap and OpenSidewalks development efforts. By working with these standards groups, the UW Team will maximize the likelihood that the data formats they build into the planned extensions of the Soundscape and Multimodal AccessMap applications, as well as the new Digital Twin application, can be used in any community that can generate the data contained in those standards.

The six current TDEI stakeholder groups formed for the UW ITS4US Deployment Project are as follows:

1. A local community GIS and mapper group to collect neighborhood or city data.
2. An accessibility and equity oversight advisory group.
3. A paratransit accessibility and equity oversight advisory group.
4. Participatory design, testing, evaluation, and validation groups (inclusive of people with lived experience and their support network).

---

[2] http://accessmap.io/.

[3] https://www.microsoft.com/en-us/research/product/soundscape/.

5. A pathways and sidewalk mapping data standards special interest group (inclusive of travelers, application developers, data service providers, transportation service providers, and data generators).
6. An on-demand transit operational data standards (GTFS-Flex) special interest group (inclusive of travelers, application developers, data service providers, transportation service providers, and data generators).

The six groups are organized around the activities that individuals participating in each group will perform. For example, four of these six groups will work with sidewalk data. The local community group will engage members of local groups (either public or private) as part of an investigation into how to use these groups to vet sidewalk data and supplement data obtained through automated procedures. In contrast, the pathways and sidewalk standards group will concentrate on the data standards themselves. These two groups may have some minor overlap but will mostly be two distinct groups of individuals and organizations working on different aspects of the collection, vetting, and use of sidewalk data. The last two groups that will work with sidewalk data are equity-focused groups, which will concentrate on the overriding equity issues associated with the collection and use of sidewalk data. Much of the work for this project will be devoted to resolving the needs associated with these data collection and vetting tasks, along with the development of data provisioning services that distribute these data for use in a variety of applications once they have been collected.

The UW Team will conduct a series of Advisory Committee meetings with interested participants from the six TDEI stakeholder groups, with each series focusing on one of the three data standards. The meetings will focus on how the built environment features should be communicated to users. Conversations will also discuss how those needs must be reflected in terms of how data are metricized in the data standards and thus how they can be collected, either by crowdsourcing, image detection, direct measurements, or other techniques.

4.2.1. User Needs Breakdown

Since this project involves the development of data standards, data infrastructure, *and* accessible mobility applications, the user needs for this project are divided into the following five separate user group categories to capture the user needs from each unique perspective. Unlike the stakeholder groups described above, these categories are functionally oriented. They are designed to capture the needs associated with specific functional activities. Examples of these categories are shown in **Table 3**. Note that specific organizations can fit into one or more of these functional categories.

1. **Data Generators (DG)—**Entities in this group include ***data producers*** from governmental bodies, transportation agencies, or the private sector. Governmental bodies and transportation agencies that own and operate sidewalk infrastructure or transportation hubs typically produce data about these assets. Private-sector data companies typically produce data about travel environments in support of their own mobile applications, some of their customers who consume these data, and digital cartography. Entities in this group may or may not be regulated under other data collection requirements and/or restrictions.
2. **Transportation Service Providers (TS)—**Entities in this group include ***data contributors*** from public- or private-sector transit agencies or transportation operators. They may offer fixed-route or on-demand transit service or may own, operate, and maintain transit station facilities. This user group wishes to inform customers of

transportation service or transit station facility options and may share data directly with application developers or make data available to data aggregators.

3. **Data Service Providers (DS)—**Entities in this group include both transportation service providers that make their own data available to outside application developers and, more importantly, ***data aggregators*** that obtain data from multiple sources (e.g., transit service data from multiple transit agencies, or sidewalk data from multiple cities); fuse those data into a seamless data structure; and provide that seamless data structure to application developers.
4. **Application Developers (AD)—**Entities in this group include ***data consumers*** that create digitally based, user-facing applications with data from public- or private-sector organizations that disseminate data for mapping or travel. Application developers depend on the availability of data from providers of those data to generate solutions that meet the needs of digital-device-users.
5. **Digital Device End Users Experiencing Travel Barriers (DU)—**Users in this group include a specific group of ***data consumers****,* primarily individuals with the lived experience of some disability or their caretakers who utilize digital cartography and information to make informed travel decisions. These decisions include, but are not limited to, identifying optional routes for desired trips and obtaining specific navigational directions for route plans they select. The needs of the end users drive the intent and design of the applications but not the data tools and infrastructure.

Table 3. Examples of users in each user group category.

User Group	Group Abbreviation	Example Organizations
Data Generators	DG	Mapping companies. universities, cities, counties, walking advocacy groups, crowdsourcing, ADA paratransit service providers (e.g., MV Transit)
Transportation Service Providers	TS	Transit agencies, software companies that provide transit service software (e.g., Trillium, INIT, CTS Software, Trapeze, etc.)
Data Service Providers	DS	Google, Microsoft, Facebook, OpenStreetMaps, OpenMobility Foundation, transit agencies, state DOTs, etc.
Application Developers	AD	OpenTripPlanner, RouteMatch, Moovit, AccessMap, Transit App, OneBusAway, CityMapper, Clever Works, Hacon, etc.
Digital Device End Users Experiencing Travel Barriers	DU	Individuals with lived experience, advocacy groups (e.g., Lighthouse for the Blind, AARP, Veterans Affairs)

Source: University of Washington.

Table 4 contains an initial summary of user needs for this project. Each column contains the following information:

- **UN ID—**A unique ID by which to identify the user need.
- **Major Desired Capability and Rationale—**The capability desired by the user group in a solution free manner and the rationale for the need for the capability in the system.
- **Source—**Traceability back to previous research, standards development workshops, or other efforts in which the user need was captured from stakeholders.

Please note that the data standards development efforts have operated in an agile software development method and will likely continue past the ConOps development effort. Therefore, the user needs list presented in **Table 4** will be periodically updated to reflect any changes due to developments of that ongoing work. Refer to **Section 2** for a more comprehensive list of the sources cited in this table.

4.2.2. Priorities Among Changes

Table 4 also prioritizes each of the user needs by classifying them as essential, desirable, or optional and provides a justification for why each need falls into each category:

- **Essential needs.** Needs that shall be provided by the new system.
- **Desirable needs.** Needs that should be provided by the new system.
- **Optional needs.** Needs that might be provided by the new system.

Table 4. Transportation Data Equity Initiative user needs.

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-DG1	DGs need data collection techniques that produce routable pathway networks that describe the path infrastructure in objective, neutral detail and include detailed pathway locations, connectivity, features, and characteristics.	Parent	Essential	A common standard that describes pedestrian pathway graphs, both the traversable paths and their characteristic features that define a routable graph. Routable graphs are needed for any navigation, wayfinding, or travel planning application, as well as for any transportation network analytics.	OpenSidewalks data schema development, GTFS development
UN-DG2	DGs need access to a common, sustainable process for uploading data and metadata, including data provenance features, to shared data repositories.	Parent	Essential	A common data sharing governance policy provides well-understood mechanisms for collecting and uploading data (or otherwise making data accessible to data aggregators), making data standards more widely applicable.	GTiO, OpenSidewalks data schema development
UN-DG3	DGs need clear, unambiguous guidance/guidelines on generating data, including data standard specifications, schemas, and coding instructions.	Parent	Essential	DGs require clear schemas to enable quality data generation.	OpenSidewalks, GTFS-Flex and GTFS-Pathways data schema development

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-DG4	DGs need data standard specifications that are published, version-tracked, vetted, and include governance provisions that allow for effective management of data updates and revisions.	Parent	Essential	DGs require the ability to identify the most current version of a standard and have confidence that the data obtained are accurate.	OpenSidewalks, GTFS-Flex and GTFS-Pathways data schema development
UN-DG4a	DGs need data standard examples.	Child (UN-DG4)	Essential	Examples are necessary for clarifying how data are coded and how the standard can be used.	OpenSidewalks, GTFS-Flex and GTFS-Pathways data schema development
UN-DG4b	DGs need each data standard element and attribute to have specified allowable values and error tolerance levels, where applicable.	Child (UN-DG4)	Essential	Allowable values and error tolerance values are required for initial vetting of data.	OpenSidewalks, GTFS-Flex and GTFS-Pathways data schema development
UN-DG5	DGs need each data standard schema to include information about the database structure and database metadata according to agreed models and schemas and to use standard classifications and vocabularies.	Parent	Essential	This information is required to provide the clarity needed by DGs for collecting accurate data and storing those data within the standard schema.	OpenSidewalks, GTFS-Flex and GTFS-Pathways data schema development

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-DG6	System participants, including both users (ADs) and producers (DGs), need a common definition of data regarding the meaning of the terms used to describe data contents and proper usage of the data.	Parent	Desirable	Data producers and consumers require a human-level understanding of the semantic relationships between different data elements and relationship with real-world entities. Commons requires a common understanding of the semantics used by all groups of stakeholders.	OpenSidewalks, GTIO
UN-DG7	DGs need consistent information models and accepted terminologies/coding systems, which provide the semantic foundation for the sharing of information. Key to this sharing is the ability to not only share labels but to maintain consistency of meaning, particularly across organizations or national boundaries.	Parent	Essential	Semantic foundations are required for the effective sharing of information. Key to this sharing is the ability to not only share labels, but to maintain consistency of meaning, particularly across organizations or different domains.	GTiO
UN-DG8	DGs need tools to vet the data they generate to ensure the data conform to standards and are of consistent, acceptable quality.	Parent	Essential	Generation of large data sets may work well in aggregate, but individual errors occur. DGs familiar with the details of their lived environment are excellent sources for data vetting.	OpenSidewalks

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-TS1	TSs need to be able to publish consistent, standardized, digital data describing the services they provide and the travel environments they manage.	Parent	Essential	Travelers use Internet-based wayfinding and travel planning applications to discover travel options, identify the best choice for them from among options, and book trips.	King County Mobility Coalition, AccessMap, ATTRI, GTFS-Flex data schema development, GTFS-Pathways data schema development
UN-TS2	TSs need to have an effective common data approach through which they can understand, analyze, visualize, and compare their ridership and service efficacy to those of other TSs,	Parent	Desirable	An effective common domain data approach establishes a standards-based approach to business process development and for official industry-wide metrics and performance measures. Transportation agencies are using data analytics to increase throughput, improve security, and help create a better experience for users. Data management and governance principles are, therefore, integral components of organizational strategies and business processes at TSs. Evaluation mechanisms include comparison within and between TSs.	GTiO, W3C, ISO, OGC, Fishman, 2020

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-TS2a	TSs need a common data approach that is coordinated with other TSs	Child (UN-TS2)	Desirable	A common, coordinated approach ensures that agencies measure the same data in the same manner, ensuring consistency of comparisons and use.	GTiO, W3C, ISO, OGC, Fishman, 2020
UN-TS2b	TSs need a common data approach that provides a common set of guidelines across agencies and governments.	Child (UN-TS2)	Desirable	Guidelines are needed to ensure that agencies understand the procedures and standards being implemented.	GTiO, W3C, ISO, OGC, Fishman, 2020
UN-TS3	TSs need to be able to take an organizational approach to data management that reflects and points to oversight and accountability models in order to use data commons effectively.	Parent	Desirable	Data management and governance principles are integral components of organizational strategies and business processes at TSs.	GTiO
UN-TS4	TSs need to be able to name body/bodies responsible for and having authority to publish transportation data.	Parent	Essential	Data management and governance principles are integral components of organizational strategies and business processes at TSs.	GTiO
UN-TS5	To operationalize transportation and transportation data services effectively, TSs need to be able to rely on a sustainable, properly governed data commons.	Parent	Essential	A common data platform provides a single-point location for sending data to a wide audience of customers, which lowers the costs of data distribution and reduces implementation barriers for application development, deployment, and operation.	GTiO, GTFS-Flex data schema development, GTFS-Pathways data schema development

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-TS5a	The data commons needs to be comprehensive, timely, supported by metadata in conformity with appropriate standards.	Child (UN-TS5)	Essential	These characteristics are required by the common platform in order to ensure interoperability across agencies, reduce the cost of tooling the data generation and vetting processes.	GTiO, GTFS-Flex data schema development, GTFS-Pathways data schema development
UN-TS5b	The data contained in the commons needs to be released in multiple formats for different audiences, and in compliance with any applicable laws and regulations.	Child (UN-TS5)	Essential	Different audiences for these data require information to be delivered in different formats (e.g., text versus audio), and thus the data stored in the data commons need to be releasable in those different formats to meet diverse end user needs.	GTiO, GTFS-Flex data schema development, GTFS-Pathways data schema development
UN-TS6	TSs need to offer simple digital transportation data that simplify in-person transactions.	Parent	Essential	TSs are placing greater emphasis on customer experience.	GTiO, GTFS-Flex data schema development, GTFS-Pathways data schema development
UN-TS7	TSs need to offer more and better inclusive travel options in urban areas.	Parent	Desirable	The ATTRI target populations are under-served by current travel options.	ATTRI, Fishman (2020)
UN-TS8	TSs need to make their inclusive travel services easier to discover.	Parent	Desirable	TSs are placing greater emphasis on customer experience.	ATTRI, Fishman (2020)

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-TS9	TSs to be able and willing to accept edits needed to their data.	Parent	Desirable	External stakeholders often identify errors in published data. To maintain data quality, vetted feedback from stakeholders needs to be incorporated into published data, a two-directional feedback loop.	ConOps Walkthrough Feedback
UN-DS1	DSs need to define and adhere to an approach to data governance with respect to open data about pedestrian paths, transportation environments, and on-demand travel services.	Parent	Essential	For organizations to share, distribute, and consume data, data governance processes must be understood by all stakeholders, keeping in mind the purpose for which data are being collected and used. Data governance methods can be centralized, replicated, federated, collaborative, or decentralized.	W3C, OGC and ISO
UN-DS1a	Data governance needs to be a systemic, coordinated, and collaborative approach that offers good practice implementations and examples for handling data interoperability and integration issues from a data management perspective.	Child (UN-DS1)	Essential	These attributes are required to both maintain support for data sharing, and to ensure that newly identified issues are correctly addressed these.	W3C, OGC and ISO
UN-DS2	DSs need a sustainable business model, including resulting performance measures, to keep interoperable data sharing repositories accessible.	Parent	Essential	DSs rely on data consumption of the data they provide to support their business process.	W3C, ISO

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-DS3	DSs need to identify cost-effective ways to aggregate and distribute standardized data that describe the built environment, transportation service, and transportation infrastructure features from multiple agencies or jurisdictions.	Parent	Essential	DSs' goal to help facilitate widespread adoption of the data they disseminate must provide and encourage utilization of those data by other parties. Dissemination is contingent on scalability, extensibility, and interoperability in different geographic markets where there may be distributed data sources.	GTFS development, deployment, and operation, OpenSidewalks data schema development
UN-DS4	DSs need to adopt and agree on common data governance procedures, allowing interoperable sharing and data federation of standardized pathway feature and characteristic data, as well as transit service data and transit facility data.	Parent	Desirable	A common data governance provides recognized processes to share and access a single source of truth for shared data even among distributed stakeholder participants. Data governance eschews interoperability, which, in turn, offers the ability to serve wider audiences, lowering the costs of data distribution, and reducing implementation barriers for application development, deployment, and operation.	GTiO, GTFS development, deployment, and operation, OpenSidewalks data schema development

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-DS5	DSs need to ensure that use of an interoperable data infrastructure will not increase the costs of using the technology (with the exception of marginal initial adoption costs), create difficulties in supporting accessible products, lengthen the time of development for end-user-facing applications, or serve only a small market.	Parent	Desirable	Interoperability should not bring greater complexity or costs, and should reduce implementation barriers for application development, deployment, and operation. It is acknowledged that some initial implementation costs are likely to be required.	GTiO
UN-DS6	DSs need to ensure connectivity of features across different levels of transit stations (e.g., elevators, stairs).	Parent	Essential	Without easily identifiable connections between environments (e.g., from a station to a sidewalk network or bus stop), it is not possible to generate multi-modal trip navigation instructions useful to the target population.	ConOps Walkthrough Feedback
UN-DS6a	DSs need to ensure that data linkages exist when different transit agencies share a physical transit stop.	Child (UN-DS6a)	Desirable	More than one agency may provide service to a specific location. However, they often use different names for their stops. Data that describe these joint or nearby stops need to clearly identify their location in order for navigation directions to be specific enough to help many users make transfers at these locations.	ConOps Walkthrough Feedback

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-DS7	DSs need to ensure that data remains fresh.	Parent	Desirable	If data are not up to date, end users lose confidence in the information they receive and stop using the applications that deliver that information, losing the benefit of the data collection and sharing activities.	ConOps Walkthrough Feedback
UN-DS8	DSs need to support two-way information sharing, with reference to the originator of the data, to help ensure that the ecosystem of data is high quality.	Parent	Desirable		ConOps Walkthrough Feedback
UN-AD1	ADs need data standard specifications to offer clear guidance/guidelines on accessing data, including how to access data and what data are being accessed.	Parent	Essential	ADs need consistent access to data in order to drive innovations in multimodal transportation, accessible transportation planning, and first-mile/last-mile problems, and to narrow the gap between the transit services a community provides and the services its residents need.	Fishman (2020)
UN-AD1a	Data standard specifications need to be published, version-tracked, and vetted.	Child (UN-AD1)	Essential	ADs require the ability to identify the most current version of a standard and have confidence that the data obtained are accurate.	Fishman (2020)
UN-AD1b	Data standard usage examples must be provided.	Child (UN-AD1)	Essential	Examples are necessary for clarifying how data are coded and how the standard can be used.	Fishman (2020)

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-AD1c	Each data standard element and attribute needs to have specified allowable values and error tolerance levels, where applicable.	Child (UN-AD1)	Essential	Allowable values and error tolerance values are required for development of applications.	Fishman (2020)
UN-AD2	ADs need data standards to specify attributes that support in-application interpretation of the available environment/service viz-a-viz the needs of the stakeholder population.	Parent	Desirable	Data standards that reflect end user needs offer greater customization and personalization, which, in turn, offer opportunity for scalable adoption.	OpenSidewalks data schema development, GTFS-Flex data schema development, GTFS-Pathways data schema development, AccessMap development, GTiO
UN-AD3	ADs need interoperable data that minimize the need for special design requirements when diversifying products geographically or to different user populations.	Parent	Desirable	Access to generalizable, standardized data offers opportunity for scalable, cost-effective paths to building accessible applications that close information gaps about pathway accessibility, transportation service, or transit station facilities.	GTFS development, deployment, and operation, AccessMap development

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-AD4	ADs need access to standardized transactional data for on-demand transportation services or mode transfer options in order to integrate these travel options into navigation applications that enable all passengers to seamlessly complete trips involving two or more modes.	Parent	Essential	Information on on-demand transportation services is not as standardized as other transit information, making it challenging to universally find and report.	TCRP 210, AccessMap development, GTFS-Flex data schema development, GOFS data schema development
UN-AD5	ADs need standard transportation service descriptions that establish a common understanding of service attributes.	Parent	Essential	The usability of end-user applications is dependent on a common understanding of transportation service attributes.	TCRP 210, GTFS-Flex data schema development
UN-AD6	ADs need access to detailed information regarding travel environments that connect mode transfers or trip segments in order to integrate these travel options into navigation applications.	Parent	Essential	Information on the pathways that allow for transfer connections is not as available or as standardized as other transit information, making it challenging to utilize.	GTFS-Pathways data schema development, AccessMap development
UN-AD7	ADs need a well-known and centralized governance body and community responsible for the facilitation of the continued discussion, development and maintenance of data standards.	Parent	Essential	Having a single place/community where developers can go to ask questions or propose changes, etc. ensures that the data can be used correctly, and that improvements in the data standard occur as needed over time.	ConOps Walkthrough Feedback

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-AD8	ADs need sidewalk data to describe connections between nodes of the larger transportation network to allow navigation applications to determine routing segments that are critical to traversing some segments of many complete trips.	Parent	Essential	End-user applications have difficulty providing routing functionality without sidewalk data being connected to the rest of the roadway network.	OpenSidewalks data schema development
UN-AD9	ADs need pathway features and characteristics, transportation service, and transit station facility description data need to be compiled from reliable sources to ensure their accuracy and comprehensiveness.	Parent	Desirable	Accuracy and comprehensiveness are elements that help build trust in recurrent users that benefit from these data.	OpenSidewalks data schema development, GTFS-Flex data schema development, GTFS-Pathways data schema development, AccessMap development
UN-AD10	ADs need pathway features and characteristics, transportation service, and transit station facility description data to be accessible in different geographical locations in order to improve the usability and scalability of end-user applications.	Parent	Desirable	Having standardized data widely available (geographically) will improve the market for application developers, which encourages the development and deployment of travel applications that increase use of existing transportation services.	GTFS development, deployment, and operation, AccessMap development

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-AD10a	ADs need access to pathway features and characteristics data with standardized attributes.	Child (UN-AD10)	Essential	Developing custom accessibility applications or translating different pathway feature and characteristic data sources into a standardized format would be too costly for application developers to consider.	AccessMap development
UN-AD10b	ADs need data from multiple geographic locations and transit agencies in standardized formats.	Child (UN-AD10)	Essential	In order for applications to scale, they need data to be available in multiple geographic markets. Data in each of those markets need to be formatted similarly.	AccessMap development
UN-AD11	ADs need descriptors on the data provided in terms of collection date, confidence level, completeness.	Parent	Essential	Because infrastructure conditions change over time, time stamps describing the age of data, as well as confidence levels associated with those data items are needed to allow application developers to understand the reliability of the data, and pass that reliability information on to users, to maintain the credibility of the application.	AccessMap development

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-AD12	ADs need to be able to understand and have confidence in the data governance policies for the data they will be accessing in order to have confidence in the data they are retrieving and using to describe pathway access features and characteristics, transportation services, and transit station facility descriptions. This includes having confidence that the data source contains vetted data and has policies and agreements in place to ensure that it is sustainable, reliable, and trusted over time.	Parent	Essential	In order to attract and retain application developers, potential developers need to have confidence that the single source of truth for pathway features and characteristics, transportation service, and transit station facility description data can be counted on for accurate data now and long into the future.	GTFS development, deployment, and operation, AccessMap development
UN-AD13	ADs need to protect end user privacy by ensuring that interoperable transportation data sharing does not offer access to personal data, whether intentionally or unintentionally.	Parent	Essential	Information sharing and interoperability bring both opportunities and risks to users if their data are unintentionally shared or intentionally shared without their knowledge.	AccessMap studies, OpenData Watch
UN-DU1	DUs need to be able to set boundaries on the allowed release of their personal data in order to gain functionality, while being protected from unapproved data releases.	Parent	Essential	Users are willing to give up some privacy in exchange for better functionality. But boundaries on the release of private data are needed.	AccessMap studies. OpenData Watch, ConOps Feedback

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-DU2	DUs need accessible transportation data need to be clear, understandable, and interpretable when presented to a traveler without that individual requiring special knowledge or training.	Parent	Essential	Information about travel, travel options, and accessibility of travel options should be simple to understand for all travelers.	AccessMap studies, TCRP 210
UN-DU3	DUs need access to accessible, integrated, fluid travel information, including first- and-last-mile options.	Parent	Essential	The Complete Trip concept points to a growing need to make travel more seamless for all travelers with minimal barriers, stoppages, transfers, or digital platforms that need to be accessed to complete a single trip.	Fishman et al. (2020), ATTRI
UN-DU4	DUs need to be able to discover travel options with enough detail to make informed decisions on the best option to meet their unique mobility needs.	Parent	Essential	Travel planning and information services must take each individual's travel preferences into account when calculating "best" paths; otherwise, the route may be inaccessible to that individual.	AccessMap development, ATTRI, Fishman et al. (2020)
UN-DU5	DUs need solutions that organize and declutter the transportation marketplace so that they do not need to use multiple different applications to determine travel options which meet their individual needs across multiple travel environments and services.	Parent	Essential	Travel planning and information services must take each individual's travel preferences into account when calculating "best" paths; otherwise, the route may be inaccessible to that individual.	AccessMap development, ATTRI, Fishman et al. (2020)

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-DU6	DUs need traveler information to be presented in a way that does not expose the user's private data.	Parent	Desirable	Information on on-demand transportation services is not as standardized as other transit information, making it challenging to universally find. This need is particularly acute for those who cannot use or do not have regular access to either a private vehicle or fixed-route transit.	ATTRI, TCRP 210, GTFS-Flex data schema development
UN-DU7	DUs need access to customizable information regarding travel environments, including multilevel and indoor environments, which connect them to or from their vehicle boarding locations, or that facilitate mode transfers or trip segments in order to ensure that any specific accessibility preferences can be met.	Parent	Essential	Information on transfer connections is not as standardized as other transit information, making it challenging to utilize.	ATTRI, OpenSidewalks data schema development, AccessMap development, Soundscape development, GTFS-Pathways data schema development

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-DU8	Stakeholder populations with accessibility preferences need access to transportation network data that is objective and interpretable in order to self-determine whether the physical infrastructure is accessible to them.	Parent	Essential	End-user applications will not function properly without objective and interpretable transportation network data.	OpenSidewalks data schema development, AccessMap development, Soundscape development, GTFS-Pathways data schema development
UN-DU9	Stakeholder populations with accessibility preferences need access to personalized travel planning and information services that are timely, accurate, and available either pre-trip or en-route that can recommend comprehensive "best" paths as a function of each individual's travel preferences.	Parent	Essential	Travel planning and information services must take each individual's travel preferences into account when calculating "best" paths; otherwise, the route may be inaccessible to that individual.	ATTRI, AccessMap development

UN ID	Major Desired Capability and Rationale	Parent/ Child (ID of Parent)	Priority	Justification	Source
UN-DU10	Personalized travel planning and information services need to be available in multiple accessible formats based on the specific requirements of stakeholder populations with accessibility preferences in order to help them obtain information relating to transportation and improve their access to transportation services.	Parent	Desirable	Multiple accessible formats would increase the number of end users that can be served by the end-user applications.	ATTRI, AccessMap development, Soundscape development
UN-DU11	Stakeholder populations with accessibility preferences need travel solutions that are responsive to their real-time needs and wants.	Parent	Essential	Real-time responsive capabilities are important for negotiating changes, emergencies, or spontaneous changes to travel conditions.	ATTRI, AccessMap development, Soundscape development

Source: University of Washington and Cambridge Systematics.

4.3. Changes Considered but Not Included

During the TDEI stakeholder engagement efforts, the following two capabilities were considered, but ultimately not included in the concept development of this project.

The first capability relates to real-time data for OpenSidewalks and GTFS-Flex Realtime data standards. The UW Team intentionally excluded the release and publishing of real-time data for OpenSidewalks and GTFS-Flex Realtime. One important exception is the GTFS-Pathways Realtime feed, which is intended to be specified, as it would report relevant information about infrastructure unavailable for use at transit facilities (like elevators).

GTFS-Flex Realtime was selectively not included because of justified public concerns about the unintended sharing of private and PII about riders (for example, addresses or eligibility) through the publishing of real-time vehicle locations of on-demand transit. It is believed that to adequately address these concerns and undertake the effort of securing PII information in the GTFS-Flex Realtime feeds, this project will require funding, legal, policy, and technical support beyond what is feasible in this program effort. This risk will be mitigated through open discussion and by allowing the adoption of GTFS-Flex Realtime feeds, if and when such feeds become available. Since the minimum viable product (MVP) for Multimodal AccessMap and the other proposed applications is a service that provides navigational directions, not real-time conditions, incredible benefit can still be achieved by publishing the universal static feeds. Real-time data for OpenSidewalks were not included because a reliable source for that information is not currently available.

The second capability that was requested by stakeholders but will not be included as part of the proposed UW ITS4US Deployment system is the provision of unintuitive built environment features. As part of the three standards development efforts described in **Section 1.5**, TCAT assembled a set of desirable built environment features. For each of the identified features to be usable by the digital device end users, the information must be

1. Tagged correctly in the data schema;
2. Able to be collected in an automated manner;
3. Able to be collected by crowdsourced sidewalk reporters in an objective manner;
4. Able to support nongraphic representation; and
5. Intuitive so that digital device end users can indicate their preferences.

For example, crosswalks that have pedestrian push buttons can easily meet all five criteria because

1) Their tag would be universally understood by all user groups listed in **Section 4.2.1**;
2) The pedestrian push button infrastructure is standardized and, therefore, easily identifiable by mapping services;
3) Crowdsourced sidewalk reporters could easily be trained to identify this type of infrastructure along sidewalks;
4) Locations of pedestrian push buttons can be identified via Global Positioning System (GPS); and

5) It would be intuitive for digital device end users to indicate whether the presence of pedestrian push buttons is important to their trip.

In considering an unintuitive built environment feature, such as street furniture, it might be easy to identify and would be intuitive for digital device end users to indicate their preference. However, for automated or manual data collection and nongraphic representation, the lack of standardization in the form or function of street furniture would pose a problem (refer to **Figure 11** for several examples). Several such built environment features will not be incorporated into the data standards until these types of issues have been resolved.

Figure 11. Photos. Examples of street furniture.

Source: Getty Images.

4.4. Assumptions and Constraints

This section describes the standards, rules, regulations, and/or processes with which a proposed system will need to comply. These items are divided between defined assumptions and defined constraints that are important to note.

4.4.1. Assumptions

Defined assumptions focus on conditions that are accepted to be true. In the context of the proposed system, the following assumptions apply:

- **OpenSidewalks is accepted as a sidewalk pathway tool—**Since the proposed system intends to use OpenSidewalks as a primary data schema, it is assumed that contributors to the system (e.g., cities, counties, municipalities, states, private-sector entities, etc.) will utilize that standard.
- **GTFS remains the standard for fixed-route transit service—**Since the proposed system intends to use GTFS to capture fixed-route transit service data among many transit agencies, it is assumed that the standard will remain the de facto standard used by transit agencies.
- **GTFS-Pathways and associated extensions are formally adopted as standard and used by transit agencies—**The GTFS-Pathways extension and its affiliated extensions are assumed to be eventually adopted as a formal GTFS standard. Upon its adoption, it is assumed that transit agencies with station infrastructure will utilize this standard to provide pathway data and make those data readily available.
- **GTFS-Flex extension is formally adopted as the standard and used by transit agencies—**The GTFS-Flex extension is assumed to be eventually adopted as a formal

GTFS standard. Upon its adoption, it is assumed that transit agencies with demand-responsive transportation services will utilize this standard for purposes of discovery in trip planning.

- **The system will be economically scaled—**As the numbers of users and data contributors grow, the system will be scaled in an economical manner.
- **Existing software and services are modified to support new data feeds—**Any existing software tool that is proposed as part of this system will be modified as part of the system to accommodate new data standards and services.
- **Contributors actively participate in submitting data in the proposed data standards—**Since this proposed system is heavily reliant on data contributors, it is assumed that a sufficient number of contributors for a geographic area will participate.
- **Self-sufficiency—**The system will operate on its own with minimal administrator involvement in terms of setting up data. With the exception of validation, data can be added, requested, and transmitted without the need for administrator approval, allowing many processes to be automated. System maintenance is still required, but the effort for normal operations is anticipated to be minimal.

4.4.2. Constraints

Defined constraints focus on external requirements, limits, or other factors that may impact the development and operation of the proposed system.

- **The stakeholder population is limited to certain groups as part of the design.** For purposes of this proposed system, the stakeholder population includes people with disabilities, older adults, or anyone who belongs to one or more of the following categories:
    1. People who experience difficulties accessing pedestrian environments without being provided detailed prior knowledge about the infrastructure connectivity and built environment (either for lack of accessibility or safety information or signage in their native language);
    2. People who use demand-responsive transit options (e.g., Dial-a-Ride or paratransit services);
    3. People who need prior knowledge about transit stations or transit stops because of their reliance on accessibility features within the transit infrastructure (e.g., the need to use elevators and not stairs or escalators, or the need to identify the location of ticket machines before using an elevator); and
    4. People who experience difficulty with typical mobility applications because they are not built with accessibility features in mind).
    Other stakeholders in applicable targeted user groups of the ITS4US Program—such as people with hearing challenges and veterans—may utilize and benefit from the proposed system, but the primary design focuses on the listed stakeholder groups.
- **Use of OpenSidewalks for sidewalk data—**The proposed system will utilize the OpenSidewalks data schema to map the pedestrian network, as it is a comprehensive format that aligns with the goals and objectives of the proposed system. It currently is in

official draft standard form, meaning it may be subject to changes in the future. Such changes may require the proposed system to be modified if system objectives can only be solved with later schema, which may require iterative efforts.

- **Use of GTFS for transit service and station data—**The proposed system will utilize GTFS and its associated extensions as part of the transit feed data collection. GTFS is a widely adopted data standard among transit agencies, but—like all data schema—it has its limitations. Although this standard is the incumbent in the foreseeable future, other competing data schema may be adopted at a later date. Such changes will require the proposed system to be modified to support future data schema, which will require effort by system operators.
- **Limitations of Data Schema for Proposed Data Standards—**The proposed data standards for this project (draft or adopted) have outlined data schema, which provides a limited but defined number of data inputs that can be received by the proposed system. While these data standards are likely to change with newer versions, each structured data schema will provide a constrained number of data input options.
- **Standards Adoption Timeline**—The proposed system intends to provide services to end users by utilizing standards that are still under development, namely the proposed GTFS extensions. Efforts concurrent to development of the proposed system aim to advance these standards into community agreement, acceptance, and adoption, but these steps are dependent on other factors. Delays in adoption or emergence of competing alternatives can have impacts on the proposed system.
- **Reliance on AccessMap—**The proposed system intends to provide its services through the AccessMap platform, which will be modified to accommodate enhanced data feeds (new version will be referred to as Multimodal AccessMap). AccessMap is an existing platform that provides pedestrian-built environment information to users with specified preferences to help them make informed routing decisions. Like any existing software tool, it has some natural constraints due to its architecture, original design, existing policies, and current capabilities in terms of what it can deliver. It inherently relies on continued support from its sponsoring organization (TCAT). To mitigate reliance, the proposed system will allow for independent, third-party application developers to access the same data feeds and provide services as well.
- **Reliance on Soundscape—**The proposed system intends to provide its services through the Soundscape platform, which will be modified to accommodate enhanced data feeds. Soundscape is an existing platform that provides audible pedestrian cues to users with specified preferences to help them make informed routing decisions and explore the built environment that surrounds them as they travel. Like any existing software tool, it has some natural constraints due to its architecture, original design, existing policies, and current capabilities in terms of what it can deliver. It inherently relies on continued support from its sponsoring organization (Microsoft). To mitigate reliance, the proposed system will allow for independent, third-party application developers to access the same data feeds and provide services as well.
- **Reliance on Digital Twin—**The proposed system intends to provide its services through the Digital Twin platform, which will be developed to accommodate enhanced data feeds. Digital Twin is a proposed platform—to be built from other augmented reality tools that exist today—that will provide pre-trip, virtual reality simulation to allow travelers to explore their upcoming trip to help them make informed routing decisions. Like any existing software tool, it has some natural constraints due to its architecture, original design,

existing policies, and current capabilities in terms of what it can deliver. It inherently relies on continued support from its sponsoring organization (Unity Technologies). To mitigate reliance, the proposed system will allow for independent, third-party application developers to access the same data feeds and provide services as well.

- **Geographical Limitations—**The proposed system is designed to be employed in any feasible location geographically, meaning it could be launched in any environment with relative ease if the right criteria were present (e.g., existence of pedestrian built-environment or existence of transit services, etc.). However, as a data service, its coverage is limited to areas where data are being collected and reported by these services. If a community was not collecting sidewalk information (either by the municipal government, private citizen crowdsourcing activities, or third-party data collection services), then the proposed system would consequently not be able to provide quality sidewalk routing data in that locale. Similarly, if transit service in that locale did not report service or station information, then the proposed system would not be able to provide that information, either. Similarly, in environments where sidewalks and transit service did not exist, the proposed system could only report that such services were not available.

5. Concept for the Proposed System

This section defines the background and scope of the proposed system, describes the major aspects of the proposed system and its affiliated stakeholders, and outlines its modes of operations. This section also discusses the support environment in which the proposed system will operate, as well as the operational policies and constraints that should be considered as part of its design. The details presented in this section explain how the proposed system is envisioned to meet the user needs and requirements outlined in **Section 4**.

At a high level, this proposed system will deliver a universal data framework that allows the ability for downstream applications to customize information to DUs in a personalized way. Many facets of the proposed system require co-creation, enhancement, and extension of certain draft data standard schema, namely OpenSidewalks, GTFS-Pathways, and GTFS-Flex. Utilizing these data as a foundation, the proposed system will provide open data end points (i.e., application program interfaces (API)) and data tools for three accessible mobility applications, and will set the stage for many additional applications to be provided by others.

5.1. Background and Scope

The core vision for the proposed system is that travelers need information they can trust. Previous research revealed that many travelers—particularly those with disabilities—remain underserved by the current offering of “new mobility” applications because many relevant pieces of information are spread across multiple applications or not available at all. Stakeholders in this research indicated a desire to be better connected, have the ability to travel more with informed options, and have access to personalized trip planners and services that align with their individual requirements and preferences. Offering new mobility applications that could be used equitably and inclusively by all populations would bridge the current gap but would also require a comprehensive streamlining of infrastructure for scalable data collection, maintenance, information dissemination and sharing, and analytics nationwide.

Detailed, accurate data about pedestrian spaces, travel environments, and travel services are crucial for any trip planner, trip concierge, wayfinding, or exploratory mobility application, particularly for travelers with disabilities, older adults, veterans, those with low income, and rural populations that currently are underserved. The proposed system aims to enhance available data standards and provide the data infrastructure necessary to support the pedestrian-built environment, transit station environment, and transit service information portions of personalized, accessible, multimodal trip planning and exploration applications. Key components include the following:

1. The generation and provision of data that describe transportation infrastructure and services.
2. Trip planning and visualization of pedestrian infrastructure that are focused on traveler preferences.

3. Open data standards for flexible transit services and pedestrian networks that allow data to be easily and consistently used by digital applications regardless of the geographic area or transportation service provider from which those data come.
4. Integration of a more complete mobility analysis system to resolve various first-mile and last-mile problems with a focus on traveler preferences and considerations.

Efforts associated with this proposed system include the following tasks:

- Testing, refinement, and inclusion of automated sidewalk data collection technologies—such as advanced analytics used by mapping technology companies—to populate sidewalk databases.
- Establishment of a mechanism by which cities, counties, states, or private organization infrastructure owner-operators can submit their pedestrian infrastructure-built environment data and vet data submitted by others.
- Incorporation of data from crowdsourced applications to enable private citizens to share local map updates and vet data submitted by others, particularly in regions that are not thoroughly mapped by other entities.
- Refinement of the OpenSidewalks data standard to support more travel preferences in order to encourage widespread use and adoption by application developers that wish to publish sidewalk routing data.
- Refinement of the GTFS-Pathways extension standard to facilitate navigation through multidimensional transit stations in order to support transit use by allowing effective routing of travelers through multilevel transit facilities, as well as enhance the discovery of features and amenities within those facilities.
- Refinement of the GTFS-Flex extension standard to support the discovery and use of on-demand transportation services.
- Creation of tools that help generate data that describe on-demand transportation services in order to enable widespread inclusion of those services by application developers into their trip planning software.
- Development of data pipelines and APIs to ingest and distribute all three data standards at a national scale.
- Development of validation toolsets for assembling sidewalk and transit environment data from multiple providers, as well as establishment of processes to build a comprehensive data environment out of disparate data sets.
- Creation, operation, and maintenance of a data storage repository.
- Creation, operation, and maintenance of public-facing APIs to allow application developers to request data.
- Enhancement of existing multimodal personalized routing web and mobile applications that address the needs of people with mobility limitations, particularly supporting A-to-B wayfinding and urban exploration.
- Enhancement of existing orientation, mobility, and exploration applications that enable blind, vision disabled, or deafblind travelers to navigate in spontaneous travel scenarios

and explore new, unfamiliar pedestrian environments without having to specify a destination.

- Enhancement of existing virtual reality simulation tools that allow travelers (specifically addressing the needs of sighted older adults and multilingual, multicultural travelers) to explore, assess, and visualize a trip path through a transit station.
- Creation of an operating environment for end-user tools to allow demand-responsive transit agencies to publish GTFS-Flex feeds.
- Creation of an operating environment for end-user tools to allow transit station surveyors and ADA consultants to publish their findings in the GTFS-Pathways extensions format associated with the surveyed transit hub.
- Exploration of feasible partnership and business paths to allow commercial and public entities to collect, maintain, and share pedestrian infrastructure maps sustainably in a standard format and help facilitate widespread scalability.

This proposed system will create a data environment that unifies the user experience for the pedestrian-built environment. At its core, this proposed system will develop the data processing components that allow data producers and data contributors to submit their relevant sidewalk and transit information, facilitate the processing of data into a network of disparate pieces, and produce data-on-demand for application developers that provide services to digital device users. It will consolidate several disparate services into a single platform to help make accessing the data stream more seamless and more comprehensive overall. Additionally, by establishing requirements for use standards—namely use of the OpenSidewalks and GTFS data schema—it will provide a complete network that is ready to use, as opposed to scattered files of data in varying formats. **Figure 12** provides a concept diagram of how this proposed system will facilitate the exchange of data.

This proposed system will accomplish other goals. Sidewalk data have historically been difficult to collect and document, mostly because of their expansiveness (e.g., many miles in a community), limited budgets for owner-operators to collect those data, and the lack of an understanding of what attributes are a priority for pedestrians. The proposed system will utilize sidewalk data provided by municipalities that collect this type of information when it is available and reliable, but recognizes the need for other resources to fill existing gaps in the gathering of these data. Mapping companies have a business model that provides routing information as a service to users. These companies often utilize advanced analytics to evaluate aerial mapping or LiDAR data to estimate attributes for routes, often allowing information to be gathered at a wide scale very quickly and at lower cost than traditional data collection methods. Similarly, crowdsourcing communities—utilizing mobile applications—have grown in popularity, helping fill gaps of information that other data collection may miss. The proposed system will include all of these participant groups as key contributors. The vision is that—as this proposed system is rolled out in its initial markets—other groups of similar type will join and help facilitate widespread national adoption.

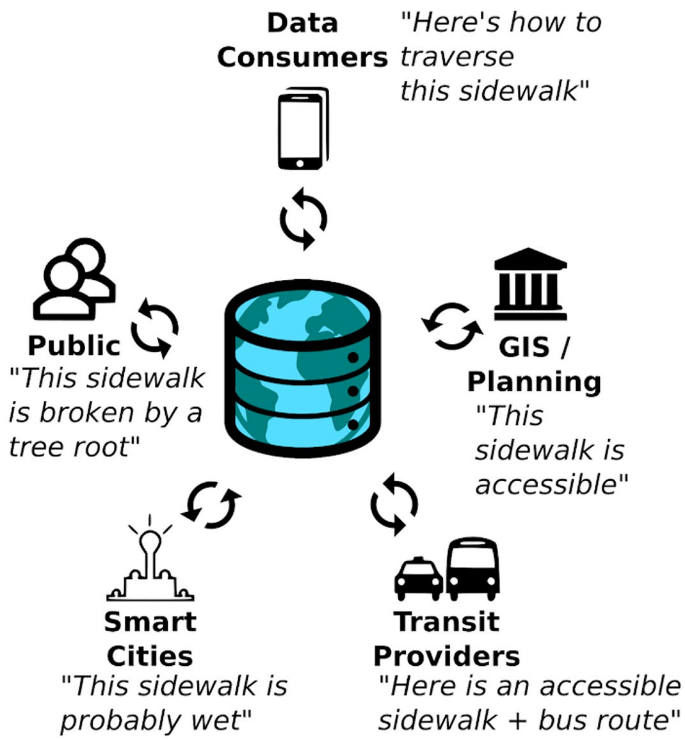


Figure 12. Infographic. Interoperable data infrastructure that enables many downstream stakeholders.

Source: Nicholas Bolten, Veronika Sipeeva, Sumit Mukherjee, Anissa Tanweer and Anat Caspi. A pedestrian-centered routing approach for equitable access to the built environment. 2017. IBM J. RES. & DEV. VOL. 61 NO. 6:10 [November/December 2017] 10.1147/JRD.2017.2736279.

For digital device users experiencing travel barriers, this proposed system will facilitate a data environment in which pedestrian navigation services can thrive, particularly those services that focus on individuals with specific travel requirements and preferences. As part of the development of the data processing tools, the proposed system also will expand the capabilities of two existing applications to include newly available data. These existing applications will focus on a specific set of user preferences, helping expand capabilities of users to navigate along planned routes or spontaneously. It also will allow for new, third-party application developers to access these data resources to develop new, accessible mobility applications.

5.2. Description of the Proposed System

The proposed system will greatly increase the availability of pedestrian pathway data and flexible transit information to all travelers, build sustainable data infrastructure that enables widespread availability for data contributors and application developers, and utilize data standards to help efficiently structure the data needs. In order to accomplish these objectives, the proposed system will rely on several technological subsystems to facilitate the various subtasks that address specific user needs. These subsystems will be organized into a general framework that accomplishes each element necessary to complete the task.

At a high level, a successful system (and all associated task-oriented subsystems) requires the following: 1) a means to collect data; 2) a means to vet, update, and further process the data; and 3) a means to distribute those data to targeted user groups. Various subsystems that serve a role to the proposed system are allocated among these three steps.

Source: University of Washington and Cambridge Systematics.

This proposed system will operate in this framework, with varying levels of effort and/or development among the three functions outlined in **Table 5**. In general, components are broken out among the functions at a high level, with further details provided in the respective subsections in **Section 5.2.1**.

Table 5. Summary of the subsystem components of the proposed system.

Function	Description	Subsystem Components of the Proposed System
Data Collection	These components involve data sets and/or data flows that offer information on the pedestrian-built environment (e.g., sidewalks, pedestrian pathways, etc.), transit station facilities, transit services (on-demand or fixed route), and other data relevant to multimodal travel choices (e.g., meteorological weather data).	• Mapping Technology Company Sidewalk Data Producer Subsystem. • Infrastructure Owner-Operator Sidewalk Data Producer Subsystem. • Crowdsourced Sidewalk Data Aggregator Subsystem. • Transit Agency Data Contributor Subsystem. • Weather Data Service.
Data Processing	These components comprehensively receive, validate, and store data in the data repository to be used in travel planning.	• OpenSidewalks Service Subsystem. • GTFS Service Subsystem.
Information Distribution	These components distribute relevant data sets from the data repository for the accessible mobility environment upon request. These components also collect data from the processing components, convert those data into their own applications, and offer their own service to end users with specific preferences.	• Sidewalk Data Processing Subsystem. • GTFS Data Processing Subsystem. • Wayfinding Application Subsystem. • Auditory Orientation Subsystem. • Environment Simulation Subsystem. • Third-Party Application Subsystem.

Source: University of Washington and Cambridge Systematics.

Many components make up the overall proposed system, and most are owned, operated, and maintained by different stakeholders. Many components reside in their own respective subsystem and are provided their own operating environment, often under the ownership of their respective owner organization. It also is noteworthy that ownership of some key components may change during the lifecycle of the proposed system. To make this solution truly scalable, one alternative is that the data processing components be adopted by one or more commercial data service providers, which would have the resources to expand this system nationally by recouping the value of having the data. This business model is one consideration to note because it will impact the operating system in which parts of the proposed system runs, but it will not change the overall framework. External-facing data interfaces will be necessary among data producers and contributors, the processing components, and the data consumers because these systems will all likely reside in their own operating environments. Personnel, costs, and other operational environment considerations to support these operating systems will vary depending on the organization that operates the respective subsystem.

Figure 13 illustrates major system components, their functionalities, and the respective data flows that are part of this proposed system. Primary interfaces with external systems involve primarily the data flows from the data producers and contributors (e.g., pedestrian-built environment, transit station/service, etc.) defined in the “Information Collection” function, as these interfaces will have to be established for each data resource. An example of this model is how transit agencies from across the world generate GTFS data, which are then accessed by companies such as Google and applications such as the Transit App to deploy navigation applications that use those data. Other interfaces with external systems include processed data flows to applications that serve end users, although the proposed system aims to establish a defined API to facilitate this sharing of data to interested data consumers. Whereas **Figure 5** illustrates the overall project vision, **Figure 13** shows the proposed system broken out among its subsystems. **Section 5.2.1** details the role that each of the subsystems shown in **Figure 13** will play in the proposed system. Each subsystem and its components, in the context of the ITS4US Program, can be subdivided into several different efforts. These efforts include the following:

1) Components that the UW Team will directly develop and test, which primarily include the data validation and data services technologies that serve as the focal point for this project. In the context of **Figure 13**, these components are labeled with a “1” and include the data processing pipelines, the data repository itself, and the service pipelines.
2) Components that the UW team will assist in developing to encourage data contributions, namely tool sets through which the data providers will be encouraged to submit data. In the context of **Figure 13**, these items are labeled with a “2” and consist of tool sets that will serve groups such as municipal governments, transit agencies, and other data providers.
3) Components that represent software demonstrations whose development the UW team will support to demonstrate the success of the pipelines. These include the three applications that have been vetted to provide the services needed by underserved end users. In the context of **Figure 13**, these components are labeled with a “3” and include TCAT Multimodal AccessMap, Microsoft Soundscape, and Unity Technologies Digital Twin.
4) Other components that provide data used within the TDEI and that both already exist and can be obtained via existing APIs operated by data service providers, such as weather and topographic elevation data, are shown in **Figure 13**, but are not labeled with a

number. Similarly, third party applications which will be supported by the TDEI, but that are not part of the formal TDEI deliverables are not labeled with a number.

Figure 14 shows a high level overview of the basic data flows being added by this project that are envisioned for the proposed system's operating environment. Details on the operating environment are described in **Section 5.4**. One important consideration for this proposed system is that ownership of the components may change with time. For example, different weather services or topographic elevation data sources may be substituted from time to time. Applications that currently are managed, operated, and hosted by the UW may be transferred to a private-sector partner (or several partners) that can advance scalability.

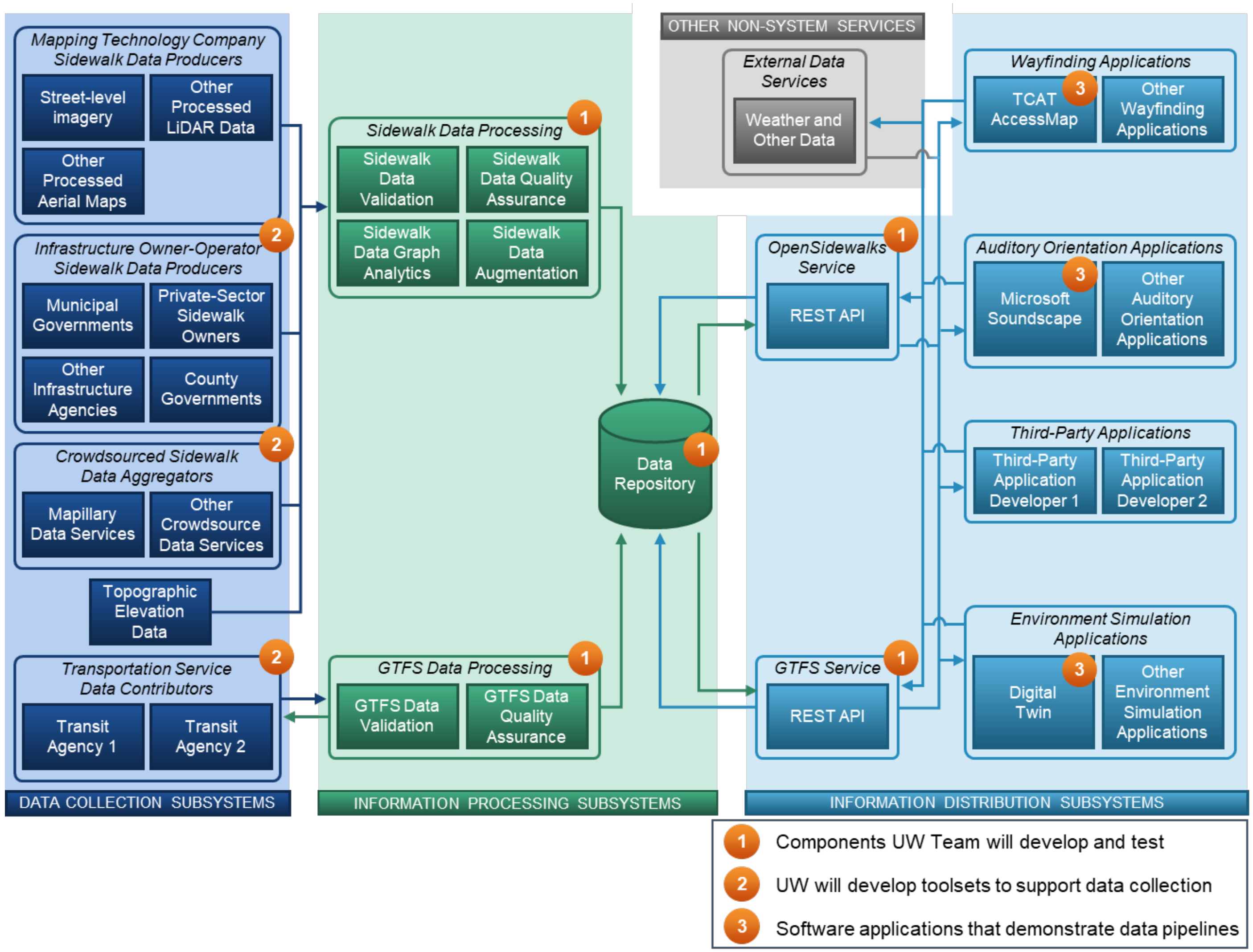


Figure 13. Diagram. Context diagram for the proposed Transportation Data Equity Initiative system.

Source: University of Washington and Cambridge Systematics.

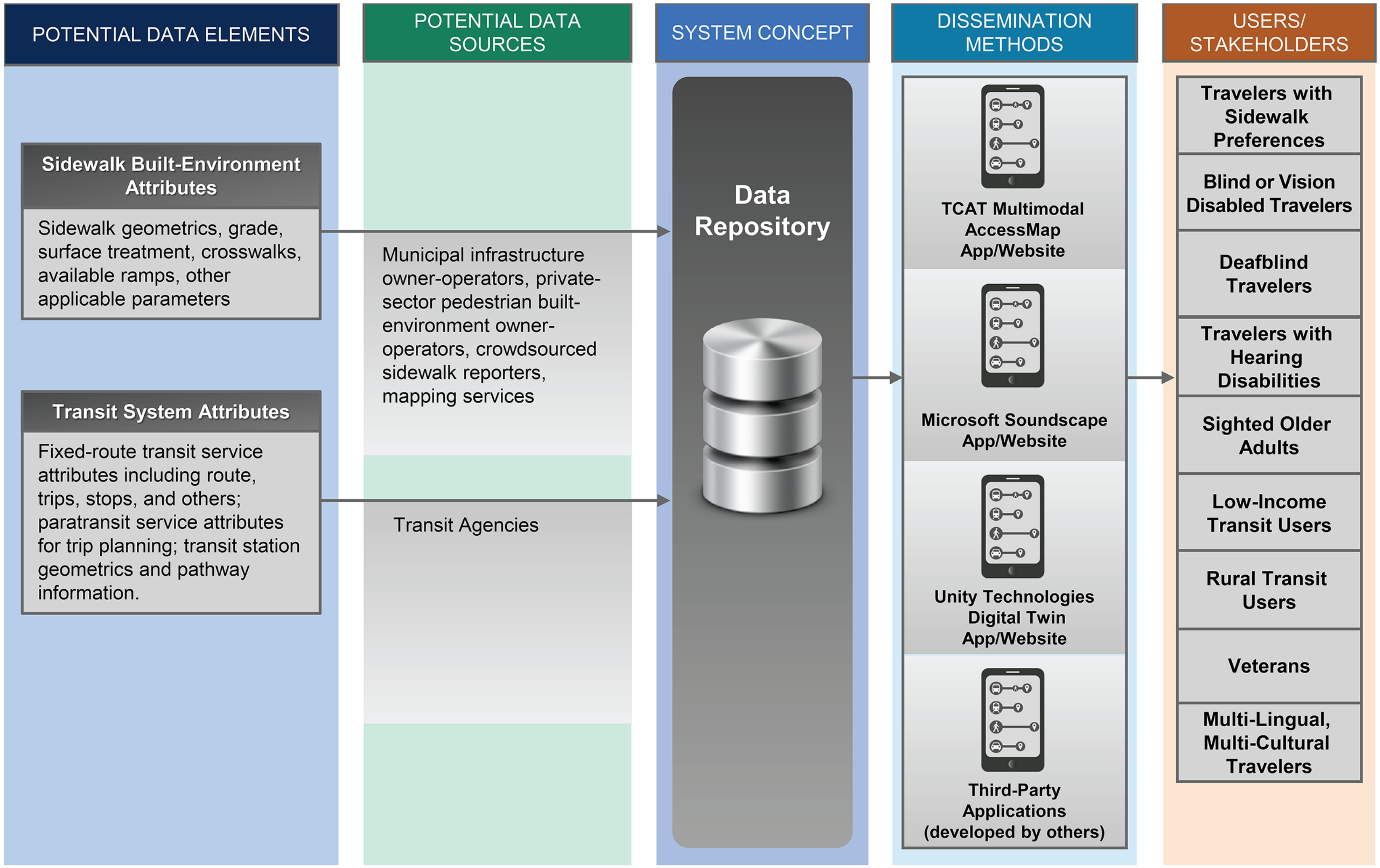


Figure 14. Diagram. Data flow diagram for the proposed Transportation Data Equity Initiative system.

Source: University of Washington and Cambridge Systematics.

5.2.1. Subsystems

The proposed system comprises various subsystems. Generally speaking, a subsystem is made up of several major system components that internally work together to collect, process, and distribute information within that subsystem, often by coupling relevant existing components to a new component. In the case of the proposed system, many of the components are developed and significantly modified in order to accommodate and produce a complete system. As a result, the overall system is decomposed into many relevant subsystems, with each subsystem serving a distinct role in collecting, processing, and distributing data. The subsystems for the proposed system are discussed in the following sections.

5.2.1.1 Data Collection

Mapping Technology Company Sidewalk Data Producer Subsystem

This subsystem manages the conversion of LiDAR and photo imagery data into sidewalk attribute data stored in the routable OpenSidewalks data standard. It includes any number of data producers that provide mapping services and are in the business of collecting pedestrian-built environment data, typically through use of advanced technology for data collection and extensive data processing. Several data providers are in the business of offering high-resolution mapping and geospatial information, often generating attributes through advanced analytics. These providers are envisioned to be private-sector organizations with business models that revolve around providing data as a service. As more data are collected on the built environment, more services can be offered to their consumers. For example, Google Street View—a free service to public users—is one tool that provides street-level imagery on a wide scale and, with analytics capabilities to recognize features and attributes in imagery, could potentially generate information on sidewalks. Other mapping services also operate in this arena; for example, freight delivery robots are often equipped with video and other sensors and could perform this task as part of determining whether specific neighborhoods can be served by that service.

Advanced analytics will allow these data producers to capture significant amounts of sidewalk data in a relatively short time and at a lower cost than traditional manual processes. This will allow for a rapid expansion of coverage in a short time. While they may not capture the entire sidewalk network or all its desired attributes, they provide enough data for other data providers (e.g., infrastructure owner-operators, crowdsourcing groups, etc.) to fill in uncaptured sidewalk links and missing sidewalk features.

All data will need to be collected by these mapping service companies following the OpenSidewalks data schema in order to be inventoried by the proposed system. These data producers will likely have to submit their sidewalk data to the data repository, but alternative systems may be designed in which the proposed system actually pulls the data from these participating data producers.

Infrastructure Owner-Operator Sidewalk Data Producer Subsystem

This subsystem manages the conversion of existing pedestrian-built environment data into the appropriate data standard or the provision of missing sidewalk attributes to other sidewalk databases that can be used for network routing. It includes any number of data producers that are infrastructure owner-operators of pedestrian-built environments, particularly sidewalks, and that may have collected or be interested in collecting data on their sidewalk environments. This subsystem is meant to be one mechanism to aid in the scaling of the proposed system by allowing communities with inventoried data to contribute that data, expanding sidewalk coverage.

Data producers that support this subsystem are primarily envisioned as city government organizations that own sidewalks, mainly because pedestrian transportation modes tend to receive greater focus within cities, but other producers include other sidewalk-owning county, state, or other municipal organizations. To participate in the overall proposed system, these data producers will need to collect and store geographically mapped and attributed sidewalk data for their pedestrian-built environment. These sidewalk data will need to be compatible with, or conflatable to, the OpenSidewalks data schema in order to be inventoried in the proposed system. These data producers will likely have to submit their sidewalk data to the data repository, but alternative systems may be designed in which the proposed system actually pulls the data from these participating data producers.

This subsystem also includes private-sector data producers that have a beneficial motivation to publish sidewalk data. For example, some businesses—such as community commercial districts, malls, or major office complexes—also may want to report sidewalk data to help encourage foot traffic or to help route visitors to specific buildings or destinations. One paratransit operator in the Seattle metro region currently collects sidewalk and path data in the OpenSidewalks data standard to determine the ability of clients to reach fixed-route transit services as part of their eligibility check for paratransit. These OpenSidewalks data are maintained locally by the firm, and the same data can be used to determine whether other nearby clients can access transit services. They also are shared with the public OpenSidewalks instance.

Other services, such as nonprofit organizations focused on helping the disabled, also may opt to collect and report sidewalk data to help their user populations. Similar to public-sector counterparts, all data to be collected by these organizations will need to follow the OpenSidewalks data schema or be merged with such data in order to be inventoried by the proposed system. These data producers will likely have to submit their sidewalk data to the data repository, but alternative systems may be designed in which the proposed system actually pulls the data from these participating data producers.

Crowdsourced Sidewalk Data Aggregator Subsystem

This subsystem manages the conversion of crowdsourced sidewalk data into the appropriate data standard. It includes any number of data providers that collect end user feedback on the asset condition of the pedestrian-built environment. These could range from municipal government organizations with city services that report features (e.g., “311” capabilities for citizens to report a broken sidewalk); to a private-sector application service that allows users to provide feedback (e.g., a sidewalk mapping application in which users can report issues in the application, similar to Waze); to a trusted community organization tasked with vetting sidewalk data and attributes similar to the trusted individuals that vet OpenStreetMaps changes before those changes are published. At the initial phase of the project, Mapillary will serve as a primary data system by which these data are contributed via this subsystem.

Key differences between other data and crowdsourced data are the frequency and scale with which data are reported. Unlike other data sources that may infrequently contribute a large quantity of data, crowdsourced data are reported frequently and for a smaller area (e.g., as far as the user walks on a given trip). However, despite their smaller scale, crowdsourced data accomplish two things that larger-scale data collection cannot: 1) they can provide information for areas where broader data collection efforts fail, such as when sidewalks are occluded from viewing by imagery and LiDAR; and 2) they provide feedback that is more closely tied to a user's personal experience, which can be more useful than objective numbers.

All data collected by crowdsourced data providers will need to be compatible with the OpenSidewalks data schema. These data providers will likely have to submit their sidewalk data to the data repository, but alternative systems, such as data intake and schema translation tools, may be designed in which the proposed system actually pulls the data from these participating data aggregators. Where crowdsourcing is used with trusted third parties to vet sidewalk data entered in bulk, specific applications will be provided to the individuals and groups that will perform those tasks.

Transportation Service Data Contributor Subsystem

This subsystem manages the conversion of transit feed data into the appropriate GTFS data schema. It includes any number of transportation service providers (e.g., public- or private-sector transit service providers or transportation operators) that convert their physical transit environment and transit services data into one of the GTFS data formats, which includes transit services that operate fixed-route or on-demand transit services. This subsystem includes GTFS extensions that may be adopted by transit agencies that wish to increase the availability of digital descriptions of their facilities, allowing a better understanding of services in order to encourage use from prospective riders.

All data that are published in a GTFS format are based on information from each transportation service provider, so effort involved in this data production and data storage resides in the transportation service provider's operating environment. Newer GTFS extensions will require transportation service providers to undertake additional effort to set up these data feeds.

Transportation service providers that operate station infrastructure will benefit from publishing information in GTFS-Pathways, and transportation service providers with demand-responsive transit services will benefit from publishing information in GTFS-Flex. This comprehensive list of GTFS data will need to be published and made available for collection by the proposed system.

All data collected by participating transportation service providers will be published on a web service, either open to the public or through a requested API service. The data processing components will need to query each participating transportation service provider to request its specific feed data. For this proposed system, all transit data will need to follow the GTFS data schema.

5.2.1.2 Information Processing

Sidewalk Data Processing Subsystem

This subsystem manages the validation and quality assurance checks of sidewalk data prior to their storage in the data repository. As a singular service, it receives the pushed sidewalk data from the data producers and contributors, and queues them for validation and quality assurance. As an additional service, this processing element also may utilize elevation data from a credible topographic data source to aid in slope calculation; whether they are pushed or pulled data is yet to be determined.

In this subsystem, sidewalk and elevation data will be validated according to a predefined schema that identifies the allowable data types, non-null values, and custom constraints that align with the expected qualities of these data. Data schema will likely exist for both OpenSidewalks and elevation data. As part of validation, a quality assurance check will be necessary to ensure that the data are credible. This will be an automated process, although the process may vary depending on the participating data producers, contributors, aggregators, and the data they are able to contribute. For example, new data received from a credible data producer (e.g., a well-known mapping service) for a new part of town may undergo automated checks to verify that the data are reasonable and within expectations. Alternatively, new data received from a less-credible data aggregator (e.g., a new crowdsource party) may undergo secondary checks by "approved validators" to make sure the data are realistic for the environment. This secondary process is modeled after that used by OpenStreetMaps.

With various data sources contributing to the data repository, this subsystem will process the accepted data to generate an updated graph network in accordance with the OpenSidewalks data schema. Where new data are added, the processing effort will identify how, where, and whether those data augment or replace existing data or represent new pedestrian paths. New path segments must be connected to the existing pedestrian network and to other new network segments and nodes, and they must contain a minimum set of attribute/features that allow those connected segments to be included in trip plans.

This subsystem is made of new components and represents one of the larger development efforts for this proposed system. It also requires the cooperation of multiple organizations. It is envisioned to be part of the proposed processing system's operating environment along with other processing and storage components. The exact type of operating environment to be used during demonstration will be determined as part of the system design. However, the long-term goal is for this task to undertaken by a commercial data service provider—or several commercial data producers—that has the processing means to expand this component as needed and allow it to more easily support a wider geographic area.

GTFS Data Processing Subsystem

This subsystem manages the validation and quality assurance checks of GTFS data feeds prior to their storage in the data repository. As a singular service, it pulls data from the various transportation service providers that publish GTFS data feeds and queues them for validation and quality assurance.

In this subsystem, GTFS data feeds will be validated according to a predefined schema that identifies the allowable data types, non-null values, and custom constraints that align with the expected qualities of this data. Separate validation schema will be made for GTFS, GTFS-Pathways and its associated extensions, and GTFS-Flex, noting that some of these schema may need to be adjusted during the initial rollout of this system if standards for the newer GTFS extensions have yet to be adopted or are evolving. When data are invalid according to the schema, those data points are removed from the pipeline and reasons of failure are documented.

Validated GTFS data feeds will then run through a quality assurance check as part of this subsystem. This check is expected to be an automated process, as transportation service and transit station facility description data are generally structured by credible resources. However, some manual processes may be necessary for "approved validators" to make sure that data from unusual conditions are correctly handled by the system, given the complexity of some transit services being described in the newer GTFS standards.

This subsystem is made of new components and represents one of the larger development efforts for this proposed system. It is envisioned to be part of the proposed processing system's operating environment along with other processing and storage components. The exact type of operating system used during the demonstration of the system for this project will be determined as part of design. However, the long-term goal is for this subsystem to be undertaken by a commercial data service provider—or several commercial data service providers—that has the resources and business plan required to support ongoing operations, as well as the means to expand this component as needed and allow it to more easily support a wider geographic area.

5.2.1.3 Information Distribution

OpenSidewalks Service Subsystem

This subsystem manages the distribution of sidewalk data to application services and other external sources that make requests. These requestors issue data requests via this subsystem's Representational State Transfer Application Program Interface (REST API) for a particular geographic area, and acceptable requestors are issued sidewalk data in the OpenSidewalks data schema for that geographic area. As an additional service, this subsystem polls a credible meteorological weather service for that geographic area and provides weather as part of the data request.

In the context of the proposed system, this subsystem serves as a primary data service for Digital Twin, Multimodal AccessMap, Soundscape, and various other third-party applications that request sidewalk path data in a particular geographic area. This subsystem is made of new components and represents one of the larger development efforts for this proposed system. It is envisioned to be part of the proposed processing system's operating environment along with other processing and storage components. The exact type of operating system during demonstration will be determined as part of the design. However, the long-term goal is for the subsystem to be undertaken by a commercial data service provider—or multiple commercial data producers—that has the processing means to expand this component as needed and allow it to more easily support a wider geographic area—ideally nationally or internationally. It will need to provide a specification for the OpenSidewalks API, which will need to be updated as new versions of the OpenSidewalks data schema are developed.

General Transit Feed Specification Service Subsystem

This subsystem manages the distribution of transit data to application services and other external sources that make requests. These requestors issue data requests via this subsystem's REST API for a particular geographic area, and acceptable requestors are issued transit service and infrastructure data in the GTFS data schema for that geographic area.

In the context of the proposed system, this subsystem serves as a primary data service for Digital Twin, Multimodal AccessMap, and Soundscape, and it will at some point serve that same purpose for various other third-party applications that request transportation service and transit station facility description data in a particular geographic area. This subsystem is made of new components and represents one of the larger development efforts for this proposed system. It is envisioned to be part of the proposed processing system's operating environment along with other processing and storage components. The exact type of operating system during demonstration will be determined as part of the design. However, the long-term goal is for the subsystem to be undertaken by a commercial data service provider—or several commercial data producers—that has the processing means and business plan to expand the geographic scope of this system as needed and to allow it to support a wider geographic area more easily, eventually providing national or international coverage. It will need to provide a specification for the GTFS API, which will need to be updated as new extensions are added to the GTFS data schema.

Wayfinding Application Subsystem

This subsystem manages application services that query the data repository for sidewalk and transit data, receive those data, process them into their own user interface, and then provide useful A-to-B wayfinding and urban exploration information to end-users with mobility limitations. Within the application's current geographic area, application services within this subsystem will poll the REST API for the OpenSidewalks and GTFS Service location-specific data. The application services in this subsystem will then process the data in accordance with their goals and objectives, and then report those data to the end-users that utilize the application service.

At the initial phase of the project, Multimodal AccessMap may serve as a primary application for this subsystem. This would require modifications to the existing AccessMap application to incorporate enhanced multimodal data of relevance that are provided by the proposed system, including the addition of enhanced sidewalk data (e.g., side slope data) and transit information. Efforts to modify this application will occur as part of the proposed system.

Other third-party application services that focus on wayfinding may be added to this subsystem as part of subsequent efforts. Regardless of the service, it is envisioned that each application service will operate in its own operating environment, likely hosted or supported by the organization that owns that application. For Multimodal AccessMap, the immediate-term operating environment is hosted and supported at the UW, with longer-term potential for adoption by a commercial routing service.

Auditory Orientation Subsystem

This subsystem manages application services that query the data repository for sidewalk and transit data, receive those data, process them into their own user interface, and then provide useful navigation information for spontaneous travel scenarios for blind, vision disabled, or deafblind digital device end users. Within the application's current geographic area, application services within this subsystem will poll the REST API to request location-specific data from the OpenSidewalks and GTFS Services. The application services in this subsystem will then process the data in accordance with their goals and objectives, and then report those data to digital device end users that utilize the application service.

At the initial phase of the project, Microsoft's Soundscape may serve as a primary application for this subsystem. This application currently provides auditory beaconing information for points of interest. Modifications to Soundscape will be necessary to accommodate the enhanced data of relevance that are provided by the proposed system. This application will be modified as part of the proposed system.

Other third-party application services that focus on auditory navigation may be added to this subsystem as part of subsequent efforts. Regardless of the service, it is envisioned that each application will operate in its own operating environment, likely hosted or supported by the owner organization. For Soundscape, it will remain in Microsoft's designated operating environment.

Environment Simulation Subsystem

This subsystem manages application services that query the data repository for transit station facility description data, receive those data, process them and disseminate them through their own user interface, and then provide useful navigation information for pre-trip visualization and exploration of a potentially multilevel transit station. For the user-designated transit station of choice, application services within this subsystem will poll the REST API to request information for that particular transit station from the GTFS Service. The application services in this subsystem will then process the data in accordance with their goals and objectives, and then disseminate those data to digital device end users that utilize the application service.

At the initial phase of the project, Unity Technologies' Digital Twin is expected to serve as the primary application for this subsystem. This application currently provides augmented reality experiences for users. Modifications to Digital Twin would be necessary to accommodate an augmented reality environment in a multilevel transit station, which currently does not exist. This application will be modified as part of the proposed system. Other digital twin software solutions exist, and could be used as part of this project, should project outcomes indicate other developers should provide this solution.

Other third-party application services that focus on pre-trip augmented reality experiences may be added to this subsystem as part of subsequent efforts. Regardless of the service, it is envisioned that each application will operate in its own operating environment, likely hosted or supported by the owner organization. For Digital Twin, it will remain in Unity Technologies' designated operating environment.

Third-Party Application Subsystem

This subsystem manages all other application services that are both third-party (i.e., independent of the proposed system's development) and not a wayfinding, auditory orientation, or environment simulation application. These application services utilize the proposed system but offer a different service altogether, such as focusing on a different traveler group or presenting information with a different delivery method. Similar to other subsystems, application services within this subsystem will query the data repository for sidewalk and transit data, receive those data, process and disseminate them through their own interface, and then provide useful information to digital device end users that aligns with the services offered by that application. They would poll the REST API for OpenSidewalks and GTFS Service data for the location that is applicable.

This subsystem is a feature of the proposed system. Application services developed within it will operate in their own operating environment, likely hosted or supported by the owner organization.

5.2.1.4 Other Supporting Systems

External Data Services

External data services may include a weather data service to provide meteorological weather data of relevance to the proposed system. Its data, which may include real-time reported conditions or forecasts, are among the few parts of the system that include data that changes on a frequent basis (as real-time conditions occur). The intent is to support applications that offer additional preference capabilities to users, such as those who may not want to walk on steep slopes after rain.

Unlike in other subsystems, the data service providers—namely groups like the National Weather Service—are organizations that produce data for other purposes, such as for a public service. As such, they are indirect actors in the proposed system and should experience no modifications to their existing systems, except as a request to connect to their data service.

5.2.2. Performance Characteristics

The performance of the proposed system will be guided by the Performance Measurement Plan, to be developed as part of Phase I. Performance requirements for individual system components will be specified as part of the systems requirement phase.

Performance measures under consideration include:

- Production of Sidewalk Data—Number of variables collected on sidewalks, quality and accuracy of variables collected on sidewalks, and coverage area collected in terms of the percentage of sidewalks for which vetted data are available within a jurisdiction.
- Production of Transit Data—Number and percentage of transit agencies generating GTFS-Flex data, number of stations mapped using GTFS-Pathways, and quality of data collected.
- Use of Sidewalk and Transit Data—Total number of users on newly developed applications, change in the total number of users on enhanced applications, and customer satisfaction of application users.

5.2.3. Requirements

5.2.3.1 Safety

The safety of personnel and users in the proposed system will be maintained by following the Safety Management Plan, developed as part of the planning activities in phase 1. The Safety Management Plan will examine risks associated with equipment failure, application error, and user error, as well as define a mitigation approach based on the impact severity level of the error.

5.2.3.2 Security and Privacy

Security of the proposed system will be provided through IT safeguards in each respective system to prevent unauthorized access. None of the proposed components currently or will collect PII at any step. For user-facing tools, users will have the option to input their trip preferences, but those preferences will be generalized and not tied to a user's unique identity. In AccessMap, for example, all personal selections (including a user's preferred maximal uphill elevation for routing) are kept on the personal device.

5.2.3.3 Integrity

The proposed system will utilize data validators (checks to ensure that the submitted data fall within specified ranges, are formatted correctly, and include the required variables) and quality assurance processes to check any new data that are received from data contributors. While the proposed system will not be able to automatically discard inaccurate data that are reported by a data contributor (e.g., a transit agency accidentally publishes a new bus stop in an incorrect location), the validation and quality assurance steps will preserve the integrity of the data by allowing storage in the data repository of only information that aligns with defined data schema and other checks. As data history is built for a particular environment, these validators and quality assurance checks will become more robust in identifying potential errors.

5.2.3.4 Continuity of Operations

The core data repository—which serves as the fundamental central point for data sharing—will be stored in the cloud, which will have inherent redundancies as part of the subscription-based service. In the event of a system issue, failover will occur, and the data repository will remain available.

The applications associated with the proposed system all have their own storage plans and redundancy capabilities, which may differ by application and organization. Loss of service due to outage will depend on the application. That said, by maintaining continuity of the central data repository, an outage of one application will not affect the functionality of other applications.

5.2.4. Quality Attributes

Quality attributes are nonfunctional requirements that evaluate system performance. They are critical constraints and restrictions on the design of the system that measure success based on user experience. Further specifics on requirements such as these will be discussed in the system requirements phase of this project, but general quality attributes are defined in this section.

- **Accessibility—**This is a measure of how usable the proposed system is to underserved travelers. The proposed system will collect data that are relevant to travelers with distinct travel preferences and will utilize software applications that are designed for underserved travelers. It will allow new applications to be developed that can further accommodate users with specific preferences.
- **Accuracy—**This is a measure of how close measurements are to a specific value. The proposed system will report information about the pedestrian-built environment, transportation services, and transit station facilities based on information from several sources, so it should provide that information with sufficient accuracy. While accuracy will be dependent on the accuracy of data that are provided by these services, having multiple sources of input—particularly the pedestrian-built environment, which can be reported by municipalities, crowdsourced users, and mapping company algorithms—and the ability to use multiple sources to cross check submitted data will increase the chances that highly accurate data will be circulated.
- **Affordability—**This is a measure of how affordable the system is. The proposed system will store its data and make them available at no cost. While there will be limited control over independent application developers that elect to use the data and charge users for the application, the availability of free information will provide the potential for application developers to enter the market and offer the service for free. In addition, the business model used by most large-scale technology firms is to give away navigation services in return for advertising viewing, allowing affordable access for people of all income strata.
- **Correctness—**This is a measure of how correct an output is relative to an input and/or a specification. The proposed system will use objectively measured data. Those will greatly increase the correctness of navigation directions and other outputs to individuals because

those outputs can be tuned to the specific preferences of the individual. For example, an input of a narrow sidewalk at a particular location will be reported as part of the output for user preferences that indicate this as an item of interest.

- **Dependability—**This is a measure of the system's availability, reliability, and maintainability. The proposed system will be designed to have good availability and reliability to preserve system credibility with associated user groups. Since this is not a mission-critical system responsible for life preservation or safety, it will not be overdesigned to provide uninterrupted dependability, but it will meet or exceed dependability measures for systems of a similar type.
- **Interoperability—**This is a characteristic of the system to work with other products or systems. By utilizing REST APIs and publishing relevant documentation, the proposed system will allow new, third-party application developers to utilize the data easily and efficiently. New data sources also will be able to contribute by following established guidance for sharing data with the data repository.
- **Learnability—**This is a quality of products and interfaces that allows users to quickly become familiar with them. The proposed system will provide information that allows digital device end users to quickly and comprehensively become familiar with the offered services. While the data processing elements may be a bit technical for the average user, they too will be well-documented and designed in an easy-to-understand manner to help facilitate use by new application developers.
- **Maintainability—**This is the ease with which a product can be maintained in order to maximize its useful life. The proposed system will be made up of several parts that are maintained in their own respective operating environment.
- **Scalability—**This is a property of a system that handles the growing amount of work required when resources are added to the system. The proposed system will be capable of adding new data collection services, which will require expanded storage space to accommodate new data. For data distribution services, the proposed system will allow services to be added, with a potential need for increased bandwidth, depending on the number of calls to the REST API. In the long term, a potential outcome for the proposed system will be partial or full adoption by a commercial data processing service, which often has the resources available to allow relatively easy scaling and expansion in comparison to standalone systems.
- **Timeliness—**This is a characteristic of how well the system completes a task before or at a previously designated time. The proposed system will deliver information to digital device end users that is as timely as readily available. For example, the end user will receive information on a recently reported sidewalk condition, as opposed to one that is dated. The proposed system will make credible data available for use in a timely fashion.
- **Usability—**This is the degree to which a system achieves quantified objectives related to effectiveness, efficiency, and user satisfaction. For this project, "users" can be both application developers and digital device end users. The proposed system will allow new third-party applications to be developed in the future that may better align with goals and objectives. The usability of the data system will be demonstrated with these three applications. Additionally, these three software applications also will allow testing of the usability of the data by digital device end users.

5.3. Stakeholders and Actors of the Proposed System

The following sections present the stakeholders and actors of the proposed system.

5.3.1. Stakeholders

Stakeholders, as presented in **Table 6**, represent the entities that will be materially affected by the outcome of the proposed system. Stakeholders include all of the actors that directly interact with the proposed system (discussed in **Section 5.3.2**), as well as the non-actors that provide oversight, project development, or advice. Those identified in this section are the non--actor stakeholders.

Table 6. Transportation Data Equity Initiative stakeholders and key roles.

Stakeholder	Type	Role in the Proposed System
Taskar Center for Accessible Technology and Washington State Transportation Center at UW	System Manager/ System Integrator/ Developer	TCAT and TRAC will develop the proposed data repository concept and work with data service provider partners to make it available. TCAT will lead and coordinate with data producers, data contributors, data aggregators, and data consumers to complete the proposed system. TCAT will coordinate with other stakeholder groups to confirm that the proposed system iteratively aligns with their defined user needs. TCAT will continue development and promotion of the OpenSidewalks data standard and incorporation of on-demand transportation services into Multimodal AccessMap, and will work closely with actors to facilitate adoption of the three data standards.
Cambridge Systematics	Systems Engineering/ Operations Planning	Cambridge Systematics is a transportation consulting firm and partner for TCAT/TRAC's development effort. Cambridge Systematics will provide systems engineering and system performance evaluation services for the development of planning documents that aid in the design of the proposed system. Cambridge Systematics will also help define, plan, and structure the data services and example applications.

Stakeholder	Type	Role in the Proposed System
Studio Pacifica	Stakeholder Engagement	Studio Pacifica will provide leadership for relevant stakeholder engagement, as well as technical support of architectural and landscape site mapping for key transit hubs. Studio Pacifica will also assist in demonstrating how integrated, standardized information about the street environment and on-demand transit modes can solve significant information gaps in the Complete Trip, helping produce replicable, sustainable, accessibility mobility application deployments across the U.S..
City of Bellevue	Developer/ Advisory	The City of Bellevue will support TCAT during concept development for GTFS-Pathways and GTFS-Flex standards development. Bellevue will utilize its new on-demand transit service and other transit systems to help inform the requirements of updated GTFS extensions. Bellevue will participate in concept development workshops, as well as contribute available transit and sidewalk data, user experiences, and insights to help support standards development.
Unity Technologies	Developer/ Advisory	Unity Technologies will augment the team during concept development for the GTFS-Pathways and GTFS-Flex data standardization, helping represent software development companies that can apply these data to customers who wish to virtually visualize their trip. Unity will help run envisioning sessions during project development to better understand the core challenges and needs and will later utilize the GTFS data as part of an application.
Google, Inc.	Developer/ Advisory	Google will support and incorporate updates to the GTFS extensions based on developer community feedback on these standards. It will continue to be part of working groups to enhance these data standards.
Microsoft, Inc.	Developer/ Advisory	Microsoft will assist by providing input to the data standards roadmap and on how to build a successful community of practice around accessible transportation data.

Stakeholder	Type	Role in the Proposed System
Mapillary/Facebook	Developer/ Advisory	Mapillary/Facebook will assist by providing expertise to assist in the development of open data standards and on how to build a successful community of practice around accessible transportation data.
Washington State DOT	Advisory	Washington State DOT will continue to oversee the Washington state transportation system, including funding support of local paratransit applications. It will provide outreach support to encourage transit agencies to generate and provide transit data as part of their service offerings, and will potentially supply sidewalk attribute data to the OpenSidewalks data repository being developed.
Oregon DOT	Advisory	Oregon DOT will continue to oversee the Oregon state transportation system, including funding support of local paratransit applications. It will provide outreach support to encourage transit agencies to generate and provide transit data as part of their service offerings, and will potentially supply sidewalk attribute data to the OpenSidewalks data repository being developed.
Maryland DOT	Advisory	Maryland DOT will continue to oversee the Maryland state transportation system, including funding support of local paratransit applications. It will provide outreach support to encourage transit agencies to generate and provide transit data as part of their service offerings, and will potentially supply sidewalk attribute data to the OpenSidewalks data repository being developed.
King County, Washington	Advisory	King County, Washington, will advise on the pilot deployments of the Soundscape and Multimodal AccessMap applications within the county. It will coordinate with its transit agency (King County Metro) where needed to generate and provide transit data as part of its service offerings, and will potentially supply sidewalk attribute data to the OpenSidewalks data repository being developed.

Stakeholder	Type	Role in the Proposed System
Snohomish County, Washington	Advisory	Snohomish County, Washington, will advise on the pilot deployments of the Soundscape and Multimodal AccessMap applications within the county. It will coordinate with its transit agencies (Community Transit, Everett Transit, and Sound Transit) where needed to generate and provide transit data as part of their service offerings, and will potentially supply sidewalk attribute data to the OpenSidewalks data repository being developed.
Multnomah County, Oregon	Advisory	Multnomah County, Oregon, will advise on the pilot deployments of the Soundscape and Multimodal AccessMap applications within the county. It will coordinate with its transit agency (TriMet) where needed to generate and provide transit data as part of its service offerings, and will potentially supply sidewalk attribute data to the OpenSidewalks data repository being developed.
Columbia County, Oregon	Advisory	Columbia County, Oregon, will advise on the pilot deployments of the Soundscape and Multimodal AccessMap applications within the county, and will potentially supply sidewalk attribute data to the OpenSidewalks data repository being developed.
Harford County, Maryland	Advisory	Harford County, Maryland, will advise on the pilot deployments of the Soundscape and Multimodal AccessMap applications within the county. It will coordinate with its transit agency (Mid-Atlantic Regional Council (MARC)) where needed to generate and provide transit data as part of its service offerings, and will potentially supply sidewalk attribute data to the OpenSidewalks data repository being developed.
Baltimore County, Maryland	Advisory	Baltimore County, Maryland, will advise on the pilot deployments of the Soundscape and Multimodal AccessMap applications within the county. It will coordinate with its transit agencies (MTA and others) where needed to generate and provide transit data as part of their service offerings, and will potentially supply sidewalk attribute data to the OpenSidewalks data repository being developed.

Source: University of Washington and Cambridge Systematics.

5.3.2. Actors

Actors, as presented in **Table 7**, represent the stakeholders that will interact with the proposed system in some way. Unlike other stakeholders, actors that directly utilize the proposed system in some capacity. While often representing end users, actors can include data contributors and application developers with a role in the proposed system. Actors are divided among user classes, representing groups of users defined by how they interact with the system.

Although these actors/user classes will all utilize the proposed system in some capacity, each actor/user class is organizationally separate from one another. Users within a user class may have some organizational relationship (e.g., municipal sidewalk owner and transit agency), but that relationship is not relevant in the context of the proposed system. Some of the user classes—namely the data producers that publish sidewalk data—also may become end users that utilize the data for their own activities, such as communities that contribute sidewalk data, and also provide information services on transit station pathways to their citizens.

Table 7. Transportation Data Equity Initiative actors and interaction with the proposed system.

Actor/User Class	Type	Short Description	Changes to Responsibilities and Interaction with the Proposed System
Municipal Infrastructure Owner-Operators	Data Generator	Governmental bodies that own, operate, and maintain pedestrian-built environments.	User converts available sidewalk information into OpenSidewalks data schema and submits data to the proposed data repository.
Private-Sector Pedestrian-Built Environment Owner-Operators	Data Generator	Private-sector infrastructure owner-operators who own, operate, and maintain pedestrian-built environments.	User converts available sidewalk information into OpenSidewalks data schema and submits data to the proposed data repository.
Elevation Data Provider	Data Generator	Public- or private-sector organizations in the business of collecting topographic elevation data.	User converts available elevation information into OpenSidewalks data schema and submits data to the proposed data repository.
Transit Agencies	Transportation Service Provider	Public- or private-sector transit agencies or transportation operators that offer fixed-route or on-demand transit service, and may own, operate, and maintain transit station facilities.	User may need to expand their GTFS extension offerings and submit data to the proposed data repository. User also may be responsible through its paratransit operations for collecting or vetting sidewalk data.
Crowdsourced Sidewalk Reporters	Data Service Provider	Private citizens who utilize sidewalks and have the capability to report condition data.	User utilizes a tool to report sidewalk condition or attribute data to the proposed data repository.
Mapping Services	Data Service Provider	Private-sector organizations in the business of mapping pedestrian-built environment data.	User converts the data that are being collected into OpenSidewalks data schema and submits data to the proposed data repository.

Actor/User Class	Type	Short Description	Changes to Responsibilities and Interaction with the Proposed System
Weather Data Provider	Data Service Provider	Public- or private-sector meteorological organizations in the business of collecting weather data.	User may need to add the proposed system as an allowable data user.
Multimodal AccessMap Developers	Application Developer	Developers of the current service provider of sidewalk data.	User may need to expand service area, based on location of data contributed. User may need to update reporting features based on new data schema and capabilities.
Soundscape Developers	Application Developer	Developers of the current provider of audible cue information services.	User may need to expand service area, based on location of data contributed. User may need to expand reporting features based on new data schema and capabilities.
Digital Twin Developers	Application Developer	Developers of the current provider of visual built environment data services.	User may need to expand service area, based on location of data contributed. User may need to expand reporting features based on new data schema and capabilities.
Third-Party Application Developers	Application Developers	New application developers that aim to provide a service to end users.	User accesses the associated API for sidewalk and transit data from the proposed system, as desired.
Travelers With Sidewalk Preferences	End User	Travelers with routing and urban exploration preferences in sidewalk environments.	End users access the proposed system through their respective application. The system internally moves the data to service their request.
Blind, Vision Disabled, or Deafblind Travelers	End User	Travelers who wish to explore new, unfamiliar pedestrian environments.	End users access the proposed system through their respective application. The system internally moves the data to service their request.

Actor/User Class	Type	Short Description	Changes to Responsibilities and Interaction with the Proposed System
Travelers with Hearing Disabilities	End User	Travelers who benefit from additional navigation information when utilizing sidewalks or transit services.	End users access the proposed system through their respective application. The system internally moves the data to service their request.
Sighted Older Adults	End User	Travelers who seek to explore, assess, and visualize a trip path through a transit station in advance of making a trip.	End users access the proposed system through their respective application. The system internally moves the data to service their request.
Low-Income Transit Users	End User	Travelers who utilize public transportation in lieu of a more costly personal automobile.	End users access the proposed system through their respective application. The system internally moves the data to service their request.
Rural Transit Users	End User	Travelers in rural areas who utilize transit services, including on-demand services.	End users access the proposed system through their respective application. The system internally moves the data to service their request.
Veterans	End User	Travelers who typically are in rural environments and need access to veterans' services.	End users access the proposed system through their respective application. The system internally moves the data to service their request.
Multilingual, Multicultural Travelers	End User	Travelers who seek to explore, assess, and visualize a trip path through a transit station in advance in a format that aligns with their native culture or language.	End users access the proposed system through their respective application. The system internally moves the data to service their request.

Source: University of Washington and Cambridge Systematics.

5.4. Support Environment

This section describes the support concepts and environment that apply to the proposed system. It also describes the additional equipment maintenance services necessary to keep active the defined components that are part of the proposed system.

5.4.1. Core Data Repository

The UW Team will develop the data repository portion of the proposed system and will maintain it during Phase 2 and Phase 3 of the ITS4US Program. Over the long term, the UW Team will look for opportunities for commercial data service providers to potentially adopt it in the future. Commercial data service providers will provide advantages to the system in terms of scalability, allowing both the hardware and the service coverage footprint to be more easily expanded. Commercial data service providers often provide the network infrastructure, the enterprise technology services, and all supporting personnel to keep the system fully operational, as supporting this environment is critical for their business operations.

5.4.2. Data Resource Systems

Systems that contribute data will be operated and maintained by their respective hosting agency or organization. These systems will comply with the IT policies of the respective host in terms of support and will be supported independently of any data processing components. Examples of these systems include, but are not limited to the following:

- City and county GIS sidewalk databases,
- City and county traffic signal operations and asset management databases,
- Crowdsourced applications,
- Transit agency software systems used for planning on-demand transit services,
- Transit agency asset management systems for transit stations,
- Meteorological weather services,
- USGS elevation data.

5.4.3. Third-Party Applications

Third-party applications that are developed by independent organizations will be operated and maintained by their respective hosting organization. These applications will comply with the IT policies of the respective host in terms of support and will be supported independently of any data processing components. Examples of potential third-party applications include the following:

- The direct inclusion of sidewalk and transit center pathway data in the pedestrian routing function of Directions in GoogleMaps.
- The inclusion of paratransit services in the OpenTripPlanner application.
- Advocacy groups for individuals in wheelchairs hire an application developer to work with their community and local restaurants to map specific access points and directions to

those establishments and build an application that provides door-to-door navigation directions.

- The development of software applications that allow cities to prioritize curb ramp improvements in order to maximize the number of businesses that can be reached by people who require those pedestrian infrastructure attributes.
- The Veterans Administration builds an application for current and ex-service members that provides door-to-door trip planning services associated with all of its medical and rehabilitation facilities.

5.4.4. Multimodal AccessMap

Multimodal AccessMap will continue to be operated and maintained by TCAT as part of an ongoing effort in collaboration with this proposed system. It will continue to be supported in its hosted environment as offered in the current situation during Phase 2 and Phase 3 of the ITS4US Program. Similar to the proposed system’s processing components, Multimodal AccessMap may evolve with time and be adopted by a commercial data service provider that specializes in providing routing data to its users. In such a case, Multimodal AccessMap’s support environment will mirror the environment offered by the data service providers.

5.4.5. Soundscape

Soundscape will continue to be operated and maintained by Microsoft in accordance with its support environment. During the pilot demonstration period of the proposed system, this will include the new features that have been added to Soundscape to support this proposed system. This component will comply with Microsoft’s IT policies and will be supported within Microsoft’s existing system maintenance efforts.

5.4.6. Digital Twin

Digital Twin will continue to be operated and maintained by Unity Technologies in accordance with its support environment. During the pilot demonstration period of the proposed system, this will include the new features that have been added to Digital Twin to support this proposed system. This component will comply with Unity Technologies’ IT policies and will be supported within Unity Technologies’ existing system maintenance efforts.

5.5. Modes of Operation for the Proposed System

The proposed system is designed for full operation, with redundancies built into its design to allow for failover during potential disruptions of service (based on the policies of the organizations that host the components that make up the system). Preserving reliable uptime will help encourage use and facilitate wider adoption by interested parties. That said, when issues occur, several modes of operation are anticipated. These modes will include the same ones identified in the current system, as well as an additional state (i.e., “Disrupted”) that is possible in a “system of systems” environment when one isolated segment is not functioning:

- Normal,
- Disrupted,

- Degraded, and
- Failed.

5.5.1. Normal Mode of Operation

In this operational mode, the proposed system comprehensively operates as expected. All users perceive the system to be in a fully functional state. No issues are noted in the system logs for review and action by system administrators. The following describes users' experiences during normal mode of operations:

- **Data Producers, Contributors, and Aggregators—**These users upload compliant sidewalk and transit station/service data to the data repository through the normal processes that are regularly used. No errors or issues are reported to these contributors, and they receive confirmation that the data have been received. The data upload is timely.
- **Application Developers—**Application developers operate their applications in a business-as-usual operation. Upon requests from users for data in a particular geographic area, the application developers automatically query the REST API for applicable sidewalk and transit station/service data from the data repository. No errors or issues are reported to these requestors, and they receive the data that are requested. The data download is timely.
- **Digital Device End Users—**End users utilize their preferred application with their preferences. They request routing information from their applications and receive that information from the application. The routing information is generated in a timely manner.

5.5.2. Disrupted Mode of Operation

In this operational mode, the proposed system comprehensively operates as expected, but less efficiently because of some type of system architecture issue. For example, a failed primary hosting site for the data repository or a supporting application forces a failover to a redundant secondary hosting site. As another example, a degraded communications link between components causes requests to occur in a less timely fashion. Unlike a “degraded” mode of operation in which parts of the system are unavailable, a “disrupted” mode sees all components as available but not operating as promptly as under a “normal” mode of operation. In this mode, users continue to perceive the system in a fully functional state but may notice that services are not as prompt as normal. The following describes users' experiences during disrupted mode of operations:

- **Data Producers, Contributors, and Aggregators—**These users upload compliant sidewalk and transit station/service data to the data repository through the normal processes that are regularly used. No errors or issues are reported to these contributors, and they receive confirmation that the data have been received. Depending on if the issue occurred with the data repository, these users may witness that it takes longer than expected to complete the upload in comparison to a “normal” mode of operation.
- **Application Developers—**Application developers operate their applications in a business-as-usual operation. Upon requests from users for data in a particular geographic area, the application developers automatically query the REST API for

applicable sidewalk and transit station/service data from the data repository. No errors or issues are reported to these requestors, and they receive the data that are requested. If the issue occurred with the data repository, these users may witness that it takes longer than expected to receive the download in comparison to a "normal" mode of operation. If the issue occurred with the application itself, these users may witness processing times that are less responsive in comparison to a "normal" mode of operation.

- **Digital Device End Users—**End users utilize their preferred application with their preferences. They request routing information from their applications and receive that information from the application. If the issue occurred with the data repository, these users receive routing information in a timely manner, but some of the data may be a little stale. If the issue occurred with the application itself, these users may witness that the routing information takes longer than expected to generate in comparison to a "normal" mode of operation.

5.5.3. Degraded Mode of Operation

In this operational mode, the proposed system loses a critical component, either partially or fully. While other components remain fully operational, the loss of this component breaks part of the proposed system's process chain. For example, a partial failure of the data repository and loss of its redundant duplicate may only render certain select data services to be available. Another example includes corruption of data services of a particular application, causing it to cease operation. In this mode, users may notice outages in part or all of the system that impacts their ability to use the system.

Degraded modes of operation stem from primarily two types of events: partial failure of the data repository or failure (partial or full) of an application. Each event and its associated impacts are broken out in this section. When a degraded mode of operations due to the data repository experiencing a partial failure, the following are users' experiences:

- **Data Producers, Contributors, and Aggregators—**These users upload compliant sidewalk and transit station/service data to the data repository through the normal processes that are regularly used. However, some or all of these contributors receive errors or issues that the data were not successfully received. These contributors may have to upload again at a later time.
- **Application Developers—**Application developers operate their applications in a business-as-usual operation. Upon requests from users for data in a particular geographic area, the application developers automatically query the REST API for applicable sidewalk and transit station/service data from the data repository. However, some or all of the data requests trigger error or issue notifications. The application developer may automatically attempt to query the REST API again but may not receive the data as desired. In such instances, the application developer will utilize its own discretion in addressing the user data request, either by acknowledging that services are not available or by sending historical data that may be archived by the application developer.
- **Digital Device End Users—**End users utilize their preferred application with their preferences. They request routing information from their applications. If the data are available from the data repository that is still partially functional, end users may receive data like they would normally. If current data are not available from the data repository,

the application may provide historical data in lieu of current data. The application may or may not indicate use of historical data to its users, depending on the business rules specific to its owner organization. If historical data are not routinely saved by that application and current data are unavailable, the users will be notified that services are not available for their particular request.

When a degraded mode of operation is due to the complete failure of one or more applications, the following are users' experiences:

- **Data Producers, Contributors, and Aggregators—**These users upload compliant sidewalk and transit station/service data to the data repository through the normal processes that are regularly used. No errors or issues are reported to these contributors, and they receive confirmation that the data have been received. The data upload is timely.
- **Application Developers—**Application developers with applications that have failed are unable to conduct their processes, and thus are not able to query and distribute information in response to user requests. Application developers that do not have failure issues are able to operate their applications in a business-as-usual operation without impacts from the other issues. Upon requests from users for data in a particular geographic area, the application developers without failure issues automatically query the REST API for applicable sidewalk and transit station/service data from the data repository. No errors or issues are reported to these requestors, and they receive the data that are requested. The data download is timely.
- **Digital Device End Users—**End users utilize their preferred application with their preferences. For applications that are not experiencing failure issues, they request routing information from their applications, and receive that information from the application without awareness of an issue. The routing information is generated in a timely manner. For applications that are experiencing failure issues, users immediately note that services are not available. These users will have to utilize an alternative functioning application to meet their needs.

A degraded mode of operation also may occur when data contributor policies exist that make the data stale for some users. For example, some transit agencies that publish GTFS feeds have a policy to publish data only at the time of a service change, so a relocated bus stop—despite being known to the transit agency for some time—may only be published in the GTFS around the time that relocation actually occurs. This type of policy prevents users who are planning a trip in the distant future to get accurate information, as stale information would refer them to the old bus stop and not the new bus stop.

5.5.4. Failed Mode of Operation

In this operational mode, the proposed system has comprehensively failed because of complete loss of a critical component. With multiple organizations managing different components, a complete failure of all subsystems at the same time is very unlikely, but this mode of operation can occur when a critical link is lost. In the proposed system, the data repository serves as a point through which all data flows so a complete loss of the data repository will render the system as failed. The following are users' experiences during failed mode of operations:

- **Data Producers, Contributors, and Aggregators—**These users attempt to upload compliant sidewalk and transit station/service data to the data repository through the normal processes but immediately receive notification of errors or issues that prevent the data from being received. Repeated attempts result in the same failed outcome. Data being uploaded would need to be retained until the failed system is back online.

- **Application Developers—**Application developers operate their applications in a business-as-usual operation. Upon requests from users for data in a particular geographic area, the application developers automatically query the REST API for applicable sidewalk and transit station/service data from the data repository. Errors or issues are immediately detected from these requests, and the requested data are not made available. The application developer may automatically attempt to query the REST API again but will not receive the data as desired. In such instances, the application developer will utilize its discretion in addressing the user data request, either by acknowledging that services are not available or by sending historical data that were previously archived.
- **Digital Device End Users—**End users utilize their preferred application with their preferences. They request routing information from their applications. Given no data available from the data repository, the application may provide historical data in lieu of current data. The application may or may not indicate use of historical data to its users, depending on the business rules specific to its owner organization. If historical data are not routinely saved by that application and current data are unavailable, users will be notified that services are not available for their particular request.

5.6. Operational Policies and Constraints

This section provides a list of policies that may govern system operation, as well as constraints that factor into the development, operation, or maintenance of the system. Many of the operational policies and constraints for the current system in **Section 3** will continue to apply within their respective subsystems that are part of the overall system, but combinations of these various components may require the additional operational policies and constraints listed herein.

Ensuring individual privacy is a critical element for this system to succeed. The proposed system comprehensively will adopt policies that restrict use of PII to protect user privacy. With use of the OpenSidewalks and GTFS standards, PII data are not present in the data that are submitted to the data repository, nor are they present when they are distributed in response to a request. PII data *may* be present in some of the supporting applications because those applications are supported by an independent, third-party application developer that may need those data as part of its offering. However, in the event that PII data are collected locally within that application, the PII data will remain within that application and will not be shared with the data repository. It is likely that the REST API will be limited to preapproved users that will need to accept terms and conditions of use before they are granted access, which will specify that only data queries are permitted to be sent to the data repository.

The proposed system and its components will be available 24 hours a day, 7 days a week, 365 days per year. Downtime of the data repository and the supporting services that compose this overall system will be minimal. No part of this proposed system is considered critical to public safety and thus requiring expanded uptime requirements, but availability needs to be sufficient to be perceived as reliable by end users.

Parties participating in the proposed system will need to comply with the defined data standards that are used, namely the OpenSidewalks and GTFS data schema. Data producers, contributors, and aggregators will need to submit data in accordance with these data schema or else the data will not be approved. Acceptable data schema alternatives may be considered, but only if permitted by data repository administrators. The standards used for this proposed system (OpenSidewalks and GTFS) will also have their own processes and policies for updates, which will need to be accommodated by participating parties when changes occur.

The UW team will maintain the core portion of the proposed system, namely the data repository, as part of Phase 2 and Phase 3 of the ITS4US Program. That said, parts of the proposed system will reside among several entities, many of which are commercial data service providers or application developers that have the existing applications to demonstrate the data pipelines in a manner that serves user needs. Their roles, responsibilities, and participation in the proposed system may change at any time, based on business needs and other motivations. This primarily applies to supporting applications (Mapillary, Soundscape, Digital Twin), which, along with the allowance for third-party application developers, helps mitigate service failures by providing an alternative business entity to provide substitution service. If the data repository portion of the proposed system is taken on by a commercial entity, removal of service will have an impact on the whole system until a substitute data service is available. The system's primary components will need to comply with its hosting organization's IT policies for network security, but they also may necessitate accommodation of additional IT policies of partner organizations in which data are shared (e.g., a third-party application may need to comply with its own IT policies and the IT policies of the organization that hosts the data repository).

Another constraint is digital device end user safety while using applications that are supported by the proposed system. Despite a combination of data producers, contributors, and aggregators, errors will inherently exist in the sidewalk and transit service/station information. Routing applications for all modes encounter this constraint and classify their services as "information only" with no guarantee of accuracy to get around legal issues. As part of the terms and use for permitting application developers to access the REST APIs, a similar definition will need to be offered to avoid suggesting that the available information is completely accurate.

6. Operational Scenarios

This section presents 13 operational scenarios, which are also referred to as use cases. Each operational scenario describes the user need or issue that it is intended to address, as well as outcomes or benefits users are expected to gain through the deployment of the proposed system. These scenarios do not address all of the desired improvements but serve to demonstrate some of the key needs. As illustrated in **Table 8**, operational scenarios are presented for both specific "user entities" that play key roles in the operation of the proposed system and end users that directly benefit from the data to be collected and made available for distribution through a variety of Internet enabled applications.

Table 8. Summary of operational scenarios.

Number	Scenario	Actors Involved	End-User Benefit
1	Sidewalk data generation, collection, and vetting.	• Large technology mapping companies. • Municipal infrastructure owner/operators.	• Increased availability of sidewalk data and information. • Improved sidewalk data and information.
2	Vetting of sidewalk data and street crossing identification.	• Data service provider that operates OpenSidewalks. • Organizations and individuals interested in vetting sidewalk, pathway, and street crossing data. • Organizations that promote active transportation.	• Improved sidewalk data and information.
3	Generation and vetting of GTFS-Pathways data.	• Owner/operator of complex transit centers. • Data aggregators of GTFS-Pathways data. • Application developers.	• Increased availability of GTFS-Pathways extension data and information on transit sidewalk infrastructure. • Improved GTFS-Pathways data.

Number	Scenario	Actors Involved	End-User Benefit
4	Generation and vetting of GTFS-Flex data.	• Agencies funding on-demand transit services. • Operators of on-demand transit services. • Data aggregators of GTFS-Flex data. • Application developers that desire access to detailed data about on-demand transit services.	• Increased availability of GTFS-Flex extension data and information on on-demand transit service.
5	Individual with mobility disability uses verified sidewalk and transit data to navigate through several cities.	• Travelers with sidewalk preferences. • Municipal infrastructure owner-operators. • Crowdsourced sidewalk reporters. • Transit agencies. • Multimodal AccessMap developers.	• Navigation from origin to destination with integration of comprehensive sidewalk and transit data.
6	Veteran with mobility disability traveling from a rural home to the Veterans Affairs (VA) hospital for a medical appointment.	• Rural transit users. • Municipal infrastructure owner-operators. • Transit agencies. • Multimodal AccessMap developers.	• Navigation from origin to destination with comprehensive GTFS-Flex data, and information on on-demand transit service.
7	Blind, vision disabled, or deafblind individual uses verified sidewalk and transit data.	• Blind, vision disabled, or deafblind travelers. • Municipal infrastructure owner-operators. • Crowdsourced sidewalk reporters. • Transit agencies. • Soundscape developers.	• Navigation from origin to destination with integration of comprehensive sidewalk and transit data.

Number	Scenario	Actors Involved	End-User Benefit
8	Multilingual tourist tries to conduct pre-trip planning for a multilevel transit station.	• Multilingual, multicultural travelers. • Municipal infrastructure owner-operators. • Transit agencies. • Digital Twin developers.	• Pre-trip planning with comprehensive mapping of transit station features and GTFS-Pathways data.
9	Low-income traveler utilizes a third-party application (One-Call/One-Click Service) to reach a destination.	• Low-income transit users. • Municipal infrastructure owner-operators. • Transit agencies. • Third-party application developers.	• Navigation from origin to destination with integration of comprehensive sidewalk and transit data.
10	Travelers with sidewalk preferences utilize data generated by a city government.	• Travelers with sidewalk preferences. • Municipal infrastructure owner-operators. • Multimodal AccessMap developers.	• Increased availability of sidewalk data and information. • Improved sidewalk data and information. • Navigation from origin to destination with integration of comprehensive sidewalk data.
11	Travelers with sidewalk preferences utilize data generated by civic organization.	• Travelers with sidewalk preferences. • Crowdsourcer sidewalk reporters. • Multimodal AccessMap developers.	• Increased availability of sidewalk data and information. • Improved sidewalk data and information. • Navigation from origin to destination with integration of comprehensive sidewalk data.

Number	Scenario	Actors Involved	End-User Benefit
12	Travelers with sidewalk preferences utilize data generated by an aerial mapping company's analytics engine for aerial images.	• Travelers with sidewalk preferences. • Mapping services. • Multimodal AccessMap developers.	• Increased availability of sidewalk data and information. • Improved sidewalk data and information. • Navigation from origin to destination with integration of comprehensive sidewalk data.
13	Transit users utilize GTFS-Flex and GTFS-Pathway extensions through a navigation application.	• Travelers with sidewalk preferences. • Transit agencies. • Multimodal AccessMap developers.	• Increased availability of transit data, through GTFS-Pathways and Flex extensions. • Navigation from origin to destination with integration of comprehensive transit data.

Source: University of Washington and Cambridge Systematics.

Sections 6.1 through 6.13 provide the full set of operational scenarios associated with this ConOps. The first four scenarios describe the collection, processing, and use of the data that can be generated at scale and that can be used in a variety of applications that provide significant benefits to the underserved populations defined previously.

The remaining scenarios describe a variety of example situations in which the proposed system significantly improves end users' ability to complete travel by identifying trip paths that are accessible to them as individuals based on their specific travel needs and preferences. Each of these remaining scenarios demonstrates how a data contributor and/or an application developer could become part of the proposed system and help provide the necessary information to these end users. For example, one of the operational scenarios illustrates how a low-income individual is able to utilize the proposed system to make a complete trip, as well as how an independent third-party application developer is able to become part of the proposed system.

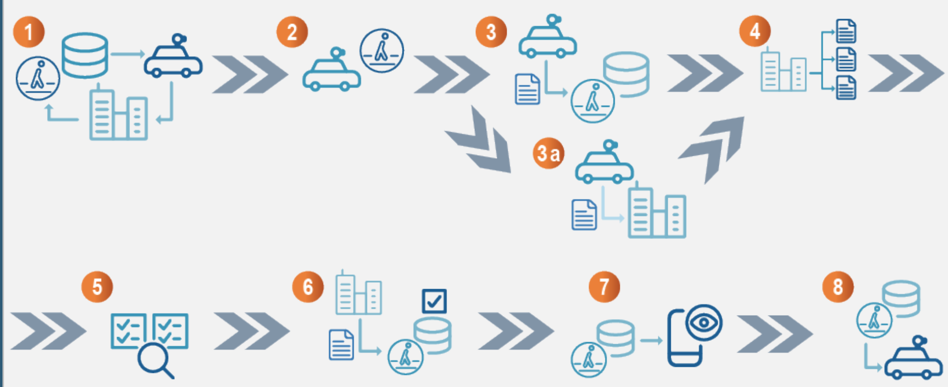
The actual data collection and end user data requests for information are separated in time and space. A single operational scenario is therefore not presented showing the flow of data from collection to end user. Such a scenario would entail the performance of scenarios 1 to 4 (to collect the data required for delivery to the end user) and any one of the remaining nine scenarios (to deliver the collected data to end user.)

6.1. Sidewalk Data Generation, Collection, and Vetting

Table 9 provides the detailed operational scenario, including constraints and preconditions, the main flow, any alternate flows, and post-conditions.

Table 9. Sidewalk data generation, collection, and vetting.

Scenario #1	Sidewalk Data Generation, Collection and Vetting
Short Description	In this use case, a technology mapping company uses their proprietary visual and LiDAR imagery data to generate a routable sidewalk dataset using the OpenSidewalks data standard. That dataset describes a specific city's sidewalk network and includes all visual features, including sidewalk width. However, nonvisual features are added by incorporating data stored in city databases, which are conflated with the routable network to add those features to the network database.
Goal	The goal of this use case is to illustrate one of the expected relationships between the sidewalk database and sidewalk infrastructure owners. This is one the major processes by which sidewalk data will be collected and made available for use by data generators and vetted to ensure that the data accurately represent the sidewalk network.
Constraints	• A significant constraint in this use case is the availability of high-quality imagery data and the willingness of the mapping company to allow the use of that proprietary imagery to compute descriptive sidewalk details. • A second constraint in this use case is the need for the participation of the local city, which maintains data in a city-specific database about their sidewalk network for asset management purposes, and can use that database to both vet the routable sidewalk data and supply information about features and attributes which cannot be estimated from imagery. • Another constraint is the need to conflate the two datasets (the routable network generated from imagery with the city's sidewalk/traffic signal attributes dataset), as the city dataset is not stored in the OpenSidewalks data format, and it is necessary to correlate (conflate) the two geographic referencing systems.
Geographic Scope	Urban or suburban communities with sidewalk infrastructure.
Actors	• Mapping Services • Municipal infrastructure Owner-Operators • Travelers With Sidewalk Preferences

Scenario #1	Sidewalk Data Generation, Collection and Vetting
Illustration	 *Source: University of Washington and Cambridge Systematics.*
Preconditions	1. The technology company must have determined that it is in their business interest to generate and share detailed sidewalk data to be used for pedestrian routing (or share the imagery data with the sidewalk database operator who is then responsible for generating the initial routable sidewalk database). 2. The city has approved data sharing with the operator of the open sidewalk database.

Scenario #1	Sidewalk Data Generation, Collection and Vetting
Main Flow	1. For a particular geographic area, the sidewalk database operator is able to receive sidewalk data from the technology mapping company, and will validate it using data from the city. 2. The technology firm uses their imagery and LiDAR data to generate the initial routable sidewalk network database using the OpenSidewalks data standard and performs initial data vetting to ensure that all developed data fall within allowable values and error tolerances, per their internal data validation policies. 3. The technology firm shares that base dataset with the operator of the OpenSidewalks data service, which stores the file as “submitted but not vetted.” 4. The City uses software tools and directions provided by the OpenSidewalks data service operator to conflate their sidewalk asset management file against the OpenSidewalks base file, adding data the city maintains to that file, and generating a “review” file where discrepancies between the city database and the initial OpenSidewalks database are noted. (e.g., the city has sidewalks which do not appear in the OpenSidewalks file, or where matches between the city’s database and the OpenSidewalks database cannot be automatically identified due to differences in the location references in the two database files, or where data in the city’s files differ from that reported in the OpenSidewalks dataset). 5. City staff manually review and resolve the noted discrepancies within the OpenSidewalks file—and where appropriate within their own database. 6. The City uploads the updated OpenSidewalks file to the sidewalk database operator, where it is now listed as “vetted.” 7. The sidewalk database operator updates the public version of the OpenSidewalks database, as well as the metadata which describes the newly available geographic coverage. 8. The technology mapping company downloads a copy of the new OpenSidewalks data and adds that data to their corporate mapping data system for use by their in-house pedestrian routing application.
Alternate Flow(s)	3a. The technology mapping company acts as the OpenSidewalks data service provider and thus works directly with the City to add additional sidewalk attributes and vet the uploaded sidewalk data.

Scenario #1	Sidewalk Data Generation, Collection and Vetting
Post-conditions	• Other cities or local communities notice the positive impact of mapping their sidewalks environments, through integration with navigation applications, and request the addition of their sidewalks to the OpenSidewalks database. • The availability of better sidewalk path data spurs multiple application developers to build applications that use those data. • Individuals with disabilities become aware through their advocacy groups that new navigation applications are available which allow them to travel more freely. This results in those users trying and adopting those applications, which in turn results in the mobility of those individuals improving.
Information Requirements	• Sidewalk Data: Attributes that are encompassed in OpenSidewalks data specification, including, but not limited to, pedestrian pathway attributes (length, width, etc.), road crossings, curb and ramp information, and incline.
Related User Needs	UN-DG1, UN-DG2, UN-DG3, UN-DG4, UN-DG4a, UN-D4b, UN-DG5, UN-DG6, UN-DG7, UN-DG8, UN-DS1, UN-DS1a, UN-DS2, UN-DS3, UN-DS4, UN-DS5, UN-DS7, UN-DS8

Source: University of Washington and Cambridge Systematics.

6.2. Vetting of Sidewalk Data and Street Crossing Identification

Table 10 provides the detailed operational scenario, including constraints and preconditions, the main flow, any alternate flows, and post-conditions.

Table 10. Vetting of sidewalk data and street crossing identification.

Scenario #2	Vetting of Sidewalk Data and Street Crossing Identification
Short Description	In this use case, the OpenSidewalks data service provider works with local active transportation and disability advocacy groups to vet sidewalk and street crossing data stored in the database.
Goal	The goal of this use case is to illustrate another of the expected relationships between the sidewalk database and users of that data. This example is designed to also illustrate one of the key mechanisms available for maintaining the quality and integrity of the sidewalk database over time, through the use of highly interested volunteers. Individuals with lived experience are particularly useful in identifying locations where streets can be crossed safely, even when that crossing is unmarked (e.g., intersections without crosswalk markings.)

Scenario #2	Vetting of Sidewalk Data and Street Crossing Identification
Constraints	• A significant constraint in this use case is the need to develop a network of approved individuals or groups that are tasked with identifying and verifying errors in the database as well as changes in the reported infrastructure. (This process is similar to what is currently used for OpenStreetMaps.) • A second constraint in this use case is the need for the production and distribution of software applications that allow these individuals and groups to easily perform these tasks.
Geographic Scope	Communities with sidewalk infrastructure stored in the OpenSidewalks database.
Actors	• Travelers with Sidewalk Preferences • Crowdsourced Sidewalk Reporters • Operator of the OpenSidewalks portion of the data repository, including approved individuals to vet incoming data.
Illustration	 *Source: University of Washington and Cambridge Systematics.*
Preconditions	1. This use case assumes that the individuals or groups that are performing the vetting have already been identified, selected, and have agreed to participate in these activities. 2. This use case may include some type of incentivization effort to help encourage crowdsourced reporters. For example, certain verification efforts (e.g. a high-priority sidewalk segment on a busy street) may have a higher incentive for verifying, encouraging participants to pursue that segment first. A contributor that regularly submits reliable data for high-priority segments may be denoted as a “Top Contributor”, helping showcase their hard work among their peers. *3.* This use case assumes that this project has developed software tools and applications which allow the vetting process to be done quickly and efficiently by those individuals, and that those individuals have access to additional information (e.g., can physically visit locations) in order to make vetting determin*ations.*

Scenario #2	Vetting of Sidewalk Data and Street Crossing Identification
Main Flow	1. Sidewalk network data are made available to the vetting organization/individual. 2. Software for performing vetting and requesting changes is made available to the vetting organization/individual. 3. Organization/Individuals are notified of geographic locations for which vetting is required. This can be because users of applications that use the sidewalk data have reported data inaccuracies, or because new data are being prepared for release. 4. Individuals with permission investigate the identified location or series of locations, and, using the tools provided, update or mark the data that describe the location as valid. This includes marking new crossings, or changing parameters that describe sidewalk features and attributes. 5. Vetting results are uploaded to the OpenSidewalks data service provider. 6. The OpenSidewalks service provider updates the public database with any required changes.
Alternate Flow(s)	3a. The OpenSidewalks service provider might perform these same tasks with private companies that operate on the sidewalks of interest and collect data on that infrastructure, such as robotic freight delivery vehicles. Software on those robotic devices which collect imagery or other data could be used to routinely vet the data which describe the paths those devices are traversing.
Post-conditions	• The benefits of the vetting process are noticed by cities attempting to keep their asset management systems up to date. Those cities sign partnership agreements that provide for sharing of data with the OpenSidewalks service provider. Under these agreements, the city notifies OpenSidewalks when infrastructure changes are made, and the OpenSidewalks software notifies the city when specific negative changes are reported and verified by users. (e.g., a sidewalk panel fails or when an intersection crossing previously included in the database is deemed by users to be unsafe and is removed from the database.)
Information Requirements	• Sidewalk Data: Attributes that are encompassed in OpenSidewalks data specification, including, but not limited to, pedestrian pathway attributes (length, width, etc.), road crossings, curb and ramp information, incline.
Related User Needs	UN-DG1, UN-DG2, UN-DG3, UN-DG4, UN-DG4a, UN-DG4b, UN-DG6, UN-DG8, UN-DS1, UN-DS1a, UN-DS2, UN-DS4, UN-DS7, UN-DS8

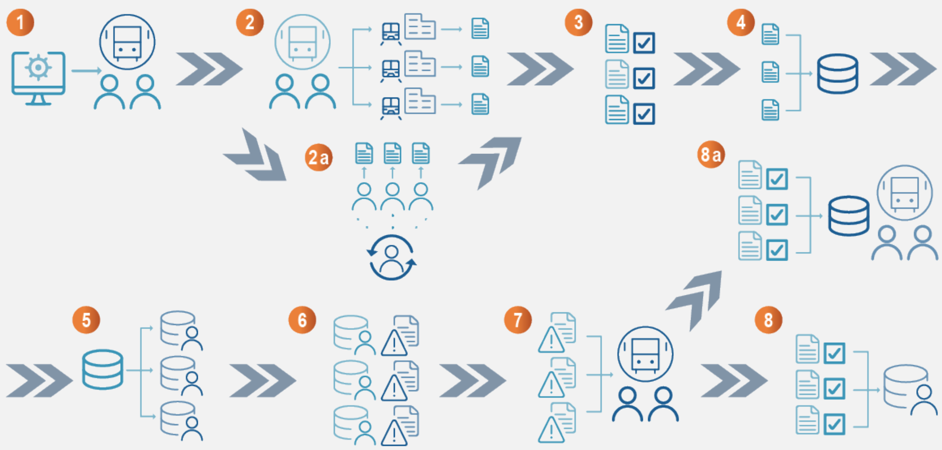
Source: University of Washington and Cambridge Systematics.

6.3. Generation and Vetting of General Transit Feed Specification for Pathways Linking Together Locations within Stations Data

Table 11 provides the detailed operational scenario, including constraints and preconditions, the main flow, any alternate flows, and post-conditions.

Table 11. Generation and vetting of General Transit Feed Specification for pathways linking together locations within stations data.

Scenario #3	Generation and Vetting of GTFS-Pathways Data
Short Description	In this use case, transit agencies that own and operate major transit centers will use tools and procedures developed in this project to generate and publish GTFS-Pathways data.
Goal	The goal of this use case is to illustrate how transit agencies will generate GTFS-Pathways data that can be used by a wide variety of application developers to produce applications that assist individuals with mobility disabilities navigate transit centers.
Constraints	• A significant constraint in this use case is that transit agencies will need to assign resources to collect and initially publish GTFS-Pathways data. • A second constraint in this use case is that the tools and procedures needed by those agencies to perform those tasks in a cost-efficient manner do not currently exist and must be developed as part of this project. • A third constraint is that, until GTFS-Pathways data are available for use, there is limited incentive for application developers to build applications which use that data to provide travel benefits to individuals with mobility disabilities. Until those applications exist, there is little incentive for transit agencies to generate those data.
Geographic Scope	Transit agencies throughout the United States that own, operate, and maintain complex transit centers.
Actors	• Transit Agencies (who own complex transit centers) • Third-Party Application Developers • Sighted Older Adults • Multilingual, Multicultural Travelers

Scenario #3	Generation and Vetting of GTFS-Pathways Data
Illustration	 *Source: University of Washington and Cambridge Systematics.*
Preconditions	1. This use case assumes that this project has developed software tools, applications, and procedures which allow transit agencies to cost-effectively collect and distribute data about the layout of transit centers and the features contained within those centers. 2. This scenario assumes that a data aggregator exists that plays the role of aggregating GTFS-Pathways data from multiple transit agencies in order to provide application developers with a single location from which to obtain that data.
Main Flow	1. The transit agency obtains software, hardware (if required), and training that allow its staff to collect data that describe the layout and features of their transit centers. 2. The transit agency staff use those tools to generate data files which describe their transit centers. 3. The transit agency staff review the data collected and ensure that the automatically tagged features and attributes within each transit center are correctly tagged, adding or correcting tags as required. 4. The vetted transit center data are published in the GTFS-Pathways standard along with supporting GTFS-extension data. 5. Data service providers that are aggregating GTFS-Pathways data pull the newly published GTFS-Pathways data and incorporate that data into their data service. 6. The data service provider's data ingestion process checks the newly obtained data for errors and reports any errors discovered. 7. Errors that are discovered are reported to the transit agency. 8. Data that have passed the quality assurance checks are published as part of the aggregated GTFS-Pathways feed maintained by the data service provider, where they can be accessed via API by authorized users.

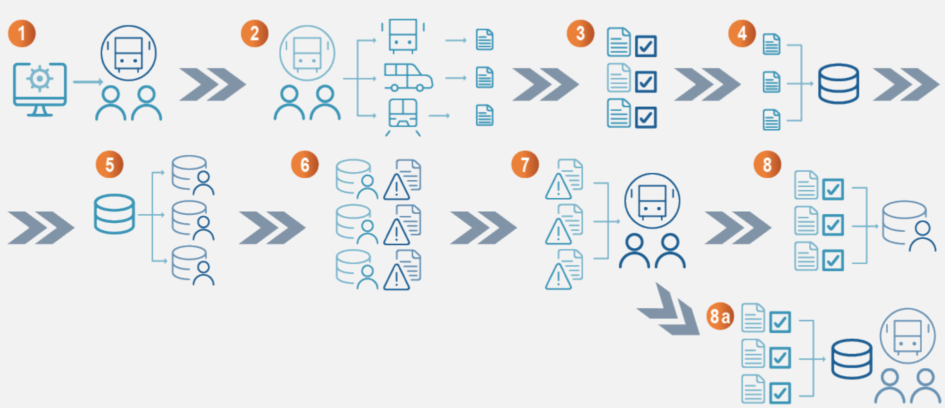
Scenario #3	Generation and Vetting of GTFS-Pathways Data
Alternate Flow(s)	2a. The transit agency may hire a contractor to perform the data collection task, or contract the work out to community-based organizations. 8a. The transit agency may maintain their own GTFS-Pathways API which can be directly accessed by authorized application developers.
Post-conditions	• The availability of GTFS-Pathways data spurs multiple application developers to build applications that use those data to provide new information services to people with mobility disabilities. • Individuals with disabilities become aware through their advocacy groups that new navigation applications are available which allow them to travel more freely. This results in those users trying and adopting those applications, which in turn results in the mobility of those individuals improving. • Other transit agencies notice the positive impact that mapping their transit centers has on the ability of people with mobility disabilities to use their facilities. Those agencies then request access to the software, hardware, and training necessary for their collection and publication of data that describe the layout and facilities of their transit centers. • Other transit agencies publish their own GTFS-Pathways data as well as other GTFS data.
Information Requirements	• GTFS-Pathways—An extension of GTFS that uses a graph representation to model the inside of a transit station, including the pathways that connect different locations within the station.
Related User Needs	UN-DG1, UN-DG2, UN-DG3, UN-DG4, UN-DG4b, UN-DG6, UN-DG8, UN-TS1, UN-TS4, UN-TS5, UN-TS5a, UN-TS5b, UN-TS6, UN-TS7, UN-TS9, UN-DS1, UN-DS1a, UN-DS2, UN-DS3, UN-DS4, UN-DS6, UN-DS6a, UN-DS7, UN-DS8, UN-AD1c, UN-AD3, UN-AD4, UN-AD5, UN-AD6, UN-AD9, UN-AD10, UN-AD10a, UN-AD10b, UN-AD11, UN-AD12

Source: University of Washington and Cambridge Systematics.

6.4. Generation and Vetting of General Transit Feed Specification for Demand-Responsive or Paratransit Service Data

Table 12 provides the detailed operational scenario, including constraints and preconditions, the main flow, any alternate flows, and post-conditions.

Table 12. Generation and Vetting of General Transit Feed Specification for demand-responsive or paratransit service data.

Scenario #4	Generation and Vetting of GTFS-Flex Data
Short Description	In this use case, transit agencies that fund or operate on-demand transit services will use tools and procedures developed in this project to generate and publish GTFS-Flex data.
Goal	The goal of this use case is to illustrate how transit agencies will generate GTFS-Flex data that can be used by a wide variety of application developers to produce applications that assist individuals with mobility disabilities discover and then use on-demand transit services.
Constraints	• A significant constraint in this use case is that transit agencies will need to assign resources to generate and initially publish GTFS-Flex data. • A second constraint in this use case is that the tools and procedures needed by agencies to perform those tasks in a cost-efficient manner do not currently exist and must be developed as part of this project. • A third constraint is that, until GTFS-Flex data are widely available for use, there is limited incentive for application developers to build applications that use GTFS-Flex data to provide travel benefits to individuals with mobility disabilities. Until those applications exist, there is little incentive for transit agencies to generate those data.
Geographic Scope	Transit agencies throughout the United States that fund or operate on-demand transit services.
Actors	• Transit Agencies • Third-Party Application Developers • Rural Transit Users • Veterans
Illustration	 *Source: University of Washington and Cambridge Systematics.*

Scenario #4	Generation and Vetting of GTFS-Flex Data
Preconditions	1. This use case assumes that this project has developed software tools, applications, and procedures which allow transit agencies to cost-effectively collect and distribute data about on-demand transit services and the features/constraints associated with those services. 2. This scenario assumes that a data aggregator exists that plays the role of aggregating GTFS-Flex data from multiple on-demand transit service providers in order to provide application developers with a single location from which to obtain that data.
Main Flow	1. The transit agency (or service provider) obtains software and training that allow its staff to generate data that describe the on-demand transit services they provide in the GTFS-Flex data standard. 2. Transit agency (or service operator) staff use those tools to generate GTFS-Flex data files which describe their on-demand transit services. 3. The transit agency (or service operator) staff review the data that has been generated, along with automated quality assurance reports, to ensure that the on-demand services are correctly described. 4. The vetted on-demand transit service data are published in the GTFS-Flex standard along with any additional supporting GTFS-extension data. 5. Data service providers that are aggregating GTFS-Flex data pull the newly published GTFS-Flex data and incorporate that data into their data service. 6. The data service provider's data ingestion process checks the newly obtained data for errors and reports any errors discovered. 7. Errors that are discovered are reported to the publishing transit agency. 8. Data that have passed the quality assurance checks are published as part of the aggregated GTFS-Flex data feed maintained by the data service provider, where they can be accessed via API by authorized users.
Alternate Flow(s)	8a. The transit agency may maintain their own GTFS-Flex API which can be directly accessed by authorized application developers.

Scenario #4	Generation and Vetting of GTFS-Flex Data
Post-conditions	• The availability of GTFS-Flex data spurs multiple application developers to build applications that use those data to provide new traveler information services to people with mobility disabilities. • Individuals with disabilities become aware through their advocacy groups that new navigation applications are available which allow them to travel more freely. This results in those users trying and adopting those applications, which in turn results in the mobility of those individuals improving. • Other transit agencies notice the positive impact that publishing their on-demand transit service data has on the ability of people with mobility disabilities to use their services. Those agencies then request access to the software and training necessary to cost-effectively generate and publish data about their on-demand services. • Other transit agencies publish their own GTFS-Flex data resulting in improved mobility for people with mobility disabilities over a wider geographic area.
Information Requirements	• GTFS-Flex: An extension of GTFS that adds the capability to model demand-responsive transportation services beyond the fixed-route public transportation that is modeled by current GTFS datasets.
Related User Needs	UN-DG2, UN-DG3, UN-DG4, UN-DG4a, UN-DG3b, UN-DG6, UN-DG8, UN-TS1, UN-TS2, UN-TS2a, UN-TS2b, UN-TS4, UN-TS5, UN-TS5a, UN-TS5b, UN-TS6, UN-TS8, UN_TS9, UN-DS1, UN-DS2, UN-DS3, UN-DS4, UN-DS5, UN-AD4, UN-AD5, UN-DS1a, UN-DS7, UN-DS8, UN-AD4, UN-AD5, UN-AD6, UN-AD9, UN-AD10, UN-AD12

Source: University of Washington and Cambridge Systematics.

6.5. Individual with Mobility Disability Uses Verified Sidewalk and Transit Data to Navigate Through Several Cities

Table 13 provides the detailed operational scenario, including constraints and preconditions, the main flow, any alternate flows, and post-conditions.

Table 13. Individual with mobility disability uses verified sidewalk and transit data to navigate through several cities.

Scenario #5	Individual with Mobility Disability Uses Verified Sidewalk and Transit Data to Navigate Through Several Cities
Short Description	In this use case, a digital device end user who has mobility impairments wishes to navigate from an origin to a destination, using sidewalks and transit services that are available and can accommodate their specific travel preferences. The local city has previously mapped their sidewalk environment and sent it to the data repository for validation and storage. A transit agency within the same region also produced fixed-route transit service schedule information, using the GTFS standard, and sent it to the data repository. The Multimodal AccessMap application, which assists a user with a mobility disability in this scenario, draws from this data repository. The digital device end user uses Multimodal AccessMap to navigate from their origin to destination successfully.
Goal	The goal of this use case is to illustrate the process of an individual with a mobility disability utilizing sidewalk and transit data to navigate to their desired destination in various cities. This is accomplished through sidewalk and transit data collection, validation, and dissemination from a central data repository to a navigation application. In this case, the application is Multimodal AccessMap, hosted by a large technology and mapping company.
Constraints	• A significant constraint in this use case is the absence of comprehensive, scalable sidewalk data, due to different stakeholders not gathering data in the same workspace and the costliness of manually collecting data. • Another constraint in this use case is the absence of sidewalk data that allows the user to identify and use a personal profile that describes their travel capabilities and preferences relative to those sidewalk attributes, as opposed to binning all disabled users into a single category. This is due to a lack of a widely adopted sidewalk data coding standard. • Another constraint is the lack of fusion between multiple modes, where a user can utilize a pedestrian sidewalk, a transit service, and another pedestrian sidewalk as part of their complete trip. Some services exist, but they focus only on general sidewalk information and fixed-route transit service. • Another constraint is that although data will be collected and validated from various sources, errors can exist in the sidewalk and transit service/station information.
Geographic Scope	Urban or suburban communities with sidewalk infrastructure and transit service.

Scenario #5	Individual with Mobility Disability Uses Verified Sidewalk and Transit Data to Navigate Through Several Cities
Actors	• Travelers With Sidewalk Preferences • Municipal infrastructure Owner-Operators • Crowdsourced Sidewalk Reporters • Transit Agencies • Multimodal AccessMap Developers
Illustration	 *Source: University of Washington and Cambridge Systematics.*
Preconditions	1. The sidewalk data in the city was efficiently mapped using the OpenSidewalks data format. 2. The data repository has successfully validated, and quality assured the data submitted by the city. 3. Multimodal AccessMap is approved to make requests through the proposed system's REST API for sidewalk and transit data. 4. Multimodal AccessMap has the capability to receive user travel preferences on the user's local device and can identify relevant routes that are received from the data repository that align with the user's preferences.

Scenario #5	Individual with Mobility Disability Uses Verified Sidewalk and Transit Data to Navigate Through Several Cities
Main Flow	1. On an early Monday morning, a digital device end user decides a take a trip to a scheduled work meeting. They wish to utilize sidewalks and fixed-route transit service and, since they have mobility limitations, they want routes that align with their specific travel preferences, such as sidewalks with minimal slopes. Since they must navigate to an unfamiliar location, they decide to use Multimodal AccessMap in order to find a route that aligns with their unique travel preferences. 2. The digital device end user enters their destination and travel preferences into Multimodal AccessMap. 3. The digital device end user receives directions, which includes a sidewalk route and a transit service. They note that Multimodal AccessMap suggests a few detours on the sidewalk route that allow them to avoid sections of sidewalk that lack the desirable characteristics for their preferences, such as curb ramps. However, the route is efficient enough for them to reach their destination on time. 4. The user arrives at his destination on time and is happy with the route that Multimodal AccessMap provided them.
Alternate Flow(s)	2a. User decides that they are feeling energetic today and are willing to travel up or down steeper hills if it shortens the trip to their transit pickup location. User changes their profile preferences for this trip, for example increasing the maximum sidewalk grade to 3 percent while keeping minimum sidewalk width to 4 feet. Multimodal AccessMap plans a new route that uses a combination of sidewalk and transit service that meets the new criteria. The new route is shorter in both distance and time, but includes segments with a 3 percent grade. User accepts this tradeoff and selects the route.
Post-conditions	1. Other cities or local communities notice the positive impact of mapping their sidewalks environments, through integration with navigation applications, and begin to do so as well. 2. User is confident in the application's ability to provide useful information, and is likely to utilize it to support other unfamiliar trips. 3. User routinely adopts the application for regional trip making because they know recommended route from home to work as their routine route. When changes occur (e.g., sidewalk is damaged), user knows they have a resource available to find a new suitable route by pulling up the app at that time. 4. User begins traveling more frequently, because they are confident they can get to and from a wide variety of destinations they were unsure they could reach previously. 5. User feels may feel encouraged to contribute observations as a crowdsourced contributor to help identify issues for other users.

Scenario #5	Individual with Mobility Disability Uses Verified Sidewalk and Transit Data to Navigate Through Several Cities
Information Requirements	• Sidewalk Data: Attributes that are encompassed in OpenSidewalks data specification, including, but not limited to, pedestrian pathway attributes (length, width, etc.), road crossings, curb and ramp information, incline, path surface material, public transportation connections. • Fixed-route transit service: Attributes that are encompassed in GTFS data specification, including, but not limited to, agency, stops, routes, trips, and stop times.
Related User Needs	UN-TS1, UN-TS5, UN-TS6, UN-DS3, UN-DS4, UN-AD6, UN-AD7, UN-AD8, UN-AD9, UN-AD10, UN-AD1, UN-AD12, UN-AD13, UN-AD14, UN-AD15, UN-AD16, UN-DU1, UN-DU2, UN-DU3, UN-DU4, UN-DU5, UN-DU6, UN-DU7, UN-DU8, UN-DU9, UN-DU10, UN-DU11

Source: University of Washington and Cambridge Systematics.

6.6. Veteran with Mobility Disability Traveling from a Rural Home to the Veterans Affairs Hospital for a Medical Appointment

Table 14 provides the detailed operational scenario, including constraints and preconditions, the main flow, any alternate flows, and post-conditions.

Table 14. Veteran with mobility disability traveling from a rural home to the Veterans Affairs Hospital for a medical appointment.

Scenario #6	Veteran with Mobility Disability Traveling from a Rural Home to the VA Hospital for a Medical Appointment
Short Description	In this use case, a digital device end user in a rural community who does not own a personal vehicle wishes to navigate from an origin to a destination, using sidewalks and transit services that are available. Some sidewalk data has been mapped by the local municipality and sent to the data repository, but—being a rural area—the available infrastructure is extremely limited. The local transit agency offers paratransit services and reports this service data to the data repository using the GTFS-Flex data standard. Once the digital device end user confirms their eligibility for paratransit service through their traditional method, they use Multimodal AccessMap to locate paratransit services.
Goal	The goal of this use case is to illustrate the process of a veteran with a mobility disability utilizing a navigation application to locate a paratransit service and travel from their rural home to a VA hospital for a medical appointment. This is accomplished through a navigation application using local transit authority data on paratransit service formatted in the GTFS-Flex extension, to plan a multimodal route.

Scenario #6	Veteran with Mobility Disability Traveling from a Rural Home to the VA Hospital for a Medical Appointment
Constraints	• A constraint is the lack of fusion between multiple modes, where a user can utilize a pedestrian sidewalk, a transit service, and another pedestrian sidewalk as part of their complete trip. Some services exist, but they focus only on general street information and fixed-route transit service. • Another constraint is the lack of widespread adoption by transit authorities of the GTFS-flex extension. • Another constraint is that although data will be collected and validated from various sources, errors can exist in the sidewalk and transit service information.
Geographic Scope	Communities with on-demand or fixed-route transit service.
Actors	• Rural Transit Users • Municipal infrastructure Owner-Operators • Transit Agencies • Multimodal AccessMap Developers
Illustration	 *Source: University of Washington and Cambridge Systematics.*
Preconditions	1. The sidewalk data was efficiently mapped where available. 2. An on-demand paratransit service is available at the user's location. The paratransit agency provides GTFS-Flex data to the data repository. 3. The data repository has successfully validated, and quality assured the incoming data. 4. Multimodal AccessMap is approved to make requests through the proposed system's REST API for sidewalk and transit data. 5. Multimodal AccessMap has the capability to receive user travel preferences on the user's local device and can screen relevant routes that are received from the data repository that align with the user's preferences.

Scenario #6	Veteran with Mobility Disability Traveling from a Rural Home to the VA Hospital for a Medical Appointment
Main Flow	1. On a Wednesday morning, a rural veteran has a medical appointment scheduled at the nearest VA hospital. This rural veteran does not own a personal vehicle. As they are unfamiliar with how to reach the hospital, they decide to use Multimodal AccessMap to find the best route. 2. Upon entering the hospital's address into Multimodal AccessMap, they notice that they are provided the best route, which also happens to be the fastest. Using the data repository information, Multimodal AccessMap determines that there is a local paratransit service that is able to bring the user from his home to the hospital. They are able to call the phone number and are given a ride from their home to the transit station. 3. The rural veteran successfully reaches the VA hospital.
Alternate Flow(s)	None.
Post-conditions	1. Other transit authorities notice the accessibility benefits of providing GTFS-Flex extensions for their paratransit user base and begin to do so. 2. User is confident in the application's ability to provide useful information, and is likely to utilize it to support other unfamiliar trips. 3. User routinely adopts the application for regional trip making because the user knows they have a resource available to find suitable routes by pulling up the app. 4. User begins traveling more frequently, because they are confident they can get to and from a wide variety of destinations they were unsure they could reach previously. 5. User may feel encouraged to contribute observations as a crowdsourced contributor to help identify issues for other users.
Information Requirements	• GTFS-flex: An extension of GTFS that adds the capability to model demand-responsive transportation services beyond the fixed-route public transportation that is modeled by current GTFS datasets.
Related User Needs	UN-TS1, UN-TS2, UN-TS3, UN-TS5, UN-TS6, UN-DS1, UN-DS2, UN-DS3, UN-DS4, UN-DS5, UN-AD6, UN-AD7, UN-AD8, UN-AD9, UN-AD10, UN-AD12, UN-AD13, UN-AD14, UN-AD15, UN-AD16, UN-DU1, UN-DU2, UN-DU3, UN-DU4, UN-DU5, UN-DU6, UN-DU7, UN-DU9, UN-DU10, UN-DU11

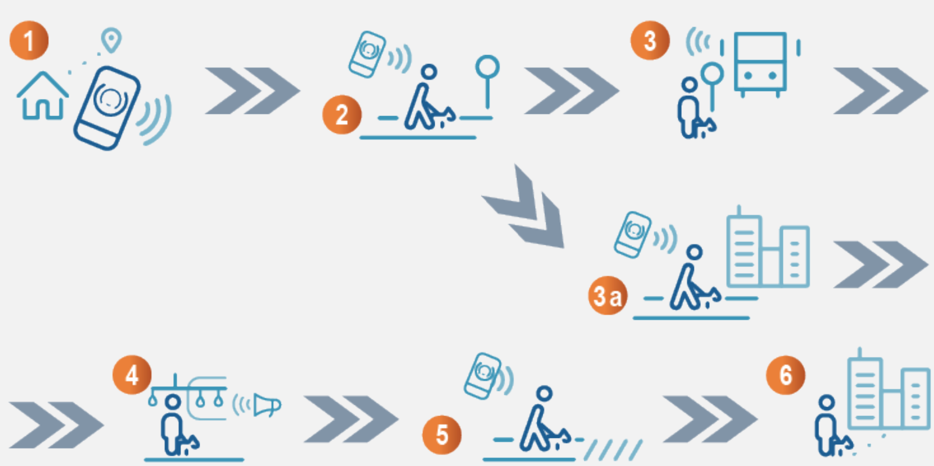
Source: University of Washington and Cambridge Systematics.

6.7. Blind, Vision Disabled, or Deafblind Individual Uses Verified Sidewalk and Transit Data

Table 15 provides the detailed operational scenario, including constraints and preconditions, the main flow, any alternate flows, and post-conditions.

Table 15. Blind, vision disabled, or deafblind individual uses verified sidewalk and transit data.

Scenario #7	Blind, Vision Disabled, or Deafblind Individual Uses Verified Sidewalk and Transit Data
Short Description	In this use case, a digital device end user who is blind or deafblind wishes to explore the environment, understanding the neighborhood they are moving through while they navigate from an origin to a destination, using sidewalks and transit services that are available and can accommodate their travel preferences. Mapping data for that user's city has been collected through a mapping technology company, which has produced general sidewalk information with attributes in the OpenSidewalks data format and submitted it to the data repository. Similarly, a local community of crowdsourcers is active in the area, providing corrections to any data errors. Soundscape, a navigation and exploration application for blind, vision disabled, or deafblind users, draws from the data repository and enables a user to navigate from their home to a shopping destination.
Goal	The goal of this use case is to illustrate the process of a blind, vision disabled, or deafblind user utilizing a navigation enhancement application, which includes verified sidewalk and transit stop location data, to explore their environment as they navigate to their destination. This is accomplished through sidewalk and transit data collection, validation, and dissemination from a central data repository to a navigation enhancement application. In this case, the application is Microsoft Soundscape. Soundscape relies on a central data repository for sidewalk and built environment data. The use case also illustrates how the blind, vision disabled, or deafblind user uses Soundscape, and the associated data, while reporting any necessary corrections.
Constraints	• A significant constraint in this use case is the absence of comprehensive, scalable sidewalk data, due to different stakeholders not gathering data in the same workspace and the costliness of manually collecting data. • Another constraint in this use case is the absence of sidewalk data that allows the user to identify and use a personal profile that describes their travel capabilities and preferences relative to those sidewalk attributes, as opposed to binning all disabled users into a single category. This is due to a lack of a widely adopted sidewalk data coding standard. • Another constraint is that Soundscape currently is a navigation application, not a route determination application, and does not suggest transit routes. It does describe the location of transit stops and the routes each stop serves. The user will need to be informed of which route to use through another service. • Another constraint is the lack of an efficient and cost-effective method for real-time validation of sidewalk conditions.

Scenario #7	Blind, Vision Disabled, or Deafblind Individual Uses Verified Sidewalk and Transit Data
Geographic Scope	Urban or suburban communities with sidewalk infrastructure and transit service.
Actors	• Blind, vision disabled, or deafblind Travelers • Municipal infrastructure Owner-Operators • Crowdsourced Sidewalk Reporters • Transit Agencies • Soundscape Developers
Illustration	 *Source: University of Washington and Cambridge Systematics.*
Preconditions	1. The sidewalk data in the city was efficiently mapped using advanced analytics and converted into the OpenSidewalks data format. 2. Users who provide crowdsourced corrections to sidewalk infrastructure do so accurately and quickly notice discrepancies between the reported data and actual conditions. 3. The regional transit agency updates the transit service information, following the GTFS standard. They submit an updated data package about once a week. 4. The data repository has successfully validated, and quality assured the incoming data. 5. Soundscape is approved to make requests through the proposed system's REST API for sidewalk and transit data. 6. Soundscape has the capability to receive user travel preferences on the user's local device and can screen relevant routes that are received from the data repository that align with the user's preferences.

Scenario #7	Blind, Vision Disabled, or Deafblind Individual Uses Verified Sidewalk and Transit Data
Main Flow	1. On a Saturday afternoon, a blind or deafblind user wishes to make a trip from their home to a downtown shopping destination. They are informed through other sources which route is recommended from their origin to destination. Using Soundscape, they are informed of the environment around them as they use a fixed-route bus from their home and then walk a few blocks to reach their destination. 2. Soundscape provides auditory cues of where to find the fixed-route bus stop and what arrival times are published, and describes the sidewalk features they will encounter prior to those features being encountered. The user navigates to the bus stop following the auditory cues to help understand their environment. They are given information about their surroundings as they walk. Deafblind travelers are able to read the auditory notifications through a braille reader. 3. The bus arrives and announces its service line. The user confirms it is their bus and they board. 4. The bus informs the user of each stop it visits. At the user's stop, the user requests a stop and departs the bus. 5. Soundscape uses audio cues (via the braille reader for deafblind travelers) to help orient the user on the sidewalk and in the correct direction, and describes the sidewalk features they will encounter prior to those features being encountered. The user utilizes the cues to stay on course. Soundscape provides the user with information about their surroundings as they walk. 6. The user successfully arrives at their destination. They are happy with the level of detail Soundscape provided about the route they chose, which assisted them in navigating.
Alternate Flow(s)	3a. The user decides that they would prefer to walk, as opposed to taking the bus. They walk on the sidewalks that follows the bus route. The Soundscape app continues to provide navigation information. The user explores the built environment along that route.

Scenario #7	Blind, Vision Disabled, or Deafblind Individual Uses Verified Sidewalk and Transit Data
Post-conditions	1. Other departments of transportation notice the positive impact of mapping their sidewalks environments, through integration with mobility applications, and begin to do so as well. 2. User is confident in the application's ability to provide useful information, and is likely to utilize it to support other trips both familiar and unfamiliar. 3. User routinely adopts the application when traveling because they appreciate the additional information they receive, which makes travel both more pleasant and easier. When changes occur (e.g., sidewalk is damaged), user knows they have a resource available to locate other pathways by taking advantage of the wayfinding features incorporated in Soundscape. 4. User begins traveling more frequently, because travel is less stressful, and they are confident they can get to and from a wide variety of destinations they were unsure they could reach previously. 5. User may feel encouraged to contribute observations as a crowdsourced contributor to help identify issues for other users.
Information Requirements	• Sidewalk Data: Attributes that are encompassed in OpenSidewalks data specification, including, but not limited to, pedestrian pathway attributes (length, width, etc.), road crossings, curb and ramp information, incline, path surface material, public transportation connections. • Fixed-route transit service: Attributes that are encompassed in GTFS data specification, including, but not limited to, agency, stops, routes, trips, and stop times.
Related User Needs	UN-TS1, UN-TS2, UN-TS3, UN-TS5, UN-TS6, UN-DS1, UN-DS2, UN-DS3, UN-DS4, UN-DS5, UN-AD1, UN-AD2, UN-AD3, UN-AD4, UN-AD5, UN-AD6, UN-AD7, UN-AD8, UN-AD9, UN-AD10, UN-AD11, UN-AD12, UN-AD13, UN-AD14, UN-AD15, UN-AD16, UN-DU1, UN-DU2, UN-DU3, UN-DU4, UN-DU5, UN-DU6, UN-DU7, UN-DU8, UN-DU9, UN-DU10, UN-DU11

Source: University of Washington and Cambridge Systematics.

6.8. Multilingual Tourist Tries to Conduct Pre-Trip Planning for a Multilevel Transit Station

Table 16 provides the detailed operational scenario, including constraints and preconditions, the main flow, any alternate flows, and post-conditions.

Table 16. Multilingual tourist tries to conduct pre-trip planning for a multilevel transit station.

Scenario #8	Multilingual Tourist Tries to Conduct Pre-Trip Planning for a Multilevel
Short Description	In this use case, an international tourist—whose primary language is not English—uses Unity Digital Twin to pre-plan their trip through a large, complex U.S. transit station. The transit agency previously utilized GTFS-Pathways to digitally represent the transit station. This information was published in the data repository.
Goal	This use case illustrates the process of a multilingual tourist conducting pre-trip planning for a complex, multilevel transit station. This is accomplished through the development an interactive digital model of a transit station using Unity Digital Twin to aid transit users in pre-trip planning.
Constraints	• A constraint in this use case is the absence of comprehensive, scalable digital twin data, due to different stakeholders not gathering data in the same workspace and the costliness of manually collecting data. • Another constraint is that digital twin technology maps an existing facility but does not take into account real-time conditions, such as entrance or exit closures. • As a pre-trip planning tool, another constraint is the lack of digital twin technology's integration with other modes.
Geographic Scope	Transit stations.
Actors	• Multilingual, Multicultural Travelers • Municipal infrastructure Owner-Operators • Transit Agencies • Digital Twin Developers
Illustration	 *Source: University of Washington and Cambridge Systematics.*

Scenario #8	Multilingual Tourist Tries to Conduct Pre-Trip Planning for a Multilevel Transit Station
Preconditions	1. The interior of the transit facility was mapped by the transit agency using the GTFS-Pathways data standard and submitted to the data repository.
Main Flow	1. An international tourist from abroad is approaching the transit station. With limited familiarity with the English language, they utilize Digital Twin in their native language. 2. The user enters their origin or destination into the digital twin. In this case, they will be arriving at the taxi stand and will need to get to a train platform that is on the lower level of the station. Digital Twin provides a three-dimensional representation of the transit station, showing the user which door to enter, which hallway to follow, where the elevator and stairs are, how to purchase a train ticket from the vending machine, and how to ultimately access the train platform. Once at the main concourse level, they are shown where amenities are available in the train station. All information is conveyed in a format that the user understands, factoring in language and cultural understanding. 3. The user feels confident in navigating the transit station. They are able to walk from their origin to their destination within the transit station with minimal challenges.
Alternate Flow(s)	1a. A older local user is an infrequent user of their local transit station, and does not use transit because they are not confident that they can find their way through the major transit station they must use. They utilize Digital Twin to help them better plan their trip and confidently disembark at the central station during a busy rush hour period. 3a. If the user gets lost within the station, they are able to utilize Digital Twin again to reorient themselves, as well as understand any unfamiliar local amenities that they take note of.
Post-conditions	1. After reviewing their path through the station using Digital Twin, the user becomes confident that they can easily use transit, and is likely to continue to utilize Digital Twin to support other unfamiliar trips involving transit. 2. User begins traveling more frequently on transit, because they are confident they can navigate environments that were confusing previously.
Information Requirements	• GTFS-pathways: An extension of GTFS that uses a graph representation to describe a transit station, with nodes signifying locals and edges signifying the pathways within the station.
Related User Needs	UN-DG1, UN-DG10, UN-TS1, UN-TS5, UN-TS6, UN-DS1, UN-DS2, UN-DS5, UN-AD1, UN-AD2, UN-AD3, UN-AD4, UN-AD5, UN-AD10, UN-AD12, UN-AD15, UN-AD16, UN-DU2, UN-DU4, UN-DU7, UN-DU8, UN-DU9, UN-DU10

Source: University of Washington and Cambridge Systematics.

6.9. Low-Income Traveler Utilizes a Third-Party Application (One-Call/One-Click Service) to Reach a Destination

Table 17 provides the detailed operational scenario, including constraints and preconditions, the main flow, any alternate flows, and post-conditions.

Table 17. Low-income traveler utilizes a third-party application (one-call/one-click service) to reach a destination.

Scenario #9	Low-Income Traveler Utilizes a Third-Party Application (One-Call/One-Click Service) to Reach a Destination
Short Description	In this use case, a third-party application developer utilizes sidewalk data and GTFS transit data to provide an enhanced one-call/one-click service for underserved user groups. The sidewalk data, which is collected by local cities or communities and verified, and the GTFS transit data, is stored in a central data repository. The third-party application is able to provide multimodal directions via a phone service, benefiting low-income users that may not have data plans and could not previously participate in services offered by other three mobile applications.
Goal	This use case illustrates the process of a low-income individual, who does not have a cellphone data plan, utilizing a service to reach their destination. This is accomplished through a third-party service utilizing centrally located sidewalk and transit data to develop a unique navigation application.
Constraints	• A significant constraint in this use case is the absence of comprehensive, scalable sidewalk data, due to different stakeholders not gathering data in the same workspace and the costliness of manually collecting data. • Another constraint in this use case is the absence of sidewalk data that allows the user to identify and use a personal profile that describes their travel capabilities and preferences relative to those sidewalk attributes, as opposed to binning all disabled users into a single category. This is due to a lack of a widely adopted sidewalk data coding standard. • Another constraint is the lack of fusion between multiple modes, where a user can utilize a pedestrian sidewalk, a transit service, and another pedestrian sidewalk as part of their complete trip. Some services exist, but they focus only on general sidewalk information and fixed-route transit service. • Another constraint is the lack of an efficient and cost-effective method for real-time validation of sidewalk conditions.
Geographic Scope	Urban or suburban communities with transit service and sidewalk data.

Scenario #9	Low-Income Traveler Utilizes a Third-Party Application (One-Call/One-Click Service) to Reach a Destination
Actors	• Low-Income Transit Users • Municipal infrastructure Owner-Operators • Transit Agencies • Third-Party Application Developers
Illustration	 *Source: University of Washington and Cambridge Systematics.*
Preconditions	1. A third-party application developer has an innovative idea for a new navigation service, one that includes sidewalk and transit routing through a one-call/one-click service without the need for end-users to have a cellphone data plan. 2. The sidewalk data in the city was mapped in the OpenSidewalks data format and submitted to the data repository. 3. Transit services in the region provide their fixed-route and on-demand service information to the data repository using the GTFS data standards. 4. The data repository has successfully validated and quality-assured the incoming data. 5. The third-party service is approved to make requests through the proposed system's REST API for sidewalk and transit data. 6. Third party service has the capability to identify relevant routes that are received from the data repository that align with the user's preferences. 7. Multimodal AccessMap, Soundscape, and Digital Twin do not have the capability to provide information to nondigital device users. 8. Nondigital device user has access to phone number for this service.

Scenario #9	Low-Income Traveler Utilizes a Third-Party Application (One-Call/One-Click Service) to Reach a Destination
Main Flow	1. A nondigital device user elects to make a trip from an origin to a destination in an unfamiliar area. They have limited travel preferences, but can only receive information via phone calls. The user calls the one-call/one-click service for transportation options. 2. The one-call/one-click service operator provides origin to destination routing for the user. The user immediately receives detailed directions. They note that the route includes a short walk, followed by a bus, followed by another short walk. 3. The user follows the directions, utilizing both the sidewalk and fixed-route transit service to guide them. The proposed route aligns with their preferences and is the shortest path. 4. The user arrives at the destination successfully.
Alternate Flow(s)	3a. Following the application's route to the grocery store, the user notices one of the sidewalk segments has been damaged significantly, and is in need of repair. Through the one-call/one-click service phone number, they are able to report an issue and the approximate location. The one-call/one-click service operator asks if an alternate route is preferred. The user confirms the request, and a new route is provided from that point forward, avoiding the damaged sidewalk segment.
Post-conditions	1. The user is confident in the application's ability to provide useful information, and is likely to utilize it to support other unfamiliar trips. 2. User routinely adopts the application for regional trip making because they know recommended route from home to work as their routine route. When changes occur (e.g., construction closes a sidewalk), user knows they have a resource available to find a new suitable route by pulling up the app at that time.
Information Requirements	• Sidewalk Data: Attributes that are encompassed in OpenSidewalks data specification, including, but not limited to, pedestrian pathway attributes (length, width, etc.), road crossings, curb and ramp information, incline, path surface material, public transportation connections. • Fixed-route transit service: Attributes that are encompassed in the GTFS data specification, including, but not limited to, agency, stops, routes, trips, and stop times.
Related User Needs	UN-DG1, UN-DG2, UN-DG3, UN-DG4, UN-DG5, UN-DG6, UN-DG7, UN-DG8, UN-DG9, UN-DG10, UN-TS1, UN-DS1, UN-DS2, UN-DS3, UN-DS4, UN-DS5, UN-AD1, UN-AD2, UN-AD3, UN-AD4, UN-AD5, UN-AD6, UN-AD7, UN-AD8, UN-AD9, UN-AD10, UN-AD11, UN-AD12, UN-AD13, UN-AD14, UN-AD15, UN-AD16, UN-DU1, UN-DU2, UN-DU3, UN-DU4, UN-DU5, UN-DU6, UN-DU7, UN-DU8, UN-DU9, UN-DU10, UN-DU11

Source: University of Washington and Cambridge Systematics.

6.10. Travelers with Sidewalk Preferences Utilize Data Generated by a City Government

Table 18 provides the detailed operational scenario, including constraints and preconditions, the main flow, any alternate flows, and post-conditions.

Table 18. Travelers with sidewalk preferences utilize data generated by a city government.

Scenario #10	Travelers with Sidewalk Preferences Utilize Data Generated by a City Government
Short Description	In this use case, a city government launches an initiative to improve their pedestrian environment for with mobility disabilities. As part of the initiative, they decide to map their sidewalk environment. Coordinating with Multimodal AccessMap, their sidewalk data are integrated into the navigation application.
Goal	The goal of this use case is to illustrate the process of travelers with sidewalk preferences utilizing a navigation application to reach their destination, with the data originating from a city Government. This is accomplished through a city becoming a new data contributor and their data being integrated into an existing navigation platform. In this case, Multimodal AccessMap is used as an example.
Constraints	• A significant constraint in this use case is the absence of comprehensive, scalable sidewalk data, due to different stakeholders not gathering data in the same workspace and the costliness of manually collecting data. • Another constraint in this use case is the absence of sidewalk data that allows the user to identify and use a personal profile that describes their travel capabilities and preferences relative to those sidewalk attributes, as opposed to binning all disabled users into a single category. This is due to a lack of a widely adopted sidewalk data coding standard. • Another constraint is the lack of an efficient and cost-effective method for real-time validation of sidewalk conditions. • Another constraint is that although data will be collected and validated from various sources, errors can exist in the sidewalk information.
Geographic Scope	Urban or suburban communities with sidewalk infrastructure.
Actors	• Travelers With Sidewalk Preferences • Municipal infrastructure Owner-Operators • Multimodal AccessMap Developers

Scenario #10	Travelers with Sidewalk Preferences Utilize Data Generated by a City Government
Illustration	 Source: University of Washington and Cambridge Systematics.
Preconditions	1. The sidewalk data was efficiently mapped where available. 2. The data repository has successfully validated, and quality assured the incoming data. 3. Multimodal AccessMap is approved to make requests through the proposed system's REST API for sidewalk and transit data. 4. Multimodal AccessMap has the capability to receive user travel preferences on the user's local device and can screen relevant routes that are received from the data repository that align with the user's preferences.
Main Flow	1. A local city Government has launched an initiative to improve their pedestrian environment for with mobility disabilities. The initiative began as physical infrastructure changes, including improved pedestrian crossings, ramps, and sidewalks. However, the city has determined that they must also map their sidewalk environments and ultimately make the data available to their residents through existing navigation applications. 2. The city maps their sidewalk environment and coordinates with Multimodal AccessMap, a navigation application that uses sidewalk and transit data. Their sidewalk data are integrated into the application via their central data repository. 3. Individuals who have mobility disabilities are now able to utilize Multimodal AccessMap for trip planning. The application provides detailed sidewalk directions, while taking their personal travel preferences into account.
Alternate Flow(s)	None.
Post-conditions	1. Other cities or local communities notice the positive impact of mapping their sidewalks environments, through integration with navigation applications, and begin to do so as well. 2. Users with mobility disabilities become confident in the application's ability to provide useful information, and use it to support their trip making. 3. Users with mobility disabilities begin traveling more frequently, because they are confident they can get to and from a wide variety of destinations they were unsure they could reach previously.

Scenario #10	Travelers with Sidewalk Preferences Utilize Data Generated by a City Government
Information Requirements	• Sidewalk Data: Attributes that are encompassed in OpenSidewalks data specification, including, but not limited to, pedestrian pathway attributes (length, width, etc.), road crossings, curb and ramp information, incline, path surface material, public transportation connections.
Related User Needs	UN-DG1, UN-DG2, UN-DG3, UN-DG4, UN-DG5, UN-DG6, UN-DG7, UN-DG8, UN-DG9, UN-DS1, UN-DS2, UN-DS3, UN-DS4, UN-DS5, UN-AD6, UN-AD10, UN-AD14, UN-AD15, UN-AD16, UN-DU1, UN-DU2, UN-DU4, UN-DU5, UN-DU9, UN-DU10, UN-DU11

Source: University of Washington and Cambridge Systematics.

6.11. Travelers with Sidewalk Preferences Utilize Data Generated by a Civic Organization

Table 19 provides the detailed operational scenario, including constraints and preconditions, the main flow, any alternate flows, and post-conditions.

Table 19. Travelers with sidewalk preferences utilize data generated by a civic organization.

Scenario #11	Travelers with Sidewalk Preferences Utilize Data Generated by a Civic Organization
Short Description	In this use case, a local nonprofit committed to accessibility decides to produce detailed sidewalk data for integration with Multimodal AccessMap. They coordinate with the application in order for their data to follow the correct standards and be integrated into the application's central data repository.
Goal	The goal of this use case is to illustrate the process of travelers with sidewalk preferences utilizing a navigation application to reach their destination, with data originating from a civic organization. This is accomplished through a civic organization providing crowdsourced data to a navigation application, such as Multimodal AccessMap.

Scenario #11	Travelers with Sidewalk Preferences Utilize Data Generated by a Civic Organization
Constraints	• A significant constraint in this use case is the absence of comprehensive, scalable sidewalk data, due to different stakeholders not gathering data in the same workspace and the costliness of manually collecting data. • Another constraint in this use case is the absence of sidewalk data that allows the user to identify and use a personal profile that describes their travel capabilities and preferences relative to those sidewalk attributes, as opposed to binning all disabled users into a single category. This is due to a lack of a widely adopted sidewalk data coding standard. • Another constraint is the lack of an efficient and cost-effective method for real-time validation of sidewalk conditions. • Another constraint is that although data will be collected and validated from various sources, errors may exist in the sidewalk information.
Geographic Scope	Urban or suburban communities with sidewalk infrastructure.
Actors	• Travelers With Sidewalk Preferences • Crowdsourcer Sidewalk Reporters • Multimodal AccessMap Developers
Illustration	 *Source: University of Washington and Cambridge Systematics.*
Preconditions	1. The sidewalk data was efficiently mapped where available. 2. The data repository has successfully validated, and quality assured the incoming data. 3. Multimodal AccessMap is approved to make requests through the proposed system's REST API for sidewalk and transit data. 4. Multimodal AccessMap has the capability to receive user travel preferences on the user's local device and can screen relevant routes that are received from the data repository that align with the user's preferences.

Scenario #11	Travelers with Sidewalk Preferences Utilize Data Generated by a Civic Organization
Main Flow	1. Within a U.S. city, a nonprofit is advocating for programs to improve accessibility for individuals with mobility disabilities. Having noted Multimodal AccessMap as a reliable navigation application for sidewalk data, they realize their potential for providing crowdsourcing support. 2. The nonprofit has an active group of members that regularly conduct fieldwork and document infrastructure conditions within the city. Coordinating with Multimodal AccessMap developers, they implement a system where their active community generates comprehensive sidewalk data within their city. Multimodal AccessMap provides them with the resources needed, including the necessary fields they must populate. 3. With this system in place, Multimodal AccessMap users in the city notice that Multimodal AccessMap is available. Using the navigation application within this city, they notice a substantial difference in the quality of the routing data the application is providing, as it delivers them the routing information they need to meet their individual travel requirements.
Alternate Flow(s)	None.
Post-conditions	1. Other civic organizations notice the positive impact of crowdsourcing and decide to create similar initiatives. 2. Users are confident in the application's ability to provide useful information, and are likely to utilize it to support other trips. 3. Users begin traveling more frequently, because they are confident they can get to and from a wide variety of destinations they were unsure they could reach previously.
Information Requirements	• Sidewalk Data: Attributes that are encompassed in OpenSidewalks data specification, including, but not limited to, pedestrian pathway attributes (length, width, etc.), road crossings, curb and ramp information, incline, path surface material, public transportation connections.
Related User Needs	UN-DG1, UN-DG2, UN-DG3, UN-DG4, UN-DG5, UN-DG6, UN-DG7, UN-DG8, UN-DG9, UN-DG10, UN-DS1, UN-DS2, UN-DS3, UN-DS4, UN-DS5, UN-AD6, UN-AD10, UN-AD14, UN-AD15, UN-AD16, UN-DU1, UN-DU2, UN-DU4, UN-DU5, UN-DU9, UN-DU10, UN-DU11

Source: University of Washington and Cambridge Systematics.

6.12. Travelers with Sidewalk Preferences Utilize Data Generated by an Aerial Mapping Company's Analytics Engine for Aerial Images

Table 20 provides the detailed operational scenario, including constraints and preconditions, the main flow, any alternate flows, and post-conditions.

Table 20. Travelers with sidewalk preferences utilize data generated by an aerial mapping company's analytics engine for aerial images.

Scenario #12	Travelers with Sidewalk Preferences Utilize Data Generated by an Aerial Mapping Company's Analytics Engine for Aerial Images
Short Description	In this use case, a large aerial mapping company decides to produce an analytics engine capable of generating sidewalk data. They coordinate with Multimodal AccessMap to ensure the correct data standards are followed. Their data are ultimately integrated with the navigation application, and users are able to utilize the sidewalk data for trip planning purposes.
Goal	The goal of this use case is to illustrate the process of travelers with sidewalk preferences utilizing a navigation application to reach their destination, with data generated by an aerial mapping company's analytics engine for aerial images. This is accomplished through an aerial mapping company developing an automated system of developing sidewalk data. It also discusses how this data would adhere to OpenSidewalks data standards and contain the necessary level of detail.
Constraints	• A constraint in this use case is the absence of sidewalk data that allows the user to identify and use a personal profile that describes their travel capabilities and preferences relative to those sidewalk attributes, as opposed to binning all disabled users into a single category. This is due to a lack of a widely adopted sidewalk data coding standard. • Another constraint is the lack of an efficient and cost-effective method for real-time validation of sidewalk conditions. • Another constraint is that although data will be collected and validated from various sources, errors may exist in the sidewalk data.
Geographic Scope	Urban or suburban communities with sidewalk infrastructure.
Actors	• Travelers With Sidewalk Preferences • Mapping Services • Multimodal AccessMap Developers

Scenario #12	Travelers with Sidewalk Preferences Utilize Data Generated by an Aerial Mapping Company's Analytics Engine for Aerial Images
Illustration	 *Source: University of Washington and Cambridge Systematics.*
Preconditions	1. The sidewalk data was efficiently mapped where available. 2. The data repository has successfully validated, and quality assured the incoming data. 3. Multimodal AccessMap is approved to make requests through the proposed system's REST API for sidewalk and transit data. 4. Multimodal AccessMap has the capability to receive user travel preferences on the user's local device and can screen relevant routes that are received from the data repository that align with the user's preferences.
Main Flow	1. A large aerial mapping company sees the potential of their analytics engines to be used with sidewalk data and would like to create an analytics engine for creating this type of data. 2. They coordinate with the OpenSidewalks data standards group, which provides the mapping company with the necessary metadata and data standards they must adhere to. 3. The aerial mapping company develops their analytics engine, which is able to convert aerial imagery into data that is usable and integrated into Multimodal AccessMap's central data repository. 4. Due to the scalable production of sidewalk data, users of applications that take advantage of the availability of objective, accurate sidewalk data, such as Multimodal AccessMap. notice that their applications are available in a larger number of cities and geographical areas.
Alternate Flow(s)	None.
Post-conditions	1. Other aerial mapping companies notice the market for developing analytics engines for sidewalk data mapping and create similar products, which are used for sidewalk data generation. 2. Through improved sidewalk data, users are confident in the application's ability to provide useful information, and are likely to utilize it to support other unfamiliar trips. 3. User begins traveling more frequently, because they are confident they can get to and from a wide variety of destinations they were unsure they could reach previously.

Scenario #12	Travelers with Sidewalk Preferences Utilize Data Generated by an Aerial Mapping Company's Analytics Engine for Aerial Images
Information Requirements	• Sidewalk Data: Attributes that are encompassed in OpenSidewalks data specification, including, but not limited to, pedestrian pathway attributes (length, width, etc.), road crossings, curb and ramp information, incline, path surface material, public transportation connections.
Related User Needs	UN-DG1, UN-DG2, UN-DG4, UN-DG5, UN-DG6, UN-DG7, UN-DG8, UN-DG9, UN-DG10, UN-DS, UN-DS2, UN-DS3, UN-DS4, UN-DS5, UN-AD6, UN-AD10, UN-AD14, UN-AD15, UN-AD16, UN-DU1, UN-DU2, UN-DU4, UN-DU5, UN-DU9, UN-DU10, UN-DU11

Source: University of Washington and Cambridge Systematics.

6.13. Transit Users Utilize General Transit Feed Specification for a Demand-Responsive or Paratransit Service and for Pathways Linking Together Locations within Stations Extensions Through a Navigation Application

Table 21 provides the detailed operational scenario, including constraints and preconditions, the main flow, any alternate flows, and post-conditions.

Table 21. Transit users utilize General Transit Feed Specification for a demand-responsive or paratransit service and for pathways linking together locations within stations extensions through a navigation application.

Scenario #13	Transit Users Utilize GTFS-Flex and GTFS-Pathway Extensions Through a Navigation Application
Short Description	In this use case, a regional transit agency decides to include the GTFS Pathways and Flex extensions in their weekly GTFS dataset. Once they do so, this use case also demonstrates the automatic integration with Multimodal AccessMap and the improved user experience.
Goal	The goal of this use case is to demonstrate how transit user and travelers with mobility disabilities, utilize a navigation application with the GTFS-Pathways and Flex extensions. This is accomplished through a transit agency adding GTFS Pathways and Flex extensions to their existing GTFS data, which are then incorporated into navigation applications, Multimodal AccessMap in this case.

Scenario #13	Transit Users Utilize GTFS-Flex and GTFS-Pathway Extensions Through a Navigation Application
Constraints	• A constraint in this use case is the lack of fusion between multiple modes, where a user can utilize a pedestrian sidewalk, a transit service, and another pedestrian sidewalk as part of their complete trip. Some services exist, but they focus only on general sidewalk information and fixed-route transit service. • Another constraint is the lack of an efficient and cost-effective method for real-time validation of sidewalk conditions. • Another constraint is that although data will be collected and validated from various sources, errors may exist in the sidewalk data and transit service/station information.
Geographic Scope	Urban or suburban communities with fixed route and on-demand transit service.
Actors	• Travelers With Sidewalk Preferences • Transit Agencies • Multimodal AccessMap Developers
Illustration	 *Source: University of Washington and Cambridge Systematics.*
Preconditions	1. The data repository has successfully validated, and quality assured the incoming data. 2. Multimodal AccessMap is approved to make requests through the proposed system’s REST API for sidewalk and transit data. 3. Multimodal AccessMap has the capability to receive user travel preferences on the user’s local device and can screen relevant routes that are received from the data repository that align with the user’s preferences.

Scenario #13	Transit Users Utilize GTFS-Flex and GTFS-Pathway Extensions Through a Navigation Application
Main Flow	1. A regional transit agency in the U.S. currently operates several fixed-route transit routes. They are also aware of several on-demand and paratransit services that operate in their region. 2. In an effort to improve transit accessibility, they decide they would like to expand the data offered through their GTFS portal. The transit agency publishes an updated GTFS dataset weekly. Improvements to the data will include data in the GTFS pathways extension, which describes the layout of transit station infrastructure and pathways through that infrastructure, and GTFS Flex, which describes on-demand transportation services that are available. 3. When the transit agency releases their GTFS data, containing the data in these extensions, Multimodal AccessMap automatically integrates it into their central data repository, and therefore their navigation application. 4. Users who utilize the application for trip planning in the region now notice new transit service options. Those options now provide more detailed instructions on navigating through transit stations, as well as the availability of on-demand services.
Alternate Flow(s)	None.
Post-conditions	1. Other transit agencies realize the benefit of providing the GTFS Pathways and Flex extensions as part of their GTFS data. 2. Through access to these new GTFS data, users are confident in their navigation application's ability to provide useful information, and are likely to utilize it to support other trip making activity. 3. Users begin traveling more frequently, because they are confident they can get to and from a wide variety of destinations they were unsure they could reach previously.
Information Requirements	• GTFS-Pathways—An extension of GTFS that uses a graph representation to model transit stations, including the pathways that connect different locations within the station. • GTFS-Flex: An extension of GTFS that adds the capability to model demand-responsive transportation services beyond the fixed-route public transportation that is modeled by current GTFS datasets.
Related User Needs	UN-TS1, UN-TS2, UN-TS3, UN-TS5, UN-TS6, UN-DS1, UN-DS1, UN-DS2, UN-DS3, UN-DS4, UN-DS5, UN-AD6, UN-AD10, UN-AD14, UN-AD15, UN-AD16, UN-DU1, UN-DU2, UN-DU3, UN-DU4, UN-DU5, UN-DU6, UN-DU7, UN-DU9, UN-DU10

Source: University of Washington and Cambridge Systematics.

7. Summary of Impacts

7.1. Operational Impacts

The proposed system will have a direct impact on the operational roles and responsibilities of several actors.

- **Data producers, contributors, and aggregators will have to send data to the data repository—**Upon implementation of the proposed system, data producers, contributors, and aggregators will send data to the data repository. Some of these entities may already be doing this as part of their standard operating procedure, primarily the transit agencies that send data to Google to distribute as part of GTFS. Others will have to commit labor resources to submit data as they are added or updated.
- **Application developers will need to utilize the REST API—**Application developers that wish to utilize the data repository will need to gain approval to use the REST API. This may require integration updates to their various applications. These application developers will need to maintain their connection to the data repository in order to receive data on a periodic basis.
- **Application developers will need to notify digital device end users when data are not available**—For a scalable system, application developers assume that data are available beyond their current geographic scale. If application developers expand their geographic footprint, they will need to institute some kind of means to inform their end users when pathway data are not available.
- **Data formats will need to adhere to new data standards—**Information will be published in existing and relatively new data schema, which include OpenSidewalks and GTFS (and its affiliated extensions). Data producers, contributors, and aggregators that wish to contribute to the data repository will need to convert their data into one of the approved formats, which may require some effort and experience. Application developers that wish to utilize this data repository will need to understand the data specifications.
- **Data will need to be validated—**To preserve credibility, data validation is a necessary step. While an automated option may exist for some data elements, it is likely that the validation process will include some manual verification steps. The organization that operates and maintains the data repository may need to deploy data validators, either through their organization or as part of a recruiting effort to enlist volunteers.

7.2. Organizational Impacts

The proposed system will impact the organizations that utilize the proposed system.

- **Data producers, contributors, and aggregators, and application developers will need training on the specifications of the new data standards**—Entities submitting and consuming data from the data repository will need staff who are trained in the new data specifications. Understanding how the specifications work will be necessary for the data to be collected, transmitted, and disseminated in the correct format. Public sector data contributors may be able to leverage the processes established place by the transit agencies after adoption of the enhanced GTFS data specification.

- **Data producers and transportation service providers will need to identify staff to make updates—**As new information is digitized, municipal transportation agencies and transit agencies will need to commit staff resources to adding the latest information to the data repository. This may entail varying time commitments, depending on the amount of network that is added during each incremental change. Transit agencies have some experience already by describing their fixed-route transit system via GTFS.
- **The data validation role will need to be identified—**As noted earlier, data validation is a critical component of the data repository. Data validators may be part of the organization that operates and maintains the data repository, or they may be volunteers located within cities supported by end-user applications. Organizations may need to plan for formal roles to oversee data validation, even if the process is run by volunteers.
- **The data repository will need to be maintained—**The organization that operates and maintains the data repository will need to financially support maintenance of that repository, including, but not limited to, expanding user volumes, data storage capacity, and data analytics capability as needed.
- **Application developers may need to shift resources from data integration to system expansion—**Implementation of the proposed system will serve data from a multitude of sources from a single location, as opposed to spread across separate systems as in the current situation. Job responsibilities of integration engineers may be shifted to a different purpose, such as expanding the resources needed to operate a much larger geographic footprint.

7.3. Impacts During Development

The proposed system will have impacts during development in Phase 2:

- **The data standards committees need to release new versions—**For the proposed system to advance, the OpenSidewalks and GTFS extensions data specifications will need to reach an interim milestone version so that designers can begin to build the proposed system. Committee meetings to determine the appropriate updates to the data standards are currently ongoing in the planning phases of this project, but these discussions will need to result in a set formal specifications, with the understanding that new versions may be released in the future. This may require agreements that are more accelerated than originally planned.
- **Data producers, contributors, and aggregators will need to gain access to the proposed system—**As the proposed system is built, data producers, contributors, and aggregators will be needed for real-world testing. While pilot data in select geographic areas may be a starting point, system development will require a plan to expand the number of contributors to the proposed system. To test the functionality of the data pipelines, some entities may need to prematurely integrate with the proposed system.

- **Temporary downtime will be needed to activate enhanced features in the existing applications—**As the proposed system is built, enhancements will be made to AccessMap (new version referred to as Multimodal AccessMap), Soundscape, and Digital Twin in order to add the supplemental features enabled by this proposed system. While it is likely that modifications will be made and tested in a separate sandbox environment (i.e., not requiring the main systems to go offline during development), some temporary downtime may occur as the new updates are released in the active version.
- **Pilot demonstration and acceptance testing will be required—**Before the proposed system goes live, all actors may have to accommodate pilot demonstration and acceptance testing requirements. This accommodation may require human effort to support the precondition, testing, and post-condition observations necessary to verify whether the system meets the proposed systems requirements.

8. Analysis of the Proposed System

8.1. Analysis of the Proposed System

This section describes the benefits, limitations, and/or disadvantages of the proposed system.

8.1.1. Benefits

This subsection summarizes the key benefits that are expected from deployment of this proposed system. The anticipated benefits are listed in **Table 22**, with additional details provided following the table.

Table 22. High-level benefits of the proposed Transportation Data Equity Initiative system.

Performance Measures	Project Benefits
Mobility and Safety	• Improved Complete Trip experience for users with specific travel preferences. • Improved pathway user experience for pedestrians. • Improved transit experience for users who require fixed or on-demand transportation service information. • Improved experiences navigating transit stations and facilities.
Efficiency	• Defined single integration point to which interested data producers, contributors, and aggregators can send their data. • Defined data standards specifications to provide data format and content guidance for data sharing. • Ease of geographic scalability. • Expandable solutions enabled through a community of third-party application developers.
Accessibility	• Increased access to existing transit services for riders.
Asset Preservation	• Improved capabilities for infrastructure owner operators to document and receive feedback on their infrastructure assets.

Source: University of Washington and Cambridge Systematics.

- **Improved Complete Trip experience for users with specific travel preferences—**The proposed system will enable users with specific travel preferences to plan a trip from origin to destination, utilizing walking and/or transit modes that align with those specific travel preferences. Current mainstream solutions do not cater to specific travel preferences, grouping all disabilities under the same category.

- **Improved pathway user experience for pedestrians—**Adoption of the OpenSidewalks data standard will provide guidance for data producers, contributors, and aggregators to aid in sidewalk data collection. Application developers can then utilize that sidewalk data to provide routing guidance to interested pedestrians, particularly those with specific travel preferences.
- **Improved transit experience for users who require fixed or on-demand transportation service information—**Continued utilization of GTFS and the adoption of GTFS-Flex data standards will provide opportunities for transit agencies to increase digital awareness of their offered services. Application developers can then utilize those transportation service data to provide routing guidance to interested transit users, particularly those with specific travel preferences.
- **Improved experiences navigating transit stations and facilities—**Adoption of GTFS--Pathways and other affiliated extensions will provide opportunities for transit agencies to increase digital awareness of their complex, multilevel transit stations. Application developers can then utilize those transit station facility description data to provide routing guidance to interested transit users, particularly those with specific travel preferences.
- **Defined single integration point for to which interested data producers, contributors, and aggregators can send their data—**Data producers, contributors, and aggregators want their data to be as widely available as possible to help increase the number of users who benefit from access to those data. Establishing a data repository will provide data producers, contributors, and aggregators with a single integration point, from which data contributions can be made more widely available to end users. This approach is more scalable than data repositories separated by data type.
- **Defined data standards specifications to provide data format and content guidance for data sharing—**Data producers, contributors, and aggregators often look to data standards to help them formulate their reporting requirements. Establishment of data standards for pathway feature and characteristic data, transportation service data, and transit station facility description data will help achieve these needs. Piloting these data standards will help prove the UW ITS4US Deployment concept, attract interest, and facilitate rollout. Adoption of data standards will allow for lower cost application development for infrastructure owners, greatly lowering the costs of other uses of those data and thus providing large secondary benefits to agencies collecting those data.
- **Ease of geographic scalability—**This proposed system will utilize data standards that can be applied easily. Interested cities, transit agencies, or other partners can simply become an approved contributor to the proposed system and share data from their geographic location. Providing the data in a standardized format means that an end user of a specific mobile application can utilize the application's services in different cities without having to access multiple applications.
- **Expandable solutions enabled through a community of third-party application developers—**The proposed system will allow approved third-party application developers to utilize the data. This means that any service that is not provided as part of the three applications developed for this proposed system may be addressed by another group of developers.

- **Increased access to transit services by riders—**By increasing the information available to customers, particularly with sidewalk access to transit for individuals with specific travel preferences, transit agencies may see an increase in ridership. This may also help facilitate an awareness of accommodating pathways to lower-cost, fixed-route transit service for certain customers, which may reduce the need for more costly paratransit service that the transit agency would normally provide. Transit agencies that do pathway reviews for their paratransit service will also have insights into the built environment, reducing costs associated with sending people into the field to document pathways to support the need for paratransit.
- **Improved capabilities for infrastructure owner-operators to document and receive feedback on their infrastructure assets—**Infrastructure and transit infrastructure owner-operators will be able to document parts of the infrastructure in a standard format that will allow disparate pieces to be joined together, allowing these owners to better understand their infrastructure. Additionally, by having this information publicly available for feedback through third-party applications, these owners can be notified when issues are reported, similar to the way that traffic management centers utilize crowdsourced Waze reports to identify roadway incident locations. Rather than having to file a complaint with the community's or transit agency's information service, crowdsourced users can report asset issues (e.g., a damaged sidewalk), and the owner can more promptly create a maintenance ticket for repair.

8.1.2. Limitations

Some of the inherent limitations of the proposed system include the following:

- **The proposed system relies on data producers, contributors, and aggregators—** The proposed system is limited first and foremost by its data sharing entities. Data collection is critical for any system, but data sharing is essential for the proposed system because those shared data directly feeds a service. A minimum viable amount of pathway feature and characteristic data, transportation service data, and transit station facility description data are necessary to help inform a Complete Trip from origin to destination and maintain credibility with the end user. Cities may not want or be able to provide these data because of cost, and crowdsourced contributors may not be active in a particular area. Processing of aerial maps or LiDAR may help fill many gaps, but in some instances (e.g., if a critical section of sidewalk is blocked from view), it may not be enough to achieve the data requirement.
- **The modal choice for Complete Trips is limited—**The proposed system currently is scoped only to provide a Complete Trip in the context of sidewalks, transit stations, and fixed or on-demand transit service, with a focus on end users who have specific travel preferences. While sidewalks and transit tend to be the primary modes of choice for end users with those specific travel preferences, they are not the only modes that exist in the transportation network. The bicycle mode can offer service to some end users with certain travel preferences. Similarly, the rise of micromobility has allowed for some e-scooters to serve those users as well. While the system does not necessarily prohibit other modes, its current scope does not include them in the three demonstration end-user applications.
- **Data standards have inherent limitations—**While establishing data standards and demonstrating their benefits through this proposed system have many advantages, the

proposed system is inherently limited by the data specifications established for those standards. For example, the developers of the OpenSidewalks data schema frequently discuss whether certain attributes—while beneficial—should be included because of the low chance of an end user being able to quantify their travel preferences (e.g., an older adult would like to avoid sidewalks with a steep cross slope, but describing a cross slope is not an intuitive process with which most users are familiar). At the time of data standard adoption, data sharing entities will provide information that, at best, covers all attributes defined in the data specification, but will not provide any other beneficial information that the proposed system could utilize. Fewer attributes may encourage more adoption, but the proposed system may be missing certain insights because of the absence of other attributes that are not included in the standard.

- **Data validation is an operating cost—**When data sharing entities provide information on a particular area, the proposed system will rely on data validators to ensure that the data are complete and logically correct. Ideally, validation will occur through automated processes against multiple data sources, but in reality, the validation process may require manual observations and confirmation by an "approved individual." Even if data validators are volunteers, maintaining this base of volunteers may be a difficult undertaking, and it is not guaranteed that a data validator team could cover the entire geographic reach of the potential proposed system. In areas of limited coverage, data validation may be a limitation of the proposed system.
- **Maintenance will be ongoing—**Regardless of which organization owns, operates, and maintains parts of the proposed system, a maintenance element will be an ongoing requirement. Maintenance is not just limited to the physical upkeep of the software and systems but also requires coordination with data producers, data contributors, data aggregators, and application developers that need additional services, as well as other needs requirements. In addition, because infrastructure attributes and features change over time, it will be necessary to provide for the ability to update the data contained in all three data standards for any jurisdiction.

8.1.3. Disadvantages

Some of the inherent disadvantages with the implementation of the proposed system include the following:

- **There is no alternative to data sharing entities—**As noted in the previous section, the usefulness of the proposed system is heavily dependent on interested parties contributing data, which requires data standards that allow them to do so without excessive burden while also providing sufficient information for application developers and end users to successfully utilize. This can be a challenge; for example, King County Metro is only one of a few transit agencies that maps sidewalks as part of its paratransit service. Similarly, if transit agencies do not provide data describing their transit center facilities, those data are not likely to be available. While several options for collecting sidewalk data are proposed, alternative options for many transit services are unlikely for the proposed system at this time.
- **Use of specific data standards is required—**OpenSidewalks and some of the proposed GTFS extensions are on track to become adopted standards, but several competing standards have been proposed. While the proposed system is not prohibitive to alternative replacement standards, it is not designed to inherently alternate between

different standards, particularly those without direct translations between one another and whose inherent schema are not interchangeable (e.g., the graph-node format of OpenSidewalks versus a non-graph-node format of a competing standard).

- **Data storage and maintenance are costly—**This proposed system relies on data storage to provide information to its users, as opposed to a system that constantly pulls the latest data from contributors upon request. As a result, the costs of data storage are placed on the proposed system, as opposed to the data sharing entities. While this may incentivize contribution to the proposed system, it inherently comes with increased costs that cannot be avoided.
- **Success is tied to use—**As a path-building service to support route navigation, this proposed system offers value by providing information upon request to application developers and end users. If no end-user application developers use the data in the context of providing new services to people with mobility disabilities, then benefits to that population will be limited. Note that other uses of the data—such as for asset management—may still accrue to the infrastructure owners, but those are not the primary intended benefits from this effort.

8.2. Alternatives and Tradeoffs Considered

Given the above analysis of the proposed system, alternative options and tradeoffs have been examined in lieu of the system in its proposed form. The alternative options listed below explore different approaches to improving the ability of a pedestrian with unique preferences to navigate the pedestrian-built environment. It is important to note that some alternatives may seem intuitively nonsensical but are worth exploring to confirm that all options have been investigated and rejected for the stated reasons.

8.2.1. Alternative 1: Do Nothing

This alternative maintains the current situation, which requires no changes to the existing components, no new component development, and no changes to existing processes. The current situation in **Section 3** remains in its current form, with each component in **Figure 9** operating as its own service. This organization is most familiar to current users, and while it incurs no additional costs or effort, it fails to resolve any of the current gaps between the current system and user needs. Users need to access multiple systems to obtain information to prepare a Complete Trip and have limited advance information of the pathway. This limits the ability to travel for many underserved populations. Data producers, contributors, and aggregators do not have a common data repository for sharing resources on sidewalk data, meaning data may be scattered across different systems, greatly increasing the cost of any system that could make use of those data.

This alternative is not recommended because it maintains the same shortcomings of the current situation. Without a proposed improvement, certain user demographics have limited data resources to establish a Complete Trip, limiting their travel opportunities.

8.2.2. Alternative 2: Focus the Proposed System on One Element (Sidewalks or Transit) but Not Both

This alternative reduces the goals of the proposed system by building the same architecture for collection, processing, and distribution of data, but focusing it exclusively on either sidewalk data or transit data. Parts of the proposed system in **Section 5** would be deployed, depending on the element that was selected. This alternative could include a situation in which both elements were selected but deployed in two different systems that were of a similar design.

This alternative would allow services to be more focused on a particular travel mode. For example, by focusing the system on sidewalk data only, the design team could allocate more resources to constructing an extremely robust sidewalk data platform. This would reduce the required amount of data repository space, reduce the number of REST APIs that needed to be implemented, and perhaps shift development efforts to a greater focus on sidewalk attributes than the competing transit need (if sidewalks were the focus area). The other service could be pursued in the future as a separate system developed by other groups, ultimately providing both services to the application developers and end users to assemble a Complete Trip.

While this alternative would offer some advantages, it would also generate several disadvantages. Focusing on one of the two elements would offer no promise that the second element would ever be developed or assembled in a similar proposed system. For example, if sidewalk elements were selected, it is likely that other ongoing work would continue development and implementation of the GTFS extensions, but transit agencies might offer them only through their existing services rather than store them in a data repository environment. Even if the second data repository was created by another interested party, the inherent differences between the data repositories (e.g., different owner, IT policies, APIs, etc.) would introduce additional complexity and risk for the same outcome.

The second major disadvantage of this alternative is that it would continue to ignore a major problem that prohibits many people from traveling and completing trips they need to make. Only working to improve sidewalk data means that people who rely on on-demand services still lack a reasonable way to discover and plan to use those services. Working to improve only transit service information would mean that many individuals would still not successfully navigate the first-/last-mile portions of their trips reliably. As a result, individuals might choose to not travel because they would be uncertain about their ability to successfully complete those trips.

This alternative is not recommended because—while potential exists to eventually achieve the same end result—it introduces the additional risk of two separate systems and the need for a separate party electing to construct the second element. While many benefits would exist by increasing human effort and focus on the first element, the efforts associated with the proposed system—as well as predecessor and ongoing research, stakeholder outreach, and standards development—would yield only marginal improvements.

8.2.3. Alternative 3: Build a New Application and Host All Services as a Primary Service

This alternative reimagines the proposed system as being built primarily by an application developer whose end goal would be to build a brand new, standalone application to serve the multimodal trip needs of many users with specific preferences. In this alternative, this application developer would build both the data repository (for sidewalk and transit data) and also a primary, end-user-focused application to disseminate those data. Data producers, contributors, and aggregators would still share data with the data repository as with the proposed system. Other application developers—namely for AccessMap, Soundscape, Digital Twin, and other third-party applications—might still be involved, but would need to operate in the same market as this proposed application and would need to comply with the policies and requirements of the application developer that controlled the REST APIs.

This alternative would allow services to be comprehensively developed into a single application as part of its design, helping reduce the amount of external coordination and reliance on other applications to provide services. The application would be developed in accordance with the project's proposed user needs, thus increasing the chances of satisfying those requirements by having more internal control over the development. Other application developers would have access to the REST APIs to use the data for their own services, maintaining the ability to add features and functionalities that might not be addressed by the primary application. End users would benefit by having the vast majority of services under a single application, allowing it to be better maintained by having a large number of users.

While this alternative would offer many advantages, it would also come with several disadvantages. The costs of developing a new application to address the mobility preferences identified for this project would be significantly higher than those for developing a data repository alone. Additionally, many of the proposed services for various mobility preferences would take advantage of the services already offered by the various applications (e.g., AccessMap, Soundscape, Digital Twin), meaning that adding new capabilities for mobility preferences would not be a significant and costly addition relative to building a new application. These existing applications would also have an existing user base and an existing maintenance plan (internal to the application developer), so they would be more likely to remain sustainable in the future.

This alternative is not recommended because—despite several benefits gained by unifying all features under a single application—it would introduce significantly higher costs and would fail to take advantage of existing sustainable applications. In the future, this might be a viable business model for a potential application developer or data service provider, but for development purposes, it would be better to keep applications themselves in the purview of developers that have experience and customer bases in that arena. Additionally, pursuit of this alternative as part of development might discourage participation and use by third-party application developers that view the system as being standalone, impacting this proposed system's goal of being scalable.

8.2.4. Alternative 4: Adopt Standards and Let the Market Develop the Proposed System

This alternative aims to develop the proposed system through private-sector market motivations. Efforts regarding the proposed system would focus instead on establishment of robust standards, facilitation of widespread adoption among interested parties, and mechanisms for interested parties to make those data available. Private-sector data service providers and application developers would build the proposed system based on goals of generating profit by increasing the number of users. For example, a map service might incorporate sidewalk and transit data into its existing platform—likely by pulling data from data and transportation service providers—to increase its service offerings and boost its user base.

This alternative would significantly reduce costs by pushing implementation into the private sector. It would streamline development by involving fewer actors, allowing private-sector organizations to develop the Complete Trip with the available data. Resources from the project team could be more focused on establishing the data standards and onboarding various entities to serve as data producers, contributors, and aggregators, increasing geographic coverage.

This alternative, unfortunately, would have many disadvantages. Establishing standards and recruiting data providers would not guarantee that private industry would be motivated to move the proposed system forward, as the proposed system would need to both demonstrate a solid return on investment (ROI) and not detract internal resources from another, more profitable venture. Private-sector groups would also have different priorities that might not conform to the spirit of the project, meaning no guarantee would exist that the end product would address the project's original user needs. While providing support funding could help mandate that user needs be met, less control would exist over the degree to which these user needs were satisfied. Additionally, it is unknown whether one or more private-sector firms might attempt to build the system, but it is very likely that collaboration between parties would not occur and that the party that succeeded most in the market would restrict access to services to avoid other competitors from gaining market share.

This alternative is not recommended because it would generate too much risk of the proposed system not being deployed and of any deployed system not meeting the desired user needs of this project. While private-sector ownership might be a business model for a deployed system in the long term, it would not likely be a viable approach in the context of system development.

8.2.5. Alternative 5: Pull Data on Demand from Contributors to Reduce Data Repository Storage

This alternative aims to reduce the cost of a data repository by pulling data from contributors, as opposed to having data producers, contributors, and aggregators push data to the data repository. This envisions a scenario in which, upon request for sidewalk or transit data for a specific geographic region from an application developer, the proposed system would pull data from the applicable contributors in that region, likely by utilizing an approved list. Sidewalk and transit data would reside at the contributors' data repositories, and the proposed system would be granted access to their systems. An API would likely need to be established for each data producer, contributor, or aggregator to allow access.

This alternative would significantly reduce costs by transferring the data repository costs to the contributors, who would then respectively house their relevant sidewalk and transit data. With data producers, contributors, and aggregators updating the data in their own repositories, as opposed to sending new data to the data repository after each update, the proposed system would have a better chance of accessing the latest available information because less manual effort would be required when a data update occurred.

This alternative would have many disadvantages. First and foremost, this approach would require that public agencies build, maintain, and operate sophisticated data systems capable of interacting with multiple application developers. While a few larger agencies might be capable of performing this task, this would be impractical for most public owners of sidewalk infrastructure, and thus, such an approach would be almost guaranteed to fail for lack of data.

Even if some jurisdictions could build and operate their own live data repositories, by having multiple disparate contributors, the proposed system would have to assemble a complete network at the time of request, as opposed to in advance with time to quality-check whether the pathway connections were logical. For example, if requesting a trip through two communities that were their own data producer, the proposed system would have to quickly connect those two networks and determine in a short time how the links connected to one another. This reduction in quality assurance would increase the chance of path errors due to mismatched links, meaning that the Complete Trip data provided to application developers might have errors and would be less likely to be utilized. Additionally, an on-demand data request would limit the capabilities of approved validators to confirm whether certain data were legitimate, such as if a city reported a sidewalk condition that did not align with what crowdsourced users reported. Additionally, by adding the responsibility for maintaining a data repository for the proposed system, it is likely that some contributors might elect not to participate.

This alternative is not recommended because it would discourage use of the proposed system, both by contributors who might be reluctant to maintain their own data repository and by application developers and end users who might find errors in the data due to reduced quality assurance and validation processes.

U.S. Department of Transportation
ITS Joint Program Office-HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free “Help Line” 866-367-7487
www.its.dot.gov

FHWA-JPO-21-861

U.S. Department of Transportation