MULTIMODAL AND ACCESSIBLE TRAVEL STANDARDS ASSESSMENT

Forward-Looking Assessment White Paper

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16. Abstract

The Standards Planning for Multimodal and Accessible Travel services task will provide an assessment of standardization needs to support multimodal and accessible travel options by conducting a study to review standardization needs, assessing impacts on ITS and related standards that currently exist or are under development, and developing a roadmap for multimodal and accessible travel standardization work.

This white paper explores the challenges, gaps, and impacts of current and emerging policies, trends, and technologies to seamless travel information access and navigation for all travelers. Over 100 pieces of literature were reviewed and contributed to this report.

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Acronyms

Acronym	Definition
ADS-DVs	Automated Driving System Dedicated Vehicles
APA	American Planning Association
ATTRI	Accessible Transportation Technologies Research Initiative
AV	Automated Vehicle
CTSA	Common Transport Service Account
GBFS	General Bikeshare Feed Specification
GDPR	General Data Protection Regulation
GTFS	General Transit Feed Specification
IFMS	Interoperable Fare Management System
ISO	International Organization for Standardization
MaaS	Mobility as a Service
MAT	Multimodal and Accessible Travel
MDS	Mobility Data Specification
MOD	Mobility on Demand
PPPs	Public Private Partnerships
SIMSystem	Seamless Integrated Mobility System
TC	Technical Committee
TMCC	Travel Management Coordination Center
USDOT	U.S. Department of Transportation
WaN	Wayfinding and Navigation

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1 Introduction

1.1 Purpose

The purpose of this document is to describe the literature that is relevant to identifying the impact of multimodal and accessible travel on standards and standards development activities.

Please note that as the ICF team reviewed the literature, we focused on standards that govern how travelers use information and methods by which travel infrastructure is represented in data (e.g., features of a path of travel). These areas include how sensors work to aid travelers in navigating through and understanding the condition and reliability of the infrastructure. The standards related to manufacturing and physical design of devices are not included in this white paper or within the scope of the project.

1.2 Background

The ICF team reviewed literature regarding the current multimodal and accessible travel (MAT) state of the practice and state of the art, via existing documents and other materials, and developed a forecast based on:

- Analysis of the results of the literature review
- Additional innovations that might impact MAT standards over the next 5 to 10 years
- How these innovations will affect standards requirements

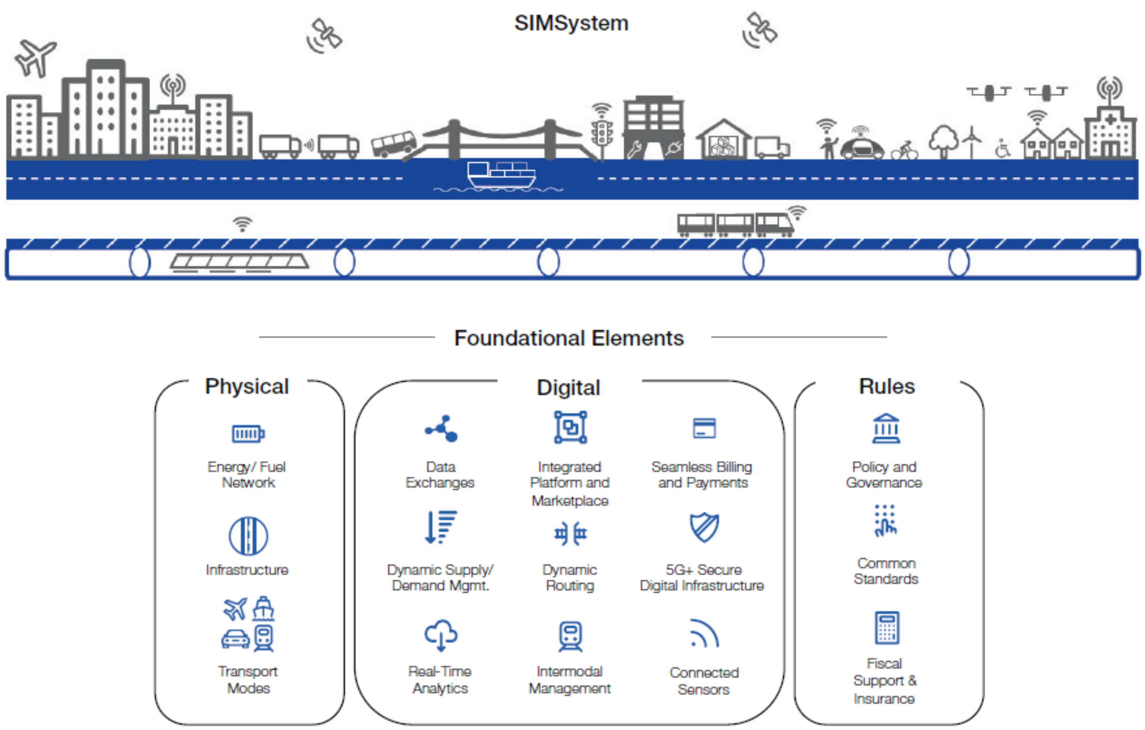
Over 100 pieces of literature were reviewed, including the U.S. Department of Transportation (USDOT) Strategic Plan; the USDOT Vision and Roadmap for Mobility on Demand (MOD) and Accessible Transportation Technologies Research Initiative (ATTRI) programs and research outcomes; and relevant industry reports. The literature that was reviewed is listed in the bibliography.

Because this Task Order is being conducted as part of the MOD program, the following is how USDOT defines MOD as of March 2019:

> USDOT's concept of **Mobility on Demand is a vision for "an integrated multimodal network of safe, carefree, and reliable transportation options that are available to all."** MOD is built on four guiding principles: user-centric, technology-enabled, partnership-driven, and mode-agnostic. A traveler-centric system promotes choice in personal mobility and increases access to modes and destinations. By being technology-enabled, the system can leverage emerging technologies and innovations to enable integration of mobility options. The partnership-driven nature of MOD emphasizes collaboration and transformation between traditional and non-traditional partners. Lastly, its mode-agnostic foundation encourages an integrated, multimodal approach based on local needs and goals. This vision of MOD merges the supply of mobility provided by public agencies, private providers, and even individuals with the demand for improved personal mobility and movement of goods.

One piece of literature from the World Economic Forum sums up a vision of MAT that uses MOD as its basis—it describes a "Seamless Integrated Mobility System" (SIMSystem).[1] In this vision, "Better integration and interoperability across modes, geographies and functionalities will help move people and goods more seamlessly and efficiently through the transport system. [It] aims to accelerate adoption of a 'SIMSystem,' drive coordination among all actors, and avoid a proliferation of potentially conflicting standards, rules, and technologies. It puts forth the Forum's perspective on the need for a seamless integrated mobility system, the vision for how that system could function, and its key characteristics, as well as the challenges that will need to be solved along the way. It provides a set of working principles that can serve as guideposts for the public and private sector to effectively collaborate, creating a shared understanding of the complex obstacles that will need to be—and can be—addressed."[2]

Figure 1 shows the SIMSystem as a "system of systems" that "moves people and goods more efficiently by creating interoperability across physical assets like cars and buses, digital technologies like dynamic pricing and shared data exchanges, and the governance structures, standards and rules by which they operate."[3]



Source: World Economic Forum, 2018

Figure 1. Key Elements of a SIMSystem[4]

1 World Economic Forum. (2018). Designing a Seamless Integrated Mobility System (SIMSystem): A Manifesto for Transforming Passenger and Goods Mobility.

2 Ibid, p. 6.

3 Ibid, p. 9.

4 Ibid, p. 9.

According to the World Economic Forum, "[i]n addition to physical and digital interoperability, a SIMSystem relies on having a rules-based framework of regulations, standards, agreements, protocols, and other intangible elements to operate across modes, geographies, and functionalities seamlessly. Today, transport is governed by a wide range of organizations that exist across multiple geographies and transport modes. Organizing the various elements of a SIMSystem will require collaboration among the various governmental and non-governmental entities spanning city, state, and national boundaries on laws, protocols, and standards. The public sector will have to regulate service providers to ensure consumers are appropriately protected and broader societal goals are met, while also creating conditions that encourage and incentivize private-sector innovation. The private sector, collaborating with non-governmental and intergovernmental organizations as well as academic institutions, should actively lead the development of shared standards for a SIMSystem's underlying technology and data."

One of the key MAT concepts that is prominent in this project and is mentioned throughout this white paper is the "complete trip." As shown in Table 1, the complete trip identifies all of the possible stages of a traveler's journey, including key transitions (for example, boarding a vehicle, paying a fare) and major points of mobility access.

Table 1. Complete Trip Stages

Trip Stage	Description
Pre-trip	Traveler may engage in: • Trip planning • Reservations • Trip confirmation • Trip payment This stage could happen at any location (e.g., home, work, doctor's office, while already traveling)
Trip origin	The location of the traveler when embarking for the first station, stop, park-and-ride, or pickup point
Between trip origin and location where first mobility service accessed	Travel between the trip origin and the first stop, station, or pickup point (if applicable). Could include crossing streets, navigating indoor spaces, etc.
Where first mobility service accessed	At station, stop, terminal, park-and-ride, or pickup location (could repeat if it is a multimodal trip): • Bus stop/ridesource (e.g., Uber, Lyft) pickup point • Station platform • Off-board payment location (e.g., ticket or fare vending machine) • Platform/stop entry (e.g., faregates) • Bikesharing or scooter docking station/dockless bike or scooter location • Carsharing location • Station entrance and common areas • Terminal location (including ferry terminals)
Board first mobility service	Boarding a vehicle/bicycle/scooter/other mobility service
On-board access	• Paying once onboard vehicle (e.g., at farebox) • Traveler securement (if applicable)
En route, using first mobility service	Onboard vehicle/bicycle/scooter (this can repeat if it is a multimodal trip): • Inside tunnel/underground • At street surface

Trip Stage	Description
Before alighting, first mobility service	• Undo securement (if applicable) • Paying right before alighting the vehicle (e.g., in a “tap-on, tap-off” fare payment situation)
Alighting, first mobility service	Alighting a vehicle/bicycle/scooter/other mobility service
Travel between alighting point and transfer point	Travel between alighting location and transfer location (this can repeat if it is a multimodal trip). Could include crossing streets, navigating indoor spaces, etc.
Travel between final mobility service stop and final destination	Travel between the final stop and the trip destination

This white paper is organized into the following sections:

- **Section 2 – Dimensions and Characteristics of Multimodal and Accessible Travel (MAT).** This section provides the background for determining the types of standards that should be considered and explored in this project based on the literature review. MAT user and stakeholder needs; current and future MAT technologies, data and applications; and related business impacts and drivers identified in the literature review are described in this section.
- **Section 3 – Types of Standards To Be Considered and Explored.** This section describes the types of MAT standards to be explored further (as part of Task 3). This section reiterates the social equity considerations and relevant policies and standards to enable MOD as described in the MOD Operational Concept.
- **Section 4 – Potential Impacts on Standards Development.** This section describes the state of research and development that may impact the potential standards, including plans for future work in the 5- to 10-year timeframe. This section focuses on the potential impacts on accessible travel standards development based on the current state and future direction of MAT systems.
- **Section 5 – Gaps Analysis.** This section describes where gaps exist in the technologies, data and data collection, specifications, and standards needed to support MAT.
- **Section 6 – Next Steps.** This section presents the next steps in the project, specifically discussing the next task, Task 3 – Survey of Existing Standards and Standards Under Development

2 Dimensions and Characteristics of Multimodal and Accessible Travel (MAT)

This section provides the background for determining the types of standards that should be considered and explored in this project based on the literature review. It describes MAT user and stakeholder needs; current and future MAT technologies, data and applications; and related business impacts and drivers identified in the literature review.

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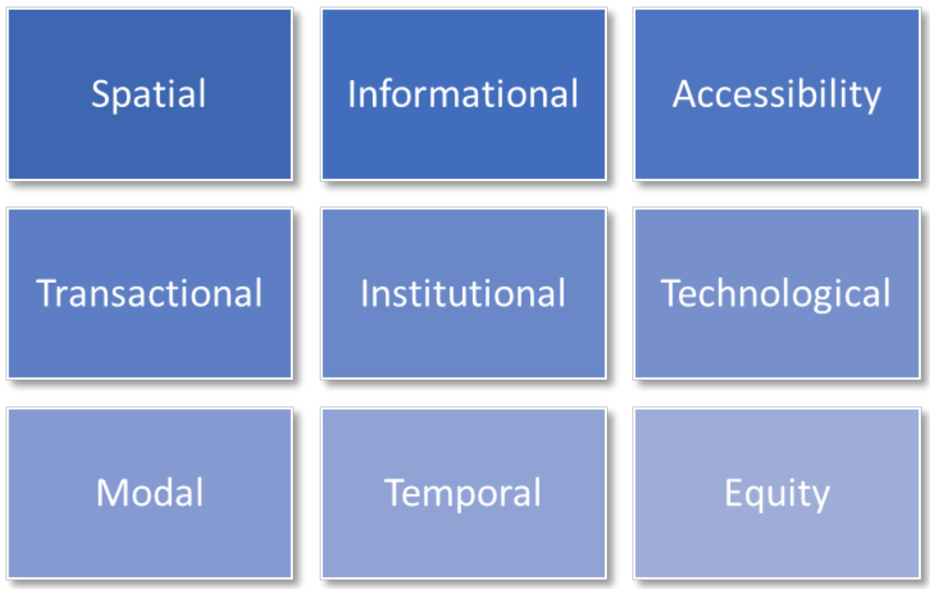

Figure 2. Dimensions Identified for Standards Framework

The following MAT dimensions together provide a framework of standards to consider

- **Spatial** identifies the physical location of a traveler at each stage of a "complete" trip, along with the infrastructure associated with each location (e.g., sidewalk ramps, lack of elevator), the features associated with the location (e.g., points, lines, paths), and the land use associated with the locations.
- **Informational** identifies data and information needs, and potential communication/ dissemination media at each trip stage and each stage of service provision.
- **Accessibility** can be infrastructure-based (handled in the spatial dimension), vehicle-based, and person-based (e.g., needs such as mobility aids and personal care attendants, abilities and opportunities to access life activities such as jobs, health care, and entertainment). Please note that in this white paper we differentiate between access and accessibility for people with disabilities. Access to mobility services refers to equity (this dimension is

described below), and accessibility refers to a facility, vehicle, or other infrastructure being built in such a way that it can be traversed by a person with disabilities.

- **Transactional** covers trip request, reservation, and payment, and data exchange, sharing and privacy.
- **Institutional** identifies the organizations that provide transportation services and the relationships among the mobility service providers.
- **Technological** identifies the types of technology that facilitate MAT. These include, but are not limited to those identified in the MOD Operational Concept, the ATTRI program, and the Future of Mobility white paper (written in January 2018 for the California Department of Transportation [Caltrans]).
- **Modal** identifies the types of transportation services that comprise MAT.
- **Temporal** identifies variations in the availability of opportunities across the day, week, or other time period.
- **Equity** identifies characteristics such as economic disadvantages, digital poverty, and the urban and rural divide.

Each dimension overlaps with one or more of the other dimensions, with relationships that are described below. Further, these dimensions cover the four most important principles of MAT identified in the literature: safety, equitable access, access for people with disabilities, and accountability/data access.

2.1 Spatial Dimension

The first aspect of the **spatial** dimension identifies the physical location of the traveler at each trip stage and the infrastructure associated with each location. Possible trip stages in a complete trip are depicted in Table 1.

At each trip stage, identifying standards requires that we examine not only the most obvious steps, such as boarding and alighting vehicles, but also the hidden steps, such as paying a fare onboard a vehicle, being secured if traveling in a wheelchair, or navigating between the final stop and the trip destination.

For example, the literature identifies new General Transit Feed Specification (GTFS) extensions, including GTFS-Pathways,[5] which contain GTFS-Stations (defines stations and entrances), GTFS-Levels (describes the inside of the station schematically, between its entrances/exits and its platforms, to route riders using trip-planning software [e.g., routing somebody in wheelchair with a step-free journey from entrance to platform, or somebody traveling with a stroller or other rolling item with as few steps as possible]), GTFS-PathwayClosures (describes the evolution of the station through time [e.g., which pathway is being closed at which time for construction, or what the opening schedules are of an entrance linked to a mall]), and GTFS-PathwayUpdates (describes the real-time evolution of the station [e.g., an elevator is down, if entrances are closed because of a demonstration or event]). International Organization for Standardization (ISO) Technical Committee (TC) 204 is extending the geographic data files not only to incorporate connected and automated driving systems, but also to represent, in more detail, multimodal and accessible features such as stairs, vertical conveyances, curbs, paths, and more.

In terms of infrastructure associated with travelers' locations, identifying standards will focus on

[5] GTFS-Pathways Extensions Proposal. (n.d.). Retrieved from bit.ly/gtfs-pathways

the accessibility of the infrastructure and any other factors that will affect a traveler's ability to access or traverse a location. Features such as gradients, curb cuts, and elevation are represented in crowdsourced data such as OpenStreetMap and may support the development of standards to represent infrastructure elements.

2.2 Informational Dimension

The **informational** dimension takes into account travelers' information needs and potential communication/dissemination media at each trip stage (identified above) and at each stage of service provision (described below). As stated in the literature, "Multimodal traveler information has an important role to play and is an incentive to the users to change their mobility routines (from exclusive use of car to non-exclusive use). Some studies have estimated the potential of multimodal information on modal shift as around 5 percent."[6]

Sample information needs and potential media for public transit, according to the literature, are shown in Table 2 and Table 3. Additional needs and potential media for other travel modes (e.g., bikesharing, ridesourcing) will be identified as part of Task 3.

Table 2. Sample Information Needs

Sample Information Needs
Next vehicle arrival prediction time
Real-time vehicle location
Availability of information dissemination
Identification of service disruptions
Information on planned detours
Schedule information during special events (e.g., Boston marathon)
Emergency information (e.g., evacuation due to fire)
Vehicles/routes available for transfer
Display/announcement of the current route
Real-time information on availability of elevators and escalators
Number of cars on the next train
Parking availability
Wi-Fi access points and real-time information on availability
Fare information

Table 3. Sample Potential Communications/Dissemination Media

Sample Potential Communications/Media
Web – Includes web applications that can be used on fixed-end computers or mobile devices
IVR – Includes applications that are accessed via interactive voice response (IVR) systems
CSS – Customer support service staff who are accessible via telephone
Short message service (SMS) – Two-way messaging service that is accessible on mobile devices
Alert notification – Subscription alerts that are sent to customers based on their preferences
Social media – Includes notification of service information and disruptions
Mobile device-only applications

6 Multimodal Information, Version 1. Commission's Expert Group on ITS.

Dynamic message signs (DMS) in stations/at stops
Public address (PA) onboard transit vehicles

Given guidance from the literature, the information dimension may be grouped into several categories:

- Static information that represents the infrastructure and its condition (e.g., similar to the "rough pavement index" used to gauge roadway conditions)
- Service availability, reliability, and performance information that represents scheduled, dynamic, event, and incident data related to travel modes
- User preferences and selections including reservations, media access, payment, and privacy choices

Another aspect of the informational dimension is cybersecurity. Significant work is currently underway related to cybersecurity, and much of MAT activities will benefit from other markets and modes advancing improved security policies. For example, integrated payment will benefit from Payment Card Industry (PCI) standards and the General Data Protection Regulation 2016/679 (GDPR) adopted by the European Union.

2.3 Accessibility Dimension

According to the Accessible Transportation Technologies Research Initiative (ATTRI):

"The accessibility of a transportation system can be described in terms of the ability of individuals to go from home to a destination without breaks, or in terms of a travel chain with various links such as trip planning, travel to station, station and stop use, boarding vehicles, using vehicles, leaving vehicles, using the stop or transferring, and travel to destination after leaving the station or stop. If one link is not accessible, then access to a subsequent link is unattainable and the trip cannot be completed. Thus, the travel chain defines the scope of potential research and development in accessible transportation."[7]

Further: "Accessibility not only considers the movement ability within transport network, but also takes the value of destinations into account." While we will not be extending the standard identification beyond transport-related accessibility, we will keep in mind (as described in the spatial dimension above) that MAT facilitates important life components, such as employment, health, community participation and generally leading an active life. Finally, we are using the ATTRI user needs as described in the ATTRI User Needs Assessment Report[8] to assist in the standards identification that will take place in Task 3.

The **accessibility** dimension can be divided into the following categories:

- Vehicle-based (e.g., wheelchair lift or ramp, wheelchair tie-downs), including human-machine interfaces
- Person-based (e.g., needs such as mobility aids and personal care attendants, abilities, and opportunities to access life activities such as jobs, health care, and entertainment)

This dimension is influenced greatly by the Americans with Disabilities Act (ADA), which contains

7 Accessible Transportation Technologies Research Initiative (ATTRI)
8 ATTRI User Needs Assessment Report. https://rosap.ntl.bts.gov/view/dot/31320

rules governing transportation. However, when the ADA became law in 1990, technology such as smartphones, electronic displays (e.g., real-time transit information signage) and onboard technology did not exist. The ADA Accessibility Guidelines provided guidance on the accessibility of some technology (e.g., viewing angle of signage), but did not specifically address accessibility for the majority of transportation-related technology. Fortunately, transport agencies often use the ADA Accessibility Guidelines to develop policies, including those for ensuring that technology used to facilitate mobility is accessible.

The literature suggests that the accessibility dimension should further consider a person's changing mobility needs as they age—moving from active aging to less active older age. These needs include keeping active and connected with the community, staying safe, being informed, and maintaining independence. Additional elements within each of these needs will assist the ICF team in identifying relevant standards and standards gaps.

Other accessibility aspects will also be considered to identify MAT standards and standards gaps, including:

- An extension of GTFS, called GTFS-Vehicles,[9] which describes the vehicles themselves (Does the vehicle have air-conditioning? Is there a ramp for riders in wheelchair? Is the bus full?). It includes GTFS-VehicleCouplings (describes the coupling of vehicles into composed vehicles like trains [Which carriage is the restaurant carriage? Which one is First Class? In which one can I go with a wheelchair?]), GTFS-VehicleBoardings (describes where the vehicle stops on a platform [Where should I wait on the platform? Combined with VehicleCouplings, this tells where my carriage will stop; which carriage is best for alighting close to my exit?]), GTFS-VehicleDoors (describes the properties of each door of a vehicle [Can we board or alight at this door? Is this door wheelchair accessible?])
- Automated Driving System Dedicated Vehicles (ADS-DVs)[10] that have the potential to yield positive, life-altering mobility benefits for people with disabilities, including those who are unable to obtain a driver's license. ADS-DVs would mean that people with disabilities can independently get in and out of the vehicle, safely secure themselves and their mobility aid devices, and operate the vehicle. Standards are vital for establishing interoperability of complex, highly integrated vehicle systems, including the human-machine interface. New ADS-DV accommodations must be engineered and validated to facilitate use of ADS-DVs by new/non-traditional user communities, including a subpopulation of the disability community.[11]
- Elements that describe the value of an accessible trip: effective communication, responsive service, standardized content and services, and personalization.[12]
- Existing regulations and barriers to accessibility that will be affected by potential standards that will be identified in Task 3.

2.4 Transactional Dimension

The **transactional** dimension covers trip requests (for on-demand services), reservations (where necessary) and payment, and data exchange, sharing and privacy. While there is considerable

9 GTFS-Vehicles Extensions Proposals. (n.d.). Retrieved from bit.ly/gtfs-vehicles

10 SAE International (2018). J3016 Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. Warrendale, PA.

11 Chang, A. and S. W. Gouse. 2017. "Accessible Automated Driving System-Dedicated Vehicles."

12 Amadeus IT Group, "Voyage of discovery: Woring towards inclusive and accessible travel for all."

standards work described in the literature to address this dimension of MAT, there are very few published and mature open standards and specifications available that deal directly with mobility on demand and accessible travel.

Mobility as a Service (MaaS) is one tool that can be used in MOD and has transactional elements. According to the MaaS Alliance, a European public-private partnership (PPP) creating the foundations for a common approach to MaaS:

> MaaS "is the integration of various forms of transport services into a single mobility service accessible on demand. To meet a customer's request, a MaaS operator facilitates a diverse menu of transport options, be they public transport, ride-, car- or bike-sharing, taxi or car rental/lease, or a combination thereof. For the user, MaaS can offer added value through use of a single application to provide access to mobility, with a single payment channel instead of multiple ticketing and payment operations. For its users, MaaS should be the best value proposition, by helping them meet their mobility needs and solve the inconvenient parts of individual journeys as well as the entire system of mobility services."[13]

MaaS differs slightly from the existing definitions of MOD in that MaaS emphasizes mobility aggregation through an app-based subscription service providing infrastructure, information, and fare integration. MOD, on the other hand, encompasses a strong emphasis on both personal travel and goods delivery, even though most current MOD deployments in the United States do not yet contain a goods delivery component and are mainly focused on the movement of people. In addition, the vision of MOD emphasizes the interaction between the supply of mobility options provided by both public and private providers and the demand for improved personal mobility and goods movement.

Aspects of transactional activities are described in the literature using the MOD standard development recommendations, which were described in the MOD Operational Concept. The following categories and a selection of requirement-related activities that support those recommendations are included in the next sections.

Standards to Facilitate Multimodal Data Representation and Integration

- Transit Cooperative Research Program (TCRP) Web-Only Document 62, Standardizing Data for Mobility Management,[14] explores opportunities for the standardization of data relevant to mobility management systems. This document creates a framework for data exchange standards by focusing on one of three potential data exchange approaches—"The approach in which an 'industry' group of some type agrees on data formats and a mechanism for data communication and publishes these as the standards for data exchange." The ICF team is awaiting the final report from this TCRP project (G-16) to provide further information for Task 3.
- The GTFS family of specifications, which includes GTFS-realtime, GTFS-flex, and GTFS-ride
- Standardization of formats for all traffic and travel data from all public and private modalities and the creation of a National Access Point (NAP) for data to deliver the baseline for

[13] MaaS Alliance. (n.d.). What is MaaS? https://maas-alliance.eu/homepage/what-is-maas/

[14] National Academies of Sciences, Engineering, and Medicine. (2013, November). Standardizing Data for Mobility Management.

Multimodal Travel Information Services (MMTIS) in all EU-member countries for mobility from all mobility actors resulting from EU regulation 2017/1926[15]
- ISO 5.1 (DIS 20524-1, AWI 20524-2) is developing multi-modal and public transport extensions[16]

Standards for Data Exchange

- The Los Angeles Department of Transportation Mobility Data Specification (MDS), which is "a data standard and [Application Programming Interface] API specification for mobility as a service providers, such as Dockless Bikeshare, E-Scooters, and Shared Ride providers who work within the public right of way. Inspired by the General Transit Feed Specification (GTFS) and General Bikeshare Feed Specification (GBFS). Specifically, the goals of [MDS] are to provide API and data standards for municipalities to help ingest, compare and analyze mobility as a service provider data." [17]
- "Data makes MaaS happen"—the MaaS Alliance Vision Paper on Data[18] describes use cases that focus on the role of data-sharing and exchange within MaaS. This paper describes the following 10 specific roles for data and data exchange:
  - User account management
  - Optimal routing
  - Information on combined mobility solutions matching one's needs at that given moment
  - Reservation and bookings
  - Retrieving availability of vehicles, including car/bike/scooter-sharing fleet or rides
  - Vehicle booking
  - Unlocking the vehicle
  - Payment
  - Digital ticketing
  - Providing the user with solid time-critical information

Privacy and Open Data Standards

- Efforts aimed to open data and develop sharing standards will improve transparency and accessibility, while encouraging the private sector to develop new features and apps that take advantage of these data feeds. Local governments and public agencies can meet future data needs by establishing a technology or data officer to manage the collection, sharing and dissemination of transportation data, as well as creating a data dashboard to process and track travel behavior data.[19]
- Recognition of the role of neutral third-party data brokers like SharedStreets that aggregate and anonymize data to protect personally identifiable information (PII) and mobility service provider trade secrets, while providing useful insights to the public sector.

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15 ERTICO, "Making Travel Data Accessible for Better Journey Planning," October 24, 2017, https://erticonetwork.com/making-travel-data-accessible-better-journey-planning/

16 ITS Standardization Activities of ISO TC 204. 2018, p. 10. [https://isotc.iso.org/livelink/livelink/fetch/-8846111/8847151/8847160/ITS_Standardization_Activities_of_ISO_TC_204.pdf?nodeid=19964169&vernum=-2]

17 City of Los Angeles Mobility Data Specification. https://github.com/CityOfLosAngeles/mobility-data-specification

18 MaaS Alliance. (2018). "Data makes MaaS happen - MaaS Alliance Vision Paper on Data"

19 Shaheen, S., Cohen, A., & Martin, E. (2017). Smartphone App Evolution and Early Understanding from a Multimodal App User Survey.

- Open source software and data sources that by specifying data content and open application programming interfaces create de facto standards. Examples include OpenStreetMap and OpenTripPlanner.
- Development of a digital data master plan to take stock of operational data, establish data sharing standards, and create data handling and privacy standards for the trusted data platform, other mobility platforms, and connected infrastructure.[11]

2.5 Institutional Dimension

The **institutional** dimension identifies the organizations that provide transportation services and the relationships among them. There is a wide variety of mobility service providers, both private and public, making it challenging to identify standards according to the literature. However, this dimension is necessary for this project because efforts to facilitate mobility must consider the institutional relationships among all mobility stakeholders. Table 4 shows several of these stakeholders and their potential roles.[20]

Table 4. Overall Stakeholders in a Transportation/Mobility Ecosystem

Stakeholder	Roles
Rural and Suburban areas, Cities, Regions	Create, coordinate, and monitor transportation ecosystem
Transport Service Providers (e.g., public transit/ paratransit providers, human service transportation [HST] providers)	Provide optimized and connected local transport offerings
Enabling Services – Technology and Data	Support the setup and operation of a collaborative transportation ecosystem in terms of customer applications and data analytics
Mobility Service Providers (e.g., bikesharing, scooter-sharing, carsharing, and ridesourcing)	Offer mobility services other than public transit/ paratransit and HST
Mobility Service Customers	Demand and pay for a seamless travel experience

Source: Kieslinger, M. MaaS new business and service approaches, Session SIS39. 2018 ITS World Congress.

Key topics that need to be considered in identifying standards and the development of standards in the institutional dimension[21] include:

- Partnership of stakeholders
- Diversity of stakeholders
- Addressing stakeholder concerns through partnerships
- Roles and responsibilities of stakeholders through inter-agency agreements
- Partnership between stakeholders and the State, and between stakeholders and the Federal government

20 Kieslinger, M. (n.d.). MaaS new business and service approaches, Session SIS39. 2018 ITS World Congress.

21 Federal Transit Administration. (December 2017). Reference Manual for Planning and Design of a Travel Management Coordination Center (TMCC), FTA Report No. 0117.

- Communities that sustain and update standards as technologies advance and new transportation services emerge[22]

2.6 Technological Dimension

The **technological** dimension identifies the types of technologies that facilitate MAT. These include, but are not limited to, those identified in the MOD Operational Concept,[23] Reference Manual for Planning and Design of a Travel Management Coordination Center (TMCC),[6] the ATTRI State of the Practice Scan,[24] and Future of Mobility white paper (written for Caltrans, January 2018). According to this literature, the enabling technologies include:

Customer Service Applications and Systems

- TMCC customer interface—user interface and user experience
- Better traveler information and trip planning systems, particularly for customers with accessibility challenges, with features to enable usage by people with disabilities (e.g., text-to-speech and voice recognition, ability to change contrast and color schemes, touch and gesture input, and screen magnification)

Communications and Security Technologies

- Vehicle communications (e.g., mobile data computers and other mobile communications devices) and connected vehicles, and wireless networks and mobile technologies, especially 5G with its potential to improve machine to machine (M2M) and Internet of things (IoT) communication
- Improvements in security technology, such as encryption, virtual private network (VPN), and secure tunnels are required, along with a centralized identity management system

Integrated Payment

- Integrated fare and tariff payment and management (payment, collection, and processing) systems

Location-Based, Mapping, and Tracking Technologies

- Location-based technologies, including automatic vehicle location (AVL), computer-aided dispatch (CAD), and other systems that assist the operations of demand-response door-to-door service. These are commonplace but will require system redundancies to deal with GPS unavailability, mapping techniques such as simultaneous location and mapping (SLAM), cooperative mapping (between vehicles), and indoor mapping.

Emerging Vehicle and Infrastructure Technologies Including Automated and Connected Vehicles

- Automated and connected vehicles, the associated smart infrastructure and their ability to provide insight to transportation operators

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22 This is the typical governance structure associated with standards or open specifications.
23 Federal Highway Administration. (September 2017). Mobility on Demand: Operational Concept Report.
24 Giampapa, J. A., Steinfeld, A., Teves, E., Dias, M., & Rubinstein, Z. (April 2017). Accessible Transportation Technologies Research Initiative (ATTRI): State of the Practice Scan.

- Smart infrastructure to enable multimodal prioritization of people and goods movement

Assistive and ITS Technologies

- Real-time information to help reduce uncertainty and wait times for mobility services
- Power-assist and power wheelchairs that can reduce fatigue during the first/last mile and longer pedestrian routes

Wayfinding and Navigation

- Smartphone apps and websites for transportation and pedestrian travel planning
- In-vehicle navigation systems, websites, and smartphone apps readily available for those who drive personal vehicles
- Announcements for stops and train platforms presented in parallel over speakers and as text on screens that serve a wide range of users
- Adaptive and preferential signal control for high-occupancy vehicles (HOV) and other stakeholder priority and preemptive treatment (e.g., pedestrian-only cycles on signal lights that are especially helpful for intersections with complex layouts and high volumes)

Automation and Robotics

- Technologies for precision-docking that can make boarding and alighting easier
- Rail platform doors that can help prevent passengers from falling onto tracks or being struck by trains
- Personal vehicles that are becoming increasingly automated and intelligent, which potentially lowers effort and difficulty for certain users

Data Integration

- The number of relevant data sources is rising due to increased open data releases by public agencies. Successes include the rapid growth in transport apps due to the public release of schedule and real-time data by transit agencies
- Crowdsourcing that can be an effective method for filling information gaps, if implemented properly
- Parking information and meter payment apps that can help those with mobility and dexterity disabilities
- Web-based map tools that are helpful for scouting accessible routes and building entrance features
- Ranging technologies such as Bluetooth beacons, RFI transponders, and DSRC triangulation that can help provide low-cost localization inside buildings
- Data collection and data reference models, and data dictionaries that ensure consistent semantics[25]
- Gamification and other algorithms to create connected travelers and support artificial intelligence, real-time simulations, and contribute to big data repositories

Enhanced Human Service Transportation

- End-to-end multimodal trip planning, part of which supports interregional trip planning
- “One call” information centers that support discovery of services and technologies

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[25] ISO TR 17185-2:2015 Intelligent transport systems – Public transport user information – Part 2: Public transport data and interface standards catalogue and cross references

- Integrated payment systems that reduce confusion for people with cognitive and visual disabilities
- Flex-route transit (including traditional paratransit and other on-demand services such as microtransit) that can reduce paratransit demand and improve travel by people with disabilities
- Dynamic scheduling, decision support, and dynamic monitoring that have the potential to improve paratransit efficiency and service delivery
- Ridesourcing that offers increased transportation options to many people with disabilities
- Coordinated ridesharing for older adults
- Improved pedestrian infrastructure near bus stops by local municipalities that can positively impact accessibility and use of fixed-route transit

2.7 Modal Dimension

The **modal** dimension identifies the types of transportation that comprise MAT. While the types of modes continue to grow, currently the modes shown in Figure 3 are being considered in the exploration of MAT standards.

Also, when investigating standards, private and public transportation mode characteristics will be considered. These include[26]:

- Service initiator (e.g., public, private, employer-sponsored, property-sponsored)
- Service configuration (e.g., demand responsive, fixed route, service route)
- Passenger capacity
- Stop configuration (e.g., many-to-one, many-to-many)
- Ride request format (e.g., on-demand, no arrangement, pre-arranged)
- Fare collection type (e.g., online, cash, ticket, free/subsidized)
- Access requirements (e.g., technology restrictions, general public)
- Multimodal level of service (see http://asap.fehrandpeers.com/mmlos)
- Performance of mode according to availability (times and locations served), typical speeds, space needed for vehicles, carrying capacity, potential users, and limitations
- Facility requirements (e.g., quality and quantity of facilities)

[26] National Academies of Sciences, Engineering, and Medicine. (2018). Private Transit: Existing Services and Emerging Directions.

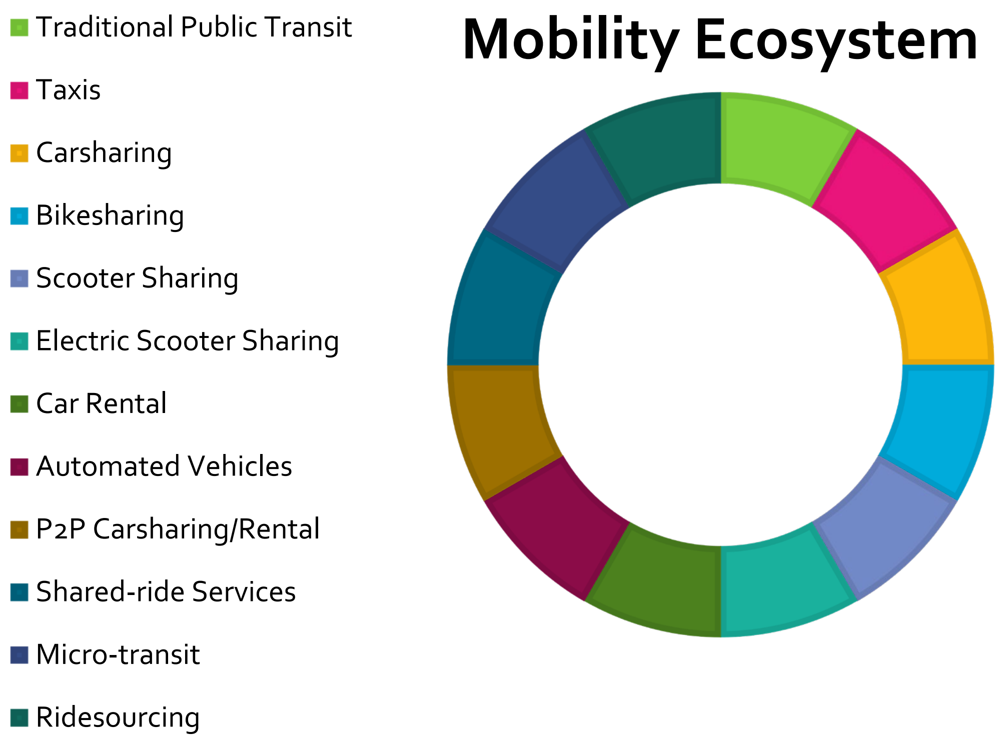

Figure 3. Current Modes Within the Mobility Ecosystem

Note: Each mode does not have an equal share of the mobility ecosystem; the equal slices are for illustration only.

2.8 Temporal Dimension

The **temporal** dimension identifies variations in the availability of opportunities across the day, week, or season, as well as availability of on-demand transportation services to facilitate those opportunities. True on-demand transportation has the potential to reduce wait time, increase travel-time reliability, provide advance booking options, and reduce travel time.[27] While the literature indicates very limited standards in this category, the ICF team will explore potential standards that will have an impact on this dimension of the framework. For example, we will examine dynamic curb or right-of-way management (e.g., limiting vehicle access within designated areas during times of peak pedestrian use) and pricing strategies (e.g., congestion pricing) to increase mobility service availability and reliability.

2.9 Equity Dimension

The **equity** dimension identifies characteristics of technology-enabled transportation such as

[27] Federal Highway Administration. (August 2017). Travel Behavior: Shared Mobility and Transportation Equity.

economic disadvantages, digital poverty, and the urban and rural divide.[28] While directly related to the **accessibility** dimension, equity is being addressed in new mobility services in the literature as well as in reality. The New Mobility Playbook,[29] developed by Seattle Department of Transportation, stated:

"New mobility services could leave already marginalized populations behind if:

- The service is marketed in only one or two languages or is culturally inappropriate
- The services are too expensive
- The physical locations of the services exclude communities of color or low-income neighborhoods
- The services do not accommodate the unique needs of families with children, youth, older adults, women, or people with disabilities
- The algorithm or the human providers discriminate against minorities or classes of people such as LGBTQ, people of color or of certain ethnicities using names or pictures
- Some residents do not know how to use these services"

Further, TRB's Special Report 319[30] states that "because the new technology-enabled services are provided primarily by the private sector and because they are evolving so rapidly, issues of fairness and equity raised by these services and the established modes with which they often compete are complex, multidimensional, and sometimes conflicting. The dimensions of these issues can be characterized in terms of (1) firms, markets, and competition; (2) regulations, subsidies, and social services; (3) geographies and jurisdictions; and (4) stakeholder groups" (such as those mentioned earlier in this white paper).

Finally, identifying standards and standards gaps in this dimension will take into consideration the STEPS to Transportation Equity framework[31] including: Spatial, Temporal, Economic, Physiological, and Social barriers. For each barrier category, shared mobility opportunities and challenges are explored along with policy recommendations. Each element of STEPS should be considered in terms of developing potential policies regarding MAT systems as shown in Appendix A.

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[28] Chapter 5 of the MOD Operational Concept outlines five key challenges: (1) discrimination against protected classes; (2) accessibility for older adults and people with disabilities; (3) economic accessibility; (4) digital poverty; and (5) urban and rural divide.

[29] City of Seattle. (2017). New Mobility Playbook

[30] National Academies of Sciences, Engineering, and Medicine. (2016). Between Public and Private Mobility: Examining the Rise of Technology-Enabled Transportation Services.

[31] Federal Highway Administration. (August 2017). Travel Behavior: Shared Mobility and Transportation Equity.

3 Types of Standards To Be Considered and Explored

This section describes the types of MAT standards to be explored further (as part of Task 3). Also, this section discusses relevant policies and standards according to the literature reviewed to enable Mobility on Demand (MOD) as described in the MOD Operational Concept.

The types of standards to be explored include, but are not limited to the following:

- Path of travel standards
- Data sharing, exchanges and privacy
- Integrated payment
- Wayfinding and navigation
- Automation and robotics
- Human-machine interfaces
- Other pertinent types of standards

Please note that each type of standard does not cover all the dimensions described in Section 2. Where possible, the ICF team defines standard types in this section in terms of the relevant dimensions.

3.1 Path of Travel Standards

Path of travel standards are critical to facilitating a seamless "complete" trip. These types of standards include those related to accessible infrastructure, vehicles, mode transitions (e.g., boarding and alighting vehicles, safely crossing streets) and real-time information.

3.1.1 Infrastructure

In terms of accessible infrastructure, considerations for MAT standards were discussed by the American Planning Association (APA)[32] related to improving mobility for people with disabilities through AVs. The following outlines the elements mentioned by the APA that we will take into consideration when identifying MAT standards and standard gaps:

- Employing and building on Complete Streets[33] (e.g., through narrower lanes, higher through-put and potentially smaller vehicles) that can reallocate space previously used for automobiles back to transit, human-powered, and active travel modes

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[32] Crute, J., Riggs, W., Chapin, T., & Stevens, L. (2018). PAS Report 592: Planning for Autonomous Mobility.

[33] Smart Growth America. What Are Complete Streets? https://smartgrowthamerica.org/program/national-complete-streets-coalition/publications/what-are-complete-streets/

- Lessons learned from communities where conventional streets were converted to "shared streets"[34]
- Performance standards, in terms of a few of the dimensions mentioned in Section 2 (e.g., social equity/transport effectiveness, transport efficiency, livability/sustainability, street level multimodal effectiveness)
- Roadway design standards, including context-sensitive access/curb management, signage and lane markings, design of multimodal infrastructure, and smart traffic signals designed for pedestrians with disabilities[35]
- Safety standards, including ability for sensors to detect bicycle signage, lane markings, hand signals, passing at safe distance, avoid "dooring," safe travel speeds in multimodal context, and recording/sharing collision data

Another aspect of paths of travel standards is that they can be composed of data that describes the physical path of travel. The ISO TC 204 Working Group 3 on ITS database technology has taken the lead on modeling paths of travel including paths for vehicles, bicycles, and pedestrians; junctions (including curb cuts); and obstacles (potholes, elevators, etc.). However, physical standards, such as those for roadway design, do not describe how to model the information for use in technology. This emphasizes the need for considering both the physical and data standards as mentioned in Section 2.

3.1.2 Vehicles

In terms of vehicles, we will consider standards associated with the types of vehicles that are used to provide mobility services.

A reported by SAE International, a standard development organization developing standards for the automotive and aerospace industries, the majority of trips are made not by foot but by a vehicle. Thus, accessibility considerations in the design of vehicles are critical in ensuring that vehicles are a viable travel mode for people with disabilities.[36] This accessible design can come in three forms: (1) adaptive devices and controls to enable driving for people with disabilities, (2) accessible vehicle design to accommodate people with disabilities and their mobility aid devices and/or wheelchairs, and (3) accessible design for vehicles that are highly automated (i.e., SAE levels 4 and 5 as identified in SAE J3016) whether they are available in the form of shared mobility (e.g., ridesourcing or microtransit) or personally owned and operated.

In terms of control modifications for vehicles, adaptive devices and controls are necessary for people with certain disabilities who would like to drive vehicles that are not highly automated (i.e., SAE levels 0 to 3, as identified in SAE J3016). Research, standards, and regulation related to vehicle control modifications are limited. Existing standards focus on defining minimum acceptable design requirements and performance criteria for adaptive equipment that is used by people with disabilities, including those developed by the SAE Adaptive Devices Standards Committee. The existing portfolio of standards focuses on control modifications (e.g., reduced effort steering, gas, and brakes, and testing procedures for adaptive control systems).

As mentioned in Section 2, Automated Driving System Dedicated Vehicles (ADS-DVs)—vehicles

34 U.S. Department of Transportation. (2017). Accessible Shared Streets: Notable Practices and Considerations for Accomodating Pedestrians with Vision Disabilities.

35 Pallone, T. (2017, September 19). Smart Traffic Signals Designed for Pedestrians with Disabilities.

36 Chang, A. & S. W. Gouse (2017). Accessible Automated Driving System Dedicated Vehicles. A White Paper of SAE International.

designed to be operated exclusively by level 4 and level 5 automated driving systems as described in SAE J3016—have the potential to expand mobility opportunities for even greater numbers of people, including people with disabilities, who are unable to obtain a driver's license. Original equipment manufacturers and technology companies are working to develop, refine, and deploy ADS-DVs for the purposes of providing transportation services.[37] Accessible ADS-DVs would mean that people with disabilities are able to independently (1) get in and out of the vehicle, (2) safely secure themselves and their mobility devices, and (3) operate the vehicle. Putting ADS technology aside, the challenge to ensure that all three of these accessibility aspects are met is not expected to be a technological challenge, but rather would involve considerable sources for architectural and configuration changes within the vehicle.

ADS-DVs could potentially bring enormous mobility benefits for people with disabilities, especially those who are unable to currently obtain a driver's license. This group may include individuals with visual or auditory disability, or with cognitive impairments. Much of the design considerations for ADS-DVs for these groups may be on exchange of information between the vehicle and the passenger. Though little research has been conducted specifically for ADS-DVs, there is a significant knowledge base on the application of universal design principles on human-machine interface (HMI) in other related fields, including internet and smartphone accessibility. Much of this knowledge could be borrowed and applied to HMI for ADS-DVs. The HMI considerations for ADS-DVs may address how the passenger negotiates pickup/dropoff locations as well as route choice. Furthermore, consideration may be needed for communication protocol in cases of emergency.

3.2 Data Sharing, Exchange and Privacy Standards

Data sharing, exchange and privacy standards correspond directly to the informational and transactional dimensions. In many ways, new and emerging transportation services, situational awareness, and travel options depend on data to drive and enable their functionality. As stated in the New Mobility Playbook,[38] "Our streets flow with a rich stream of data generated by traffic sensors, on-vehicle sensors, and mobile data from ride-hailing, car share, and other services. This flow of data could give us more insights into emerging travel patterns and the effects of new mobility services on the way people use transportation. **But the flow of data is currently unstructured and our community has concerns about privacy.** We will advance solutions that protect publicly identifiable information, while expanding our data infrastructure. We will relay travel information in culturally sensitive and appropriate ways."

The New Mobility Playbook statement puts in perspective how critical data sharing, exchange, and privacy is to mobility. Seattle, Washington, plans "to work with regional and national partners in the short term to establish a neutral trusted data platform that houses data from new mobility service providers, sensors, and other data sources, automates data analytics, and enables predictive analytics."[39]

Data Types, Content and Quality

In terms of data formats, syntax, meaning and quality, we will consider current and emerging activities that are developing standards, open specifications and demonstration outputs.

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37 Ibid.

38 City of Seattle. (2017). New Mobility Playbook.

39 City of Seattle. (2017). New Mobility Playbook, Appendix A.

- Taking into account the different types of data: static/periodic data (such as GTFS), real-time data (such as GTFS-real-time) and unstructured data (such as raw data and data from social media).
- Data is a central component and facilitator of smart city mobility initiatives because it is essential to providing an evidence-based approach for cities to measure the impacts from new technologies.[40]
- Following the activity of SharedStreets,[41] which is working with cities and companies to set standards for how data about vehicle activity and physical infrastructure is described, modeled, and shared.
- Following the "development and adoption of shared-mobility information standards, such as the General Bikeshare Feed Specification (GBFS) and the Los Angeles Mobility Data Specification (MDS), which is meant to cover carsharing, ridesourcing, microtransit, and other new mobility services."[42] MDS currently only covers dockless bikesharing and scooter sharing and is now just expanding into carsharing.
- Methods for acquiring and presenting data specific to the needs of ATTRI and other stakeholders.
- Data quality, access rights, and use policies, because they can vary considerably.
- Progress on San Francisco's development of a data reporting and warehouse strategy to coordinate and consolidate existing data streams in order to improve the inadequate data available from mobility service providers. This effort addresses several of the 10 Guiding Principles that serve as a framework for evaluating emerging mobility services and technologies.[43] The Guiding Principles are shown in APPENDIX B.
- The ICF team will closely monitor ATTRI and MOD Sandbox projects that are generating specifications in order to determine the overall impact of development of key elements of data standards, such as data semantics, syntax and content, and data collection descriptions.

Data Sharing and Exchange

In terms of data sharing and exchange, we will consider organizations and projects developing exchange standards.

- Following the activity of MobilityData, an initiative of the Rocky Mountain Institute.
- Following the activity of OpenMobility Data, which is a collaborative open data initiative by TransitScreen and MobilityData.
- Following the implementation of the EU's Commission Delegated Regulation 2017/19261, which establishes the specifications necessary to ensure the accessibility, exchange and update of static and dynamic transportation data, and any subsequent related regulations.

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40 Shaheen, S., Martin, E., Hoffman-Stapleton, M., & Slowik, P. (2018). Understanding How Cities Can Link Smart Mobility Priorities Through Data.

41 SharedStreets (http://sharedstreets.io/) is a nonprofit digital common for the street. It is a data standard and platform that serves as a launching pad for public-private collaboration, and a clearinghouse for data exchange.

42 Shared-Use Mobility Center. (2016). Shared Mobility and the Transformation of Public Transit: Research Analysis.

43 San Francisco County Transportation Authority (SFCTA). (n.d.). *Emerging Mobility Guiding Principles*. Retrieved from SFCTA: https://www.sfcta.org/emerging-mobility/principles

- The final report from TCRP Project G-16, Development of Open Data Standards for Demand Responsive Transportation Transactions.[44]
- Data sharing and interoperability will form the foundation of transportation apps, in particular, mobility apps. Public and private entities could play a critical role in facilitating and defining data sharing through PPPs. [45]

Data Privacy

- Privacy laws for individuals, companies and public agencies will need to be considered, especially as related to HIPAA laws. In addition, there are liability concerns of having a person with a disability rely on a robot or other automated technology to assist in decision-making and give direction to a more vulnerable population.
- Privacy standards in shared AV fleets and ridesourcing fleet access, including the use of anonymous data to ensure data privacy.
- Recommendations resulting from the ATTRI Institutional and Policy Issues Assessment[46] including PII privacy and governance issues.

3.3 Integrated Payment Standards

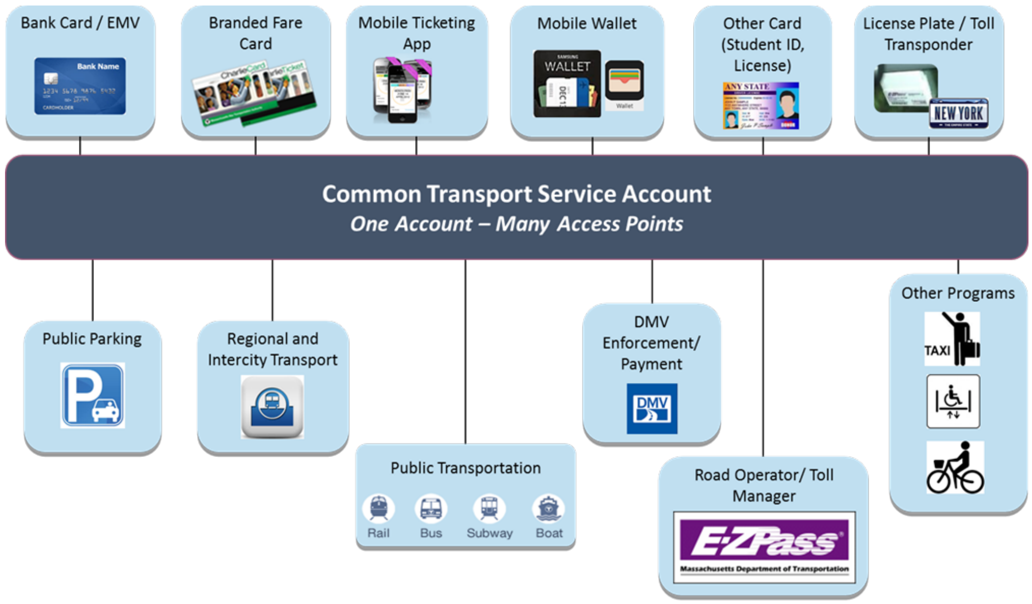
Payment integration is the ability for a person to pay for access rights to one or more mobility services using the same or linked payment media, whether it be for (as illustrated in Figure 4):

- Traditional transportation services such as transit, commuter rail, toll, parking, taxi, paratransit, vanpool
- Emerging mobility services such as dynamic tolling or parking, electric charging vehicles, and MOD services
- A combination of multimodal services

44 As of February 7, 2019, this report has not been completed, but is expected to be completed by mid-2019

45 Shaheen, S., Cohen, A., & Martin, E. (2017). Smartphone App Evolution and Early Understanding from a Multimodal App User Survey.

46 Department of Transportation. (2017). Accessible Transportation Technologies Research Initiative (ATTRI): Institutional and Policy Issues Assessment Task 6: Summary Report.



Source: ISO TC 204, 2019

Figure 4. One Account and Many Access Points[47]

From a traveler's point of view, integration consists of acquiring access rights, validating the rights at the service point of entry, charging for the service, payment, and reviewing usage/transactions. The owner of the mobility service may not be the same payment service or organization that sold the access rights.

From a mobility service operator's point of view, integration consists of defining the rules associated with services and certifying the types of credentials that can pay for the service; engaging with merchants (or their bankers) who sell the credentials; collecting, validating, storing and forwarding access rights information associated with service price; and receiving and reconciling payment from the banking institution (from the merchant's account) against transaction records. Except for the devices that collect the access rights information, the mobility operator financial transaction domain falls into the banking network purview.

There are many alternative scenarios, access rights media and methods, institutional governance, and technologies that inform variations of these two points of view. Issues such as refunds or payment cancellations should also be accounted for in the integrated payment standards and processes.

The dimensions associated with the current payment integration systems and those that are in the early stages of being deployed are described in the subsections below.

3.3.1 Assessment Associated With the Spatial Dimension

In the payment area, the spatial dimension may be associated with the following needs for location information:

47 ISO TC 204 WG 8. ISO 21724-1 Intelligent transport systems—Common Transport Service Account Systems—Part 1: Framework and Use Cases. [TBD, 2019]

- Location where electronic value or prepaid token is purchased. In some cases, the value is discounted or a surcharge is added to the cost based on where the traveler purchases value or a token. For example, a ticket bought on a train costs more than one that is bought online or at a ticket booth, while paying for parking may cost more when paying on a mobile app than when paying at the vending station or an on-street meter.[48]
- Location of assets that grant access rights to a traveler may be associated with validation readers that sense the media through visual recognition or other methods, require travelers to "tap" their media to a reader, or show their media to the operator.[14]

Fare or fees may be structured on distance, path, or the number of links taken. When a mobile device is used, an app can track the path, while stationary readers may track the media to calculate time and distance traveled. In most cases spherical (latitude and longitude) or linear referencing measures associated with the transportation network may be used.

Spatial data concepts and interface standards, including accuracy and quality requirements, for these spatial needs are well-defined and mature.

3.3.2 Assessment Associated With the Informational and Transactional Dimensions

The informational and transactional dimensions have several categories of data and interface descriptions and message exchange needs that are defined as use cases by several standards and MOD projects (ISO DTR 21724-1; ISO CD 24014-1 Version 3; and emerging implementations like TriMet and LA Metro that are in the process of developing interfaces and standardizing data). Categories include:

- Point of media sale (secure ID) to account system (for anonymous accounts) and electronic value or token purchase to account system (associated with secure ID)
- Registration and customer profile and preference, including payment media to account system
- Exchange of account profile between multimodal accounts (including account owner granting privacy rights)
- Customer bookings and sales (for pre-paid electronic value or tokens/tickets)
- Transactions for access rights (validated against price catalogue or algorithm)
- Remittance and reconciliation of payment against services provided (between service providers)
- Transport Service Rules[49]
  - Transport service usage rules describe the transport service itself and how it should/may be used.
  - Transport service pricing rules describe how fee/fares are calculated, and transactions are validated and authenticated by the appropriate product owner.
  - Transport service commercial rules describe how the involved roles will be paid, e.g., the split of the price paid (by the user) between the transport service manager and the transport operation manager.

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48 National Academies of Sciences, Engineering, and Medicine. (2017). Multiagency Electronic Fare Payment Systems.

49 ISO TC 204 WG 8. ISO 24014-1:2015 Public transport—Interoperable fare management system—Part 1: Architecture. [2015]

  - Transport customer rules cover requests to link accounts, requests for benefits, requests to pay for multimodal, and multiple transport services. For example, when a transport service user links his public transport account (and secure ID) information to pay for or receive discounts for bikesharing or parking services near a rail station.
- Action list (valid and invalid media lists) distribution to devices and systems at point of sale, point of entry, account system, and banking network
- Usage and transaction information

Most requests and validation of payment data and interfaces that support a mobility service financial transaction adopt the standards for banking, specifically ISO/IEC 8583 financial transaction card originated messages-interchange message specification.

3.3.3 Assessment Associated With the Accessibility Dimension

Acquiring access rights and presenting proof of those rights at the point of entry are addressed in the accessibility dimension. The emergence of new physical media that do not require contactless bank cards or even mobile phone supports, but are linked through a secure ID to a back-office system, provides for "hands-free" payment.

- Acquiring access rights: The physical issues associated with payment media are becoming less significant with the emergence of wearables and presence-sensing technologies (for example, "be in" validation methods).[50] Accessible websites and voice recognition tools also support acquiring media and paying for services.
- Special payment category and privacy: Requires special rider classes (senior, discount, plus-1 companion) that may include storing certification and other HIPAA-related information.

3.3.4 Assessment Associated With the Institutional Dimension

The mobility service payment actors and their roles and responsibilities are in transition. International standard role-based and functional based architectures are as seen by the Common Transport Service Account (CTSA) and Interoperable Fare Management System (IFMS) architecture and use case technical reports. These internationally consensus-based technical reports assign responsibilities to roles in order to decompose functions, information flows, and events to a role that may be conducted by single or multiple organizations, or public or private entities, or a combination. The CTSA describes a high-level, big-picture institutional framework, while the IFMS focuses on access right credentialing and integrity. The CTSA model incorporates mobility providers of all modes. Even while the IFMS study focuses on public transport, including transformative services, its model represents many other modes, including parking, tolling, and EV charging. The CTSA report identifies different terms, yet common responsibilities, between tolling architectures and the CTSA roles.

3.3.5 Assessment Associated With the Technological Dimension

The integrated payment trend is enabled through several technologies including:

- Broadband communications
- Contactless payment media

[50] National Academies of Sciences, Engineering, and Medicine. (2008). Guidebook for Mitigating Fixed-Route Bus-and-Pedestrian Collisions.

- Payment validation readers and devices
- Back office account management tools
- Security encryption methods

3.3.6 Assessment Associated With the Temporal Dimension

The temporal dimension is incorporated into the pricing structure of the service offering. For example, peak versus non-peak, weekend versus work-week service, and amount of time allowed between transfer to another service. In addition, most media, tokens, and stored value include an activation and expiration date.

Temporal data concepts and interface standards, including configuring time period requirements (date, date range, time, time range, recurring time periods), are well-defined and mature.

3.3.7 Assessment Associated With the Equity Dimension

The equity dimension in the domain of integrated payment is a significant issue. Equity issues include:

- **Limited available payment methods for un- or underbanked communities.** Unbanked or underbanked travelers may not have access to credit and debit cards to store online for systems that require an active bank card to charge. These may include ride hailing, bikesharing, toll lanes, and carsharing, among other modes.
- **Limited access to on-demand mobility services.** On-demand services are typically reserved through a mobile app. Communications between the phone and the service provider is necessary to hail the service. Rural communities may have cellphone coverage gaps, thereby potentially limiting access to on-demand services. Accessing services from a landline limits where travelers can book and pay for different modes. Additionally, travelers with lower income may only have pay-as-you-go smartphone data plans rather than data subscriptions. The data plans may limit access particularly when the plan value needs to be replenished and the traveler does not have access to retail outlets that take cash.
- **Fewer available mobility services serving specific areas.** Mobility services are not distributed equitably throughout all regions, or densely enough to serve the population. For example, in rural and some low-income areas, multimodal services are not available or are priced too high to access.

3.4 Wayfinding and Navigation Standards

Wayfinding and Navigation (WaN) consists of navigational tools to assist a traveler in avoiding obstacles and finding their way through indoor and outdoor environments. While recent development of WaN tools has been primarily focused on technologies, such as mobile wayfinding applications and on-site mapping and directional systems, non-technological tools may include visual and tactile paths, individual assistance throughout a facility, and directional and informational signage.

Technology-based solutions allow accurate directional information personalized for each user’s path of travel. Location-based technologies have become the key component of providing accurate, comprehensive WaN assistance to travelers using any mode of transport, including walking. GPS is reliable for outdoor use, whereas indoor navigation systems require ranging technologies (beacons or Wi-Fi triangulation) to provide accurate directions and other information. Outdoor navigation solutions have become even more reliable through crowdsourcing applications that allow travelers to report obstacles throughout their travel journey, such as construction zones and car accidents. For example, Google acquired Waze, a crowdsourcing application that allows travelers to input information about obstacles they have encountered along their way. At this time, crowdsourcing applications are beginning to be available for indoor or outdoor walking or biking routes, because they are necessary for promoting the use of multimodal transportation among people with disabilities. Other technology-based solutions include making WaN information available on the web, or at on-site kiosks with maps and other directional information.

People with disabilities are generally less likely to own and/or operate personal vehicles due to their functional limitations and are more likely to use public or private transportation and paratransit services. Additionally, the general population of people with disabilities has a lower income level than the non-disabled population so public transportation is often the most financially feasible option. In rural communities, transportation options are less available and often require a short commute to the bus stop, train station, or other pickup point.

Individuals with disabilities, specifically older adults and those with low income, are also less likely to utilize technologies to assist in WaN, either because they are not familiar with how to use the technology or because they simply cannot afford a smartphone, tablet, etc. Also, as mentioned in Section 3.3.7, lower income individuals may have smartphones, but they may not have regular access to data plans if they are using pay-as-you-go cellular plans. Another challenge is the inconsistent accessibility and usability of technologies. This is due to the minimal focus on ensuring that individuals with disabilities are able to use the technology, specifically those with vision loss, and design guidance for usability, specifically for those with cognitive disabilities.

When developing WaN standards that address the travelers with disabilities, therefore, all facets of WaN solution possibilities should be incorporated. Special attention should be given to those who have limited access to or knowledge of how to use technology-based solutions, as well as to those who use transportation facilities or stops with minimal wayfinding features or available assistance. Incorporating people with disabilities into planning for standards development may provide unique insights into their varying needs, as required by the Full and Fair Participation Federal requirement, under Title VI of the National Environmental Policy Act.

3.4.1 Assessment Associated With the Spatial Dimension

The spatial dimension of WaN is significant in that it identifies the location of the traveler at each stage of the trip. The spatial dimension also encompasses transitions from each touchpoint in the journey. A common challenge for individuals with disabilities is the transition from each major transport mode or facility. Independently navigating in the community can be quite daunting because there is minimal assistance available and access to information about the path of travel is lacking. Others are also concerned with these types of characteristics, including people who ride bicycles and scooters, push baby carriages or trams, etc. The description of the path, including its condition, and challenges posed by transitions at junctures between paths (e.g., curb cut between walking path and road) contribute to the WaN information. Data collected, stored, and provisioned for one WaN app should meet requirements for all target users whether the user is for people with or without physical or cognitive disabilities.

In the spatial dimension, each step in a person’s journey must be considered. Special attention should be given to the segments outside the main transport modes, including how someone gets from their starting point to the first stop in their journey and how each transport mode or facility is entered/accessed.

3.4.2 Assessment Associated With the Informational Dimension

The informational dimension is incorporated into WaN because the traveler wants information about their trip, such as how to get from Point A to Point B (both within a facility and between each transport mode). The traveler wants to know if there are any obstacles within a facility or on their path of travel, such as construction or inoperable elevators, and the route information for each transport mode they use. These informational elements correspond to the three groups described in Section 2.2:

- Statics representation and condition
- Service availability, reliability, and performance
- Traveler preferences

In addition, en route updates on service reliability and performance, including alternative mode preferences when encountering disruptions, are other aspects of WaN.

3.4.3 Assessment Associated With the Accessibility Dimension

The accessibility dimension is a significant component of WaN, specifically with the infrastructure, location, and person-based categories as described in previous sections.

3.4.4 Assessment Associated With the Technical Dimension

Potential technologies to assist travelers with disabilities as they navigate through their journey may include:

- Smartphone apps and websites for transportation and pedestrian travel planning
- In-vehicle navigation systems, websites, and smartphone apps that are readily available for those who drive personal vehicles
- Announcements for stops and train platforms, presented in parallel over speakers and as text on screens, that serve a wide range of users
- Pedestrian-only cycles on signal lights, which are especially helpful for intersections with complex layouts and high volumes

These scenarios will be investigated when reviewing whether current, new, and emerging standards meet these needs.

3.5 Automation and Robotics Standards

As stated in the ATTRI User Needs Assessment, automation and robots are expected to improve mobility for individuals with disabilities who are unable or unwilling to operate personal vehicles. Public transportation agencies have a growing interest in using automated vehicles to address first/last mile mobility issues by connecting various transportation modes to one another, thus providing a more seamless travel experience. Solutions currently being explored are individualized assistance in daily life—through virtual assistants and concierge services—to assist in planning one's entire journey, specifically with multiple modes of transportation. Also included in concierge and robotics solutions are machine vision and facial and speech recognition software to better communicate with individuals with disabilities while in a vehicle or transportation facility.

Some of the advanced technologies, like those previously mentioned, will be owned or used by individuals in their home or while traveling. They may require the user to own a computer or smartphone, affecting those with low income. The user must also have the ability to use the technology, a challenge common for those with vision loss, those with cognitive disabilities, and older adults.

3.5.1 Assessment Associated With the Spatial Dimension

Because automation and robotics can be incorporated into any setting, whether at home or in the community, the spatial dimension is applicable for this standard. Individuals with disabilities can benefit from automated assistance, but key elements are the accessibility of the technology, how well information is communicated to the user, and the extent that assistance can be provided throughout the travel journey.

3.5.2 Assessment Associated With the Accessibility Dimension

The accessibility dimension applies to the ADS-DVs component of automation and robotics. While ADS-DVs can provide a new level of independence for travelers with disabilities, the user must be able to safely operate the vehicle, as well as independently enter and exit the vehicle, and secure themselves and their mobility devices.

3.6 Human Machine Interface Standards

Human machine interface refers to the ability of a person to independently use a machine, specifically as related to the hardware and software. Touch-screen computers, kiosks, and other technologies are becomingly increasingly popular; however, for individuals with vision loss, touch screens are not easily usable. With hardware, if the machine has buttons to navigate the software but the buttons do not have any tactile indicators for how they work or what they control, then those with vision loss are once again put at a disadvantage. With this in mind, software should have an audible component and/or be compatible with screen readers.

Usability is the most significant societal consideration with regard to human machine interface. Whether accessible for someone who is blind, easily understood by someone with a cognitive disability, or physically usable by someone with severe physical limitations, the technology must address the individual needs and capabilities of all potential users. Again, to ensure usability, the disability community should be involved in testing technologies prior to deployment.

The key consideration for human machine interface standards development is detailed in the MOD Operational Concept Report.

> "Standardization for the Underlying Technologies Used in Different MOD Apps: To aggregate MOD services and integrate a variety of real-time information sources, smartphone apps (and other web-based services) must be able to interface, provide necessary data, and disseminate information. As the IoT and Machine-to-Machine (M2M) communication are expanding, MOD-related apps should be able to interact with other transportation-related interfaces for a user-friendly and integrated experience."

Among the largest benefits of the MOD model is the interconnectivity of multiple transportation options, with a centrally located space for comprehensive information about each. However, if there are not standards in place that ensure individuals with disabilities can independently use these technologies, then the interconnectivity of the transportation options only goes as far as the transportation mode itself. In other words, the traveler may be able to use the transportation, but if the technology behind these connections is not consistent, then information will be missed and the user will be negatively impacted.

3.6.1 Assessment Associated With the Spatial Dimension

The spatial dimension can be incorporated into human-machine interface at any point in the traveler's journey where technology is used for payment, wayfinding, or accessing information. As discussed in Section 4.6, the hardware and software must be accessible so it can be used by an individual with vision loss, a wheelchair user or someone of short stature, and a person with limited dexterity.

3.6.2 Assessment Associated With the Informational Dimension

Human-machine interface incorporates the informational dimension through the ability for a person with disability to use the technology. For example, if a mobile application has information about delays, route changes, or service disruptions, but the app cannot be used by a person using a screen reader, then this information is missed.

3.6.3 Assessment Associated With the Transactional Dimension

Once again, the transactional dimension is incorporated into human-machine interface, because the technology must be accessible and usable by individuals with various disabilities.

3.7 Other Types of Standards

In *Preparing for the Future of Transportation: Automated Vehicles 3.0*, the now multimodal perspective on automated vehicle safety is prominent, as is the commitment of USDOT to "support the development of voluntary technical standards and approaches as an effective non-regulatory means to advance the integration of automation technologies into the transportation system."[51] The ICF team will follow standards development activities for automated vehicles with an eye toward MAT.

Other types of standards that the ICF team will consider are in the area of connected vehicles, including the following major approaches to communication[52]:

- Vehicle to vehicle (V2V)
- Vehicle to infrastructure (V2I)[53]
- Vehicle to pedestrian (V2P), including the following technologies:
  - Unilateral pedestrian detection and driver notification: Technologies that provide collision alerts only to the driver
  - Unilateral vehicle detection and pedestrian notification: Technologies that provide collision alerts only to the pedestrian
  - Bilateral detection and notification: Systems that provide collision alerts to both drivers and pedestrians in parallel

Similar detection technologies are under development and deployed to detect scooters and bicycles. Additionally, to support CV/AV navigation, new technologies are under development to collect and

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[51] U.S. Department of Transportation. (2018). Preparing for the Future of Transportation: Automated Vehicle 3.0.
[52] U.S. Department of Transportation. (n.d.). Connected Vehicles: Vehicle to Pedestrian Communications.
[53] U.S. Department of Transportation. (n.d.). ITS Standards Training I261: Vehicle-to-Infrastructure (V2I) ITS Standards for Project Managers.

model centimeter geometry accuracy of road networks.[54] Standards such as the SAE J2735 Dedicated Short Range Communications Data Dictionary[55] provide building blocks to generate an information model of the infrastructure. Yet most of the guidance work underway focuses on vehicles rather than active transportation modes, including walkway conditions that impact walking and wheelchair navigation.

54 For example, the Lane Mapping tool and Connected Vehicle Message Validator under development by USDOT (Turner-Fairbanks).

55 SAE J2735 Dedicated Short Range Communications (DSRC) Message Set Dictionary (2016-03-30) includes MAP standards that model intersections, road network, modal right of ways including walkways and junctions.

4 Potential Impacts on Standards Development

This section describes the state of research and development that may impact the potential standards, including plans for future work in the 5- to 10-year timeframe. This section focuses on the potential impacts on accessible travel standards development based on the current state and future direction of MAT systems.

The MAT area is in a state of flux, given the following:

- A growing number of emerging mobility solutions being deployed around the U.S. and abroad
- Lack of Federal legislation in specific areas that directly affect MAT
- Lack of standards related to some elements of the “complete trip,” such as transition from boarding a vehicle to sitting in the vehicle
- Wide variation in how emerging mobility solutions are being deployed, managed, and regulated
- Lack of understanding of changes in travel behavior, resulting from the availability of new mobility services and tools
- Emerging technologies that are faster, cheaper, and easier to use

A summary of impacts on potential standards as well as plans for future work in the 5- to 10-year timeframe can be found in the literature contained in a special issue of *The Journal of Public Transportation* entitled, “The Future of Public Transportation,”[56] “Future of Mobility White Paper”[57] and “Future of Mobility: Questions We Are Afraid to Ask,” a session held at the 2018 ITS World Congress in Copenhagen, Denmark.[58]

The key impacts and future work are described in the next subsections.

4.1 Spatial

The following future spatial-related considerations will have an impact on standards development.

- Most experts predict urban areas will become more dense, increasing congestion and traffic, and displacing low income populations. Multimodal alternatives include added bicycle lanes, walking paths, assets to aid people with disabilities, bicycle docking stations, dockless bikes and scooters, and parking for carsharing.

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56 *Journal of Public Transportation*, Volume 21, Issue 1, 2018, https://scholarcommons.usf.edu/jpt/vol21/iss1/

57 Shaheen, S., Totte, H., & Stocker, A. (2018). Future of Mobility White Paper. UC Berkeley: Institute of Transportation Studies (UCB). http://dx.doi.org/10.7922/G2WH2N5D Retrieved from https://escholarship.org/uc/item/68g2h1qv

58 Sampson, E., Schweiger, C., Spencer S., et al. (2018, October). *Congress Report: 25th ITS World Congress*.

- With improvements in automated data collection technologies to support CV/AV safety, the number of pilots, demonstrations, tools, and data models representing the road network and other environments are proliferating. In their standards gap analysis, the EU study identified location, referencing harmonization including “model solutions and use cases looking at accuracy, completeness, and timeliness” as well as conversion guidance.[59]

The effect on MAT standards development from this view of the future is that existing transportation network standards will need to be expanded to incorporate features and conditions needed to support multimodal and accessible services by all travelers.

4.2 Informational

Sensor, monitoring, and data capture devices, such as smartphone and vehicle sensors, are increasing the efficiency of transportation fleet operations and will have a significant impact on the accuracy and quality of information content.

Because data collection is the most resource-intensive activity needed to support travel information, the information models, their meaning, and the formats in which they are stored are critical issues that will affect the development of standards to support MAT. A number of emerging mobility solutions being deployed in the United States, including ATTRI and MOD Sandbox projects, each collect and model their own data, and create their own vocabularies and data concepts. Other efforts, such as the continuing development of the GTFS family of specifications, smart city mobility efforts, SharedStreets initiatives, and more, will create the same situations. Additionally, crowdsourced data platforms and open source software tools, such as OpenStreetMap and OpenTripPlanner, are additional tools with their own data names and semantics.

In terms of public transit data, “Only recently have transit agencies discovered the value of data—both the data they provide to the public (open data) and the data generated by transit technology (e.g., automatic vehicle location). Agencies have been turning the latter into traveler information for their customers (e.g., real-time information). In the future, this data will be combined with many other types of data, including non-transit travel data, so that the agency can determine what services are needed by customers and what services should be modified, expanded, or eliminated. We can expect that transit agencies in 5 to 10 years will integrate the data listed in Table 5 on a routine basis to improve mobility.[60]

Table 5. Future Mobility Data Integration[58]

Data	Example
Transit timetables	Point-to-point schedules
Real-time transportation information	Real-time transit vehicle location, next transit vehicle arrival/departure, real-time passenger counts by location, incident information, and traffic flow/congestion information

[59] ISO TC 209 Working Group 19 background material from CEN / TC 278 20180312 PB PT 1703 Report VI.

[60] Schweiger, Carol. 2018. Improved Mobility through Blurred Lines. *Journal of Public Transportation*, 21(1): 60-66. DOI: http://doi.org/10.5038/2375-0901.21.1.7. Available at: https://scholarcommons.usf.edu/jpt/vol21/iss1/7, p. 64.

Data	Example
Transit performance metrics, historical and real-time	On-time performance, ridership (e.g., number of boardings/alightings by location)
Transit reliability	Percentage of customers who waited less than the scheduled time between vehicles, percentage of vehicles that arrived at their final destination no more than a certain amount of time after they were scheduled to arrive, a vehicle departing no more than a certain amount of time later than the expected interval between vehicles
Transit customer satisfaction	Overall satisfaction, likelihood of continuing to use transit, likelihood of recommending transit, and perception of transit reliability
Transit route characteristics	Geometry
Transit stop/station characteristics, both static and dynamic	Amenities (static) and real-time passenger flow (dynamic)
Multimodal journey planning results	Results of trip planning via Google directions for driving, transit, cycling, and walking
Social media/network mapping regarding transportation	Tweets about service interruptions
Transport-sharing usage, both real-time and historical	Bikeshare, carshare, taxi, and ridesourcing origins and destinations, and usage
Transportation payments	Fare, toll, and congestion payment amounts and locations
Travel behavior data, both quantitative and qualitative	Survey results
Parking data	Real-time and historical capacity
Package delivery data, both real-time and historical	Package delivery times and locations

The overall impact on standards development given the future of this dimension will be significant because of the sheer number of mobility solutions that individually collect and model their own data, and create their own vocabularies and data concepts. It might be possible to standardize these aspects of mobility services, but due to the nature of the information needs of each mobility service, it will be challenging to standardize them. However, it may be possible to develop standards for each mobility service. For example, all carsharing services would have to collect data on the location of all available cars, carsharing cost, carsharing rules, etc.

4.3 Accessibility

Accessibility issues will continue to directly and indirectly affect equipment, information, and user accessibility standards development in the future. Examining the future of mobility for people with disabilities yielded several views of the near-term that will affect standards development, as described in the literature[61, 62, 63], many of which dealt with AV user interfaces and design as follows:

AV user interfaces need to be accessible and accurate.

- Vehicles may require refreshable Braille and an auditory system that notifies the driver where the car is at any given time and the progress of their trip. Oral notifications and alerts should be considered.
- There is a concern that AVs would communicate (exclusively) aurally but would also need any audible information to be conveyed visually.
- The anticipation that self-driving vehicles would utilize speech input as a default means of interaction is a concern. For example, the system could inaccurately interpret utterances or generally perform poorly, based on past experiences with Apple's Siri, Microsoft's Cortana, and Amazon's Alexa.
- Blind and low-vision people have indicated that they found their personal smartphone to be very accessible and would prefer to control a self-driving vehicle using a smartphone application.

AV design needs to be fully accessible.

- Industry experts have responded to the disability community's advocacy for universally designed AVs as being nearly impossible to develop fully accessible AVs. Instead, they point to the dispatch model of ridesourcing or microtransit where individual needs of a rider are matched with vehicles that are designed appropriately.
- People who use wheelchairs would benefit if manufacturers design AVs so that a ramp or lift system could be integrated into the body of the car. Alternatively, manufacturers could design AVs so that they could be easily and affordably fitted with a wheelchair ramp or lift system as an after-market modification. Another issue for those who rely on a wheelchair for mobility is how to stow the wheelchair when they ride in the car.
- From an intellectual and developmental disability perspective, heavy reliance on navigation needs interfaces with minimal complexity to increase ease of use; mobile phones being used to receive remote support; and vehicle's ability to provide supervision and tracking to ensure safety of those with intellectual and developmental disabilities.

The Smart City project in Columbus, Ohio,[61] included a Trade Study to identify the best technical solution among proposed viable solutions for the Mobility Assistance for People with Cognitive Disabilities (MAPCD) Project—one of nine projects in the "Smart Columbus" portfolio. The project's goal was to enable people with cognitive disabilities to travel more independently on fixed-route bus service as a more cost-effective alternative to paratransit. While this is a narrow use case for MAT standards, many of the same complete trip considerations will likely apply for physically disabled users. Columbus identified the following evaluation criteria as essential

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61 Claypool, H., A. Bin-Nun, and J. Gerlach. (2017). Self-Driving Cars: The Impact on People with Disabilities. The Ruderman White Paper. Available at: http://rudermanfoundation.org/white_papers/self-driving-cars-the-impact-on-people-with-disabilities/

62 Brinkley, J., B. Posadas, J. Woodward, and J. Gilbert. Opinions and Preferences of Blind and Low Vision Consumers Regarding Self-Driving Vehicles: Results of Focus Group Discussions. Available at: https://drive.google.com/file/d/1TSnwxzdwZNC7y1bMRNJeX-xdvm_7_Pmb/view.

63 *Smart Columbus: Mobility Assistance for People w/ Cognitive Disabilities Trade Study*. (March 2018), pp. 33. https://smart.columbus.gov/uploadedFiles/Projects/Smart%20Columbus%20MAPCD%20Trade%20Study%2020180319.pdf

elements for travel support applications for the traveler and caregiver:

For the traveler:

- Phone-based application
- Knowledge of real-time transit information (using GTFS-realtime)
- Ability for the traveler to speak to the caregiver for safety and other purposes
- WCAG 2.0AA standard/508 compliant

For the caregiver:

- Ability to send alerts to the individual (passive monitoring)
- Ability to track an individual (active monitoring)

This study determined that existing apps called Wayfinder and Compagnon could be modified to meet the needs identified above. (The Wayfinder app was the preferred solution.)

These use-case scenarios support augmenting current development of standards to assess their application to MAT needs.

The overall impact of this dimension on standards development is significant as the accessibility of various mobility services and their uses differs greatly. For example, the accessibility of vehicles through the use a wheelchair lift or ramp and in-vehicle equipment, such as a tie-down does not apply to bikesharing. However, the accessibility of facilities that a traveler might use, such as a transit station, can be described in a standardized way due to the provisions of the ADA, for example. In any case, the impact on MAT standards development will possibly cause standards development organizations (SDOs) to begin to examine how to define the accessibility of all mobility services.

4.4 Transactional

The literature suggests that the future may have an increase in the number of transactional systems, such as road and transportation user charging, which will directly affect MAT standards development. More of these systems may produce a fairer and more equitable pricing system, and better balanced transportation demand and supply.

Similar to the informational dimension, a number of emerging mobility solutions are generating similar and overlapping messages and application programming specifications using different invocation methods and data concepts. Building transactional processes that use the same language and meaning may be a challenge due to not only the proliferation among U.S. demonstrations and pilots, but also the growing implementation worldwide—for example, GTFS versus geographic data files.

The work of the Secure Technology Alliance Transportation Council (https://www.securetechalliance.org/applications-transportation/) may advance standards in this dimension in the near-term. One of their focus areas is secure multimodal transportation payment systems.

The overall impact on standards development will be the need to begin to examine the similarities among various MAT-related transactions to determine the feasibility of standards in this dimension.

4.5 Institutional

Institutional issues, which are typically much harder to address than technological ones, will have various impacts on MAT standards development. These issues include:

- Outdated legislation will not work to manage brand-new mobility schemes like AVs or dockless bikes. A wholesale regulatory review is required.
- Shared mobility PPPs are becoming more common, but are difficult to implement and often do not progress past the pilot phase. Multiple studies cite this as a major reason for low transit ridership.
- The public sector has an opportunity to leverage public rights of way, regulating the private sector so that rides for low-income individuals become subsidized through permit fees.
- Shared automated fleets may be operated by private or public entities and may also exist in the peer-to-peer (P2P) marketplace; generally there is much uncertainty regarding future business model manifestation.
- Best practices and types of shared mobility partnerships are constantly evolving.
- Several distinct types of shared mobility PPPs have emerged and can be classified as:
    - First and last mile to public transit (i.e., complementing existing routes or lines)
    - Existing public transit overlay (e.g., peak shaving of existing routes) or substitution (e.g., replacement of existing or discontinued services)
    - Services for people with disabilities
- In a political environment, it is uncertain how politicians can be convinced to think long-term in transportation and move to bipartisan views of transportation needs of the community.

The overall impact on MAT standards development in the institutional area is perhaps the most significant of all of the dimensions described in this white paper. The nature of institutional issues make it challenging to standardize primarily because they can change quickly. Further, some institutional issues have a political basis, making it even more challenging to develop standards. Finally, with a wide variety of legislation across the United States and internationally, standardizing this aspect of MAT will be challenging.

4.6 Technological

There are a wide variety of technological issues that will impact MAT standards development in the future. Also, there are technologies that are not yet being studied to improve mobility through faster processing and more effective data collection and integration. For example:

- Quantum computing. Today's computing speeds do not handle many of the processing requirements needed to collect, transact, and provide real-time information such as fare transactions for open payment.
- 5G is expected to be available for large-scale deployment in 2019, and could be used to dramatically increase accuracy and flexibility of AV sensing technology. 5G is expected to be 100 times faster than 4G LTE and 10 times faster than Google Fiber. This could allow for myriad of uses including virtual reality, IoT applications, and AVs.

AV technologies, although creating breakthroughs in sensing technologies, provide improve to vehicle safety and control which will impact the traveling infrastructure in a myriad of ways.

- As of 2017, over 40 companies worldwide are developing AV technology. Over the last three years, $80 billion worth of AV-related investments, partnerships, and acquisitions have been made.
- Researchers exploring AV systems and network connections assert that the automated driving system must be extended to the network level, instead of as a stand-alone solution, to provide a secondary layer of safety and to access the full technology benefits. From the network perspective, 5G architecture needs to provide high flexibility, low latency load balancing for data-routing, and high-capacity nodes to allow for rapid data transmission with very low latency requirements.
- The public sector will have to understand 5G technology and interact with providers to manage the cellular infrastructure that may be required for safe AV deployment.
- There are significant risks associated with the future of ITS. For example, if the marginal cost of AVs is very low, will people travel more thus creating increased congestion?

There will be minimal impact on MAT standards development because standards are typically technology-agnostic.

4.7 Modal

While it is uncertain what number and types of mobility services will exist in 5 to 10 years, the following specific issues will affect MAT standards development.

Travel Behavior Research

- The last National Household Travel Survey was conducted in 2017 (https://nhts.ornl.gov/). Presumably, future surveys will continue to assess travel behavior changes (e.g., possible increase in millennial VMT and car-purchasing).
- Research is scarce on travel behavior for Generation Z (born roughly 1996–2012). For example, downward shifts in vehicle ownership by millennials (born roughly 1981–1996) may be due to postponed life milestones (such as marriage) and economic circumstances. However, more recent research suggests that millennials are “catching up” with older cohorts, characterized by increasing rates of holding a valid driver’s license coupled with their increasing number of trips by car-as-driver.[64]

New Mobility Options

Public acceptance of new mobility services is assumed—few people are thinking about what is needed for public acceptance. For example, many discussions of future mobility assume sharing a vehicle with others. However, we do not know how vehicle sharing will be accepted, especially in AVs without a driver as an “authority” figure. Technology adoption rates are accelerating, but national surveys show low propensity to use shared AVs.

Bikes and Bikesharing

The number of bikesharing users has grown to 28 million per 2016 data. Depending on a variety of factors, bikesharing can complement or replace rail or personal vehicle trips, and can be integrated into existing transportation systems to encourage multimodal mobility.[65]

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64 Garikapati et al., 2016; Newbold & Scott, 2017.

65 Shaheen, Totte, & Stocker. (2018). Future of Mobility White Paper, p. iv.

- **Electric bike** sales are on the rise with 190,000 electric bicycles sold in 2014. Integrating electric bicycles with traditional bicycles may pose on-road planning challenges because e-bikes can travel at much faster speeds, despite potentially needing to share bike lanes. (Note: research was conducted prior to wide deployments of e-bikes and e-scooters.)[66]
- Across all cities surveyed, increased **bus use** was attributed to bikesharing improving access to or from a bus line; shifts away from public transit in urban areas are often attributed to faster travel times and cost savings from bikesharing use.[67]
- In 3 out of 4 studies reviewed, more than one-third of surveyed respondents would have taken public transit, biked, or walked instead of using ridesourcing if those services had been unavailable.[68]

Ridesourcing

- Studies estimate approximately 9 percent of households suppressed purchase of vehicles or shed vehicles because of their use of ridesourcing.
- Ridesourcing companies are increasingly becoming involved in paratransit operations.

Other Multimodes

- Microtransit services may be able to add capacity and fill gaps in public transit networks. At present, many public transit authorities are experimenting with microtransit services through PPPs.

Automated Vehicle Adoption

Automated vehicle (AV) adoption may change travel behavior significantly. For example:

- Anywhere from 20 percent to 95 percent of travel on U.S. roads could be automated by 2030; fully automated taxi fleets could become reality between 2023 and 2030.
- Model results that predict change in travel demand due to AVs depend significantly on assumptions about future rates of adoption of shared AVs versus private AVs.
- There is a range of predicted impacts of AVs that depends heavily on assumptions of automated mobility costs, rates of personal AV ownership, shared AV market share, travel behavior changes, and future policy decisions.
- There is a possibility that AVs will not resolve transport issues; they could result in the creation of an entirely new problem—the permanently moving car.

Similar to the informational dimension, the modal dimension will have a significant impact on MAT standards development. This is for two key reasons: Each mobility service (a.k.a., mode) is different from all other mobility services in terms of vehicles, operations, and management, and the integration of services (e.g., the multimodal aspect of MAT) can be accomplished using a number of different approaches. For example, in the latter situation, Mobility as a Service (MaaS), one possible “integration” approach strives to provide a one-stop-shopping experience for accessing and paying for multiple modes, and may be operated by the private or public sector. Further, there are numerous business models that can be used to integrate mobility services. Finally, there are mobility service providers who will not share operational data (e.g., ridesourcing companies). So standardizing based on mode could be challenging.

[66] Ibid. p. 45
[67] Ibid. p. 46.
[68] Ibid. p. 47.

However, an approach such as Los Angeles's Mobility Data Specification could be used to develop MAT standards in this dimension. As the MDS is further enhanced and expanded, it could be considered as the basis for a MAT standard covering this dimension.

4.8 Temporal

Temporal impacts on MAT consist of several factors:

- Dynamic pricing based on time of day, day of week for parking, highways, and arterials will impact travel using alternative modes. This temporal factor should take accessibility and equity into account.
- Right of way usage based on temporal factors; for example, different space usage could create barriers to mobility services for people with disabilities, and fragment bicycle and pedestrian networks.
- Performance metrics based on time series and statistical methods will differ when incorporating different timeframes, sampling methods, and updated frequency rates.

There are temporal aspects of almost of all of the dimensions mentioned in this section. The impact on standards development will be minimal as temporal factors could be added to MAT standards as long as the other dimensions are addressed during future standards development.

4.9 Equity

A variety of equity issues will have an impact on MAT standards development.:

- As transportation networks increasingly rely on wireless services and technologies, equitable mobility will depend on access to broadband internet, smartphones, and bank accounts.
- Tracking public transit use according to actual ridership characteristics can more accurately identify inequities in existing public transit networks. This is especially important because census data are not published as frequently and may not be collected at accurate scales.
- Despite launching pilots aimed at broadening access, actual usage by low income individuals has been comparatively small; limited studies have examined potentially discriminatory effects of ridesourcing.
- For dense urban areas, requirements to locate bikesharing and carsharing in poorly served neighborhoods as a condition of approval could support equity efforts. However, this alone is not a guarantee that vehicles will be available to those who are disadvantaged.
- Some experts believe public agencies can have a tangible impact on equity by focusing on low-cost, low-risk options, yet others contend that because procurement rules move slowly and policies are generally restrictive and inflexible, the government is not suited to accommodate rapid technology change.
- Cities have partnered with shared mobility companies to offer services for disadvantaged populations that can target people with disabilities, older adults, or people with lower incomes. This includes on-demand paratransit services in which a public agency outsources services to a shared mobility provider in an effort to reduce costs and improve service levels.
- Accents and regional dialects/idioms may cause issues with speech inputs, likely disproportionately impacting minority and immigrant populations.

Because MAT activities can be assessed in terms of their equity implications, future standards development could account for equity issues.

5 Gaps Analysis

This section describes where gaps exist in the technologies, data and data collection, specifications, and standards needed to support MAT. In this section, the literature identifies areas where gaps exist, however, there are areas where gaps may exist that are not cited. This section summarizes by MAT domain and technology areas where gaps in standards may exist.

5.1 Gaps Related to Multimodal and Accessible Travel

Several key factors emerge from the discussion on dimensions, types of, and impact on standards:

- Awareness of all traveler populations and their needs
- Multiple efforts to develop local solutions
- Lack of interoperability and integration (of information and transactions) across different mode and service providers

For example, the ATTRI Institutional and Policy Issues Assessment Task 6 Summary Report,[69] identified several major issues associated with the development and deployment of advanced technologies with potential to improve mobility for people with disabilities. These included the "lack of awareness of disability needs, weak research and development incentives, underutilized potential of transportation network companies (TNCs) in providing paratransit services, inconsistent standards across the country, and risk and liability concerns among technology developers."

In addition, the Amadeus IT Group in "Voyage of discovery: Working towards inclusive and accessible travel for all"[70] identifies gaps in standards information and transactional dimensions as shown in Figure 5. "There are significant barriers at each stage of the customer journey to the realization of a fully accessible travel experience. These frustrations and barriers have a major impact on those travelers with accessibility needs."[68]

Specifically, the gaps were identified as part of the ATTRI State of the Practice Scan,[71] Use of Mobility Devices on Paratransit Vehicles and Buses,[72] and Effective Snow Removal for Pathways and Transit Stops[73] and summarized from the research. These gaps address not only people with disabilities, but also address other multimodal devices and services. Sections 5.1.1 through 5.1.7

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69 U.S. Department of Transportation. (2017). Accessible Transportation Technologies Research Initiative (ATTRI): Institutional and Policy Issues Assessment Task 6: Summary Report.

70 Amadeus IT Group, "Voyage of discovery: Working towards inclusive and accessible travel for all."

71 Giampapa, J. A., Steinfeld, A., Teves, E., Dias, M., & Rubinstein, Z. (April 2017). Accessible Transportation Technologies Research Initiative (ATTRI): State of the Practice Scan.

72 National Academies of Sciences, Engineering, and Medicine. (2014). Use of Mobility Devices on Paratransit Vehicles and Buses.

73 National Aging and Disability Transportation Center. (2014). Effective Snow Removal for Pathways and Transit Stops.

extend the reports to include other modes.

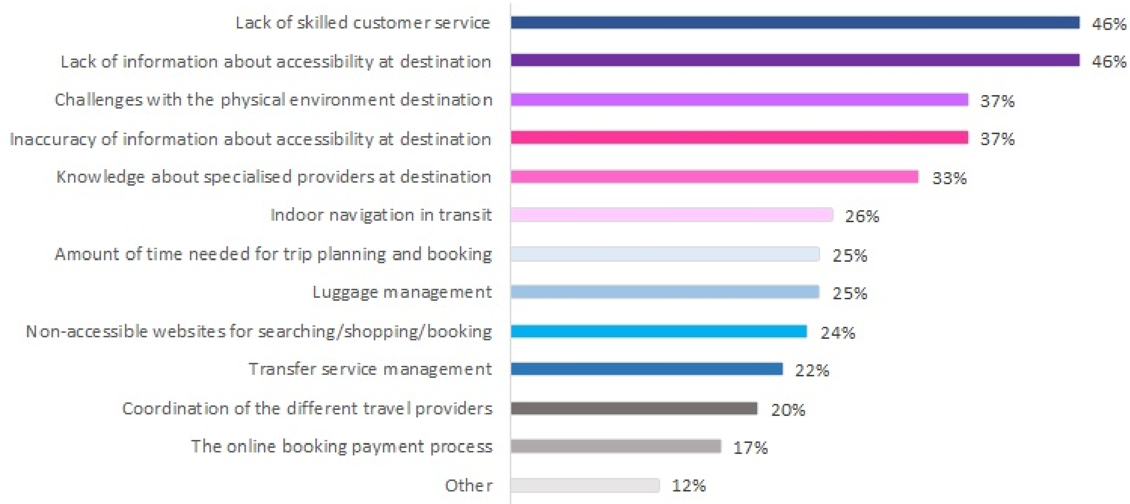

Figure 5. Most Reported Problems During the Last Trip: Pain Points and Barriers[68]

5.1.1 Wayfinding and Navigation

- Methods for incorporating user capabilities during transportation and pedestrian trip planning are rare.
- Reliable and scalable tracking and positioning sensors that work underground or in GPS-denied regions are not widely available. Good tracking and positioning are a requirement for navigation assistance.
- Infrastructure conditions, service reliability, and system performance data are typically not available for wheelchairs, bikes, scooters, and other micromobility devices.

5.1.2 ITS and Assistive Technologies

- Better methods for managing large grade changes when boarding transit vehicles are needed.
- Technologies to support first/last mile and pedestrian travel by people with cognitive disabilities are needed.
- Intelligent signal pre-emption, adaptive signal control, and pedestrian-crossing timing, particularly for people who need more time, can benefit from improvement. The signal timing issue extends beyond pedestrian and bus preferential treatment, it also includes other active modes such as bikes and scooters.

5.1.3 Data Collection, Representation, and Integration

Service providers, municipalities, and other data source stakeholders limit collection or provide access to data associated with infrastructure features, conditions, or performance that are useful for use by third parties. For example:

- Many data sources are stored in disparate locations and are hard to integrate into traveler information systems. Data quality, access rights, and use policies can vary considerably. This

will become increasingly important for automated vehicles, which require real-time, dynamic information about network conditions.
- Methods for acquiring and presenting data specific to the needs of ATTRI stakeholders are rare or lacking. Similarly, many mainstream traveler information apps are not accessible.
- Common methods for designating non-vehicular paths such as bike paths and pedestrian ways. As electric based micromobility devices become more ubiquitous, carriage way rights of the road, lane designation and path restrictions will be required. In addition, parking and storage information will need to be represented since it is already being monitored by municipalities.
- Key data, like municipal infrastructure details, are either missing or stored in ways that make use by computer systems difficult. Infrastructure features include geometry elements associated with pedestrian routes, curb cuts, railings, etc.

There are many standardization efforts[74] underway to develop methods to model indoor and "small" spaces, and assets contained in those spaces (like curb cuts and nonreflective raised pavement markers); identify technologies to more efficiently collect, verify quality, and transmit the data; and align the data with the transportation network and associated maps.

The proliferation of traveler apps to solve individual problems may require a larger effort that maps into applications that provide comprehensive traveler information. For example, how should MAT standards be integrated with existing transportation network features, conditions and performance data semantics, messages, syntax and orchestration approaches, including financial industry payment standard, and security "at-rest" and "in-transit" methods? How do transit open data and open source software map into the standard development activities?

5.1.4 Enhanced Human Service Transportation

Many of the gaps in enhanced human-service transportation information standards deal with addressing physical barriers to moving wheelchairs and scooters through transit buses and vehicles, buildings, and vertical conveyances. The dimensions of physical infrastructure and surface condition, representing "temporary or isolated disruptions" to pathways, are not well-represented by standards, and thus cannot be communicated to travelers or be incorporated into WaN trip planning. Among the issues are:

- Service personalization based on end-user needs
- Wheelchair weights and sizes accommodated by transit vehicles, including ease of movement, turning radiuses, entry-points, and ramps (particularly as wheelchair features are changed).

5.1.5 Smartphone Apps

The gaps in smartphone technology are narrowing with tools that cross-compile standard coding languages to native development tools. However, technology responsibilities overlap among several players—the handset manufacturers, the operating system vendors, and the app developers. Added to the mix are the back-office systems, communications, and platform providers who transmit, manage, and process app functionality and data. The various stakeholders affect how applications

[74] ISO TC 204 WG 3 in collaboration with CENT TC 278 is developing an extensive to develop a transportation network that includes these features and their characteristics.

work, transaction speeds, reliability, payload, privacy and security, and other performance metrics. The following technology gaps were identified in other literature[75, 76]:

- Numerous studies indicate that people are either unaware of what private information they expose or they do not understand what information they are consenting to share.
- There are growing concerns about the use of sensitive geospatial user data.
- Limited use of open data, including user interface/user experience which prevent interoperability among services and modes
- Ensuring that smartphone apps are accessible to all users. Accessibility requires apps to be usable by people with various health conditions (primarily older adults), as well as disabled individuals who need assistance.

Specific issues associated with smartphones apply to the accessibility and equity dimensions. They include the following:

- Mobility consumers are becoming increasingly dependent on smartphone hardware and applications, and the data packages required are often expensive for low-income households.
- Limited service, access, and steep data costs in rural and less urbanized locations may require alternative methods of communication to enable dynamic booking and sourcing of modes.
- Smartphone apps with a payment component may not serve the needs of unbanked users (typically lower-income households). Many smartphone apps generally require payment facilitated through credit/debit cards or mobile/internet banking. If a user is unbanked (they do not have a bank account or a credit/debit card), app-based services with a payment component (e.g., electronic fares and ticketing) may be difficult or impossible to use, leaving behind households that cannot afford to have a credit card or bank account (due to insufficient funds, bad credit history, etc.).

5.1.6 Cybersecurity Risk

There are very high-profile efforts to develop hardware, applications, policies, standards, and guidelines to address cybersecurity. These entail not only securing and hardening infrastructure, but also preserving data from corruption, preventing data disruption, and protecting personal identity data. Examples of risk identified from the literature include:

- Any API that facilitates data sharing among apps without user consent can create a number of ethical and legal issues.
- Protecting open data, proprietary data, and personal data, while still enabling information sharing with other apps and services, is a continual challenge confronting developers.
- Cloud privacy can also be a significant user concern.
- Benefits of internet-connected vehicles include enhanced engine controls, automatic safety controls, and remote control features, but make them vulnerable to malicious actors.
- In addition to hacking risk, it is possible to affect artificial intelligence systems by altering the environment they see in ways invisible to the human eye.

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75 Federal Highway Administration. (April 2016). Smartphone Applications to Influence Travel Choices: Practices and Policies.

76 Shaheen, S., Totte, H., & Stocker, A. (2018). Future of Mobility White Paper.

Note that with respect to privacy, the European Union has strict rules for the processes and requirements for sharing personal identifiable information. Many standards developed for international consumption, for example, the ISO standards, are incorporating these rules into informational and transaction standards, and designing their platforms and applications to incorporate those provisions.[77]

5.1.7 Emerging Technologies

Emerging technologies typically enhance and extend the capabilities of current methods for performing typical business processes. The enhancements enable people and systems to be more effective, perform faster or at lower costs to implement their duties and responsibilities. For emerging technologies to be effective and applied to MAT, typical "use cases" and scenarios are needed. For example, the ISO efforts[78] to identify standards for "Big Data" for ITS require the development of scenarios about how ITS components use the "technology." This is typically applied across the board to all new technologies. Several technologies may provide data, processing, or physical infrastructure that support MAT objectives, including IoT sensor and management tools, ranging technologies for indoor navigation, visual imaging and other real-time image processing. Many of these already have standard development projects underway.

5.2 Other Gaps

Finally, in terms of gaps in data quality and the implication for data standards, there are four distinct types of gaps that have been identified in the literature:

- **Measurement gaps**, which include gaps due to data existence, uncertainty/unreliability, precision/accuracy and structural/formatting issues, as well as overall gaps with respect to measurement precision and accuracy. All data sources have **measurement gaps.**
- **Spatial gaps** that arise when the spatial scope of the data is not sufficient for metric computation (e.g., data does not cover the geographic area being used).
- **Temporal gaps** that arise when the temporal scope of the data is not sufficient for metric computation.
- **Disaggregation gaps** that arise when the data are not disaggregated to an extent that is sufficient for metric computation. This occurs when the data does not provide adequate detail—that is, each data point represents the aggregation of more specific data, and there is no way to revert back to its original form.

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77 Example includes process implemented to issue updated version of ISO TR 24014-1 (ISO TC 204 WG 8 meeting notes).

78 ISO JTC 1 committees and ISO TC 204 Big Data Study Group (see meeting notes from April 28, 2017).

6 Next Steps

This white paper summarizes the results of the ICF team's extensive literature review. It also presents a framework that can be used to assess various MAT standards in Task 3. Further, we examined current technologies that are being used in MAT, discussed the potential impacts on MAT standards development based on research and development activities that describe the next 5 to 10 years in MAT, as well as gaps in MAT standards, data, and technology.

Based on the results of Task 2, which are provided in this white paper, the ICF team will conduct Task 3: Survey of Existing Standards and Standards Under Development. The Task 3 white paper will result from the following steps: (1) conducting a high-level survey of standards-related activities, (2) developing detailed information cards on highly relevant standards-related activities, and (3) analyzing and mapping out standards-related activities.

Step 1 – High-level survey of standards-related activities. The ICF team will connect with the organizations (SDOs and non-SDOs) to identify related committee work and specific standards-related activities, including high-profile organizations such as SAE, International Organization for Standardization, CEN, Transit Cooperative Research Program, International Telecommunication Union, Institute of Transportation Engines, American Association of State Highway Transportation Officials, the MaaS Alliance, as well as consortia and associations such as APTA, Open Geodata Consortium, Oasis, NABSA, GTFS ad hoc groups, Secure Technology Alliance, and more.

Step 2 – Information cards on highly relevant standards-related activities. The ICF team will develop a list of standards-related activities. For those of high relevance, the team will develop information cards containing scope, institution (SDO and non-SDO), maturity level, timeline, contact information, and related deployment activities.

Step 3 – Analysis and map of standards-related activities. The ICF team will analyze and map out standards-related activities to identify gaps and duplicative efforts across geographies, industries, and stakeholder communities.

Step 4 – White paper. The ICF team will develop a draft and final white paper that documents the findings of the standards surveys and the results of the categorizing and mapping activity.

As technical staff of a leading SDO and as leaders and active members of many of the standardization efforts, the ICF team members are well-positioned to have direct and recurring access to existing standards and standards under development.

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APPENDIX A. STEPS

- **Spatial –** Shared mobility may provide a low-cost solution for bridging transportation gaps, providing both a first-and-last-mile (FMLM) connection to public transit and serving as a stand-alone service option. Shared modes such as bikesharing, carsharing, and ridesourcing/transportation network companies may be deployed in underserved areas in less time at lower cost than traditional projects by leveraging private sector investment and operation of these services. However, the need to achieve full cost recovery (or make a profit) can limit the deployment of privately operated shared mobility services in lower-density and low-income communities.
- **Temporal –** Shared mobility may provide temporal benefits over traditional service models, such as reduced wait time and increased travel-time reliability, advance booking options, and reduced travel time. For users without access to automobiles in areas with limited public transit, shared mobility may significantly reduce temporal barriers.
- **Economic –** Shared mobility services can offer new travel options to users that may have lower operating cost and fares compared to existing paratransit and fixed-route transit service, particularly during off-peak and late-night hours. However, the lack of smartphone data access and credit/debit cards may be a barrier for disabled, low-income, and older adult users.
- **Physiological –** Shared mobility has the opportunity to lower the cost and diversify the range of assisted modes to users with cognitive and physical challenges. However, rapid technology change can create unforeseen access challenges for disabled users, if specific needs are not taken into account.
- **Social –** Shared mobility services have increased awareness and interest in multi-modal travel, but many have faced challenges in addressing barriers and marketing to low-income communities, minorities, and users with limited English proficiency. Despite these criticisms, shared mobility providers, advocacy groups, and researchers are continuously trying to address barriers to ensure that shared mobility services improve social accessibility through community engagement, improved product design, and marketing.

Adapted from FHWA report "Travel Behavior: Shared Mobility and Transportation Equity"

APPENDIX B. Guiding Principles for Emerging Mobility

- **Collaboration** – required between mobility service providers and the City, and then with the public to ensure continual transport improvement
- **Safety** – service providers must be consistent with the City and County's safety goals
- **Transit** – services must complement and help to satisfy the needs of public transport and other high occupancy modes
- **Congestion** – service providers must consider their impact on traffic and public transport as well as on mode choice and roadway safety
- **Sustainability** – service providers must help attain the City's greenhouse gas (GHG) emissions and reduction goals as well as help to promote non-auto modes
- **Equitable access** – services must be accessible to all people "regardless of age, race, color, gender, sexual orientation and identity, national origin, religion," or other demographics such as income and residential location
- **Accountability** – service providers must share data in order for the City and public to determine the services' benefits and impacts on transport, and whether or not the services' meet the City and County's transport goals
- **Labor** – service providers must be consistent with fair labor and pay practices and policies
- **Disabled access** – services must be accessible to disabled persons, ensuring that they receive the same or comparable level of access as persons without disabilities
- **Financial impact** – services are encouraged to demonstrate having a positive financial impact on transport investments

Source: SFCTA's Emerging Mobility Guiding Principles

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