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Mobility Data – Standards and Specifications for Interoperability

PREPARED BY

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U.S. Department of Transportation
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SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

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14. ABSTRACT

The FTA has partnered with CUTR to conduct research on transit mobility, infrastructure, and safety. This involves identifying existing standards and practices to improve these areas, as well as conducting gap analyses to determine the need for additional guidance and resources to support safe and efficient public transportation. This research aims to enhance the ongoing efforts of the USDOT by focusing on data exchange and interoperability between modes, platform vendors, and operators in the Mobility on Demand (MOD) ecosystem. This report offers a comprehensive global literature search on the interoperability of mobility services, including taxonomies, definitions, and the current state of mobility services. It also summarizes key research outcomes, presents case studies and standards, and discusses the outlook on technological advances in interoperability within mobility. The report includes findings from a survey administered to gather feedback from the mobility industry on the current state of standardization and available resources that support open data practices and integration of trip discovery, payment, and operations. Additionally, it provides an overview of the Mobility Standards and Guidelines Resource (MSGR) online tool, which was developed by the CUTR research team to inform stakeholders on the mode-specific resources available for the integration of various components of the mobility ecosystem. The report concludes by discussing key findings and outlining considerations for the FTA to support an interoperable, open, and user-centric MOD system.

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Mobility on Demand, interoperability, Mobility as a Service, open-source, standards, MSGR tool

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Abstract

The Federal Transit Administration (FTA) has partnered with the Center for Urban Transportation Research (CUTR) to conduct research on transit mobility, infrastructure, and safety. This involves identifying existing standards and practices to improve these areas, as well as conducting gap analyses to determine the need for additional guidance and resources to support safe and efficient public transportation. This research aims to enhance the ongoing efforts of the United States Department of Transportation (USDOT) by focusing on data exchange and interoperability between modes, platform vendors, and operators in the Mobility on Demand (MOD) ecosystem.

This report offers a comprehensive global literature search on the interoperability of mobility services, including taxonomies, definitions, and the current state of mobility services. It also summarizes key research outcomes, presents case studies and standards, and discusses the outlook on technological advances in interoperability within mobility. The report includes findings from a survey administered to gather feedback from the mobility industry on the current state of standardization and available resources that support open data practices and integration of trip discovery, payment, and operations. Additionally, it provides an overview of the Mobility Standards and Guidelines Resource (MSGR) online tool, which was developed by the CUTR research team to inform stakeholders on the mode-specific resources available for the integration of various components of the mobility ecosystem. The report concludes by discussing key findings and outlining considerations for FTA to support an interoperable, open, and user-centric MOD system.

Executive Summary

Background

FTA established the Standards Development Program (SDP) to focus on transit standards related to mobility, infrastructure, and safety. The program conducts research and analysis to determine the necessity of new standards or where existing standards are lacking. The program also seeks to identify existing standards that are not adequate or specific to transit that may be modified or enhanced for public transportation. Additionally, the program works with standards development organizations (SDOs) to create guidance documents, standards, or recommended practices for voluntary adoption in the industry.

USDOT envisions MOD as a multimodal ecosystem where all travelers have safe, reliable, and informed mobility options that prioritize individual, on-demand mobility.[1] Through the strategic efforts co-led by FTA, the Federal Highway Administration (FHWA), and the Intelligent Transportation Systems Joint Program Office (ITSJPO), USDOT is promoting research that addresses persistent lack of transportation access for the most vulnerable Americans living in remote areas, constrained by physical disability or economic constraints.

This research project was developed as part of FTA's Standards Development Program encapsulating the vision of USDOT for accessible, equitable, seamless, and complete trips for all travelers. As the transit industry is evolving rapidly to seek interoperability across public transportation systems and services and integrate alternative forms of mobility and technology advancements, the research aims to build upon ongoing USDOT efforts focusing on data exchange and interoperability between modes, platform vendors, and operators as part of the MOD ecosystem.

Objectives and Activities Performed

The primary goal of this research was to identify any gaps in specifications or standards and focus areas for which FTA will publish a report or issue voluntary guidance. The gaps identification considered the three aspects of the MOD ecosystem, which include trip discovery, payment, and operations.

To achieve the above objectives, the research comprised the following activities:

- Comprehensive literature search, including taxonomies, global mobility services, key research outcomes, case studies, standards, open-source specifications, and technological advances in the interoperability of mobility services.

[1] https://www.its.dot.gov/factsheets/mobilityondemand.htm

- Survey of transit stakeholders and industry experts to identify relevant demonstrations, data sharing protocols, lessons learned, and workable solutions to encountered problems in the realm of mobility interoperability.
- Classification of the identified gaps into the three components (i.e., trip discovery, payment, and operations) of the MOD ecosystem.
- Development of the Mobility Standards and Guidelines Resource (MSGR) online tool to interactively inform stakeholders on the available mode-specific standards, open-source specifications, and case studies associated with the integration of mobility services.
- Establish a set of considerations for FTA to promote interoperable, open, and user-centric MOD systems in the United States.

Findings and Conclusions

The accessibility and sharing of standardized mobility data in the United States (U.S.) is currently limited, leading to inconsistent data structures and a lack of interoperability. This may be due to the absence of policy guidelines and the high cost and time-intensive stakeholder consensus approach associated with traditional standards development processes. Nonetheless, the current efforts driven by the industry appear to be more than capable of supporting the creation of standards and specifications in mobility.

Currently, there are several significant open-source initiatives worldwide that aim to promote interoperability. These include the General Transit Feed Specification (GTFS) (including extensions such as real-time, pathway, fare, flexibility, and operational data standard), the General Bikeshare Feed Specification (GBFS), the Mobility Data Specification (MDS), Transport Operator to Mobility as a Service Provider (TOMP), General On-demand Feed Specification (GOFS), Transactional Data Specification (TDS), and City Data Standard for Mobility (CDS-M).

From the research performed, there is an apparent need to differentiate between interoperability through deep links and deep integration in the mobility sector. With deep links, a centralized end-user booking application can display various mobility services and operators available for a journey. However, users still need to pay for each vehicle or service separately and are redirected to each operator's application to complete the booking. In contrast, deep integration allows users to book and pay for their entire journey on the mobility application without needing to use individual operator applications. Currently, the mobility industry in the United States is at the first level of integration, which is information integration, as opposed to a multimodal one-stop-shop ideal for users.

The gaps identified in specifications or standards and potential focus areas for FTA issued guidance are stated below.

Trip discovery:

- Incorporating on-demand services into the GTFS. More outreach/ awareness is needed toward existing and in-progress solutions.
- Leveraging global Mobility as a Service (MaaS) initiatives, particularly open-source projects, for valuable insights on data sharing and interoperability.
- Standardizing user-centric performance metrics to consistently evaluate MOD-based datasets.

Payment:

- Integrating trip planning and payment (i.e., via deep integration).
- Establishing agreements between involved parties (user, operator, provider) to facilitate payment, acceptance, and distribution.
- Standardizing guidelines to incorporate personally identifiable information (PII) safely and securely in data, to facilitate better usability. This should cover aspects of consent, safety protocols, encryption, and ethical and legal implications. Also, these guidelines should be able to address user concerns associated with privacy.

Operations:

- Ensuring MOD/MaaS scalability by supporting the development of legal contracts associated with data sharing and non-discriminatory practices among operators/service providers.
- Standardizing the integration of existing and new back-end operations systems in transit.
- Expanding the traditional definitions and performance metrics associated with trip satisfaction and equity.

The survey further presented industry opinion on the suggested actions that FTA should consider supporting for interoperability and development of open-source standards. Responses included:

- Funding solutions or setting open-data requirements for access to funding (42%)
- Need to lead standardization (25%)
- Other initiatives, such as producing user-centric trip metrics, guidance on best practices, and reviewing existing Americans with Disabilities Act (ADA) regulations (13%)
- Facilitating agency coordination (11%)
- Accepting the status quo (9%)

Derived FTA Considerations

This research has identified the following set of considerations for FTA to advance interoperable, open, and user-centric MOD systems:

- Encourage open-source data sharing by establishing policies and requirements for the use of federal funding.
- Support industry-driven open-source mobility data standardization efforts.
- Fund demonstrations and evaluation of mobility data integration efforts.
- Promote industry awareness, knowledge, and readiness.

Section 1

Introduction

The Federal Transit Administration (FTA) entered into a cooperative agreement with the Center for Urban Transportation Research (CUTR) at the University of South Florida (USF) to identify the current landscape and recommend opportunities for government action to support the development and use of standards in transit mobility, infrastructure, and safety. This effort supports FTA's goal of promoting an integrated mobility ecosystem that supports carefree mobility for the traveling public.

FTA Standards Development Program

FTA's Standards Development Program was established to:

- Address transit mobility, infrastructure, and safety-related standards.
- Conduct background research and analysis.
  - Determine the need for new transit standards in areas where standards are lacking or where there are gaps within existing standards.
  - Identify existing standards deemed not adequate or not specific to transit that may be modified or enhanced for public transportation.
- Work with industry stakeholders or working groups to inform the standard development process, including associated transit mobility, infrastructure, and safety research reports.
- Work with SDOs, such as the American Public Transportation Association (APTA), Intelligent Transportation Society of America (ITS America), Mobility on Demand Alliance, and Society of Automotive Engineers (SAE) International to develop guidance documents, standards, or recommended practices for industry voluntary adoption.

Standards Program Research Framework

FTA's Standards Development Program is performed in accordance with the structure presented in the FTA Standards Development Program Framework.

The research project presented in this report, *Mobility Data – Standards and Specifications for Interoperability*, is consistent with the research needs identified by the industry through CUTR's Transit Standards Working Group, supports FTA's research goals and initiatives, and includes the identification of mobility data standards, protocols, and recommended practices that may serve to further FTA's transit mission.

Study Objectives

To achieve the United States Department of Transportation's (USDOT) vision for accessible, equitable, seamless, and complete trips for all travelers,

collaboration and harmonization in standardization is needed across industries representing various facets of the travel chain, whether they are segments of the trip or integration of trip segments (i.e., trip planning and payment integration). That vision, espoused by USDOT, is encapsulated in Mobility on Demand (MOD). The primary objective of this project was to identify the best practices and current mobility data developments leading to industry-driven data standards and specifications that advance the MOD vision.

This research builds upon ongoing USDOT efforts by focusing on data exchange and interoperability between modes, platform vendors, and operators as part of the MOD ecosystem. The research also reviewed international mobility data standards as appropriate to help close the gaps in MOD data exchange specifications and standards.

The research outcomes identify gaps in specifications or standards and focus areas for FTA-issued guidance, specifications, or standards. This also includes FTA support of industry-led efforts to ensure interoperability among the different components of the MOD ecosystem.

The gaps identification focuses on the following aspects of the MOD ecosystem:

- **Trip Discovery** – The research documents previous and ongoing domestic and international initiatives to develop standards to improve data sharing among service providers and public agencies.
- **Payment** – The research considers how technology is developing and what minimum level of data sharing is necessary to ensure a seamless integration between different payment systems for diverse traveler choices.
- **Operations** – The research investigates how and what data standards should be developed for public transit and mobility operations to ensure travelers are best served throughout their travel journey.

Report Organization

This report consists of six sections and begins with an introduction and study objectives. A comprehensive literature search follows that includes taxonomies and definitions, the current state of mobility services, a summary of key research outcomes identified in the scope of work, and a review of cases studies and standards or open-source specifications involving the interoperability of mobility services. The outlook and possible direction for advances of interoperability in mobility are then discussed. The results of the survey administered for industry outreach are then presented, followed by a summary of the overall findings of the literature search and survey. A brief overview of the tool developed by the CUTR research team to inform stakeholders on the available resources associated with the interoperability among various components of the MOD/MaaS ecosystem is then presented. Finally, the conclusions detail considerations for FTA to support an interoperable, open, and user-centric MOD system.

Section 2 Literature Review

Key Terms and Definitions

Researchers began the literature review by gathering key terms and definitions used in this field across the United States and internationally, as detailed in Table 2-1. This was done to understand the current outlook on uniformity across these definitions. Table 2-1 also summarizes the definitions of MOD and Mobility as a Service (MaaS), highlighting their commonalities and divergences.

Table 2-1. *Key Terms and Definitions*

Term	Definition
Shared Mobility	• The shared use of a vehicle, motorcycle, scooter, bicycle, or other travel mode that provides users with short-term access on an as-needed basis. (Shared and Digital Mobility Committee, 2018) • An innovative transportation strategy enabling users to gain short-term access to transportation modes on an "as-needed" basis. Shared mobility also includes last-mile delivery services. (Shaheen & Chan, 2016) • Transportation services that are accessed and shared among users, including public transit; taxis and other vehicles for hire. (Transportation Research Board, 2016)
Mobility on Demand (MOD)	• USDOT envisions MOD as a safe, reliable, and carefree mobility ecosystem that supports complete trips for all, both personalized mobility and goods delivery. MOD has three major guiding principles: traveler centric and consumer driven, data connected and platform independent, multimodal and mode agnostic. (Shaheen, Cohen, Yelchuru, & Sarkhili, 2017) • The USDOT Intelligent Transportation Systems Joint Program Office (ITS JPO) describes MOD as an innovative user-focused approach, which leverages transit networks and operations, real-time data, connected travelers, and cooperative ITS to allow for a more traveler-centric, transportation system-of-systems approach, providing improved mobility options to all travelers in an efficient and safe manner. (https://www.its.dot.gov/factsheets/mobilityondemand.htm) • MOD is a concept based on the principle that transportation is a commodity where modes have distinguishable economic values. MOD enables customers to access mobility, goods, and services on demand. (Shaheen et al., 2020) • MOD is an integrated and connected multimodal network of safe, affordable, and reliable transportation options that are available and accessible to all travelers. (FTA Office of Research, Demonstration and Innovation: https://www.transit.dot.gov/regulations-and-guidance/shared-mobility-definitions) • MOD is an innovative transportation concept evolving around connected travelers, where consumers can access mobility and goods delivery services on demand by dispatching or using public transportation, shared mobility, courier services, urban air mobility, and other innovative and emerging technologies. (Shaheen, Cohen, Stocker, & Martin, 2019)

Term	Definition
Mobility as a Service (MaaS)	• **United States:** MaaS is a mobility platform in which a traveler can access multiple transportation services over a single digital interface. MaaS primarily focuses on passenger mobility (and in some cases goods delivery) allowing travelers to seamlessly plan, book, and pay for a multimodal trip on a pay-as-you-go and/or subscription basis. (Shaheen & Cohen, 2020; Shaheen et al., 2020) • **Europe:** MaaS Integrates various forms of transport services into a single mobility service accessible on demand. A MaaS operator facilitates a diverse menu of transport options to meet a customer's request, such as public transport, ride-, car- or bike-sharing, taxi or car rental/lease, or a combination thereof. For the user, MaaS can offer added value by using a single application to provide access to mobility with a single payment channel instead of multiple ticketing and payment operations. (https://maas-alliance.eu/homepage/what-is-maas/; Schweiger et al., 2019). • **Australia:** MaaS provides a total mobility solution focused on the individual's need to get from A to B. It is evolving from service models that provide vehicle transport without the cost of ownership. Hensher, Mulley, and Nelson (2021) offer a more comprehensive definition: "MaaS is a framework for delivering a portfolio of multimodal mobility services that places the user at the center of the offer. MaaS frameworks are ideally designed to achieve sustainable policy goals and objectives. MaaS is an integrated transport service brokered by an integrator through a digital platform. A digital platform provides information, booking, ticketing, payment (as pay-as-you-go and/or subscription plans), and feedback that improves the travel experience. The MaaS framework can operate at any spatial scale (i.e., urban, regional, or global) and cover any combination of multimodal and non-transport-related multi-service offerings, including the private car and parking, whether subsidized or not by the public sector. MaaS is not simply a digital version of a travel planner, nor a flexible transport service (such as Mobility on Demand), nor a single shared transport offering (such as car sharing). 'Emerging MaaS' best describes MaaS offered on a niche foundation. This relates to situations where MaaS is offered on a limited spatial scale, to a limited segment of society or focused on limited modes of transport. The MaaS framework becomes mainstream when the usage by travelers dominates a spatial scale and the framework encompasses a majority of the modes of transport." • **United Kingdom:** MaaS can be used to describe digital transport service platforms that enable users to access, pay for, and get real-time information on a range of public and private transport options. (Enoch, 2018) • **ITS-Finland:** MaaS is a mobility distribution model in which a customer's major transportation needs are met over one interface and are offered by a service provider. (Hietanen, 2014)

MOD versus MaaS

The literature review shows that MOD is a term more commonly used in the United States, while MaaS is used in other parts of the world (Europe, Asia, Australia, and others). The definitions and descriptions of the two terms indicate that there are some similarities but also differences. MOD is intended to facilitate improved personal travel and goods delivery (Shaheen & Cohen, 2020). MaaS emphasizes app-based service and availability of subscription models. However, both MOD and MaaS converge on their emphasis toward physical, fare, and digital multimodal integration (Shaheen & Cohen, 2020). Figure 2-1, adopted from Shaheen and Chan (2016), highlights the differences and similarities of MOD and MaaS. This convergence allows for the identification of existing and

in-progress local and international standards/guidelines/efforts that can be applied to improve overall standardization and interoperability.

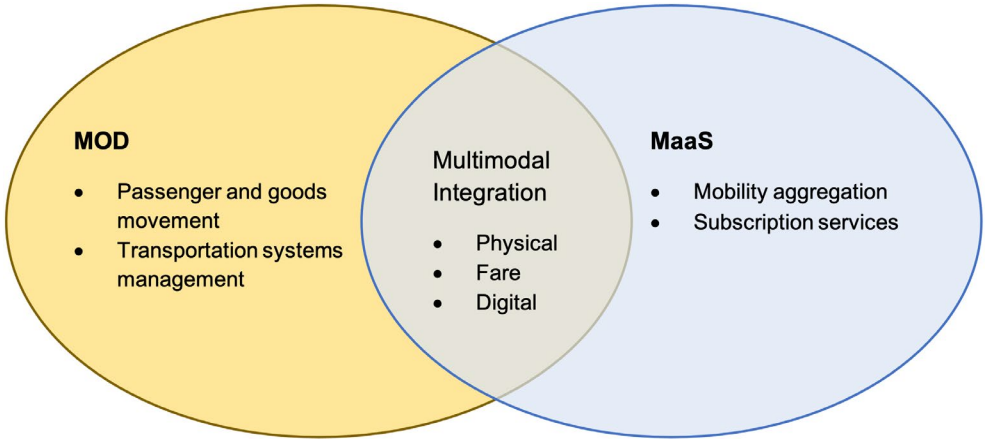


Figure 2-1. *MOD vs. MaaS (Shaheen & Cohen, 2020)*

As this project sought to uncover gaps to ensure interoperability and alignment among international and industry-led efforts, researchers identified inconsistencies in the definitions used for MaaS. These inconsistencies are further highlighted by Hensher, Chinh, and Nelson (2022) involving the use of the MaaS term by media, app developers, and transport operators to promote travel planning and companion interfaces, indicating a lack of/unwillingness to comprehend what constitutes MaaS (Hensher et al., 2022; Williams, 2021).

In a comprehensive survey of standards as part of the USDOT Multimodal and Accessible Travel Standardization Assessment (MATSA) effort, Chang et al. (2019) noted large variability when defining MaaS services, especially with respect to the emergence of various glossaries using different terms, conditions, and rules. This variability in how the MOD and MaaS ecosystems are defined prevents efforts, such as MATSA, from recommending specific standards/guidelines. The International Organization of Standardization Technical Committee 204 recently published a uniform data dictionary to facilitate consistency, standardization, and interoperability across transportation concepts, modes, and features (ISO-TR4447:2022, 2022).

Current State of MOD in the United States

As summarized by Lucken, Frick, and Shaheen (2019), MOD partnerships across the United States can be split into agency-operated and agency-subsidized (private partnerships). Out of the 62 partnerships analyzed, 47 were agency-subsidized while 15 were agency-operated (Lucken et al., 2019). Most agency-subsidized partnerships involved first-mile/last-mile connections and

enhancements to the ADA-mandated paratransit service. Agency-operated MOD partnerships are mostly restricted to low-density service areas.

The authors also conducted a survey to gauge the current understanding, interest, and challenges associated with MOD/MaaS. Key takeaways from this survey were as follows:

- Taxis, transportation network companies (TNCs), and ridesharing were the three most common types of MOD service partnerships.
- Paratransit service (28%), first-mile/last-mile connections (25%), and medical transportation (21%) were the most widely available MOD services.
- Best practices, data standards, and case studies were the three top resources suggested by the survey respondents to help prepare their agencies for MOD/MaaS.
- State agency respondents believed their role is to:
  - Regulate MOD/MaaS
  - Include MOD/MaaS in strategic plans
  - Partner with mobility providers
- Public sector challenges associated with MOD and Maas include:
  - Affordability
  - Curb space management
  - Technology access for users
  - Data sharing
  - Social equity and inclusion
- Top three uses for data sharing identified by public agencies include:
  - Performance measurement
  - Managing real-time traffic
  - Informing planning decisions
- Top five challenges associated with implementing integrated fare payment include:
  - Data sharing between organizations
  - Operational costs
  - Affordability for underserved populations
  - Accessibility for underserved populations
  - Privacy protection for travelers

Figure 2-2 summarizes the types of regulation, legislation, and guidance public transit agencies would like to see implemented to drive MOD/MaaS deployments.

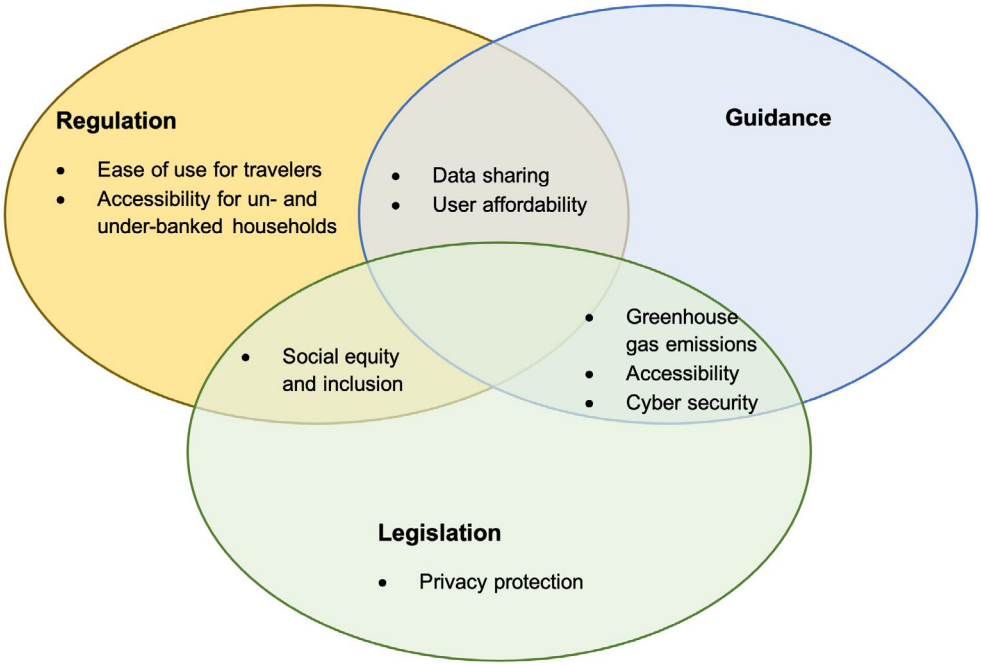


Figure 2-2. *Key policy areas of interest to agencies planning MOD/MaaS*

One of the main challenges associated with the implementation of MOD is data sharing and accessibility. In an effort to ensure free and secure data flow between mobility operators and providers, the following Mobility Data Interoperability Principles were collaboratively authored by the California Association of Coordinated Transportation, California Integrated Travel Project (Cal-ITP), Denver Regional Transportation District (RTD), Entur, Los Angeles County Metropolitan Transportation Authority (LA Metro), Massachusetts Bay Transportation Authority (MBTA), Metro Transit (MN), Metropolitan Transportation Commission, Minnesota Department of Transportation (MnDOT), MobilityData, Shared Use Mobility Center, North Carolina Department of Transportation (NCDOT), Taskar Center for Accessible Technology, Tri-County Metropolitan Transportation District of Oregon (TriMet), VIA Metropolitan Transit San Antonio, and Washington State Department of Transportation Public Transportation Division (Mobility Data Interoperability Principles, 2021):

- All systems creating, modifying, or consuming mobility data should be interoperable.
- Interoperability should be achieved through the development, adoption, and widespread implementation of open standards that support the efficient exchange and portability of mobility data.
- Transit agencies and other mobility service providers should have access to tools that present high-quality mobility data accessibly, equitably, and in real time to assist travelers in meeting their mobility needs.

- Transit agencies, other mobility service providers, and travelers should be able to select the transportation technology components that best meet their needs.
- All individuals and the public should be empowered through high-quality, well-distributed mobility data to find, access, and utilize high-quality mobility options that meet their needs as they see fit, while maintaining their privacy.

Current State of MaaS in Europe

Currently, 15 European countries offer some form of MaaS, as shown in Figure 2-3. The earliest MaaS provider in Europe was Ubigo in Sweden in 2014.

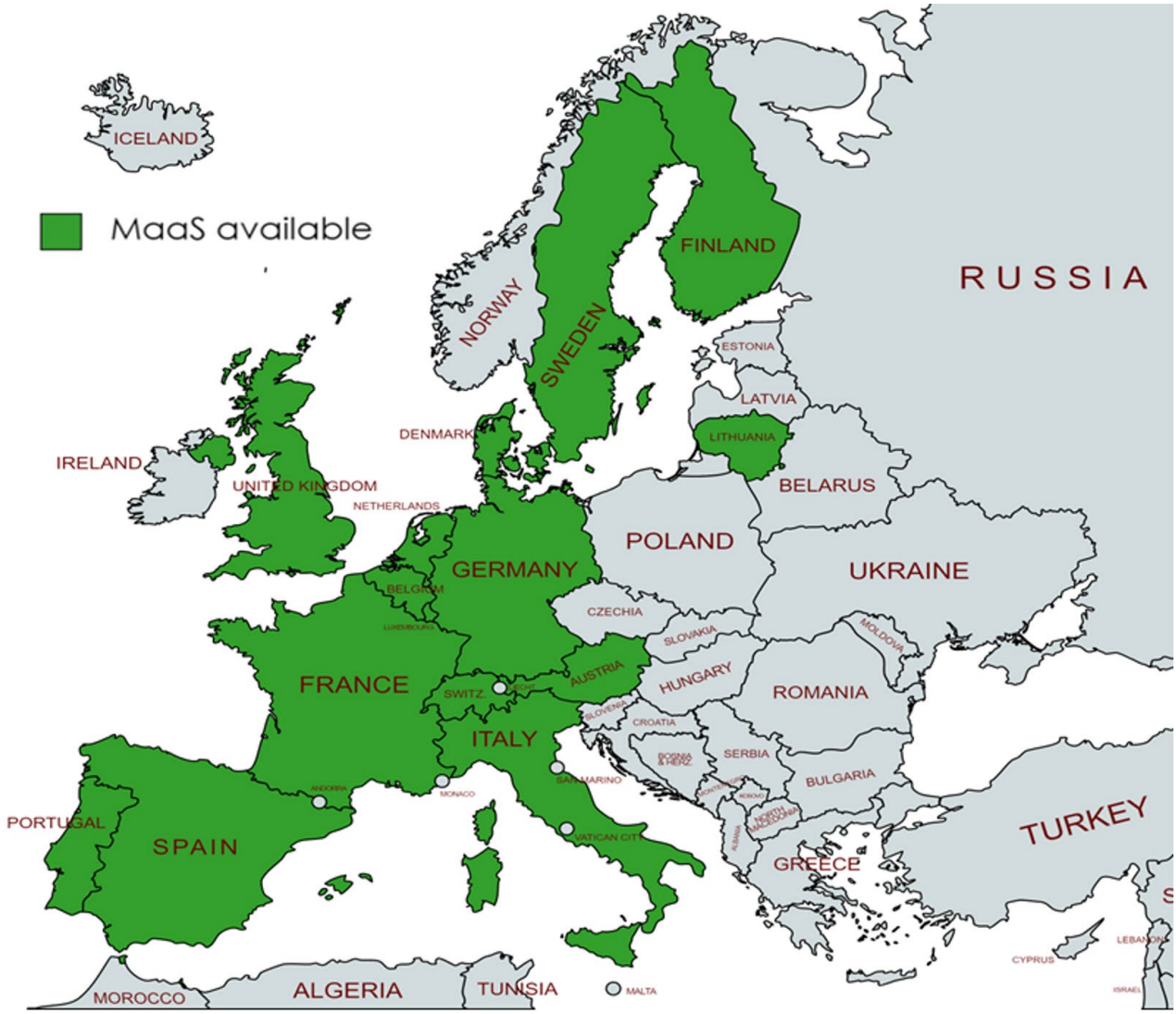


Figure 2-3. *MaaS deployments in Europe*

Sochor, Arby, Karlsson, and Sarasini (2017) identify five levels of MaaS maturity or integration, including Level 0: No integration, Level 1: Integration of information, Level 2: Integration of booking and payment, Level 3: Integration of service offer, and Level 4: Integration of societal goals. Other researchers such as Lyons, Hammond, and Mackay (2019) also provide a comprehensive breakdown of the levels of MaaS integration based on only the capabilities of existing service providers. The six levels are as follows:

- Level 0: No operation information or transaction integration across modes.
- Level 1: Information integration across modes (Google Maps, Mappy, etc.).
- Level 2: Information integration with some operation integration and transactional integration (Uber, Moovit, etc.).
- Level 3: Some journeys with fully integrated experience (Moovel, Trafi, other service providers).
- Level 4: Some modal combinations offer fully integrated experience (Whim).
- Level 5: Full operational, informational, and transactional integration across all journeys (efforts such as TOMP-API, etc.).

The MaaS integration breakdown by Sochor et al. (2017) encompasses a wider outlook by including the integration of societal goals, while Lyons et al. (2019) focuses more on the informational and transactional integration of all services. In essence, a Level 2 of MaaS integration defined by Sochor et al. (2017) is equivalent to a Level 5 of Lyons et al. (2019).

Based on the above breakdown of MaaS integration, MaaS in Europe is mostly encompassed between Sochor et al. (2017) Levels 1 and 2 or Lyons et al. (2019) Levels 2 (limited integration) and 3 (partial integration). Between 2018 and 2019, there was a significant increase in MaaS operators in Europe. However, COVID-19 led to a decrease in new deployments between 2020 and 2022. Further, MaaS providers focused on re-prioritizing their integration models to focus on user needs (i.e., safety, personalization, trustworthiness, simplicity, impartiality, and flexibility) to encourage their return to public and shared transport (Lancaster, 2021). Table 2-2 shows a summary of MaaS operators, level of MaaS integration based on Lyons et al. (2019), and their first year of service in the country.

Table 2-2. *List of MaaS Operators in Europe*

Country	City	MaaS Operator	Integration Level	Year Started
1. Austria	Vienna	Whim	4	2019
		Upstream / WienerLienen	3	2017
	Graz	Upstream / WienerLienen	3	—
2. Belgium	Antwerp	Whim	4	2018
3. Denmark	Copenhagen	HaCon / Rejseplan	3	2018
4. Finland	Helsinki	Whim	4	2017
	Turku		4	2018
5. France	Angers	RATP	3	2019
	Annemasse	RATP	3	2019
	Mulhouse	Cityway	1	2018
	Paris	RATP / Instant System	3	2019
	Saint-Etienne	Transdev	4	2019
	Région Nouvelle Aquitaine	Instant System	3	—
6. Germany	Aschaffenburg	Moovel	3	2017
	Berlin	Mobimeo / BVG Trafi / BVG	3	2018
			3	2019
	Karlsruhe	Moovel	3	2017
	Hamburg	Moovel	3	2016–2019
		Upstream	3	2017
		Mobimeo / Deutcshe Bahn	3	2019
	Hanover	Mobimeo / Deutcshe Bahn	3	2019
	Munich	MVG MVGO / Trafi	3	2021
	Stuttgart	Moovel	3	2015
		Mobimeo	3	2019
7. Italy	Cagliari	Moovit + Reach Now & URBI	2	2019 & 2017
	Catania		2	
	Milan		2	
	Napoli		2	
	Palermo		2	
	Rome		2	
	Turin		2	

Country	City	MaaS Operator	Integration Level	Year Started
8. Lithuania	Vilnius	VilniusTrafi	3	2017
9. Luxembourg	Luxembourg	HaCon / Ministry of Transports	3	2019
10. Netherlands	All	Glimble / Arriva-Moovit	2	2021
11. Portugal	Lisbon	Moovit / Wondo	2	2019
	Porto		2	
12. Spain	Barcelona	Moovit / Wondo	2	2019
	Bilbao	Moovit / Wondo	2	2019
	Madrid	MaaS Madrid & Moovit / Wondo	2	2018 & 2019
	Sevilla	Moovit / Wondo	2	2019
	Valencia	Moovit / Wondo	2	2019
13. Sweden	Gothenburg	Ubigo	4	2014
	Stockholm		4	2019
14. Switzerland	Basel	Yumuv / Axon Vibe by Swiss CFF	3	2021 / 2019
	Bern		3	
	Geneva	ZenGo	3–4	2019
	Lausanne		3–4	2019
	Zurich	Yumuv / Axon Vibe by Swiss CFF	3	2021 / 2019
15. United Kingdom	Birmingham / West Midland	Whim	4	2018
	London	Citymapper	1	2019

Adopted and modified from Essaidi et al. (2020)

Toward the end of 2021, the European Union (EU) initiated an outreach effort to understand how citizens and stakeholders interact with multimodal digital mobility services (MDMS) such as MaaS, route-planners, and travel comparison and pricing.[2] Through the online survey, the EU sought to obtain feedback on the delegated regulation (EU 2017/1926) on EU-wide multimodal travel information services that establishes necessary specifications to ensure the accuracy of multimodal travel information services within and across the borders. Specific potential policy concerns upon which feedback was sought include:

- Insufficient availability and accessibility of data.
- Sub-optimal cooperation between transport operators and mobility services.

[2] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13133-Multimodal-Digital-Mobility-Services/public-consultation_en

- Limited availability of digital tickets.
- Lack of guidelines for trip sustainability (carbon footprint, emissions) metrics.
- Inadequate payment system interoperability.
- Different licensing and distribution agreements.

The survey received feedback from 336 respondents, mostly EU citizens, business organizations, and public authorities. The findings were divided into general (traveler experience with the use of digital services) and detailed (MDMS challenges) sections (European Commission, 2022). The general findings reveal difficulty in booking multimodal journeys online mostly due to the lack of a centralized system, thus requiring visits to multiple booking sites. Further, respondents indicated that measures involving carbon footprint and emissions are crucial for the sustainability of the trip and the overall transport system (European Commission, 2022).

The responses to the detailed section indicated that the main challenges concerning data sharing and accessibility were the low quality of data and lack of access to real-time information. Participants were also asked what measures would ensure fair access to all operators to MDMS and the responses highlighted the importance of ensuring non-discriminatory treatment of parties across commercial/cooperative agreements (European Commission, 2022). Overall, the survey indicated that the respondents concurred (72%) with the suggestion to use legal or legislative actions to achieve the MDMS initiative.

Summary of Key USDOT Reports

This section summarizes the existing developments and concerns associated with MOD or MaaS, broken down by the documents suggested by the project stakeholders. The more specific findings by each document are presented in Appendix A. Five reports/documents were prioritized (Bouattoura et al., 2020; Chang et al., 2019; GAO, 2018; Schweiger et al., 2019; Shaheen et al., 2020), covering multimodal and accessible travel and guidelines associated with the integration of infrastructure, data sharing, payment systems, automation, and user interfaces/applications, and they include:

- USDOT – Multimodal and Accessible Travel Standardization Assessment (MATSA) – Survey of Standards and Emerging Standards White Paper
- USDOT – Mobility on Demand Planning and Implementation: Current Practices, Innovations, and Emerging Mobility Futures
- USDOT – Forward-Looking Assessment White Paper: Multimodal and Accessible Travel Standards Assessment-Task 2

- United States Government Accountability Office (GAO) – Public Transit Partnerships: Additional Information Needed to Clarify Data Reporting and Share Best Practices
- USDOT – Mobility on Demand Marketplace Concept of Operations Blueprint

These reports identify several existing standards that can or have been previously applied to standardize elements of multimodal and accessible travel (updated status of standards from the MATSA effort is available in Appendix B). The reports emphasize the need for interoperability among systems and the adoption of new technologies to facilitate seamless travel experiences. They also highlight the importance of supporting and evolving existing standards to ensure wider acceptance.

The reports identify various challenges related to the implementation of multimodal and accessible travel. In summary, these include the lack of standardized performance metrics, limited data sharing and integration across travel modes, and the need for clear guidelines on public-private data sharing and security. They also identify issues such as the availability of data for evaluating the impact of multimodal travel on traffic, the lack of policies addressing disruptions to conventional traffic caused by new services, and the need for integrated trip planning and payment systems.

Furthermore, the reports discuss the roles of both public and private stakeholders in enhancing the potential benefits of multimodal travel. They emphasize the importance of public-private partnerships in areas such as data sharing, first-mile/last-mile connections, off-peak service, and right-of-way access. They also present the positive impacts of community-wide integration of shared mobility modes, including environmental benefits and sustainable business opportunities.

In addition, the reports identify specific findings and common themes across the reviewed literature. These include the importance of considering the needs and capabilities of all traveler populations, the significance of reliable infrastructure and system performance information, and the challenges faced in providing accessible services for cognitively challenged individuals. The reports also emphasize the need for improved data collection, standardization, and analytics to fully utilize the potential of the generated data.

Overall, the reports offer comprehensive insights into the implementation challenges, current practices, lessons learned from demonstrations, and future directions in the field of multimodal and accessible travel standards. They underscore the need for collaboration among stakeholders, the importance of evolving standards and technologies, and the potential benefits of integrating various modes of transportation.

Case Studies Demonstrating Data Sharing and Interoperability within MOD/MaaS

This section summarizes key local and global case studies that have demonstrated mobility innovation with respect to data sharing and interoperability. Appendix C further delves into the individual case studies to highlight findings and lessons learned based on the intended project goals. By examining these real-world examples, we gain valuable insights into the possibilities and challenges associated with implementing and integrating MOD/MaaS.

United States

Twelve case studies were reviewed within the United States and they include 11 demonstrations of the MOD Sandbox Program and the Smart City Challenge – Smart Columbus, Ohio.

The MOD Sandbox Program was founded to focus on mobility innovation and advancing the vision of MOD (Martin, Cohen, & Shaheen, 2023). The main goal of the program is to improve transportation efficiency by promoting agile, responsive, accessible, and seamless multimodal service inclusive of transit through enabling technologies and innovative partnerships. In 2016, FTA selected 11 demonstration projects aligned with the program's vision to receive the allocated $8 million. These projects were chosen based on their potential to drive innovation in mobility. Each project focused on a specific aspect of transportation and mobility, ranging from incorporating bikeshare to developing smartphone mobility platforms and integrated carpooling services. The selected recipients included the Chicago Transit Authority (CTA), Valley Metro Rail, Inc. (City of Phoenix, AZ), Regional Transportation Authority of Pima County (Tucson, AZ), Pierce Country Public Transportation Benefit Area Corporation, LA Metro, Puget Sound region, San Francisco Bay Area (two projects, the Bay Area Rapid Transit District integrated carpool to transit and Bay Area fair value commuting), Pinellas Suncoast Transit Authority (PSTA), Vermont Agency of Transportation, Dallas Area Rapid Transit (DART), and TriMet.

The demonstrations yielded several notable findings. First, there was an improvement in first-mile/last-mile connectivity across various deployment locations. For example, Dallas deployed a microtransit system, San Francisco introduced a carpooling app, and Portland optimized the region's trip planner, all leading to enhanced connectivity. Second, access to travel information for passengers with disabilities improved. PSTA implemented an integrated planning, booking, and payment service for paratransit, making it easier for individuals with disabilities to navigate the transportation system. Third, the demonstrations resulted in a decrease in the use of personal automobiles. Carpooling activity improved across the deployments, and a survey in Silicon Valley found that the introduction of an integrated trip planning and travel

incentives platform led to a reduction in vehicle miles traveled by up to 40%. Other findings included improved multimodal trip options and information, decreased emissions and fuel consumption, and higher cost-effectiveness of microtransit compared to low-ridership fixed route transit.

The key lessons learned across the MOD Sandbox demonstrations and project partners can be summarized from Martin et al. (2023) as follows. First, forming and managing public-private partnerships can be challenging but rewarding if challenges such as setting terms, changes to partner business models, and technology developments are overcome. Second, data sharing agreements and requests need to be carefully tailored well in advance to prevent disagreements and ensure smooth collaboration. Many demonstrations attributed the success and ongoing technological developments to integrated data sharing and performance feeds such as multimodal trip chaining information to enhance user experience. Third, there is a need to balance private-sector profitability with the goals of equity and accessibility within the public sector. Finally, outreach at the initial stages to highlight the purpose and services offered by the demonstrations is crucial to build customer awareness and encourage participation.

Similar to the MOD Sandbox Program, the Smart City Challenge was established by USDOT in 2015 to develop ideas for an integrated and smart transportation system to help people and goods move more quickly, cheaply, and efficiently. Smart Columbus (winner of the Smart City Challenge) implemented multiple solutions aimed at transforming mobility in the city. One of the key projects was the development of a multiparty public-private MOD application targeted at underserved groups. The initiative consisted of eight individual projects, including the Smart Columbus Operating System (SCOS), a connected vehicle environment, a multimodal trip planning application, mobility assistance for people with cognitive disabilities, prenatal trip assistance, smart mobility hubs, event parking management, and the deployment of connected electric autonomous vehicles (James et al., 2018). Performance measures were evaluated in terms of safety, mobility, opportunity, environment, agency efficiency, and customer satisfaction. Efforts were made to exclude personally identifiable information (PII), payment card industry (PCI) data, or protected health information (PHI) from the SCOS to ensure privacy and security. However, challenges were encountered in implementing an integrated payment system due to the restrictions associated with PII. The lack of existing standards covering the implementation of emerging technologies with respect to data and privacy was identified as a significant gap.

The lessons learned from the Smart Columbus projects include the need for guidelines on incorporating PII information safely and securely to enable the implementation of an integrated payment system. These guidelines should cover aspects such as consent, safety protocols, encryption, and the ethical and legal implications of handling sensitive data. Public-private partnerships were

identified as crucial for successful deployments, and application programming interfaces (APIs) were emphasized as key to integrating different mobility services. Real-time big data access and usage metrics by both public and private entities were recognized as valuable for validation and improvement of the system. It was also suggested that city agencies should strive to have control over as much trip data as possible to ensure better management and planning.

To summarize, the reviewed case studies in the United States demonstrate that data integration and interoperability are pivotal in advancing seamless mobility services. By leveraging innovative technologies, fostering collaboration, and prioritizing accessibility, these initiatives enhance the customer experience and pave the way for more sustainable and efficient transportation systems.

Other Global Efforts

Thirteen global case studies were also reviewed to further assess similarities in integration efforts within MOD and MaaS implementations and lessons learned from the process. This subsection presents the main discoveries drawn from the review, while Appendix C offers a comprehensive breakdown of each case study with detailed insights. The case studies reviewed include:

- Bristol One City, United Kingdom
- iMOVE Sydney MaaS Trial, Sydney, Australia
- MaaS Jakarta, Jakarta, Indonesia
- MaaS Bogota, Bogota, Colombia
- Trafi Vilnius, Vilnius, Lithuania
- MaaS in Netherlands: seven pilots (i.e., Rotterdam, Amsterdam, Eindhoven, Limburg, Groningen-Drenthe, Twente, Utrecht-Leidsche Rijn)
- eHubs - Smart shared green mobility hubs

First, data sharing, as demonstrated in Bristol One City and other initiatives, plays a crucial role in MaaS projects, allowing for the development of innovative technologies and user-friendly interfaces. Open access to real-time and historical data enables collaborative efforts, such as the development of eco-friendly route choices and improved user experiences. Co-designing transport schemes with community organizations and engaging local governance, as seen in the Dutch MaaS pilots, are important to address social inequalities and ensure the benefits of MaaS reach all segments of society (Ministry of Infrastructure and Water Management, 2019).

Second, payment integration, as highlighted in the iMOVE Sydney MaaS Trial, is a complex yet vital aspect of MaaS. The lack of standardized APIs, as experienced in the Sydney trial, poses challenges, emphasizing the need for deep linking and seamless booking integration within MaaS apps. Pay-as-you-go subscription bundles, as observed in various case studies including the Dutch MaaS pilots, have

proven popular among users, offering flexibility and convenience. Establishing data sharing agreements with service providers, also demonstrated in the Sydney trial, is crucial for MaaS projects to ensure a wide range of transportation options can be seamlessly integrated into a single platform (Hensher et al., 2021).

Lastly, successful MaaS implementation requires collaborative partnerships and user-centered design, as showcased in MaaS Bogota and other case studies. Maas Bogota also demonstrated that engaging stakeholders through co-creation and involving them in the development process leads to user-friendly MaaS apps that cater to diverse needs. Standardized interfaces and interoperability, as highlighted in various initiatives including Trafi Vilnius, are critical for seamless integration and scalability of MaaS platforms. The Dutch MaaS pilots and eHubs both emphasized that inclusivity and equity are important, ensuring that MaaS services consider the needs of commuters, the elderly, chronically ill, and disabled individuals. Public-private partnerships, as exemplified in MaaS Jakarta, play a significant role in driving MaaS projects and promoting sustainable, shared, and green mobility options.

Overall, the findings reveal similar elements to those observed from the MOD case studies in the United States. The top factors that contribute to the development of innovative and sustainable mobility solutions are data sharing, payment integration, collaborative partnerships, user-centered design, standardized interfaces, and inclusivity.

Existing and Upcoming Standards/Guidelines

Table 2-3 highlights existing and upcoming guiding documents to facilitate the integration and interoperability of two or more components (i.e., trip discovery, payment, and operations) within the MOD/MaaS ecosystem. A more comprehensive version of this table is in Appendix D.

Table 2-3. *Summary of Integration Standards, Guidelines, and Organic Efforts*

Name/Status	Description
General Bikeshare Feed Specification (GBFS) ***Existing***	GBFS serves as an open-source specification for sharing mobility (i.e., bike) information among operators and users, allowing access to data such as station locations, vehicle availability, and geofencing rules through an application programming interface (API). However, GBFS currently lacks clear definitions for minimum required data elements and does not include information on payment/fare integration.
Mobility Data Specification (MDS) ***Existing***	MDS, developed by the Los Angeles Department of Transportation and now managed by the Open Mobility Foundation, is an open-source initiative that offers a suite of APIs for real-time information exchange on shared mobility services between cities and providers (OMF, 2020). Unlike GBFS or GTFS, MDS is designed for non-public confidential data accessibility by cities and agencies. MDS operates through six authenticated JSON APIs: provider, agency, policy, geography, authority, and metrics. With more than 130 cities and agencies currently using MDS worldwide, version 2 was released on May 10, 2023, focusing on interoperability across modes, fee schedules, and updated user agreements.

Name/Status	Description
Transport Operator Mobility-as-a-Service Provider (TOMP) ***Existing***	The TOMP-API initiative, launched in 2018 by the Dutch Ministry of Infrastructure and Water Management, aims to create a standardized technical language through an API for communication between transport operators and MaaS providers (Garcia et al., 2020). It was established alongside seven regional MaaS pilot initiatives with the goal of harmonizing efforts and standardizing processes. The TOMP-API consists of eight functional modules, including operator information, privacy and registration, planning, booking, trip execution, payment, support, and asset information. Key highlights of the initiative include significant progress in real-world API implementation, the development of a comprehensive payment framework, interoperability across multiple MaaS providers, and support for blockchain integration.
Transmodel (EN12896: Public Transport Reference Data Model) ***Existing***	Transmodel is the European Reference Data Model for public transportation covering public transportation information and service management, particularly interoperability between the information processing systems of operators and agencies in Europe. Data models derived from Transmodel help build interoperable systems. A few European data exchange standards derived from TransModel include NeTEx, SIRI, OpRa, and OJP.
MaaS Alliance: Interoperability for Mobility, Data Models, and API ***Existing***	The MaaS Alliance consists of two working groups focused on examining existing API and data models in order to define a standardized approach for information exchange in MaaS (MaaS-Alliance, 2021). This document targets transport operators and mobility data system architects, aiming to create an all-purpose API for MaaS and establish collective definitions for mobility objects, traveler journeys, and data exchange.
City Data Standard for Mobility (CDS-M) ***Upcoming (testing)***	CDS-M facilitates open communication and standardization of business-to-government (B2G) data exchange for private-public sector partnerships. It was initiated by representatives from five Dutch cities and the TOMP-API Working Group. It consists of two main components: the Standard for communication related to policy, planning, and enforcement, and the Agreement for the collection, storage, usage, security, and removal of shared data. While the Standard part is covered by the MDS, there are limitations such as its heavy focus on micro-mobility and its U.S.-centric nature, lacking coverage of EU legislation and regulation.
General On-Demand Feed Specification (GOFS) ***Upcoming***	GOFS targets on-demand services and comprises four key features: service discoverability, service description, real-time service description, and booking (MobilityData, 2021). The goal is to build on existing GTFS extensions such as Flex v2, Fare Data, Vehicle Categories, Rider Categories, and protocols from GTFS-Capabilities and GTFS-Eligibilities.
Transactional Data Specification (TDS) ***Upcoming (testing)***	TDS is a standardized data exchange framework for demand-responsive transportation (DRT) that enables seamless interaction among software systems throughout the trip life cycle (Transportation Research Board, 2020). It promotes data access equality and integration of human services transportation with MaaS. TDS adopts an open API approach, ensuring interoperability and allowing multiple entities to participate. It aims to achieve a similar level of integration as seen in the airline industry, where passengers can easily book travel across multiple airlines. The core elements of TDS include trip reservation, scheduling, cancellation, execution, and reporting.

The Future of Interoperability within MaaS/MOD

There are considerable efforts in using blockchain technology to facilitate scaling and interoperability within the mobility sector. Blockchain is being implemented/tested to securely authenticate credentials (i.e., personal information) to allow MaaS "roaming" services (just like telecom providers) across countries or states without requiring local registration in multiple applications (Bloxmove, Orange

Business Services, & Ciklum, 2021; Dutch Blockchain Coalition, 2021; Nguyen, Partala, & Pirttikangas, 2019; Paiva et al., 2021).

Blockchain works by providing a distributed ledger that facilitates the execution of smart contracts and financial transactions between participating parties (Shaheen, Totte, & Stocker, 2018). The technology prevents direct control of a database by a single entity to avoid inadvertent or malicious altering or deleting transaction records. The use of blockchain can strengthen the management of digital rights, improve the chain of custody by preventing unauthorized changes to the data, and allow users to have control of, and even monetize, their own data (Bloxmove et al., 2021; MOBI, 2021).

Nonprofit MaaS working groups, such as TOMP-API, have acknowledged the importance of blockchain to mobility and are actively implementing blockchain verifiable credentials such as decentralized identifiers (DIDs) to their data sharing framework (Bloxmove et al., 2021; Garcia et al., 2020; MOBI, 2021).

Original equipment manufacturers (OEMs), non-governmental organizations (NGOs), transit agencies, and toll road providers are converging into the Mobility Open Blockchain Initiative (MOBI), which is an emerging organization focused on using blockchain, artificial intelligence, connectivity, and internet of things to make mobility safer, greener, and more accessible. The MOBI community facilitates the development of blockchain-based standards, data exchange/monetization platforms, and decentralized smart mobility applications. MOBI also operates in the autonomous and connected mobility space, consisting of OEM partners and industry leaders (i.e., Renault, Ford, BMW, Cognizant, DENSO, Volkswagen, AWS, Hitachi America, and others) and seeks to apply the DIDs to form the basis for a "trusted trip" (defined as a trip in-progress/completed by validating DID credentials of a non-locally registered/roaming entity) (MOBI, 2021).

Similar to MOBI, the idea of a Mobility Blockchain Platform (MBP) was jointly put forward by Bloxmove (decentralized and blockchain-based urban mobility solution provider), Orange Business Services (telecom company focusing on global communication integration), and Ciklum (software development company). The MBP focuses on providing real-world applications, such as mobility, asset financing and leasing, insurance, identity services, payment, and notary/verification services. The MBP conceptualizes tokenization as a financial system that uses utility tokens (defined as smart contracts used to connect, record, and provide transparent transaction histories) to pay for network functionality and generate revenue streams for assets (digitally listed tradable mobility services) without intrinsic risks and inefficiencies.

The TOMP-API developers recently partnered with Bloxmove to evaluate the integration of blockchain technology in a real-world setting. The role of Bloxmove is to function as a decentralized credential verifier facilitating smart

contracts to book assets from service providers, while maintaining an open-source architecture. Figure 2-4 shows over 50 in-progress and implemented mobility services that use the TOMP-API standards, currently fully integrated with Bloxmove. To this end, Bloxmove has created an open-source component to facilitate seamless integration with any mobility service that uses TOMP-specific endpoints (Bloxmove, 2022).

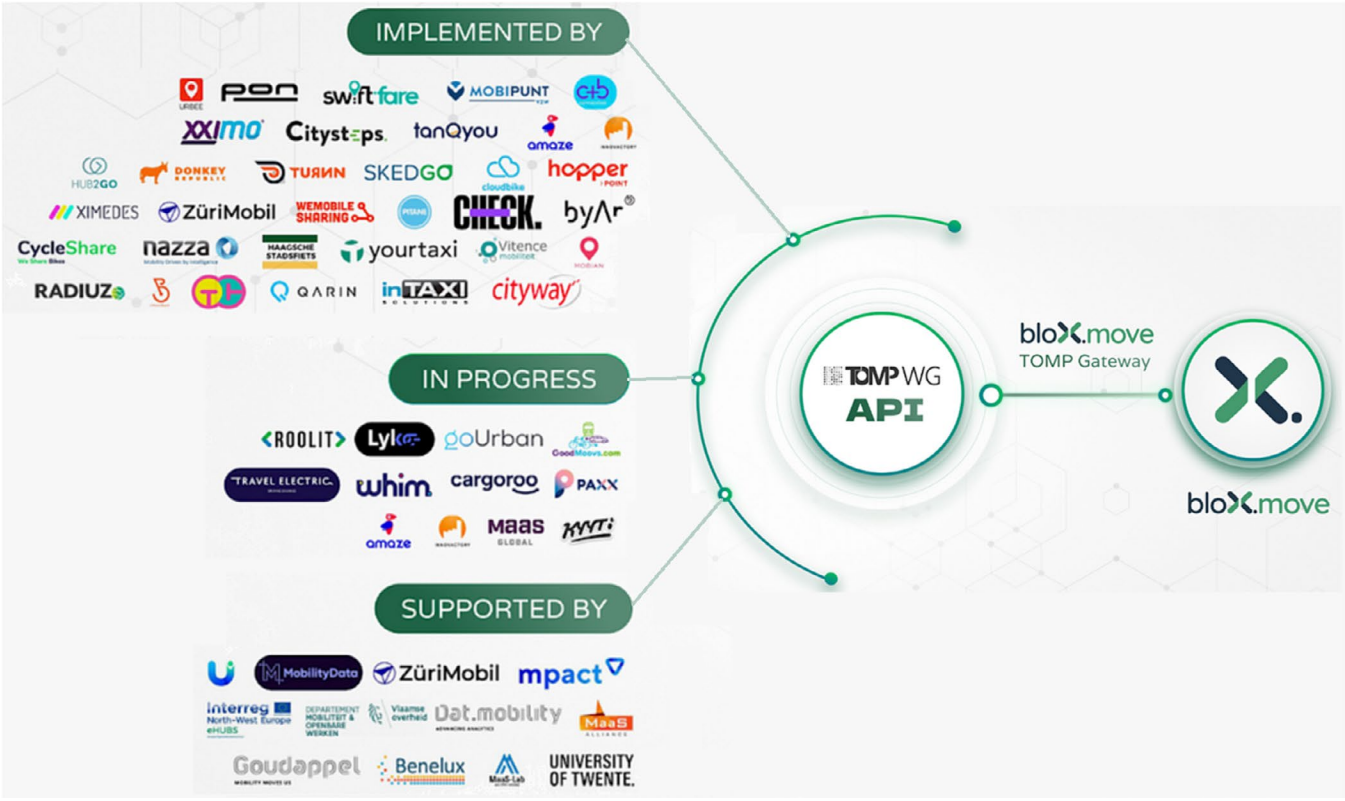


Figure 2-4. *Blockchain integration with TOMP-API (Bloxmove, 2022)*

Although these mobility-blockchain partnerships show significant promise, unforeseen issues from integrating blockchain technologies remain a concern, especially with respect to being relatively new and due to existing vulnerabilities within smart contracts (Nguyen et al., 2019).

In summary, blockchain technology has the potential to play a significant role in the MOD ecosystem, particularly in terms of:

- **Payment and Fare Collection.** Blockchain-based systems can be used to manage payment systems securely and transparently for MOD services, addressing existing concerns of interoperability, privacy, and user experience.

- **Decentralized Autonomous Organizations (DAOs).** Blockchain can be used to create DAOs to manage MOD services without the need for a centralized intermediary. This improves the overall cost efficiency and transparency for both users and service providers, promoting innovation within the sector.
- **Data, Identity, and Supply Chain Management.** Blockchain can be used to securely store and manage data related to MOD services, such as verified users, trip records, vehicle/equipment tracking, and billing information. The technology reduces the likelihood of data breaches and simplifies the process for transit agencies and service providers to access and analyze open data.

Section 3

Stakeholder Survey

In addition to the extensive literature search, the research team developed a survey instrument (Appendix E and F) to engage transit operators, industry experts, and CUTR's FTA Transit Safety Standards Working Group stakeholders, including: New York City Transit (NYCT), Southeastern Pennsylvania Transportation Authority (SEPTA), MBTA, Metropolitan Atlanta Rapid Transit Authority (MARTA), Capital Metro, LA Metro, TriMet, Bay Area Rapid Transit (BART), Washington Metropolitan Area Transit Authority (WMATA), Pittsburgh Regional Transit, APTA, Community Transportation Association of America (CTAA), National Rural Transit Assistance Program (RTAP), Amalgamated Transit Union (ATU), and Washington Metrorail Safety Commission. The goal of the survey was to identify additional relevant MOD/MaaS projects, deployments, data sharing protocols, lessons learned, and possible solutions to advance MOD/MaaS. Specifically, the survey gathered community-wide opinions/views on the following:

- Is there a need for a standard to share data within the MaaS or MOD ecosystems?
- Are current sharing protocols/practices sufficient?
- What can be added to our shared-mobility findings?
- Are there existing case studies that have addressed the gaps we have not identified?

The survey was targeted toward engaging the following groups:

- Key Organizations/Individuals
  - FTA
  - Public transportation agencies and organizations deploying MOD/MaaS
  - American Association of State Highway and Transportation Officials (AASHTO)
  - North American Bikeshare & Scootershare Association (NABSA)
  - Transportation Research Board (TRB) select committees
  - Intelligent Transportation Society of America
  - Shared-Use Mobility Center (SUMC)
  - USDOT ITSJPO
  - Academic faculty/staff
- National SDOs
  - APTA
  - Institute of Transportation Engineers (ITE)

- MOD/MaaS Community
  - MaaS Alliance
  - Open Mobility Foundation
  - SharedStreets
  - Mobilitydata.org
  - TOMP working group

Results

The survey collected 101 responses, 98 from the United States and 3 from other parts of the world. The survey was split into three categories based on the mobility background of the participant: (a) Transit Operator/Provider, (b) Private Operator/Digital Mobility Service Provider/Technology Supplier, and (c) Industry Expert/Mobility-Centric Organization/Researcher/Academic/Mobility Data Consumer. About 62% of the respondents belonged to category (a), 35% to category (c), and the remaining 3% to category (b).

Figure 3-1 shows the percentage of responses to the survey question "What do you feel is the current level of standardized mobility data access and sharing protocols?" The question received 69 responses. About 42% of the respondents noted that the industry is barely standardized, corroborating what was found in the literature review. Furthermore, 67% of the respondents expressed their support for open-source and industry-driven standards rather than international standards, as there is no "one size" that fits all.

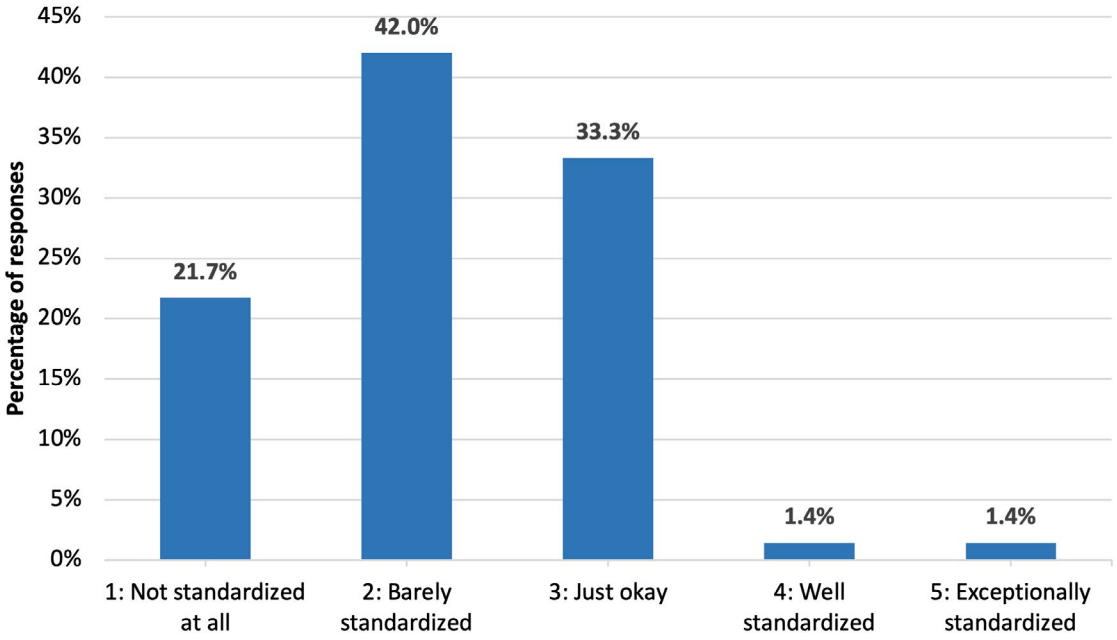


Figure 3-1. *Percentage of responses expressing the current state of standardized mobility data sharing and accessibility*

The survey also solicited opinions on suggested actions for FTA to support interoperability and development of open-source standards. Figure 3-2 shows the results sorted into five categories (raw responses are available in Appendix G). The largest share of respondents (42%) suggested that FTA fund open-source solutions or set open-data requirements for access to funding.

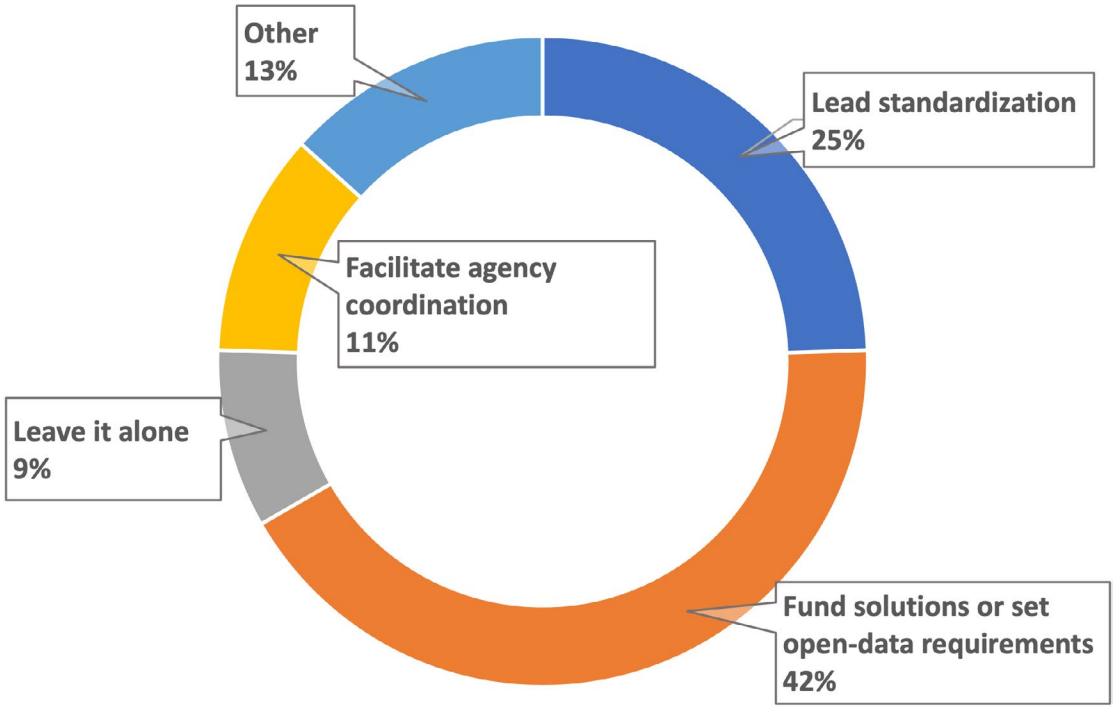


Figure 3-2. *Share of responses showing suggested actions for FTA to support open-source standardization and interoperability within MOD*

Another key outcome from the survey was the mobility community's familiarity with emerging technologies such as blockchain and their impact on interoperability within MOD/MaaS. About 85% of the respondents (44 out of the 52 total) expressed their lack of familiarity with blockchain technology and its use within the mobility sector. The remaining 15% elaborated in more detail their view about blockchain as a promising technology potentially capable of providing more benefits to both customers and operators. These respondents also indicated that blockchain technology is still in its initial stages and expressed concerns related to security not having been fully addressed.

Section 4

Summary of Findings

Figure 4-1 summarizes findings and identifies gaps in terms of three aspects of the MOD ecosystem: trip discovery, payment, and operations.

Trip Discovery	Payment	Operations
• Incorporating on-demand services into GTFS is required. GOFS being the potential solution. • Need more outreach/awareness toward existing and in-progress solutions, not limited to GTFS, GBFS, and MDS. • Learning from global outreach. Global efforts in MaaS, especially open-source projects, can provide insights into how to successfully tackle data sharing and interoperability. • Lack of standardized performance metrics to consistently evaluate MOD-based datasets. • Unavailability of data and complex traffic modeling analytics to agencies to evaluate impact of MOD on traffic. • Lacking clearly defined minimum data elements without excessive optional fillers. • Lack of guidelines for inclusion of trip sustainability (carbon footprint, emissions) in travel choice.	• Difficulty integrating trip-planning and payment (i.e., deep integration) due to data sharing restrictions and infrastructure to disseminate real-time information. • Difficulty establishing agreements between involved parties (user, operator, provider) to facilitate payment, acceptance, and distribution. • Lack of standardized guidelines for incorporating PII safely and securely in data to facilitate better usability. This should cover aspects of consent, safety protocols, encryption, and ethical and legal implications. Also, these guidelines should address general public concerns associated with privacy.	• Lack of policies tackling newly identified disruptions to conventional traffic (right-of-way access) from the increase in MOD services. • Government agencies are key to ensuring MOD/MaaS scalability, especially with respect to legal contracts for development of data sharing and non-discriminatory practices among operators/service providers. • Lack of a standard/uniform approach for the integration of existing and new back-end operations systems in transit. • Lack of follow-up/survey protocols to ensure consumer satisfaction (trip completeness/chaining) and shared knowledge of the impact of MaaS. • Limited information on the impact of equity on MOD. Need to expand traditional definitions and performance metrics associated with equity.

Figure 4-1. *Summary of gaps identified within the three specified components of the MOD ecosystem*

Although there is significant organic effort underway in developing guidelines for MOD/MaaS adoption, emphasis must be placed on reaching a consensus for standardizing taxonomy and data sharing models and protocols to ensure interoperability and global application. To further address the issue for integrated mobility, the ISO technical committee 204:TR 4447 released a summary of efforts, which are focused on merging the concepts of the European MaaS and the North American MOD (ITS, 2020; Karl, Irannezhad, & Cheong, 2020).

There is a need to distinguish between deep link and deep integration APIs. While integration via deep links displays the vehicles of the mobility service

operators in the centralized application, to book a trip, the user is redirected to the respective application of the operator to pay for the service. Deep integration, however, allows users to book and pay for their journey entirely on the mobility application without needing individual operator applications. This is the most advanced level of integration. Without deep integration, MOD would be a simple aggregator rather than a multimodal one-stop shop for mobility. Centralized mobility solutions also tend to discourage competition and increase costs on all fronts, usually transferred to the end user.

Although achieving standardization might be key, promoting and supporting the implementation of a consensus-based standard/specification might not pose the greatest challenge. Often ignored are the challenges and costs associated with the iterative nature of standards, especially with respect to fast-paced technological evolution and updates. The fast and widespread uptake of GTFS as an industry-standard points directly to the need for open standards as they provide more flexibility, inclusivity, transparency, and adaptability, especially crucial for fostering public-private partnerships.

Overall, existing entities and working groups like the MaaS Alliance, MobilityData, TOMP, Open Mobility Foundation, and Transit Operational Data Standard (ODS) are well positioned within the community and stakeholders to tackle the gaps associated with data sharing and standardization of MOD/MaaS. Table 4-1 shows a summary of the standards, specifications, and guidelines paving the course to interoperability within specific modes of MOD. Table 4-1 also presents a column (Integrated T+P+O) that consists of current efforts/guidelines that, when combined, have demonstrated the seamless integration of trip discovery, payment, and operations.

Table 4-1. *Summary of Existing and Upcoming Standards, Specifications, and Guidelines Shaping the Interoperability of Trip Discovery, Payment, and Operations*

Mode	Trip Discovery (T)	Payment (P)	Operations (O)	Integrated T+P+O
Walk	ISO 20524-1:2020	None	Public Right-of-Way Accessibility Guidelines (PROWAG) Open Mobility-Curb Data Specification	MDS/CDS-M
Bike and Micromobility	GBFS, GBFS +	Vendor specific	GBFS; Mobility Data Specification (MDS)	TOMP + MDS/CDS-M
Rail	ISO/TS 4398:2022	ISO 24014-1:2021/GTFS-Fares v2	GTFS-Realtime; APTA Rail Transit Systems Standards	TOMP + MDS/CDS-M
Fixed Route Bus	GTFS; GTFS-Realtime	ISO 24014-1:2021/GTFS-Fares v2	GTFS-Realtime; MDS; ODS; APTA Transit Communications Interface Profiles (TCIP)	TOMP + MDS/CDS-M

Mode	Trip Discovery (T)	Payment (P)	Operations (O)	Integrated T+P+O
Flex Route bus	GTFS-Flex (V2)	ISO 24014-1:2021/ GTFS-Fares v2	GTFS-Realtime; MDS; TDS	TOMP/TDS + MDS/CDS-M
Microtransit / On-demand Transit (e.g., informal vans)	GOFS/GTFS-Flex (V2)	ISO 24014-1:2021/ GTFS-Fares v2	GOFS/GTFS-Flex (V2); MDS; TDS	TOMP/TDS + MDS/CDS-M
Paratransit (ADA)	GTFS-Pathways / Pathway Updates	ISO 24014-1:2021/ GTFS-Fares v2	GTFS-Realtime; TDS; National RTAP –General Requirements for All Service Types	TOMP/TDS + MDS/CDS-M
TNC/Taxi/Sharing	GOFS	Vendor specific	GOFS; MDS	TOMP + MDS/ CDS-M

The research team also found that while there have been successful demonstrations of the integration of front-end systems (i.e., user interface such as a mobile application or website to request, book, and pay for a ride or access transportation services), standardization of back-end systems (i.e., infrastructure and technology that enable operations such as the database, server, physical equipment, and software systems that manage transit operations and logistics) remains a challenge especially among smaller/rural transit agencies. The seamless operation of both front- and back-end systems remains generally unexamined/undemonstrated in the public transit realm. An ideal seamless and scalable system should at a minimum facilitate the integration of a transit agency/operator, back-end systems provider, back-end operations integrator, mobility/on-demand operator, interoperability specification, and MOD/MaaS application or kiosk provider, using open-source practices.

Section 5

Mobility Standards and Guidelines Resource (MSGR) Tool

Another product of this research is the Mobility Standards and Guidelines Resource (MSGR) Tool. The online tool ingests the literature and survey responses from this research initiative and interactively informs stakeholders on the available mode-specific standards, open-source specifications, and case studies associated with the integration of various components of the MOD/MaaS ecosystem.[3] Industry-leading interoperability specifications are also highlighted on the homepage to broaden the outreach efforts. Figure 5-1 shows a breakdown of the tool's framework.

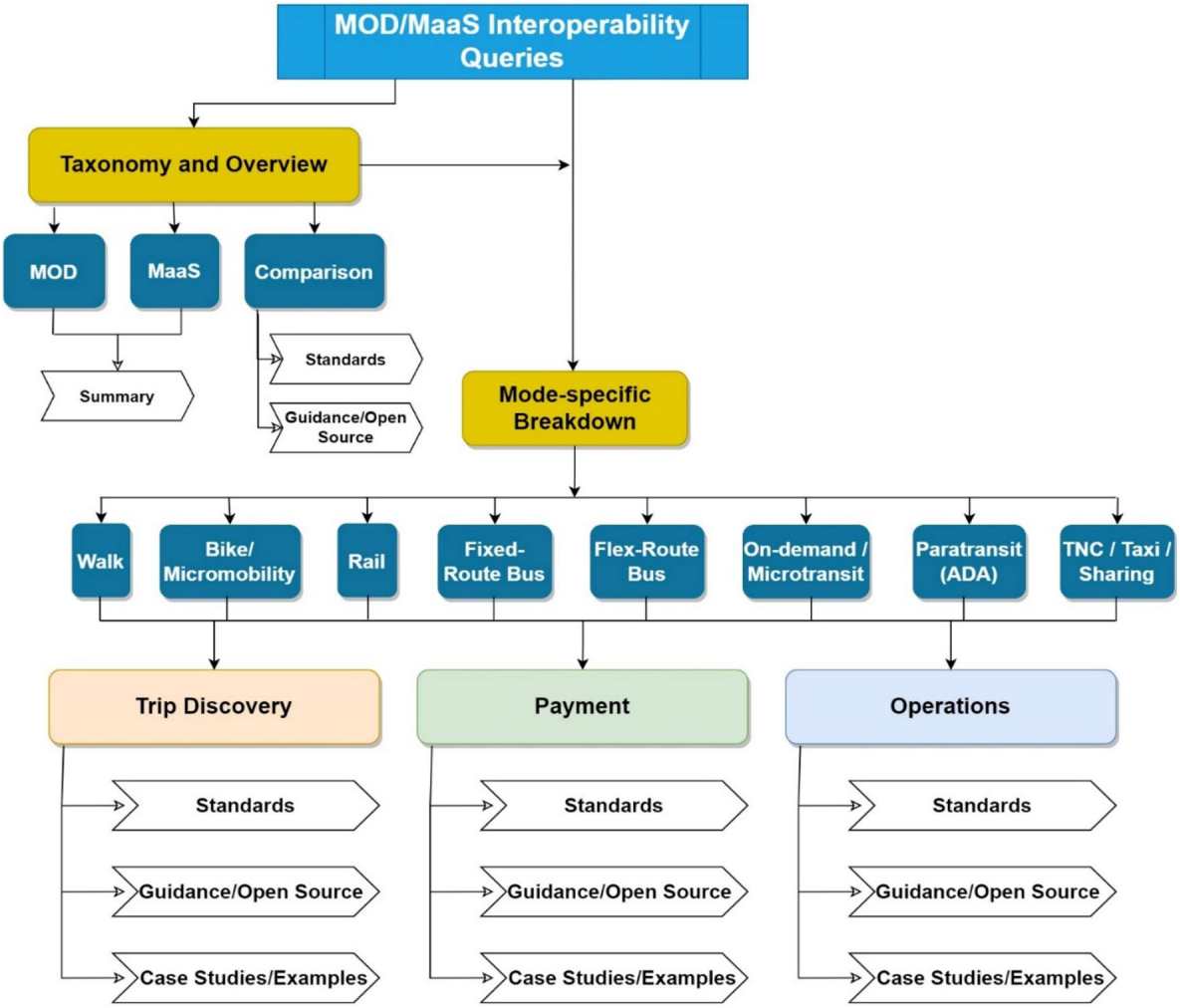


Figure 5-1. *Framework of the MSGR Tool*

[3] www.maasresources.com

The tool allows walking through the MOD or MaaS taxonomy and identifying relevant guidance and documentation by mode. Within the taxonomy and overview, a synopsis of MOD, MaaS, and their comparison are provided along with weblinks to additional material. The mode-specific breakdown lists standards, guidance, and case studies by trip discovery, payment, and operations. The blueprints for the content of each tab within the tool are available in Appendix H. Figure 5-2 shows the interface of the mode-specific component (i.e., Bike/Micromobility tab) within the tool. Figure 5-3 displays the Multi-Modal Overview section, which consolidates all the resources identified in this project. This is particularly useful for individuals acquainted with MOD/MaaS, or those seeking resources encompassing multiple modes of transportation, as it provides a convenient way to organize and explore the content. The tool also facilitates collaborative input by allowing users to submit new or missing content as shown in Figure 5-4, which is then manually verified and updated accordingly.

Figure 5-2. *MSGR Tool interface showing the Mode-Specific Breakdown tab*

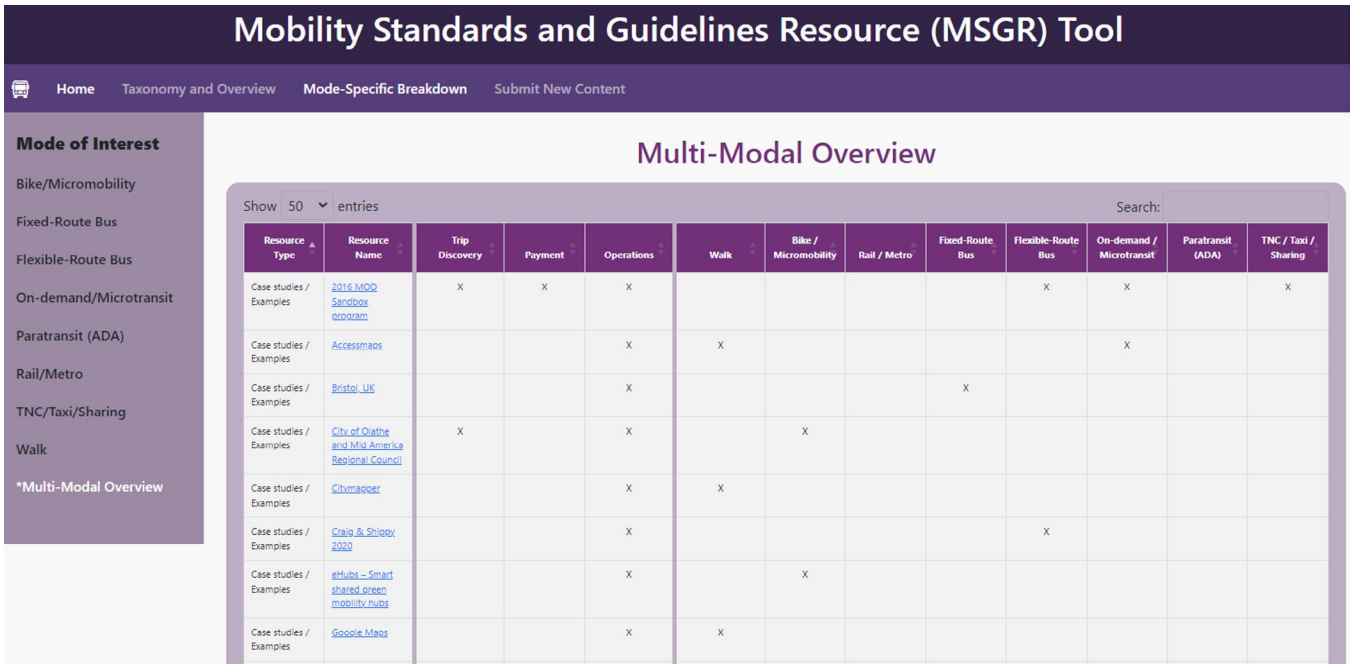


Figure 5-3. *MSGR Tool interface showing the Multi-Modal Overview section*

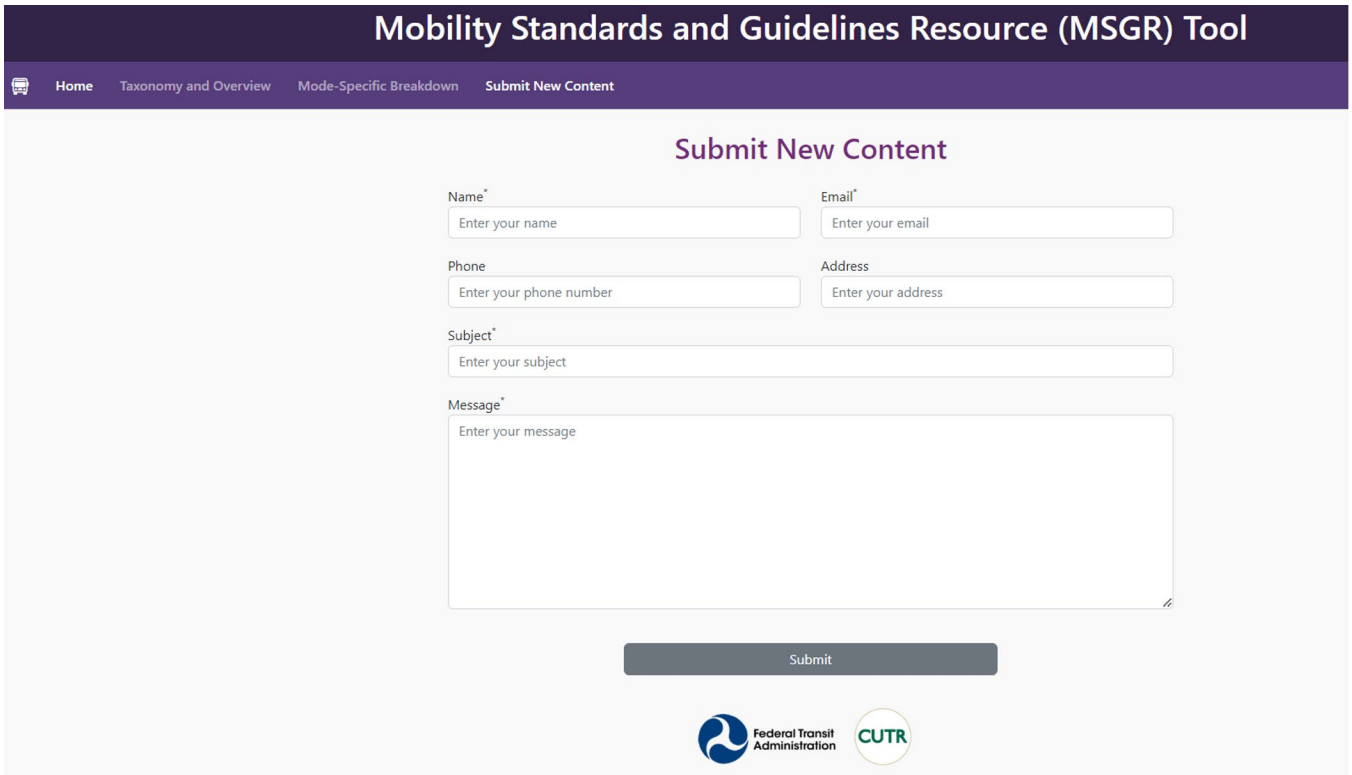


Figure 5-4. *MSGR Tool interface showing the Submit New Content tab*

Section 6

Conclusions

This research was undertaken to build upon ongoing USDOT efforts by focusing on data exchange and interoperability between modes, platform vendors, and operators as part of the MOD ecosystem. The primary objective of this project was to identify the best practices and current mobility data developments that may lead to industry-driven data standards and specifications that advance the MOD vision. An in-depth review of the literature and use case studies, complemented by a stakeholder survey, help identify gaps within the three categories of trip discovery, payment, and operations.

The present state of standardized mobility data accessibility and sharing in the United States is limited, as revealed by the literature and survey results indicating 63.7% of respondents selecting "barely standardized" or lower, resulting in inconsistent data structures and a lack of interoperability. This could be due to the lack of policy guidelines and the cost-intensive nature of the conventional standards development process. However, current industry-driven efforts supported by stakeholder input and oversight from governing bodies appear to be a robust kindle to the development of standards and specifications.

As evident from the MaaS experience lessons learned, emphasis must be placed on reaching a consensus for standardizing taxonomy and data sharing models and protocols to minimize confusion among providers, operators, and the public. An open-source approach utilizing the Mobility Data Interoperability Principles might be a good starting point to facilitate collaboration, transparency, flexibility, community engagement, cost-efficiency, and enhanced interoperability within the mobility sector.

The mobility industry is evolving rapidly. While data exchange standardization is instrumental, identifying industry disruptors and the reason behind their success is fundamental. New emerging mobility models that incorporate blockchain technology to efficiently share data across mobility providers point to higher scalability and lower integration costs. These new models are heavily decentralized and consist of a variety of mobility asset operators including public transport agencies, transportation agencies/authorities, and private transport operators.

Participating in industry-leading working groups could provide insights into successful implementations, multi-industry collaborations, potential improvements, and lessons learned within standardized data sharing protocols. Noteworthy efforts to follow during their implementation include GTFS (especially extensions such as pathways, fares, flex, operational data), GBFS, GOFS, MDS, TOMP-API, TDS, and CDS-M.

Governing bodies such as transportation policy makers are instrumental to the scalability of open-source standards. As observed from the case studies, standards development involving public/private stakeholders along with government/policy input has a greater chance for widespread adoptability. Governing bodies could consider aiding the setup of nondiscriminatory practices among operators/service providers and promote the use of proper legal contracts for development and data sharing.

Additionally, federal agencies could consider requiring clearly defined data management strategies for MOD/MaaS partnerships to qualify for federal funding. This would help ensure local agencies pay more attention to core data management (including sharing, ownership, and security) and knowledge transfer especially in the form of lessons learned for the benefit of other partnerships and end users. Knowing the data trends can help identify what the users expect/need from MOD/MaaS.

FTA Considerations and Future Research

Based on the findings of this research, the following considerations may foster interoperable, open, and user-centric MOD systems.

Encourage Open-Source Data Sharing by Establishing Policies and Requirements for the Use of Federal Funding.

Open-source data practices in transit allow transit agencies greater flexibility to adopt the most appropriate and innovative tools and technologies while maintaining interoperability across their systems or applications. FTA can encourage and support open data practices through the following:

- Envision all FTA contracts and cooperative agreements to have a provision for incentivizing and encouraging the open sharing of all core data, mutually agreed upon as nonproprietary, produced or used as part of a joint public-private partnership, with ease of portability built into the program requirements (Bouattoura et al., 2020).
- Support industry practices to define minimum data granularity for internal transit operations and public consumption to ensure uniformity and equitable access. The minimum data granularity can be derived from predefined FTA user-centric performance metrics in accordance with the Mobility Data Interoperability Principles (GAO, 2018; Shaheen et al., 2020).
- Recognize and require data elements of the GTFS (including extensions such as real-time, pathways, fares, flex, and operational data), GBFS, and MDS to be produced and shared in an open and cooperative ecosystem by all relevant software and systems procured with federal funds, including for scheduling, planning, and passenger information. FTA's *National Transit Database: Reporting Changes and Clarifications*, published in the Federal

Register on March 3, 2023, and requiring the use of GTFS feeds for all fixed route providers, was an example of such recognition.[4]

Support Industry-Driven Open-Source Mobility Data Standardization Efforts.

There are several organizations and working groups (e.g., Open Mobility Foundation, MobilityData, Cal-ITP) that facilitate the development of open-source data specification and tools. Through strategic partnerships with such entities, FTA can support projects that demonstrate the use of open-source specifications to achieve interoperability among multiple mobility modes centered around transit.

Fund Demonstrations and Evaluation of Mobility Data Integration Efforts.

FTA funding for research and demonstrations should meet the goal of scaling up data exchange through open standards and cooperation between public and private transportation service providers at the national level. This will give users access to high-quality mobility options that meet their needs, system vendors with integration efficiency, and transit agencies with the tools to continuously evaluate and improve their services.

Additionally, back-end transit operations comprise an area that is currently lacking uniformity or a standardized approach for seamless systems integration within transit agencies. Building on the existing open-source efforts by the Cal-ITP specification and the ODS working group, detailing operational data elements to define runs and assign drivers and vehicles will minimize time and development costs and prevent duplication of effort.

To showcase the technical and institutional feasibility and measure the impacts of open mobility data on travelers and transit agencies, FTA can support demonstration projects across the country to encompass a wide range of geographical characteristics, operational environments, and partnership types. These demonstrations should be based on mutual understanding with respect to existing and future intellectual property rights of private service providers and those licenses issued by third parties to private service providers. At the same time, the intellectual property involved in open data standards will be considered as open source.

[4] https://www.federalregister.gov/documents/2023/03/03/2023-04379/national-transit-database-reporting-changes-and-clarifications

Promote Industry Awareness, Knowledge, and Readiness.

Investing in the following activities and products may ensure effective knowledge transfer and continued evolution:

- Develop and validate user-centric performance metrics (i.e., wants, needs, and satisfaction) for transit agencies enabled by the integrated data feed.
- Produce best practices guide consisting of (1) readiness assessment, including required data elements and minimum data granularity, (2) synthesis of the implementation processes, and (3) potential implementation challenges and how to overcome them.
- Publish reports detailing the success, lessons learned, and next steps regarding open mobility data standards and demonstration/integration efforts.

Appendix A Summary of Key Documents and Their Findings

Report	Description	Findings
USDOT – Multimodal and Accessible Travel Standardization Assessment (MATSA) – Survey of Standards and Emerging Standards White Paper	This report discusses several existing standards that have the potential to be directly applied or have been previously applied toward the standardization of multimodal and accessible travel. Key areas identified for standards development to facilitate interoperability among systems and adoption of new technologies include: path of travel (Infrastructure, Vehicle), data sharing, exchange, privacy, integrated payment, wayfinding and navigation, automation and robotics, human-machine interface, and other standard areas (Chang et al., 2019; Shaheen et al., 2017). The document also specifically identified more than 50 standards directly to the MATSA effort. A few of those include the following: • Taxonomy of Shared Mobility: SAE J3163, SAE JA3163, ISO TC 204. • Taxonomy of Micromobility Vehicles: SAE J3194, CEN 17128. • Taxonomy of Automated Vehicles: SAE J3016, SAE J3126, ISO TC 204. • Mobility Data Sharing APIs: LA DOT Mobility Data Specification (MDS), Shared-Streets API. • Multimodal Payment Architecture: ISO TC 204 (24014 – Integrated fare management/ 21724-1 – Common Transport Service), Open APIs. • On-Demand Transportation APIs: TRB TCRP G-16, EU Mobility Platform, Standardiserat Utbyte av Trafikinformation (SUTI). • Accessible Automated Vehicles: SAE J3171. • ADA Standards: USDOT ADA Standards, ADA Accessibility Guidelines. • APIs for Integrated Multimodal Trip Planning: GTFS, GBFS, TCRP G-16, MaaS Alliance API. • Telecommunications Accessibility (ADA): ITU. • Dedicated Short-Range Communications (DSRC): SAE J2735 and SAE J2945. • APTA for Transit Systems Standards: APTA Universal Transit Fare Systems (UTFS), committee and working groups. • APTA Accessibility Standards Program: APTA Accessibility Working Group.	The document suggests that the process of standards development is evolving and does not necessarily require SDOs such as American National Standards Institute (ANSI), SAE, or other institutes to formalize the process. Initiatives such as the General Transit Feed Specification (GTFS) and MaaS API have been widely accepted and used an open-source approach since they allow for the collective and transparent development of software, codes, specifications, and guidelines (Chang et al., 2019). The document also emphasizes the need to support the longevity of existing standards, specifications, and guidelines to ensure wider acceptance and continued evolution. *Note: To add to the comprehensive summary provided in the MATSA report, the updated schedules and status of the identified standards and more are detailed in Appendix B.*

Report	Description	Findings
USDOT – Mobility on Demand Planning and Implementation: Current Practices, Innovations, and Emerging Mobility Futures	This report serves as an instrumental resource for those engaged in research, integration, demonstrations, and pilots to understand the concepts of MOD planning. The document identifies the key roles of both public (i.e., federal government, USDOT, state/local authorities, and transportation agencies) and private stakeholders (i.e., operators, service providers, supply chain managers, and consumers) in enhancing the potential benefits of MOD (Shaheen et al., 2020). The roles identified include: • Establishing strategies, policies, and regulations for transportation and MOD. • Managing multimodal transportation networks. • Providing or linking to public transportation. • Commodifying passenger mobility and goods delivery. • Offering on-demand access to mobility and goods delivery strategies for users. • Increasing accessibility and goods availability through partnerships and use cases. • Disseminating real-time information and facilitating trip planning, payment, and data access. Further, the document identifies examples of public-private partnerships that are instrumental in the success of MOD, such as data sharing, first-mile/last-mile connections, integration with third-party apps, service to low-density areas, off-peak service, paratransit service, right-of-way access and management, and risk sharing (Shaheen et al., 2020). The impacts of community-wide integration of the various shared mobility modes are discussed in detail and policy frameworks are suggested to leverage the positive impacts associated with the environmental benefits and sustainable business opportunities (Shaheen et al., 2020). The document also briefly discusses lessons learned from the implementation of the 11 MOD Sandbox projects funded by FTA.	Some challenges and lessons learned within the MOD sector include contracting and data sharing agreements with private vendors, reliability of private sector partners in terms of business models and insufficient data sharing, and ambitious initial project designs. Findings that point directly to factors that affect the implementation of MOD include: • Availability of data and complex traffic modeling analytics to agencies for evaluating the impact of MOD on traffic. • Lack of policies tackling newly identified disruptions to conventional traffic (right-of-way access) from the increase in MOD services. • Lack of guidelines for public-private data sharing and security. • Lack of integrated trip planning and payment due to data sharing restrictions and infrastructure to disseminate real-time information. • FTA does not require MOD trip characteristic data to be reported for funding (GAO, 2018). Adding this requirement would provide real-world case studies with data to analyze. • Lack of standardized performance metrics to consistently evaluate MOD-based datasets. • Lack of follow-up/survey protocols to ensure consumer satisfaction with trip completeness to establish previously unknown gaps in trip chaining and mitigate them.

Report	Description	Findings
USDOT – Forward-Looking Assessment White Paper: Multimodal and Accessible Travel Standards Assessment – Task 2	The white paper focuses on identifying the impact of multimodal and accessible travel (MAT) on standards development as part of the MOD vision of USDOT. The assessment identifies and divides the types of standards that should be considered to meet MAT user and stakeholder needs into nine dimensions: spatial, informational, accessibility, transactional, institutional, technological, modal, temporal, and equity (Schweiger et al., 2019). Open-source specifications such as GTFS are examined for compatibility with MAT. Several GTFS extensions were identified as relevant such as GTFS-Pathways, GTFS-Stations, GTFS-Levels (station schematics, entrances/exits), GTFS-PathwayClosures, GTFS-PathwayUpdates (real-time evaluation of station-elevator), GTFS-Vehicles (AC, wheelchair ramps, capacity), GTFS-VehicleCouplings (carriage stop points), GTFS-VehicleBoardings, and GTFS-VehicleDoors (accessibility information).	The document identifies several gaps related to MAT after reviewing numerous literature sources. The key gaps identified are summarized as follows: • Awareness of all traveler populations and their capabilities. • Lack of infrastructure conditions, service reliability, and system performance information. • Inadequate technologies for cognitively challenged people. • Numerous data sources with disparate storage locations. Access rights and user policies vary significantly. • Lack of interoperability across travel modes. • Use of sensitive geospatial information. • Lack of clear description for what information users are consenting to share. • Digital accessibility across all users. • Between-app data sharing without user consent using APIs could create ethical and legal issues.
United States Government Accountability Office (GAO) – Public Transit Partnerships: Additional Information Needed to Clarify Data Reporting and Share Best Practices	This report provides a comprehensive overview of public-private partnerships with respect to on-demand services. It examines the types of partnerships opted for by transit agencies and how federal requirements and funding can impact these relationships. Overall, 22 transit partnerships comprising 15 agencies were selected for assessment/interviews based on project type, type of service, and geographic location. The transit agencies included: Livermore Amador Valley Transit Authority (LAVTA), Dublin, CA; City of Centennial, CO; Washington Metropolitan Area Transit Authority (WMATA), Prince George's County, and Montgomery County, MD; PSTA, Pinellas County, FL; Metropolitan Atlanta Rapid Transit Authority (MARTA), Atlanta, GA; CTA, Chicago, IL; Massachusetts Bay Transportation Authority (MBTA), Boston, MA; Kansas City Area Transportation Authority (KCATA), Kansas City, MO; Rabbit Transit, serving 10 counties in central and southern Pennsylvania; King County Department of Transportation Metro Transit Division (King County Metro), Seattle, WA; LA Metro, Los Angeles, CA; Regional Transportation Authority (RTA) of Pima County, Tucson, AZ; Research Triangle Regional Public Transportation Authority (GoTriangle), Research Triangle Park, NC; Greater Dayton Regional Transit Authority (RTA), Dayton, OH; and Capital Metro, Austin, TX.	The report offers FTA key insights into improving data sharing and reporting. They include: • Publicly share information on transit partnerships. • Clarify which on-demand services/datasets fit public transportation and how to report into the National Transit Database (NTD). • Publicly share information on minimum data requirements and data sharing between local transit agencies and private mobility partners.

Report	Description	Findings
	The types of partnerships chosen by transit agencies in the selected projects are listed in the order of most frequently sought and involve first-mile/last-mile connections (partnerships with ridesourcing companies such as Uber and Lyft), paratransit, gaps in fixed route services, microtransit, improved technology for riders, marketing, and bikeshare.	
USDOT – Mobility on Demand Marketplace Concept of Operations Blueprint	This document focuses on exploring a MOD marketplace or a digital platform that connects users with service providers (Bouattoura et al., 2020). The authors highlight users' needs relating to a MOD marketplace, challenges when deploying a MOD marketplace from the perspective of institutional, operational, technical, and policy constraints, and key considerations for stakeholders before starting a MOD program. A detailed overview of public-private initiatives is also provided, broken down into five main categories: smart cities, MOD Sandbox projects, Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD), shared-use mobility center on-ramp projects, and public-private partnerships. The document also details examples of innovative international MOD projects: • Munich airport: real-time routing service reducing travel time of air passengers. • Singapore's first marketplace for crowdsourced bus services. • Quebec Communauto: subscription bikesharing and carsharing packages. • HERE mobility: autonomous driving, carsharing, and ridesharing platform owned by Audi, BMW, Daimler. The document identifies 10 high-level requirements for the implementation of a MOD marketplace: • Data collection • Data hub and warehouse • Multimodal trip engine • Mobile application • Trip optimization and machine learning engine • Integrated electronic payment system • Data analytics and reporting • Data mart and open data • Application programming interfaces and web widgets	The limitations associated with implementing a MOD marketplace platform in its current form can be broken down into three categories: institutional, operational, and technical issues. Institutional Issues: • Unbanked/underbanked require alternative payment methods. • Lack of accessible services especially in underserved/rural areas. • Limited full-length services that cover the entire trip. • Universal access not considered in mobility applications. • User concerns about personal identifiable information. • Differing privacy laws by state, making data collection and sharing inconsistent. • Lack of a widely adopted mobility data sharing standard. • Private institutions might want to keep discoveries proprietary. • Limited ability of public agencies to amend/enact data sharing regulations. • Lack of data analytic capabilities by agencies to fully utilize the potential of the data generated. • MOD business models are developing at a much faster pace than the time needed to plan and adopt a model.

Report	Description	Findings
		Operational Issues: • Infrastructure maintenance costs can affect MOD cost. • Curb-sharing can lead to increased congestion. Technical Issues: • Extensive development required for MOD marketplace. • Seamless multimodal and payment integration is still lacking. • Incorporating equity into MOD services regardless of technical, educational, physical backgrounds. • Lack of standardization across transportation modes creates data diversity and unifying challenges.

Appendix B Status of Relevant Standards

Table B-1. *Development Status of Standards Relevant to MOD/MaaS*

	Category	Organization	Standard	Description	Status		
					Under dev (exp date)	Published	Revised
1	Taxonomy: Shared Mobility	SAE	J3163	Consists of taxonomies and definitions for terms related to shared mobility and enabling technologies. Functional definitions of the following are also included: • Shared modes • Public transit services • Other incumbent services (i.e., car rentals, shuttles, taxis, paratransit, ridesharing, and pedicabs)		Sep 2018 *(cancelled Aug 2022)*	
2	Taxonomy: Shared Mobility	SAE	JA3163	Definitions of terms associated with on-demand and shared mobility services involving ground, aviation, and maritime transportation. Includes definitions of shared modes, services, business models, and mobility applications. This recommended practice does not include public transport.		Jun 2021	
3	Taxonomy: Shared Mobility	ISO	TC 204: TS 14812	Vocabulary on intelligent transport systems.		Apr 2022	
4	Taxonomy: Micromobility	SAE	J3194	Provides taxonomy and classification for powered micromobility vehicles to facilitate consistency across current practice and literature.		Nov 2019	
5	Taxonomy and Use: Micromobility	CEN	EN 17128	Focuses on light electrically powered vehicles (with any form of self-contained power sources). Provides definitions, machinery safety, hazards, and safety requirements.		Oct 2020	
6	Taxonomy: Automated Vehicles	SAE	J3016	Provides taxonomy and detailed definitions for the six levels of driving automation with respect to three primary actors (human, automation system, and vehicle systems/components).		Jan 2014	Apr 2021

	Category	Organization	Standard	Description	Status		
					Under dev (exp date)	Published	Revised
7	Taxonomy: Automated Vehicles	SAE	J3216	Definitions for cooperative driving automation for on-road motor vehicles. Emphasis is placed on: • Machine-to-machine communication. • Cooperative driving automation (i.e., sharing vehicle state, intent, and agreement on plan). • Dynamic driving task. • Application-oriented functionality.		May 2020	Jul 2021
8	Taxonomy: Automated Vehicles	ISO/SAE	TC 204: PAS 22736	Similar to SAE J3016 but in collaboration with ISO. Taxonomy and definitions related to on-road driving automation systems.		Aug 2021	
9	Multimodal Payment Architecture	ISO	TC 204: 24014	Guidelines on the development of interoperable transport fare management systems for multi-operator platforms. Functions of fare management defined include media management, applications management, products management, security management, and certification/ registration/identification.		Oct 2015	Jan 2021
10	Multimodal Payment Architecture	ISO	TC 204: 21724	Describes the Common Transport Service Account (CTSA) System that focuses on seamless acquisition of access rights to multiple transport services and operators. CTSA covers transport services, payment methods, and account types for service transactions (shared accounts for seamless payment across travel modes and facilities).		Jul 2020	
11	Accessible Automated Vehicles	SAE	J3171	Identifies automated driving systems passenger issues for persons with disabilities. The main disabilities covered include visual, cognitive, or physical.		Nov 2019	
12	Mobility Integration	ISO	TC 204: TR 4447	Compares the two main concepts of mobility—U.S. MOD and European MaaS.		May 2022	

	Category	Organization	Standard	Description	Status		
					Under dev (exp date)	Published	Revised
13	APIs for Multimodal Integration	MobilityData	GTFS	Data format for sharing transit feeds including schedules and geographic information via APIs. Several extensions are available: • GTFS real-time • GTFS-flex (accessibility): in progress • GTFS-continuous stops • GTFS-translations • GTFS-PathwayRoutings		Dec 2005	Sep 2021
14	APIs for Multimodal Integration	MobilityData	GBFS	Provides a common protocol for mobility operators sharing information to users/travelers. Information on type and vehicle availability such as station, dock locations/availability, geofencing rules, and vehicle characteristics is made accessible via an API.		Jan 2015	Apr 2022 (v2.3)
15	APIs for Multimodal Integration	MobilityData	GOFS	Guidelines targeting four key features: service discoverability, service description, real-time service description, and booking. The goal is to build on the existing: • GTFS-Flex V2 • GTFS-Fare Data • GTFS-Vehicle Categories • GTFS-Rider Categories • Protocols from GTFS-Capabilities and GTFS-Eligibilities	Jun 2021		
16	APIs for Multimodal Integration	TOMP	TOMP-API	Collaborative initiative to create standardized technical language between transport operators and MaaS providers using an API.		Jul 2020	Jan 2022
17	Multimodal Integration	Swedish government	SUTI	Standardiserat Utbyte av Trafik Information (SUTI) is a commonly used information exchange standard that is based on asynchronous XML messages and is used throughout Scandinavia for demand responsive transportation. Captures trip planning, real-time status updates, and trip information.		2002	

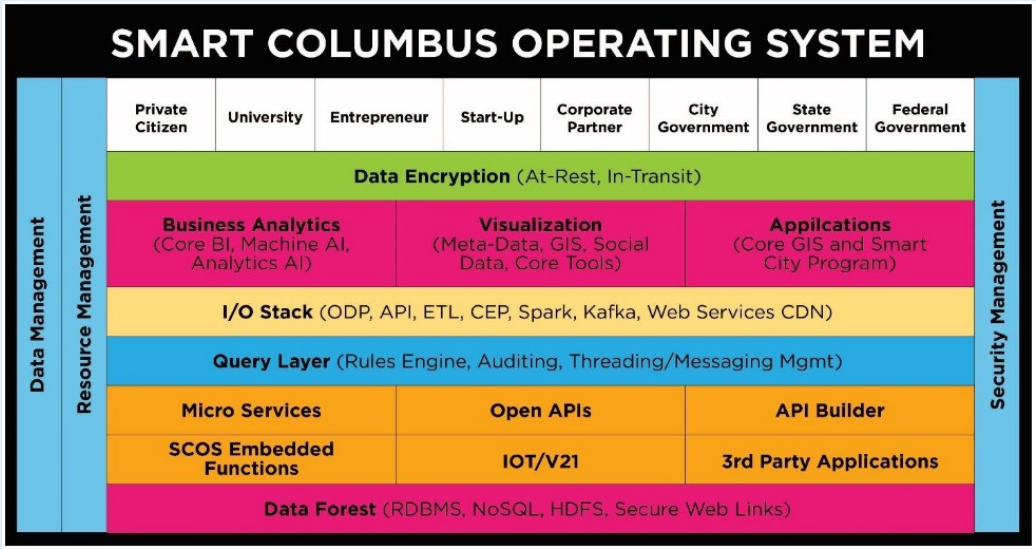
	Category	Organization	Standard	Description	Status		
					Under dev (exp date)	Published	Revised
18	Multimodal Integration	TCRP, Project G-16	TDS	Provides a set of rules for data interactions among software systems essential to demand-responsive transportation. Both structure and syntax are standardized for the entire trip life cycle, allowing participation of multiple entities by assuring full access to data to support the performance of their individual software systems (including financial transactions).		May 2020	
19	Transit Technology and Accessibility	APTA	TCIP	Interface standard to facilitate information exchange among transit business systems and devices. Consists of four volumes—narrative, data and dialog definitions, TCIP XML schema, and additional annexes.		Jun 2006	May 2015
20	Transit Technology and Accessibility	APTA	UTFS	Consists of five standards developed to establish a standardized approach to fare collection and contactless smart cards. The standards include Contactless Fare Media System: Intro and Overview, Fare Media Data Standard and Interface Standard, Regional Central System Interface Standard, Security Planning and Implementation Guidelines, and Compliance Certification and Testing.		Oct 2006	Dec 2009
21	Transit Technology and Operations	Cal-ITP; ODS working group	ODS	ODS leverages the existing GTFS and extends it to include information about personnel and non-revenue service. ODS is an open standard that currently defines deadheads and runs in a secure manner for internal operations.		Apr 2022	May 2022
22	Dedicated Short-Range Communications	SAE	J2735	Specifies data elements (basic safety messages), message sets, and data frames used by vehicle-to-everything applications. Although initially designed for DSRC, this document can be used independent of communication protocols.		Dec 2006	Sep 2023
23	Dedicated Short-Range Communications	SAE	J2945	Provides specifications for interface and performance of vehicle-to-vehicle and vehicle-to-everything deployments communication. Twelve parts available.		Jan 2012	Oct 2023

	Category	Organization	Standard	Description	Status		
					Under dev (exp date)	Published	Revised
24	Urban ITS/Mobility Integration	CEN	CEN/TS 16157	Provides standards and technical specifications for data exchange. The components include framework and context for exchanges, the modelling approach, data content, data structure and relationships and the communications specification, and traffic management applications.		Dec 2018	Apr 2020
25	Urban ITS/Mobility Integration	CEN	CEN/TS 17400	Provides principal aspects of urban Intelligent Transportation Systems (ITS) that seek to address vendor lock-in situations, interoperability between vendors, technical management, replacement, and migration strategies.		Apr 2020	
26	Micromobility Infrastructure and Data Exchange	ISO	22085 – 1 to 3	Part 1: Provides the service framework to identify the connectivity between nomadic devices, cloud servers, and micromobility in pre-trip, en route, and post-trip. Part 2: Defines functional requirements and messages set by use case and a dataset of each message to provide services for use cases defined in Part 1. Part 3: Defines a data structure and data exchange procedure based on the datasets and messages defined in Part 2.		May 2019 Jul 2021 Jan 2022	

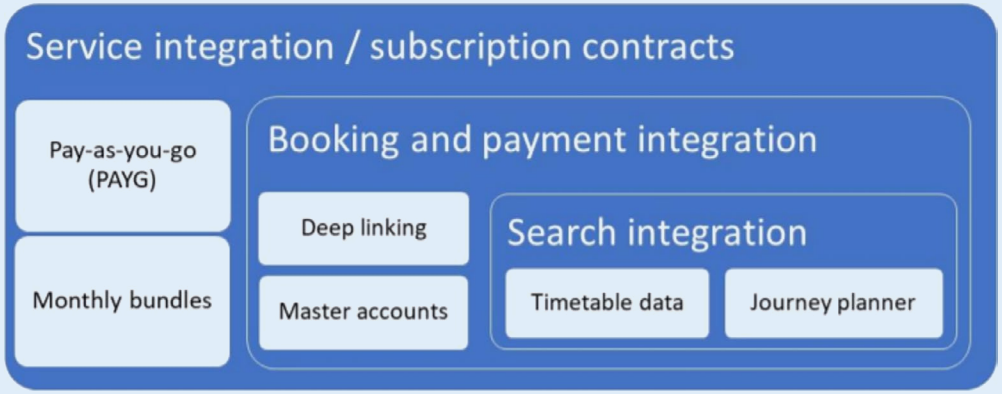
Appendix C Case Studies with Operational Data Sharing and Interoperability Protocols

Case Study	Region/URL	Description/Findings/Lessons Learned
MOD Sandbox Program: 11 Demonstrations	USA https://www.transit.dot.gov/research-innovation/mobility-demand-mod-sandbox-program	**Description:** The MOD Sandbox Program was founded to focus on mobility innovation and advancing the vision of MOD (Martin et al., 2023). The main goals of the program are to: • Improve transportation efficiency by promoting agile, responsive, accessible, and seamless multimodal service inclusive of transit through enabling technologies and innovative partnerships. • Increase transportation effectiveness by ensuring that transit is fully integrated and a vital element of a regional transport network that provides consistent, reliable, and accessible service to every traveler. • Enhance the customer experience by providing each individual with equitable, accessible, traveler-centric service leveraging public transportation's capability. In 2016, the FTA selected 11 demonstration projects aligned with the program vision to receive the allocated $8 million. The recipients included: • Chicago Transit Authority (CTA): Incorporation of Bikesharing Company Divvy • Valley Metro Rail, Inc. (City of Phoenix, AZ): Smart Phone Mobility Platform • Regional Transportation Authority of Pima County: Adaptive Mobility with Reliability and Efficiency • Pierce Country Public Transportation Benefit Area Corporation: Limited Access Connections • Los Angeles County Metropolitan Transportation Authority (LA Metro): Two-Region Mobility on Demand • San Francisco Bay Area Rapid Transit District: Integrated Carpool to Transit; Bay Area Fair Value Commuting • Pinellas Suncoast Transit Authority (PSTA): Paratransit Mobility on Demand • Vermont Agency of Transportation: Statewide Transit Trip Planner • Dallas Area Rapid Transit (DART): Integration of Shared-Ride Services into GoPass Ticketing Application • Tri-County Metropolitan Transportation (TriMet): OpenTripPlanner Shared Use Mobility **Findings:** A few notable findings from the demonstrations include: • First-mile/last-mile connectivity improved across various deployment locations. Dallas deployed the microtransit system, San Francisco deployed the carpooling app, and Portland optimized the region's trip planner. • Improved access to travel information for passengers with disabilities. PSTA deployed an integrated planning, booking, and payment service for paratransit. • Decreased use of personal automobiles. Carpooling activity improved across the deployments. Specifically, a survey of trip activity data in the Silicon Valley found that the introduction of an integrated trip planning and travel incentives platform led to a reduction in vehicle miles traveled by up to 40%. • Improved multimodal trip options and information.

Case Study	Region/URL	Description/Findings/Lessons Learned
		• Decreased emissions and fuel consumption. • Higher cost-effectiveness of microtransit when compared to low-ridership fixed route transit. **Lessons Learned:** The key lessons learned across the MOD Sandbox demonstrations and project partners are summarized below (Martin et al., 2023). • Forming and managing public-private partnerships can be difficult but rewarding if challenges (i.e., setting terms, changes to partner business models, and technology developments) are overcome. • Data sharing agreements and requests need to be carefully tailored well in advance to prevent disagreements. • Balancing private-sector profitability versus the goals of equity and accessibility within the public sector. • Outreach at the initial stages to highlight the purpose and services offered by the demonstration(s) is key to build customer awareness.
Smart Columbus, OH	USA https://smartcolumbus.com/ https://d2rfd3nxvhnf29.cloudfront.net/2021-06/SCC-J-Program-Final%20Report-Final-V2_0.pdf	**Description:** Winners of the Smart City Challenge. Implementation of multiple solutions, including the development of a multiparty public-private MOD application for underserved groups. Consisted of eight individual projects: • **Smart Columbus Operating System (SCOS):** Platform designed for big data analytics/exchange. Provides multiuser access to more than 2,000 datasets. "By ingesting, visualizing and sharing open, secure data, the [Smart Columbus] Operating System will give public sector officials and private sector innovators the insight they need to use data to empower our residents; through improved mobility, and establishing a platform for solving complex urban challenges in cities." • **Connected Vehicle Environment:** Vehicle-to-vehicle and vehicle-to-infrastructure mobility applications providing alerts to drivers, signal coordination, and preemption. • **Multimodal Trip Planning Application:** Developed smart app "Pivot" allowing users to view and reserve multi-trip itineraries including MOD/MaaS. • **Mobility Assistance for People with Cognitive Disabilities:** Smartphone app with accurate turn-by-turn navigation for older adults with cognitive disabilities to facilitate travel on the fixed route bus system. • **Prenatal Trip Assistance:** App for pregnant individuals to schedule flexible two-way transportation to medical services. • **Smart Mobility Hubs:** Physical spaces/interactive kiosks for consolidation of MOD. • **Event Parking Management:** Integrate parking information from city to provide availability and reservation services. Also provides predictive on-street parking availability. • **Connected Electric Autonomous Vehicles:** Deployed autonomous shuttles in mixed traffic. Performance measures were evaluated in terms of safety, mobility, opportunity, environment, agency efficiency, and customer satisfaction.

Case Study	Region/URL	Description/Findings/Lessons Learned
		Findings: Significant effort placed to exclude PII, PCI, or PHI data from the SCOS. To achieve this, both trust in partners and contractual accountability were implemented. Integrated payment was strategized (deployed using individual links to third-party apps) but not successfully deployed (seamless ability to pay across modes with one click due to PII restrictions). Technology providers agreed to offer free services as key leveraged partners. The design goals of the SCOS were: providing USDOT project support, analytics/visualization, open-source access, sustainability, DevOps, and privacy/security (James et al., 2018).  *Source: James et al. (2018)* Data generated are being used by public and private entities. **Lessons Learned:** The lack of existing standards covering the scope of implementing emerging technologies with respect to data and privacy was highlighted. National Institute of Standards and Technology Special Publication 800-122 and 800-153 were referenced but not sufficient. Alternatives and insights to some identified gaps were established from the expertise of entities in the private sector. • PII, PCI, or PHI restrictions hinder an integrated payment system. Guidelines to incorporate PII information safely and securely are warranted to facilitate better system usability. These should cover aspects of consent, safety protocols, encryption, and ethical and legal implications. Also, these guidelines should address general public concerns associated with privacy.

Case Study	Region/URL	Description/Findings/Lessons Learned
		• Public-private partnerships are key to achieving successful deployments. • Lack of existing standards/guidelines covering data and privacy with respect to emerging technologies. • Interfacing with APIs is key. • Real-time big data access and usage metrics by public and private entities can provide validation. • City agencies must control as much trip data as possible. Additional lessons learned from the multimodal trip planning application and common payment system: • City agencies face obstacles in requesting trip data from mobility providers as they do not control the data. • Lack of incentives to travelers and mobility providers to promote the adoption of MaaS.
Bristol One City, United Kingdom	Non-USA https://opendata.bristol.gov.uk/ https://www.connectingbristol.org/wp-content/uploads/2019/09/Connecting_Bristol_300819_WEB.pdf	**Description:** An initiative was launched to provide easy and free access to a wealth of real-time and historical data within one system, using APIs. This was done to facilitate testing and implementation of innovative technologies that would not be possible without these datasets. Data categories include Transport & Streets, Community & Housing, Health & Social Care, Environment, Council & Democracy, Population, Geography & Areas, Leisure & Tourism, Education, Planning & Laned Use, Safety, Energy, Business & Economy. **Findings:** Unrestricted live data can, without discrimination, grant interested parties access to APIs, data dictionaries, Github repositories, and community notes to collaboratively develop MaaS interfaces aimed at improving user experience toward accessing bus/train times, stops, route choices, and other travel relevant data. A few funded transit projects from this initiative include: • Eco-routes: providing drivers with eco-friendly route choices to produce fewer emissions. • Mobilized construction: supporting Bristol's road infrastructure. • ChatBot interface: making data engagement easier. **Lessons Learned:** • Co-design of transport schemes with the community organizations and transportation providers offers great insights into current needs. Emphasis placed on reduction of car traffic by expanding (seeking funding for) active travel and public transportation. • Particularly challenging to identify innovative solutions and engage local governance to address social inequalities. • Far greater benefits of sharing unrestricted transport data than limiting access. Tech community (young minds, open data hackathons, etc.) and city planners can join to tackle existing challenges in an open forum setup. New transportation apps are being constantly developed to meet public and tourist demand such as first bus, national express coach, GWR (train booking), and V-Cars.

Case Study	Region/URL	Description/Findings/Lessons Learned
iMOVE Sydney MaaS Trial, Sydney, Australia	Non-USA https://imoveaustralia.com/wp-content/uploads/2021/04/iMOVE-Sydney-MaaS-Trial-Final-Report-March-2021.pdf	**Description:** The Sydney trial seeks to create a MaaS offering that aligns with travelers' personal benefits while achieving societal goals of sustainability. A total of 92 participants were recruited to participate in the trial (Hensher et al., 2021). SkedGo is the primary API provider for the Tripi app. Functionality includes individual unique log-in, mobility wallet, trip history, current subscription plan, and other service opt-in plans. Objectives of the MaaS trial include: • To explore appropriate transport service mixes for early adopters of MaaS. • To generate first-hand knowledge of actual MaaS experiences. • To explore commercially a viable business model for MaaS as a pay-as-you-go in lieu of subscription plans. • To advance the understanding of user uptake and preferences for monthly mobility bundles. • To test the ability to influence travel behavior through introducing MaaS solutions. • To document the experience in designing, planning, and undertaking a MaaS trial. **Findings:** Booking integration: deep linking was achieved, but leaving the user to complete booking outside MaaS app. Service, booking, payment, and search integration architecture is shown below.  *Source: Hensher et al. (2021)* Really complex payment integration solution applied due to the lack of standardized APIs. All payments facilitated by a broker, Insurance Australia Group (IAG), to provide a seamless experience to participants. • Opal (smartcard ticketing system used in Sydney to pay for public transport) cards were to be used for all personal trips. • Unique Uber accounts specific to IAG were created for participants in the trial. Trips of each participant were identified and manually entered into the main app.

Case Study	Region/URL	Description/Findings/Lessons Learned
		• Cabcharge (taxi service) account similar to Uber above. • GoGet and Car rental accounts linked in a similar fashion. **Lessons Learned:** • Tripi app does not currently support payment integration. Book API integration is the best way to achieve one-stop shop for MaaS. • The process to facilitate payment integration cannot be effectively used outside of the pilot. • Establish data sharing agreements with service providers in the initial stages of the project to ensure direct API access for real-time feed. • PAYG (pay as you go) subscription bundle had the highest users across the trial.
MaaS Jakarta, Jakarta, Indonesia	Non-USA https://lyko.tech/wp-content/uploads/2021/04/LYKO-wins-the-tender-for-the-worlds-most-ambitious-MaaS-platform.pdf	**Description:** Newly awarded, eight-year contract. Partners: Lyko (intermodal end-to-end mobility service provider that supports booking and planning integration via custom APIs), Jatelindo (electronic payment solution provider), Aino (payment processing company licensed to offer electronic payment solutions for public transportation in Indonesia), and Thales (digital and deep tech leader specializing in connectivity, big data, AI, and cybersecurity). API provided by Lyko. However, limited information is available as of this writing. https://lyko.tech/en/use-cases/maas-solution/ API documentation shows protocols for collecting payment (debit/card) information from customers in a secure fashion. **Findings:** Not available.
MaaS Bogota, Bogota, Colombia	Non-USA https://techcrunch.com/2021/02/15/trafi-takes-its-mobility-as-a-service-platform-to-latam-starting-with-bogota/	**Description:** MaaS powered by Trafi app. The first iteration of the app offers real-time journey planning and tracking across the bus rapid transit and cable car network. A unique integration of a travelcard specifically for MaaS to be used across all operators and providers. **Findings:** Future iterations are aimed at deep integrations with taxi service and other service providers to plan, book, track, and pay for travel within one app. Trafi also powers other MaaS/shared-mobility apps in Berlin (BVG), Munich (MVGO), and Baltic states.
Trafi Vilnius, Vilnius, Lithuania	Non-USA https://www.trafi.com/vilnius/	**Description:** Powered by Trafi. This is the first MaaS platform in the Baltic states. Deep integration of public transport, ride-hailing (Uberm Spark), and carsharing and bikesharing (CityBee cars, CycloCity bikes). Includes the following: • Multimodal journey planner • Real-time moving vehicles on map • Integrated payment available

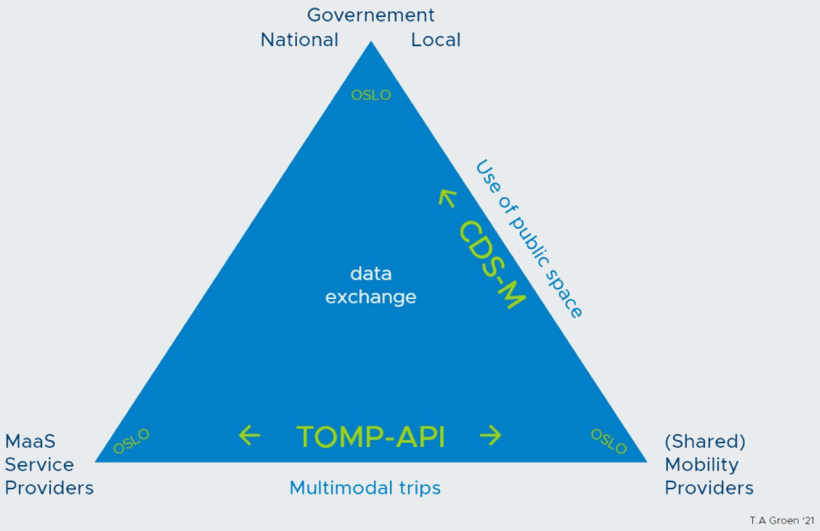
Case Study	Region/URL	Description/Findings/Lessons Learned
MaaS in Netherlands: Seven Pilots	Non-USA (Mathijsen, 2021; Ministry of Infrastructure and Water Management, 2019; Rijkswaterstaat Environment, 2019) https://maas-alliance.eu/wp-content/uploads/2019/08/MaaS-of-the-Month-Supporting-MaaS-with-pilots.pdf	**Description:** The Dutch Ministry of Infrastructure and Water Management funded seven MaaS regional pilot projects in Zuidas, Utrecht Leidsche Rijn, Twente, Groningen-Drenthe, Rotterdam-Den Haag, Eindhoven, and Limburg, which ran from 2019 to the end of 2021 (most were extended to the end of 2022 due to COVID-19 and other delays). The projects were targeted within specific neighborhoods and focused on inclusivity for commuters, the elderly, chronically ill, and disabled. Pilot initiatives and their locations/title are listed below: i. MaaS pilot Rotterdam: Rotterdam – The Hague Airport ii. MaaS pilot Amsterdam: Starting with and in Zuidas iii. MaaS pilot Eindhoven: Sustainability iv. MaaS Pilot Limburg: Borderless mobility Limburg v. MaaS pilot Groningen-Drenthe: Accessibility for rural areas vi. MaaS pilot Twente: Participation vii. MaaS pilot Utrecht-Leidsche Rijn: Vinex A model partner agreement was developed to formalize cooperation between operators and MaaS platforms (Bakermans et al., 2021). Several conditions were required to be met for task participation: • Each awarded MaaS provider must develop a trouble-free app for planning, booking, and paying. • All data must be shared (maintaining users' privacy) with transport operators and governmental organizations. • The MaaS provider must be able to fully finance their awarded portion of the project in three years, without additional support from public finances. The provider is also given the opportunity to launch the app nationally, pending success. **Description and Findings – Rotterdam:** The goal of the pilot was to improve multimodal accessibility to the Hague Airport in Rotterdam (Rijkswaterstaat Environment, 2019). A unique project that engages governmental institutions, the airport, and MaaS providers. Early stages of app development, focusing on booking integration (Wulp, Burg, & Pigge, 2020). Pilot extended to September 2022. A few lessons learned include: • Engage all involved parties, MaaS will never work otherwise. • Knowing the target users and defining good communication strategies. Expect undesirable reactions from users. • Stay in close contact with involved parties during implementation. **Description and Findings – Amsterdam:** Pilot started in Zuidas as a business-oriented service with Amaze Mobility as the selected MaaS provider. More than 10 different operators onboard and a MaaS application (Amaze) was launched on October 1, 2021 (Mathijsen, 2021). Amaze allows planning, booking, travel, payment, and services across multiple travel modes, all from one app.

Case Study	Region/URL	Description/Findings/Lessons Learned
		A few lessons learned include: • Integration of lock/unlock solution using Bluetooth. • Commercial conditions must be negotiated by operators and providers prior to awarding exclusive licenses. Lack of established transport operators willing to support the TOMP-API as a standardized data sharing protocol. **Description and Findings – Eindhoven:** Pilot focused on providing sustainable mobility to employees of the Eindhoven municipality, Brainport Smart Mobility, and Dutch semiconductor and chip manufacturer ASML (Ministry of Infrastructure and Water Management, 2019). The TURNN app was developed with support for trip status and journey information (delays, weather, jams), booking, and payment across the country. Pilot is still gathering data with limited status information. **Description and Findings – Limburg:** The pilot addressed "borderless mobility" across national borders. The geographic location of Limburg and the lack of multimodal alternatives for cross-border travel were the preliminary concerns of this project (Ministry of Infrastructure and Water Management, 2019). The lessons learned from national collaboration and data sharing will be critical for MaaS. To achieve these goals, the Glimble app by Arriva was launched in September 2021 with the provision of several forms of shared mobility. The pilot has been extended until the end of 2022 due to COVID-related delays. **Description and Findings – Groningen-Drenthe:** Pilot was focused on a HUB network of physical locations for multimodal and accessible connectivity in the provinces of Drenthe and Groningen (Rijkswaterstaat Environment, 2019). Several ongoing campaigns to highlight this project to the public include community engagement, voluntary HUB promoters, and Hubtaxis (on-demand shared taxis bringing people to the HUBs). The pilot is still ongoing and limited information exists on the status. **Description and Findings – Twente:** Pilot began in Twente to provide affordable and accessible transport to vulnerable groups (Ministry of Infrastructure and Water Management, 2019). Qarin Tranzer was awarded the pilot and launched the app Goan for public use in January 2021. As of May 2022, 1,000 users downloaded the app and 400 users linked the app to regional taxi pass (Mobiliteits Platform, 2022). However, the results so far do not meet the predicted usage. Due to COVID-19, the pilot was extended to October 2022 (Mobiliteits Platform, 2022). **Description and Findings – Utrecht-Leidsche Rijn:** The goal of this pilot was to stimulate people in Vinex and neighboring regions with high car ownership to use alternative forms of transport (Ministry of Infrastructure and Water Management, 2019). The Gaiyo transport app by Innovactory was launched (September 2020) to allow users to seamlessly plan, book, and pay for all journeys from one interface (Kasan, 2020). The app also shows real-time travel stats, traffic updates, and multimodal availability.

Case Study	Region/URL	Description/Findings/Lessons Learned
eHubs – Smart Shared Green Mobility Hubs	Non-USA https://www.nweurope.eu/projects/project-search/ehubs-smart-shared-green-mobility-hubs/	**Description:** eHubs consists of dedicated on-street locations to help users choose various sustainable electric transport options (i.e., e-bikes, e-scooters, and e-cars). eHubs is currently planned in six countries: Netherlands, Belgium, Germany, United Kingdom, France, and Ireland. **Findings:** Worked together with the TOMP-API working group to facilitate creating a technical standard interface within the MaaS ecosystem. The goal of the eHubs project was to achieve level 1 (information integration) MaaS integration (Sochor et al., 2017). No booking or route-planning was explored as part of this project. **Lessons Learned:** • The TOMP-API is easy and fast to deploy when implementing new transport options. This project was simple as the MaaS integration was kept to a minimum at level 1. • Need awareness of TOMP-API standard to ensure efficient digitalization of infrastructure.

Appendix D Existing and Upcoming Integration Standards, Guidelines, and Organic Efforts

Name/*Status*	URL	Content
North American Bikeshare & Scootershare Association – GBFS and Shared Mobility Data Policy ***Existing***	https://nabsa.net/resources/gbfs/ https://mobilitydata.org/gbfs-and-shared-mobility-data-policy/	General Bikeshare Feed Specification (GBFS) provides a common protocol for mobility operators sharing information to users/travelers. Information on type and vehicle availability such as station, dock locations/availability, geofencing rules, and vehicle characteristics is made accessible via an API. Effective data policies ensure the accessibility and accuracy of mobility data, thus building trust into mobility programs and increasing shared mobility adoption. Minimum requirements for shared mobility data policies developed by mobilitydata.org include: • Clearly defined data format, variables, and structure. • User privacy protection. • Free data access with no tokens, authentication, or API keys required, to both regulating body and public. • Ensure access to data elements required to permit, regulate, and manage shared mobility providers. The currently required data files for GBFS include the JSON index of URLS part of the API, basic information about the shared mobility system, vehicle type, availability, and docking status. GBFS also requires non-static bike ID to prevent trip tracking (especially in public datasets). Potential gaps in GBFS include: • Clearly defined minimum data elements are required without inclusion of excessive optional fillers. • GBFS does not provide any information on payment/fare integration.
Mobility Data Specification (MDS) ***Existing***	https://www.openmobilityfoundation.org/about-mds/ https://github.com/openmobilityfoundation/mobility-data-specification	MDS is an open-source initiative created by the Los Angeles Department of Transportation, now transferred to the Open Mobility Foundation (OMF). MDS provides a set of APIs focusing on real-time information of shared mobility services such as scooters, bicycles, carshare, and mopeds. MDS allows data to flow securely between cities and providers. MDS consists of six distinct authenticated JSON APIs: provider, agency, policy, geography, authority, and metrics. A key difference between GBFS and MDS is that MDS is intended for non-public use by cities and agencies. While GBFS is intended for public use, MDS provides regulators with exclusive confidential data accessibility. Both MDS and GBFS are membership organizations. As of this writing, more than 130 cities/public agencies and 40 mobility providers are using MDS. Main principles include: • Open source • Competition • Data and privacy • Harmony • Sustainability Version 2 of MDS was released on May 10, 2023, and consists of specifications for interoperability with new modes, fee schedules, and updated user agreements.

Name/*Status*	URL	Content
City Data Standard for Mobility (CDS-M) ***Upcoming (testing)***	https://www.polisnetwork.eu/wp-content/uploads/2021/03/CDS-M_Blueprint_v0.0.1.docx2_.pdf	CDS-M was developed to assist private-public sector partnerships by open communication and standardization of business-to-government (B2G) data exchange. CDS-M was initiated by representatives of five cities in the Netherlands and the TOMP-API Working Group (TOMP-WG). TOMP-WG was established by the Netherlands Ministry of Infrastructure and Water Management in 2018. The goal of CDS-M is to better understand the effects of shared mobility on public space. The standard is targeted toward transport operators and the government, and the two main components include: • The Standard (policy, planning, and enforcement) used for communication. • The Agreement (collection, storage, usage, security, and removal) for the use of shared data. The Standard part of CDS-M is covered in MDS, but with limitations such as being focused heavily on micromobility and being U.S.-centric (lack of coverage of EU legislation/regulation). CDS-M integration into TOMP-API is currently being considered via the two key blocks of functionality, operator information and asset information. Using TOMP-API provides a smoother implementation path for CDS-M among the companies already supplying data. The functional distinction between CDS-M and other operator standards (TOMP-API) is shown in the following figure.  *Source: Groen (2021)*

<table>
<tr><th>Name/Status</th><th>URL</th><th>Content</th></tr>
<tr><td>General On-demand Feed Specification (GOFS)

Upcoming</td><td>https://mobilitydata.org/mobilitydata-is-accelerating-the-standardization-of-on-demand-transportation-with-the-gofs-project/

https://mobilitydata.org/data-standard-when-the-industry-cooperates-to-find-solutions/</td><td>Incorporating on-demand services into GTFS is required. The new working group for GOFS focused on four key features: service discoverability, service description, real-time service description, and booking. The goal is to build on the existing specifications:
• GTFS-Flex v2
<table><tr><th>GTFS Trip Planner</th><th>GTFS-Flex Trip Planner</th></tr><tr><td>✓ Itineraries
✓ Departure and arrival estimates
✓ Mapping
✓ Fare information
✓ Fixed-route services

✗ Demand response transportation
✗ Route deviation
✗ Continuous stops
✗ Flag stops (or Hail-and-ride)
✗ Point deviation
✗ Point-to-zone
✗ Custom rider messages
✗ Eligibility information</td><td>✓ Itineraries
✓ Departure and arrival estimates
✓ Mapping
✓ Fare information
✓ Fixed-route services
and:
✓ Demand response transportation
✓ Route deviation
✓ Continuous stops
✓ Flag stops (or Hail-and-ride)
✓ Point deviation
✓ Point-to-zone
✓ Custom rider messages
✓ Eligibility information[4]</td></tr></table>Comparison of features between GTFS and GTFS-Flex trip planners

Source: Craig & Shippy (2020)
• GTFS-Fare Data
• GTFS-Vehicle Categories
• GTFS-Rider Categories
• Protocols from GTFS-Capabilities and GTFS-Eligibilities

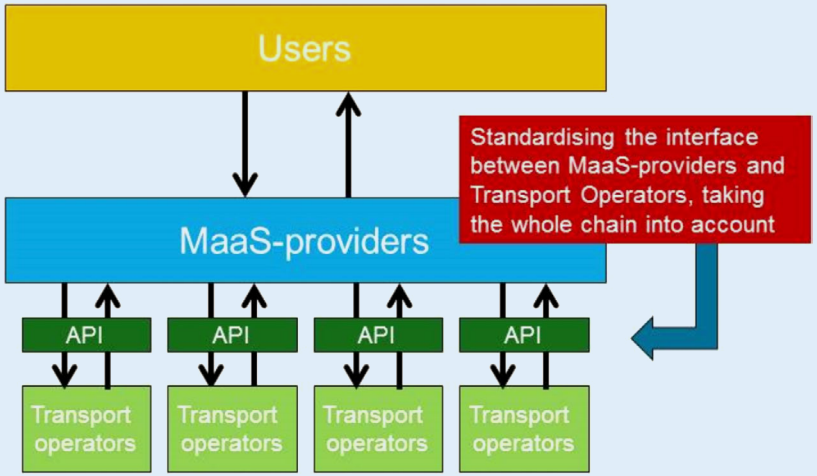
Already incorporates flexible services that perform actions on request to cater to the needs of individual riders.</td></tr>
<tr><td>Transmodel (EN12896: Public Transport Reference Data Model)

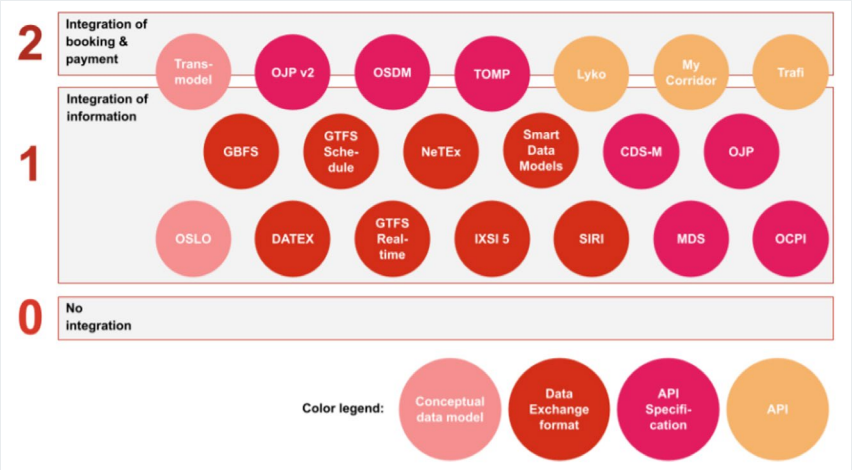
Existing</td><td>https://www.transmodel-cen.eu/</td><td>Transmodel is the European Reference Data Model for public transportation covering public transportation information and service management, particularly interoperability between the information processing systems of operators and agencies in Europe.

“Transmodel-based systems allow data from multiple sources to be integrated coherently to provide detailed, reliable information for door-to-door trips made on multiple modes; this can include information about the accessibility features of all components related to the trip, (as well as their real-time status), supporting travel by persons with restricted mobility.”

(MaaS Alliance, 2021)

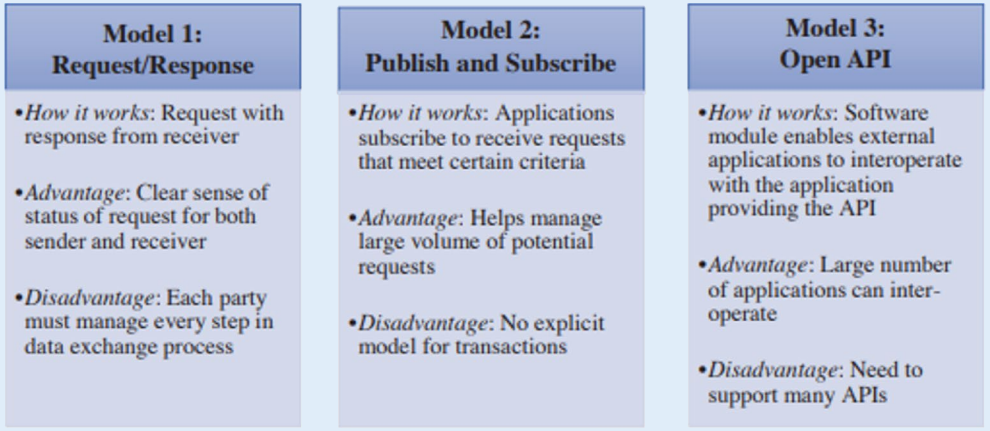
Data models derived from Transmodel help build interoperable systems. A few European data exchange standards derived from Transmodel include NeTEx, SIRI, OpRa, and OJP.</td></tr>
</table>

Name/*Status*	URL	Content
Transport Operator Mobility-as-a-Service Provider (TOMP) ***Existing***	Netherlands https://github.com/TOMP-WG/TOMP-API Blueprint for TOMP API V2 (Garcia et al., 2020) https://github.com/TOMP-WG/TOMP-API/blob/master/documents/200301%20-%20Blueprint%20for%20a%20TOMP%20API%20v1.2.pdf	The collaborative initiative (open-source working group) started in 2018 by the Dutch Ministry of Infrastructure and Water Management to create standardized technical language between transport operators and MaaS providers using an API. The TOMP-API initiative was commissioned at the same time as the seven regional MaaS pilot initiatives with an agreement stipulating the requirement for cooperation in standardizing efforts between all participating entities.  *Source: Garcia et al. (2020); Hensher et al. (2021)* The figure shows the process of standardizing APIs between operators and MaaS providers (Garcia et al., 2020). TOMP consists of eight functional modules/blocks within the API. • Operator Information: follows GBFS standards • Privacy and Registration: user sign-up, log-in, deletion • Planning: availability, ETA, and cost • Booking: book trip service • Trip Execution: access to service for booked period • Payment: fund settlement between transit operators and MaaS providers • Support: help with encountered issues • Asset Information: status, inventory, and access to assets Proposed suggestions to GBFS for future implementation (GBFS +): • Deep-link integration • System type (i.e., free_floating, station_based, or virtual_station-based) • Type of bike (ID, gears, electric, image_url, etc.) • Time to live (limit max real-time status update delay to 30 sec)

Name/*Status*	URL	Content
		Key highlights include: • Made significant strides toward standardizing the process of API implementation. Over 30 production implementations. • Developed detailed payment framework with pre- and post-payment modules. • Interoperability across multiple MaaS providers from one place still in the works. • Support blockchain integration. • Identifies existing API limitations based on user, MaaS provider, and transit operator survey. The survey indicates MaaS users are concerned about pricing integration while MaaS providers seek information on planning and trip execution (customer service, ease of use, asset specifications). Transit operators are mostly concerned with planning (terms and conditions of use, asset accountability, and feedback).
MaaS Alliance: Interoperability for Mobility, Data Models, and API ***Existing***	https://maas-alliance.eu/wp-content/uploads/2021/11/20211120-Def-Version-Interoperaability-for-Mobility.-Data-Models-and-API-_-FINAL.pdf	MaaS Alliance consists of two working groups focused on examining existing API and data models. This document is aimed at transport operators and mobility data system architects with the initial goal to define an all-purposed API for MaaS and to reach a standardized approach for information exchange across entities. The document provides collectively agreed upon definitions for objects of mobility, traveler's journey, and data exchange. It identifies five levels of MaaS maturity including Level 0: No integration, Level 1: Integration of information, Level 2: Integration of booking and payment, Level 3: Integration of service offer, and Level 4: Integration of societal goals (Sochor et al., 2017). The document notes that most existing standards fall under Level 1, as shown in the figure below. Specifications/data exchange protocols reviewed include DATEX-II, GBFS, GTFS-realtime, GTFS-schedule, IXSI-5, Lyko, MaaS Global API, Smart Data Models, OJP, TOMP-API, Transmodel, NeTEx, SIRI, TAP TSAI, and Trafi.  *Source: James et al. (2018); MaaS Alliance (2021)* The working groups also address the need to have standards developed at a global level to facilitate data sharing not only locally but also internationally. Some challenges associated with this are:

Name/*Status*	URL	Content
		• Identifying existing standards and data models. • Collaboratively agreeing on what to use at this stage of knowledge. • Studying the necessary evolutions. • Convincing stakeholders to use the solutions. Additionally, the European Commission requires certain parties within the mobility industry to adopt and work within existing European frameworks such as CEN's Transmodel. Conclusions from the exercise: • Building interoperability can be achieved by using the methodologies of Pivotal Points, Consensus Framework, and Minimum Interoperability Mechanism. • Formal standardization of MaaS is not necessary, although more consensual and collective outreach/conversation is needed between stakeholders to facilitate alignment and interoperability.
Transactional Data Specification (TDS) (Transportation Research Board, 2020) ***Upcoming (testing)***	https://sharedusemobilitycenter.org/the-transactional-data-specification-a-building-block-for-equitable-mobility-as-a-service/	TDS provides a set of rules for data interactions among software systems essential to demand-responsive transportation (DRT). Both structure and syntax are standardized for the entire trip life cycle, allowing participation of multiple entities by assuring full access to data to support the performance of their individual software systems (including financial transactions). TDS is regarded as a vital step in addressing data access inequality and integrating human services transportation with MaaS. TDS seeks to achieve interoperability using an open API (not provider-specific APIs) where providers follow data exchange using one set of message format. Individual software updates compatible with TDS do not trigger action for other providers in the network. Current practices in the United States are unique and proprietary to individual service providers, preventing exchange and cross-system interactions. The goal is to develop a similar approach to the airline industry where passengers can seamlessly book travel between multiple airlines and trips. TDS is a version of SUTI, designed while considering the following guiding principles: • Simplicity • Sufficiency • Flexibility • Adaptability • Compatibility • Technical appropriateness FTA technical assistance centers, state DOTs, and consultants are stakeholders in TDS. The figure below shows the three governing models for TDS.

Name/*Status*	URL	Content



Source: Transportation Research Board (2020)

The research team focused on the following core elements when developing TDS for DRT: trip reservation request, trip scheduling, trip cancellation, trip execution, and trip reporting.

The two key elements of the DRT TDS are:

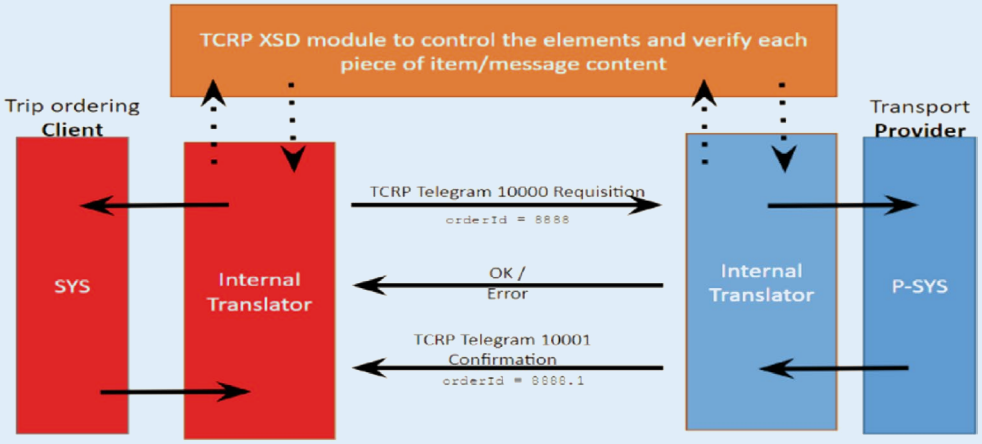
- Telegrams (core of SUTI; consist of specific message type with mandatory and optional data elements) (Larsen et al., 2018).
- Internal translation with external validation (emphasis on specification validation during data exchanges to ensure standardization and reliability).

The TDS research team further engaged stakeholders to gain insights into need, application, and challenges associated with using/switching to TDS. Identified concerns of having one common specification such as TDS are listed below:

- Wide variation in business rules and operational practices between providers and agencies.
- Lack of incentive to standardize.
- Prohibitive costs associated with switching to a new specification.
- Misspecification: This is associated with the scope of the specification and ensuring it is not too broad (does not capture what is required and feels diluted) or too detailed (too many variables and complicated to use in practice).

The research team also developed a data validation tool using the control module approach (figure below) with the following capabilities:

- Evaluating the implementation of TDS and its functionality (test messages can be sent using XML or JSON data structures).
- Simulating interoperability between the software system and other DRT application services.

Name/*Status*	URL	Content
		 *Source: Transportation Research Board (2020)*
BestMile ***Existing***	https://www.drivesweden.net/en/bestmile	Bestmile "offers the only solution of its kind that is vehicle agnostic, can manage autonomous and human-driven vehicles, supports on-demand and time-based services, integrates with multiple transport modes, and provides end-to-end applications for travelers, drivers, and operators." Bestmile's Mobility Services Platform can be used to manage fleet services by enabling operators to plan routes and stops ahead of time and to match vehicles with travelers for on-demand services. It is part of the European Union's AVENUE (Autonomous Vehicles to Evolve to a New Urban Experience) project. Provides cloud-based mobility solutions including: • Public apps • Professional apps • Integrations (public transit, MaaS, payment infrastructure) • Fleet services Maintains blogs to discuss mobility solutions. Open-source platform still under construction.

Appendix E Survey Pamphlet and Survey Link

Mobility Data – Standards and Specifications for Interoperability

Research Feedback Survey

CUTR

UNIVERSITY of SOUTH FLORIDA

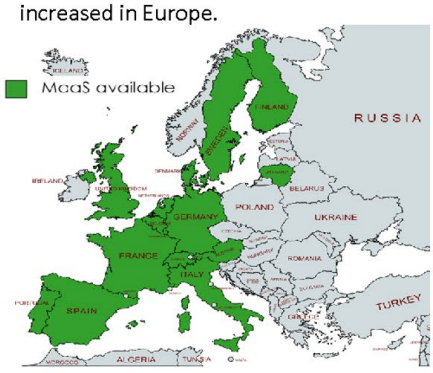
FTA RESEARCH PROJECT OVERVIEW

- **Aim:** To identify the best practices and current mobility data developments leading to industry-driven Mobility on Demand (MOD) data standards and specifications.
- **Specific Objectives:**
  - Identify existing standards and recommended practices addressing transit mobility, infrastructure, and safety;
  - Provide feedback to FTA on successful projects, identified gaps, and prioritization areas; and
  - Build on USDOT efforts on MOD/Mobility as a Service (MaaS) data exchange and interoperability with respect to Trip Discovery, Payment, and Operations.

COMPLETED REVIEW OF LITERATURE

- USDOT Multimodal and Accessible Travel Standards Assessment (MATSA) effort: Produced a comprehensive database (300 existing and emerging standards) and developed 18 Info cards showing related standards;
- Mobility on Demand Planning and Implementation: Current Practices, Innovations, and Emerging Mobility Futures [Shaheen et al., 2020]
- ITS America: MOD Smart Mobility Community Issue Letter;
- Public Transit Partnerships: Additional Information Needed to Clarify Data Reporting and Share Best Practices [GAO, 2018];
- General Bikeshare Feed Specification (GBFS) and shared mobility data policy [Americas & Europe];
- Roadmap for Multimodal and Accessible Travel (MAT) Standardization Work – Draft;
- General Transit Feed Specification (GTFS);
- LA DOT Mobility Data Specification (MDS); and
- Case studies reviewed: **Bristol One City (UK), King County-WA (USA), Smart Columbus-OH (USA), MaaS in Netherlands (including TOMP API and CDS-M), iMOVE Sydney MaaS Trial (Australia), MaaS Jakarta (Indonesia), MaaS Bogota (Colombia).**

Between 2018 & 2019, MaaS operators have significantly increased in Europe.



Some identified providers include: Axon Vibe, BVG, Citymapper, Cityway, Deutcshe Bahn, Glimble, HaCon, Instant System, MaaS Madrid, Mobimeo, Moovel, Moovit, MVG, RATP, Trafi, Transdev, Ubigo, Upstream, URBI, Whim, WienerLienen, Wondo, Yumuv, ZenGo.

Fig 1. MaaS Availability in Europe

HIGH-LEVEL OBSERVATIONS

Trip Discovery	Payment	Operations
• Lack of standardized performance metrics to consistently evaluate MOD-based datasets. • Availability of data and complex traffic modeling analytics to agencies to evaluate impact of MOD on traffic. • Clearly defined minimum data elements without excessive optional fillers. • Incorporating on-demand services into the General Transit Feed Specification (GTFS) is required. • Need more outreach/awareness towards existing and in-progress solutions, not limited to GTFS, GBFS, and MDS. • Lack of guidelines towards inclusion of trip sustainability (carbon foot print, emissions) in travel choice. • Global efforts in MaaS, especially open-source projects, can provide insights on how to successfully tackle data sharing and interoperability.	• Difficulty integrating trip-planning and payment due to data sharing restrictions and infrastructure to disseminate real-time information. • Difficulty establishing agreements between involved parties (user, operator, provider) to facilitate payment, acceptance, and distribution. • Lack of standardized guidelines to safely and securely incorporate PII information in data, to facilitate better usability. This should cover aspects of consent, safety protocols, encryption, ethical and legal implications. Also, these guidelines should be able to address general public concerns associated with privacy.	• Lack of policies tackling newly identified disruptions to conventional traffic (right-of-way access) from the increase in MOD services. • Government agencies are key to ensure MOD/MaaS scalability, especially with respect to legal contracts for development and data-sharing and non-discriminatory practices among operators/service providers. • Promising efforts showing the use of blockchain technology to facilitate "roaming" of mobility services. • Lack of follow-up/survey protocols to ensure consumer satisfaction (trip completness/chaining) and shared knowledge of the impact of MaaS. • Limited information on the impact of equity on MOD. Need to expand traditional definitions of equity.

- Distinction of "deep link" and "deep integration" is key.
- Deep integration allows users to book and pay for their journey entirely on the mobility app without re-directing to external operators, unlike deep links.
- Existing open-source working groups are well positioned to tackle the gaps associated with standardization of MaaS.
- It is critical for governing entities to guide public agencies to adopt standardized data sharing and mobility agreements.

WE REQUEST YOUR FEEDBACK

Why do we need Stakeholder & Transit Community input?

- To identify relevant MOD/MaaS projects, required support from governing bodies, data sharing protocols, lessons learned, and possible solutions to encountered problems. Specifically, the survey looks to aid to tackle the following:
  - Is there a need for a standard to share data within the mobility ecosystems?
  - Are current mobility data sharing protocols/practices sufficient?
  - What can be added to our shared-mobility findings?
  - Are there existing case studies that have addressed the gaps we have not identified?

Survey Link:
https://usf.az1.qualtrics.com/jfe/form/SV_2mdxa9mBIFFyOii

Share QR

Thank you for your valuable time!

For further questions please contact:
Sisinnio Concas, Ph.D. [concas@usfdotedu]

CENTER FOR URBAN TRANSPORTATION RESEARCH

Appendix F Stakeholders Input Survey

Start of Block: About the Survey

Mobility Data – Standards and Specifications for Interoperability
The following definitions of Mobility on Demand and Mobility as a Service are selected for the purposes of this survey and to distinguish between them. These definitions are not official and could differ for other aspects of this research.

> **Mobility on Demand (MOD)** is a vision for "an integrated multimodal network of safe, carefree, and reliable transportation options that are available to all."
>
> **Mobility as a Service (MaaS**) is centered on a marketplace where a host of transportation modes are fully integrated to ensure a seamless passenger travel experience.

Why is **Stakeholder** and **Transit Community** input necessary?
We seek input to include relevant projects, deployments, data sharing protocols, lesson learned, and viable solutions to encountered problems. Specifically, this survey looks to tackle the following:

- Is there a need for a standard to share data within the mobility ecosystems?
- Are current mobility data sharing protocols/practices sufficient?
- What can be added to our shared-mobility findings?
- Are there existing case studies that have addressed the gaps we have not identified?

Please proceed to completing the survey
Approximate survey completion time: 12 minutes

End of Block: About the Survey

Start of Block: General Question Block

Which category most accurately represents your Mobility Background?

- ○ Transit Operator / Provider
- ○ Private Operator / Digital Mobility Service Provider / Technology Supplier
- ○ Industry Expert / Mobility-Centric Organization / Researcher / Academic / Mobility Data Consumer

Which geographical region is the center of your Mobility experience?

- ○ United States
- ○ Non-United States

End of Block: General Question Block

Start of Block: TRANSIT OPERATOR/PROVIDER

Are MOD services currently being offered at your transit agency?

- ○ Yes
- ○ No, but plan to implement in the next 1–2 years
- ○ No

Which MOD services are currently available at your agency?
(Please select all that apply)

- ☐ First- and Last-Mile connections (e.g., park and ride, partnerships with shared-mobility vendors, subsidized rides to/from transit stations)
- ☐ Demand Response / Microtransit Service
- ☐ After-hour MOD service
- ☐ Equity-based transit models (e.g., service to low-income, low-ridership, night-work prominent, and more transit-reliant users)
- ☐ Transit data sharing (APIs, real-time tracking, status updates, schedule)
- ☐ Connected ecosystems (apps, kiosks, physical or virtual payment/ information centers)
- ☐ Other (please specify below)

Which MOD services does your agency plan to implement in the next 1–2 years? (Please select all that apply)

- [ ] First- and Last-Mile connections (e.g., park and ride, partnerships with shared-mobility vendors, subsidized rides to/from transit stations)
- [ ] Demand Response / Microtransit Service
- [ ] After-hour MOD service
- [ ] Equity-based transit models (e.g., service to low-income, low-ridership, night-work prominent, and more transit-reliant users)
- [ ] Transit data sharing (APIs, real-time tracking, status updates, schedule)
- [ ] Connected ecosystems (apps, kiosks, physical or virtual payment/ information centers)
- [ ] Other (please specify below)

_____

Did you experience or do you anticipate any challenges to implementing MOD services, (please state briefly)?

_____

_____

_____

Please select the closest mobility data sharing protocols your agency has in place, if any?

- ○ Open to Public with full access (no restrictions, no PII)
- ○ Open to Public with limited access (aggregate or static data only)
- ○ Open to Public per request only (no PII)
- ○ Private-internal use only (no public access)
- ○ None in place

Does your transit agency currently offer any MaaS platforms?

- ○ Yes
- ○ No, but plan to implement in the next 1-2 years
- ○ No

Please select which of these MaaS one-stop interfaces are currently implemented by your agency including public-private partnerships (please select all that apply)?

- ○ Trip Planning integration (with multiple mobility options, including transit, along with real-time information)
- ○ Booking integration (for demand response options)
- ○ Payment integration
- ○ Other _____

Please select which of these MaaS one-stop interfaces you plan to implement in the next 1-2 years including public-private partnerships (please select all that apply)?

- ○ Booking integration
- ○ Payment integration
- ○ Only Trip Planning integration (transit schedules, accessibility, delays, but no bookings)
- ○ Other _____

Please provide application names or weblinks to the MaaS platform if available.

_____

_____

Did you experience or do you anticipate any challenges when implementing the MaaS platforms, (please state briefly)?

_____

_____

What do you feel is the current level of standardized mobility data access and sharing protocols?

- ○ 5: Exceptionally standardized (all operators and vendors share same data structure and elements)
- ○ 4: Well standardized
- ○ 3: Just okay
- ○ 2: Barely standardized
- ○ 1: Not standardized at all (very inconsistent data structure and elements)

Is there a need to formally standardize the process of implementing MOD/MaaS?

- ○ Yes
- ○ No

What in your opinion is more cost-effective for efficient MOD/MaaS implementation? International standard or industry-driven standard?

- ○ International standard – please elaborate below

- ○ Industry driven – please elaborate below

List 2 to 3 of the most informative project documents/standards/guidelines/ open-source protocols that have been essential when implementing MOD/ MaaS by your agency?

Please select to what level you agree to the following statements:

	Fully Agree	Somewhat Agree	Fully Disagree	Somewhat Disagree	No Comment
Current MOD/MaaS do not provide sufficient travel information	○	○	○	○	○
Lack of data sharing is a great concern to multimodal integration	○	○	○	○	○
Fair/non-discriminatory access for all MOD/MaaS operators is not granted	○	○	○	○	○
Lack of universal data sharing, security, and reuse protocols is a concern	○	○	○	○	○
More effort must be placed on highlighting sustainable travel options (trip carbon footprints, eco score, etc.)	○	○	○	○	○

Please provide any additional observations/comments/past findings that could better this research's outcomes.

End of Block: TRANSIT OPERATOR/PROVIDER

Start of Block: PRIVATE VENDOR

Are you involved in any MOD services (private or public-private partnerships)?

- ○ Yes
- ○ No

Which areas would you be most suited to provide your expertise on (for this survey)?

- ☐ First- and Last-Mile connections (e.g., park and ride, partnerships with shared-mobility vendors, subsidized rides to/from transit stations)
- ☐ Demand Response / Microtransit Service
- ☐ After-hour MOD service
- ☐ Equity-based transit models (e.g., service to low-income, low-ridership, night-work prominent, and more transit-reliant users)
- ☐ Transit data sharing (APIs, real-time tracking, status updates, schedule)
- ☐ Connected ecosystems (apps, kiosks, physical or virtual payment/ information centers)
- ☐ Other (please specify below)

Did you experience any challenges to implementing MOD services (please state briefly)?

What MOD data access protocols do you currently provide?

- ○ Open to Public with full access (no restrictions, no PII)
- ○ Open to Public with limited access (aggregate or static data only)
- ○ Open to Public per request only (no PII)
- ○ Only Transit Agency full access (no restrictions)
- ○ Only Transit Agency limited access (aggregate or static data only)
- ○ Only Transit Agency per request access
- ○ Private-internal use only (in-house access only)
- ○ None in place

Do you currently offer any MaaS platforms?

- ○ Yes
- ○ No, but plan to implement in the next 1–2 years
- ○ No

Please select which of these MaaS one-stop interfaces are currently implemented by your company including public-private partnerships (please select all that apply).

- ○ Trip Planning integration (with multiple mobility options, including transit, along with real-time information)
- ○ Booking integration (for demand response options)
- ○ Payment integration
- ○ Other _____

Please select which of these MaaS one-stop interfaces you plan to implement in the next 1–2 years including public-private partnerships (please select all that apply).

- ○ Trip Planning integration (with multiple mobility options, including transit, along with real-time information)
- ○ Booking integration (for demand response options)
- ○ Payment integration
- ○ Other _____

Please provide application names or weblinks to the MaaS platform if available.

Were live real-time data sources readily available to you for MaaS platforms? If not, what standards/guidelines did you follow to set up data sharing protocols?

For payment integration, what access and sharing protocols did you/do you plan to follow? Please state specific guidelines/open-source projects/ standards if possible.

Did you experience or do you anticipate any challenges when implementing the MaaS platforms (please state briefly)?

What do you feel is the current level of standardized mobility data access and sharing protocols?

- ○ 5: Exceptionally standardized (all operators and vendors share same data structure and elements)
- ○ 4: Well standardized
- ○ 3: Just okay
- ○ 2: Barely standardized
- ○ 1: Not standardized at all (very inconsistent data structure and elements)

Is there a need to formally standardize the process of implementing MOD/ MaaS?

- ○ Yes
- ○ No

What in your opinion is more cost-effective for efficient MOD/MaaS implementation? International standard or industry-driven standard?

- ○ International standard – please elaborate below

_____

- ○ Industry driven – please elaborate below

_____

List 2 to 3 of the most informative project documents/standards/guidelines/ open-source protocols that have been essential when implementing MOD/ MaaS by your company?

_____

_____

_____

Please select to what level you agree to the following statements:

	Fully Agree	Somewhat Agree	Fully Disagree	Somewhat Disagree	No Comment
Current MOD/MaaS do not provide sufficient travel information	○	○	○	○	○
Lack of data sharing is a great concern to multimodal integration	○	○	○	○	○
Fair/non-discriminatory access for all MOD/MaaS operators is not granted	○	○	○	○	○
Lack of universal data sharing, security, and reuse protocols is a concern	○	○	○	○	○
More effort must be placed on highlighting sustainable travel options (trip carbon footprints, eco score, etc.)	○	○	○	○	○

Please provide any additional observations/comments/past findings that could better this research's outcomes.

End of Block: PRIVATE VENDOR

Start of Block: INDUSTRY EXPERT/RESEARCHER/ACADEMIC/ MOBILITY DATA CONSUMER

Which areas from this research do you think need more attention? (Please select all that apply)

- ☐ Trip Discovery (MOD standards for data sharing among service providers)
- ☐ Payment Systems (Identify minimum levels of data sharing for seamless integration of one-stop payments)
- ☐ Operations (Data standards to facilitate optimized transit operations)
- ☐ Other (please specify below)

_____

As experts, researchers, and data consumers, what do you feel is the current level of standardized mobility data access and sharing protocols?

- ○ 5: Exceptionally standardized (all operators and vendors share same data structure and elements)
- ○ 4: Well standardized
- ○ 3: Just okay
- ○ 2: Barely standardized
- ○ 1: Not standardized at all (very inconsistent data structure and elements)

Is there a need to formally standardize the process of implementing MOD/MaaS?

- ○ Yes
- ○ No

What in your opinion is more cost-effective for efficient MOD/MaaS implementation? International standard or industry-driven standard?

- ○ International standard – please elaborate below

_____

- ○ Industry driven – please elaborate below

_____

List 2 to 3 of the most informative documents/standards/guidelines/open-source protocols that you believe are essential when implementing MOD/MaaS.

Please select to what level you agree to the following statements:

	Fully Agree	Somewhat Agree	Fully Disagree	Somewhat Disagree	No Comment
Current MOD/MaaS do not provide sufficient travel information	○	○	○	○	○
Lack of data sharing is a great concern to multimodal integration	○	○	○	○	○
Fair/non-discriminatory access for all MOD/MaaS operators is not granted	○	○	○	○	○
Lack of universal data sharing, security, and reuse protocols is a concern	○	○	○	○	○
More effort must be placed on highlighting sustainable travel options (trip carbon footprints, eco score, etc.)	○	○	○	○	○

Please provide any additional observations/comments/past findings that could better this research's outcomes.

End of Block: INDUSTRY EXPERT/RESEARCHER/ACADEMIC/ MOBILITY DATA CONSUMER

Start of Block: WHAT TO EXPLORE FURTHER

How, in your opinion, can governing bodies/agencies such as FTA support open-source standards development and interoperability within MaaS/MOD? Please elaborate.

Please provide details (name and/or weblinks) of additional projects, case studies, MaaS/MOD platforms, standards, working groups, which can benefit this research. (Please select all that apply)

- [ ] Nothing to add
- [ ] In-progress projects/case studies/MOD and MaaS platforms
- [ ] New or existing standards
- [ ] Working groups / community forums

Are you familiar with the use of blockchain technology within the Mobility sector?

- ○ Yes
- ○ No

There are considerable discussions on using blockchain technology to facilitate interoperability within the Mobility sector. For instance, blockchain is being assessed to securely authenticate credentials (e.g., traveler eligibility information) to allow "roaming" services across jurisdictions, without requiring local registration in multiple applications. Please select to what level you agree to the following statements:

	Fully Agree	Somewhat Agree	Fully Disagree	Somewhat Disagree	No Comment
Blockchain is the future of MOD/MaaS	○	○	○	○	○
Blockchain can solve the lack of universal data sharing, security, and reuse protocols	○	○	○	○	○
Blockchain is still in initial stages and has some security concerns that have not been fully addressed	○	○	○	○	○
Blockchain promises more benefits to customers and operators when compared to traditional deep links	○	○	○	○	○
Blockchain is the best solution to interoperable deep integration (i.e., decentralized identities, secure payments, and real-time financial settlements)	○	○	○	○	○
Blockchain support and credentials should be incorporated into all current/ future MOD/MaaS standards	○	○	○	○	○

End of Block: WHAT TO EXPLORE FURTHER

Start of Block: CONTACT AND AFFILIATION:

Full Name (Please note that any personal information provided will not be distributed and will solely be used for purposes relating to this research)

Affiliation (Organization/Role)

Email (Please note that any personal information provided will not be distributed and will solely be used for purposes relating to this research)

Can we contact you for further consultation?

- ○ Yes
- ○ No

End of Block: CONTACT AND AFFILIATION:

Appendix G

Survey Results on FTA Considerations for Interoperability

Table G-1. *Raw Responses for FTA Considerations Toward Interoperability*

Action Category	Response	Participant Type
Lead standardization	The FTA should think about a model to follow and provide it as an example for the private industry to be able to visualize and adopt its use. For example, Wi-Fi standards have standard features that need to be included to meet the standard and a lot of variability in options that companies include or do not include.	Industry Expert / Mobility-Centric Organization / Researcher / Academic / Mobility Data Consumer
Lead standardization	FTA should be setting the standards—maybe even developing software/platforms—so there is an industry standard.	Industry Expert / Mobility-Centric Organization / Researcher / Academic / Mobility Data Consumer
Lead standardization	As with the internet names, the FTA should contract with an entity to guide standards development, data management, and address interoperability issues. This could be a new professional association funded by ride providers on a sliding scale based on size. This could be funded by FTA and awarded to a UTC for a five-year contract.	Industry Expert / Mobility-Centric Organization / Researcher / Academic / Mobility Data Consumer
Lead standardization	Coming up with common business requirements or user needs and then translating these into standard specification so there is a uniform structure to data across all states and service providers.	Industry Expert / Mobility-Centric Organization / Researcher / Academic / Mobility Data Consumer
Lead standardization	FTA can create the data sharing model.	Transit Operator / Provider
Lead standardization	Yes, but keep it simple, keep the paperwork volume down, keep it easy to implement and understand for EVERYONE.	Transit Operator / Provider
Lead standardization	Developing a standard through the NTD that we would all follow.	Transit Operator / Provider
Lead standardization	Support and encourage interoperability through creating standards that all parties can follow.	Transit Operator / Provider
Lead standardization	Assume leadership role in the development of; attach to requirements for funding to implement.	Transit Operator / Provider
Lead standardization	Develop standards and best practices.	Industry Expert / Mobility-Centric Organization / Researcher / Academic / Mobility Data Consumer
Lead standardization	Standardized data feed and open-source application such as real-time prediction so that agencies don't have to rely on private vendors.	Transit Operator / Provider

Action Category	Response	Participant Type
Fund solutions or set open-data requirements for access to funding	Support organizations like Mobilitydata.org that are working on international standards. It is important that these standards do not stop at our national borders. Also, support and provide funding for initial development and operations to operators to improve the amount and quality of data provided. And to standardize methods of implementation according to best practices.	Transit Operator / Provider
Fund solutions or set open-data requirements for access to funding	Provide for better funding and grant solutions for MOD.	Private Operator / Digital Mobility Service Provider / Technology Supplier
Fund solutions or set open-data requirements for access to funding	Improved consistency and standardization of guidance and funding.	Transit Operator / Provider
Fund solutions or set open-data requirements for access to funding	Holding MOD/MaaS to the same standards as traditional transit is not viable. Recognizing that a need for safe and equitable operations is still imperative, suggest a new set of standards based on findings from MOD/MaaS research projects.	Transit Operator / Provider
Fund solutions or set open-data requirements for access to funding	Ensure that data standards can be "digestible" for consumers of the data (not only for FTA but for neighboring agencies that coordinate regional planning efforts). For example, recipients of FTA funds have to submit data to the NTD. If we use the NTD to submit MaaS data, ensure the same conventions are used to submit data.	Transit Operator / Provider
Fund solutions or set open-data requirements for access to funding	Open source is critical.	Transit Operator / Provider
Fund solutions or set open-data requirements for access to funding	Fund services and pilots that embrace emerging open standards.	Transit Operator / Provider
Fund solutions or set open-data requirements for access to funding	Providing more money for planning and implementation.	Transit Operator / Provider
Fund solutions or set open-data requirements for access to funding	Yes – as a primary funding and rule setting agency, the FTA via the collaboration with organizations like APTA and Transportation Research Board (TRB), should support open-source standard development and interoperability with MaaS and MOD.	Industry Expert / Mobility-Centric Organization / Researcher / Academic / Mobility Data Consumer
Fund solutions or set open-data requirements for access to funding	Host forums, workshops, conferences that debate the merits of different standards and deliberate whether FTA wants to bless one open-source standard over another. Looking for FTA to provide guidance.	Transit Operator / Provider

Action Category	Response	Participant Type
Fund solutions or set open-data requirements for access to funding	Require open-source standards for these services as part of procurement. Standard/common procurement language would assist transit agencies in acquiring these services without having to be software/coding experts.	Industry Expert / Mobility-Centric Organization / Researcher / Academic / Mobility Data Consumer
Fund solutions or set open-data requirements for access to funding	Support the development of open standards.	Transit Operator / Provider
Fund solutions or set open-data requirements for access to funding	Provide funding for more research and training to operators. Highlight industry best practices. Provide start-up funds for pilot programs in underserved communities.	Industry Expert / Mobility-Centric Organization / Researcher / Academic / Mobility Data Consumer
Fund solutions or set open-data requirements for access to funding	Mandate standards as part of funding or licensing requirements.	Transit Operator / Provider
Fund solutions or set open-data requirements for access to funding	They should develop a full mobility program which includes requirements for open data to access funding.	Industry Expert / Mobility-Centric Organization / Researcher / Academic / Mobility Data Consumer
Fund solutions or set open-data requirements for access to funding	Establish and promote collaborative workshops. Once established, provide agencies and cities with language to require specifications in RFPs.	Transit Operator / Provider
Fund solutions or set open-data requirements for access to funding	Identifying "holes" in existing standards and funding projects that will bridge these holes. For example, an OnDemand operational model, or paratransit eligibility standard.	Industry Expert / Mobility-Centric Organization / Researcher / Academic / Mobility Data Consumer
Fund solutions or set open-data requirements for access to funding	Incentivize large data consumers (mapping providers) to adopt these standards.	Industry Expert / Mobility-Centric Organization / Researcher / Academic / Mobility Data Consumer
Fund solutions or set open-data requirements for access to funding	The governing agencies should support open-source standards in MaaS to open the market and garantee the development of multiple solutions based on.	Transit Operator / Provider
Leave it alone	Leave alone. Overly specific standards will work against private sector options in rural and smaller locations.	Transit Operator / Provider
Leave it alone	Do not require systems to standardize – it will limit system implementation options.	Transit Operator / Provider
Leave it alone	I'm not sure FTA has the power to handle the political lobbying which commercial entities use to prevent tighter intra-network integration.	Transit Operator / Provider
Leave it alone	This survey is a good start – hearing from the users and providing that to the vendors.	Transit Operator / Provider

Action Category	Response	Participant Type
Facilitate agency coordination	FTA needs to engage outside the USA. Standards are accelerating in Europe and APAC and the third-party providers are adopting these standards already, which means there will be a hurdle to overcome in the USA. Quicker adoption will be available if FTA engages externally.	Industry Expert / Mobility-Centric Organization / Researcher / Academic / Mobility Data Consumer
Facilitate agency coordination	The FTA, if involved, needs to provide clear direction and support. There should be heavy emphasis on collaboration. Other government entities shouldn't be able to infringe on public transportation's on demand space. (like Medicaid) without some cooperation and direction from the FTA.	Transit Operator / Provider
Facilitate agency coordination	IME FTA is very skilled at convening stakeholders and helping to share emerging best practices across the industry.	Private Operator / Digital Mobility Service Provider / Technology Supplier
Facilitate agency coordination	Facilitate an industry/government/transit dialogue to agree on standards. DO NOT try to do this from DoT/FTA; this is all too new and too underdeveloped.	Industry Expert / Mobility-Centric Organization / Researcher / Academic / Mobility Data Consumer
Facilitate agency coordination	Break through the turf wars and require all federal agencies to coordinate in practice, not just words.	Transit Operator / Provider
Other	I would like to bring some past experience, probably 25+ years, to the table with a working group to assemble knowledge skills and experience and lessons learned to develop the initial footprint of the universal model.	Industry Expert / Mobility-Centric Organization / Researcher / Academic / Mobility Data Consumer
Other	Reviewing ADA regulations and standards equitable services and guidelines. Funding for these services can be difficult to identify.	Transit Operator / Provider
Other	Those who need it for daily living need access to the tools that it takes to use it. Don't forget about rural USA as they have the greatest barriers to transportation and that is magnified for people with personal barriers beyond this.	Industry Expert / Mobility-Centric Organization / Researcher / Academic / Mobility Data Consumer
Other	Lead the effort and identify where new services don't support current funding/reporting requirements and provide flexibility.	Transit Operator / Provider
Other	FTA must move beyond separate categorizations of metrics such as ridership, emissions, population demographics, etc. The trips should be evaluated on outcomes. Outcome of the trip to provide equitable access to all – can a person move; safely, cleanly, in a reasonable timeframe, and achieve the goal (job, health appointment, entertainment, etc). There is currently nothing which says moving people en mass is changing broken systems and downward trends of American lifestyle: poor health; cost of living; participation in labor force; supporting local economies. Too much emphasis on speed of vehicles, aggregated emissions data, and # of riders/SOV.	Transit Operator / Provider
Other	Need to be forced do it and provided guidance for how it can be done best.	Transit Operator / Provider

Appendix H

Blueprint for the Mobility Standards and Guidelines Resource (MSGR) Tool

Table H-1. *Taxonomy*

	Summary	Standards	Guidance / Open Source
Mobility on Demand (MOD)	USDOT envisions MOD as a safe, reliable, and carefree mobility ecosystem that supports complete trips for all, both personalized mobility and goods delivery. MOD has three major guiding principles: traveler centric and consumer driven, data connected and platform independent, multimodal and mode agnostic. (Shaheen et al., 2017) The USDOT Intelligent Transportation Systems Joint Program Office (ITS JPO) describes MOD as an innovative, user focused approach that leverages transit networks and operations, real-time data, connected travelers, and cooperative Intelligent Transportation Systems (ITS) to allow for a more traveler-centric, transportation system-of-systems approach, providing improved mobility options to all travelers and users of the system in an efficient and safe manner. MOD is an integrated and connected multimodal network of safe, affordable, and reliable transportation options that are available and accessible to all travelers. [FTA Office of Research, Demonstration and Innovation]	SAE JA3163: https://www.sae.org/standards/content/ja3163_202106/ SAE J3163: https://www.sae.org/standards/content/j3163_202208/ ISO TC 204: TS 14812 https://www.iso.org/standard/79779.html	Shaheen, S., Cohen, A., Yelchuru, B., & Sarkhili, S. (2017). Mobility on Demand Operational Concept Report. Retrieved from https://rosap.ntl.bts.gov/view/dot/34258 ITS JPO – Mobility on Demand: https://www.its.dot.gov/research_archives/mod/index.htm

	Summary	Standards	Guidance / Open Source
Mobility as a Service (MaaS)	United States: MaaS is a mobility platform in which a traveler can access multiple transportation services over a single digital interface. MaaS primarily focuses on passenger mobility (and in some cases goods delivery) allowing travelers to seamlessly plan, book, and pay for a multimodal trip on a pay-as-you-go and/or subscription basis. (Shaheen & Cohen, 2020; Shaheen et al., 2020) Europe: MaaS Integrates various forms of transport services into a single mobility service accessible on demand. A MaaS operator facilitates a diverse menu of transport options to meet a customer's request, 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 by using a single application to provide access to mobility with a single payment channel instead of multiple ticketing and payment operations (Schweiger et al., 2019). United Kingdom: MaaS can be used to describe digital transport service platforms that enable users to access, pay for, and get real-time information on a range of public and private transport options (Enoch, 2018).	SAE JA3163: https://www.sae.org/standards/content/ja3163_202106/ SAE J3163: https://www.sae.org/standards/content/j3163_202208/ ISO TC 204: TS 14812 https://www.iso.org/standard/79779.html	Lyons, G., Hammond, P., & Mackay, K. (2019). The importance of user perspective in the evolution of MaaS. *Transportation Research Part A: Policy and Practice, 121*, 22–36. doi: https://doi.org/10.1016/j.tra.2018.12.010 Enoch, M. (2018). Mobility as a Service (MaaS) in the UK: change and its implications. *Government Office for Science, London*. Schweiger, C., O'Reilly, K., Chang, A., Guan, A., Okunieff, P. E., Neelakantan, R., . . . Peck, C. (2019). Forward-Looking Assessment White Paper: Multimodal and Accessible Travel Standards Assessment – Task 2. Retrieved from https://rosap.ntl.bts.gov/view/dot/53933 Transportation Research Board. (2020). *Development of Transactional Data Specifications for Demand-Responsive Transportation*. Washington, DC: The National Academies Press. https://sharedusemobilitycenter.org/the-transactional-data-specification-a-building-block-for-equitable-mobility-as-a-service/

	Summary	Standards	Guidance / Open Source
	Australia: "MaaS is a framework for delivering a portfolio of multi-modal mobility services that places the user at the center of the offer. MaaS frameworks are ideally designed to achieve sustainable policy goals and objectives. MaaS is an integrated transport service brokered by an integrator through a digital platform. A digital platform provides information, booking, ticketing, payment (as pay-as-you-go and/or subscription plans), and feedback that improves the travel experience. The MaaS framework can operate at any spatial scale (i.e., urban, regional, or global) and cover any combination of multi-modal and non-transport-related multi-service offerings, including the private car and parking, whether subsidized or not by the public sector. MaaS is not simply a digital version of a travel planner, nor a flexible transport service (such as Mobility on Demand), nor a single shared transport offering (such as car sharing). 'Emerging MaaS' best describes MaaS offered on a niche foundation. This relates to situations where MaaS is offered on a limited spatial scale, to a limited segment of society or focused on limited modes of transport. The MaaS framework becomes mainstream when the usage by travelers dominates a spatial scale and the framework encompasses a majority of the modes of transport." (Hensher, Mulley, & Nelson, 2021)		
Comparison	MOD is a term more commonly used in the United States, while MaaS is used in other parts of the world (Europe, Asia, Australia, and others). The definitions and descriptions of the two terms indicate that there are some similarities but also differences. MaaS emphasizes app-based service and availability of subscription models. MOD is intended to facilitate improved personal travel and goods delivery (Shaheen & Cohen, 2020). However, both MOD and MaaS converge on their emphasis toward physical, fare, and digital multimodal integration (Shaheen & Cohen, 2020).	ISO TC 204: TR 4447 https://www.iso.org/standard/79979.html	Chang, A., Guan, A., Okunieff, P. E., Heggedal, K., Brown, L., Schweiger, C., & O'Reilly, K. (2019). Multimodal and Accessible Travel Standards Assessment [Survey of Standards and Emerging Standards White Paper]. Retrieved from https://rosap.ntl.bts.gov/view/dot/43633 MaaS-Alliance. (2021). *Interoperability for Mobility, Data Models, and API*. Retrieved from https://maas-alliance.eu/wp-content/uploads/2021/11/20211120-Def-Version-Interoperaability-for-Mobility.-Data-Models-and-API-_-FINAL.pdf Shaheen, S., & Cohen, A. (2020). Similarities and Differences of Mobility on Demand (MOD) and Mobility as a Service (MaaS). *Institute of Transportation Engineers. ITE Journal, 90*(6), 29-35. Retrieved from https://www.proquest.com/scholarly-journals/similarities-differences-mobility-on-demand-mod/docview/2410838231/se-2?accountid=14745

Table H-2. *Mode-Specific Guidance: Walk*

	Standards	Guidance/Open Source	Case Studies / Examples
Trip Discovery	ISO 20524-1:2020: https://www.iso.org/standard/68244.html ISO 17572-4:2020: https://www.iso.org/standard/72984.html ISO 19237:2017: https://www.iso.org/standard/64111.html		Google Maps: https://www.google.com/maps Accessmaps, Seattle WA: https://www.accessmap.io/ Citymapper: https://citymapper.com/?lang=en
Payment			
Operations	Open Mobility Foundation. (2022). Curb Data Specification (CDS). https://github.com/openmobilityfoundation/curb-data-specification Public Right-of-Way Accessibility Guidelines (PROWAG): https://www.access-board.gov/files/prowag/PROW-SUP-SNPRM-2013.pdf ISO 4448 Sidewalk and kerb operations for automated vehicles (under development) https://www.mobilityits.eu/kerbside-management Consumer Technology Association ANSI/CTA-2076: https://gnc3.com/wp-content/uploads/2020/01/Inclusive-Audio-based-Network-Navigation-Systems-for-All-Persons-including-those-Who-are-Blind-Low-Vision5.pdf	Bouattoura, F., Zingalli, J., Brown, L., Gopalakrishna, D., & Neelakantan, R. (2020). Mobility on Demand Marketplace Concept of Operations Blueprint. Retrieved from https://rosap.ntl.bts.gov/view/dot/53343 Okunieff, P. E., Brown, L., Heggedal, K., O'Reilly, K., Weisenberger, T., Guan, A., . . . Schweiger, C. (2020). Multimodal and Accessible Travel Standards Assessment – Outreach Report. Retrieved from https://rosap.ntl.bts.gov/view/dot/55242 DUK Department of Transport. (2021). Inclusive Mobility: A Guide to Best Practice on Access to Pedestrian and Transport Infrastructure. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1044542/inclusive-mobility-a-guide-to-best-practice-on-access-to-pedestrian-and-transport-infrastructure.pdf CurbLR: https://www.curblr.org/	Shaheen, S. A., Cohen, A. P., Broader, J., Davis, R., Brown, L., Neelakantan, R., & Gopalakrishna, D. (2020). Mobility on Demand Planning and Implementation: Current Practices, Innovations, and Emerging Mobility Futures. Retrieved from https://rosap.ntl.bts.gov/view/dot/50553

Table H-3. *Mode-Specific Guidance: Bike/Micromobility*

	Standards	Guidance/Open Source	Case Studies / Examples
Trip Discovery		General Bikeshare Feed Specification (GBFS): https://nabsa.net/resources/gbfs/ General Bikeshare Feed Specification (GBFS) +: https://github.com/openbikeshare/gbfsplus MaaS Alliance: Interoperability for Mobility, Data Models, and API: https://maas-alliance.eu/wp-content/uploads/2021/11/20211120-Def-Version-Interoperaability-for-Mobility.-Data-Models-and-API-_-FINAL.pdf Transport Operator Mobility-as-a-service Provider (TOMP): https://github.com/TOMP-WG/TOMP-API Institute for Transportation and Development Policy. (2013). "Riding the Bike-Share Boom: The Top Five Components of a Successful System." Available at: https://itdp.org/publication/riding-the-bike-share-boom-the-top-five-components-of-a-successful-system/	Trafi Vilnius, Vilnius, Lithuania: https://www.trafi.com/vilnius/ eHubs – Smart shared green mobility hubs: https://www.nweurope.eu/projects/project-search/ehubs-smart-shared-green-mobility-hubs/ City of Olathe and Mid America Regional Council. (2018). Bike Share Implementation Strategy. https://www.marc.org/sites/default/files/2022-06/PSP-Projects-2019-Olathe_Final-Plan.pdf
Payment	ISO/TR 21724-1:2020 https://www.iso.org/standard/71511.html	Transport Operator Mobility-as-a-service Provider (TOMP): https://github.com/TOMP-WG/TOMP-API Garcia, J. R. R., van den Belt, E., Bakermans, B., & Groen, T. (2020). Blueprint for an Application Programming Interface (API) from Transport Operator to MaaS Provider (TOMP-API). https://github.com/TOMP-WG/TOMP-API/blob/master/documents/200301%20-%20Blueprint%20for%20a%20TOMP%20API%20v1.2.pdf	MaaS in Netherlands – seven pilots: https://maas-alliance.eu/wp-content/uploads/2019/08/MaaS-of-the-Month-Supporting-MaaS-with-pilots.pdf Transit app: https://resources.transitapp.com/article/396-mobile-ticketing-api-guidelines

	Standards	Guidance/Open Source	Case Studies / Examples
Operations	SAE J3194: https://www.sae.org/standards/content/j3194_201911/ ISO 43.150 Cycles https://www.iso.org/ics/43.150/x/ CEN EN 17128:2020: https://standards.iteh.ai/catalog/standards/cen/06f10ef5-7444-4c8d-bdf5-1090295e5031/en-17128-2020 MDC00001202004 Guidelines for Mobility Data Sharing Governance and Contracting: https://www.sae.org/standards/content/mdc00001202004/ ISO 4448 Sidewalk and kerb operations for automated vehicles (under development) https://www.mobilityits.eu/kerbside-management ISO 22085 – 1 through 3: https://www.iso.org/standard/75366.html	General Bikeshare Feed Specification (GBFS): https://nabsa.net/resources/gbfs/ Mobility Data Specification (MDS): https://www.openmobilityfoundation.org/about-mds/ City Data Standard for Mobility (CDS-M): https://www.polisnetwork.eu/wp-content/uploads/2021/03/CDS-M_Blueprint_v0.0.1.docx2_.pdf Transportation Research Board. (2022). Micromobility Policies, Permits, and Practices. Washington, DC: The National Academies Press. https://nap.nationalacademies.org/catalog/26815/micromobility-policies-permits-and-practices CurbLR: https://www.curblr.org/	MaaS in Netherlands – seven pilots: https://maas-alliance.eu/wp-content/uploads/2019/08/MaaS-of-the-Month-Supporting-MaaS-with-pilots.pdf City of Olathe and Mid America Regional Council. (2018). Bike Share Implementation Strategy. https://www.marc.org/sites/default/files/2022-06/PSP-Projects-2019-Olathe_Final-Plan.pdf Institute for Transportation and Development Policy. (2018).The Bikeshare Planning Guide. https://www.transformative-mobility.org/assets/publications/The-Bikeshare-Planning-Guide-ITDP-Datei.pdf Smart Columbus, OH: https://d2rfd3nxvhnf29.cloudfront.net/2021-06/SCC-J-Program-Final%20Report-Final-V2_0.pdf

Table H-4. *Mode-Specific Guidance: Rail/Metro*

	Standards	Guidance/Open Source	Case Studies / Examples
Trip Discovery	ISO/TS 4398:2022 https://www.iso.org/standard/79916.html#:~:text=This%20document%20specifies%20an%20open,a%20track%2Dbound%20transportation%20system EN 12896: Public Transport Reference Data Model: https://www.en-standard.eu/csn-en-12896-1-public-transport-reference-data-model-part-1-common-concepts/ EN 15531: https://www.en-standard.eu/csn-en-15531-2-public-transport-service-interface-for-real-time-information-relating-to-public-transport-operations-part-2-communications/	General Transit Feed Specification (GTFS): https://gtfs.org/ Caltrans – California Minimum GTFS Guidelines: https://dot.ca.gov/cal-itp/california-minimum-general-transit-feed-specification-gtfs-guidelines-v2_0 Schweiger, C., O'Reilly, K., Chang, A., Guan, A., Okunieff, P. E., Neelakantan, R., . . . Peck, C. (2019). Forward-Looking Assessment White Paper: Multimodal and Accessible Travel Standards Assessment – Task 2. Retrieved from https://rosap.ntl.bts.gov/view/dot/53933 MaaS Alliance: Interoperability for Mobility, Data Models, and API: https://maas-alliance.eu/wp-content/uploads/2021/11/20211120-Def-Version-Interoperaability-for-Mobility.-Data-Models-and-API-_-FINAL.pdf	
Payment	ISO 24014-1:2021 https://www.iso.org/standard/72507.html APTA Universal Transit Fare Systems (UTFS) https://www.apta.com/research-technical-resources/standards/technology/	General Transit Feed Specification (GTFS) – Fares v2: https://gtfs.org/schedule/examples/fares-v2/	Regional Transportation District (RTD), Uber, Masabi-Denver, Colorado: https://www.rtd-denver.com/projects/uber-collaboration MaaS in Netherlands – seven pilots: https://maas-alliance.eu/wp-content/uploads/2019/08/MaaS-of-the-Month-Supporting-MaaS-with-pilots.pdf

	Standards	Guidance/Open Source	Case Studies / Examples
Operations	EN 12896 (aka Transmodel): Public Transport Reference Data Model: https://www.en-standard.eu/csn-en-12896-1-public-transport-reference-data-model-part-1-common-concepts/ APTA Rail Transit Systems Standards https://www.apta.com/research-technical-resources/standards/rail/ APTA TCIP-S-001: https://www.apta.com/research-technical-resources/standards/technology/apta-tcip-s-001-4-1-1/	General Transit Feed Specification (GTFS) – Realtime: https://gtfs.org/realtime/ Mobility Data Specification (MDS): https://www.openmobilityfoundation.org/about-mds/ TransitCenter, The Data Transit Riders Want: https://transitcenter.org/wp-content/uploads/2018/12/TC_TransitData_Final_FullLayout_121718-1.pdf Schweiger, C., O'Reilly, K., Chang, A., Guan, A., Okunieff, P. E., Neelakantan, R., . . . Peck, C. (2019). Forward-Looking Assessment White Paper: Multimodal and Accessible Travel Standards Assessment – Task 2. Retrieved from https://rosap.ntl.bts.gov/view/dot/53933	MaaS in Netherlands – seven pilots: https://maas-alliance.eu/wp-content/uploads/2019/08/MaaS-of-the-Month-Supporting-MaaS-with-pilots.pdf

Table H-5. *Mode-Specific Guidance: Fixed Route Bus*

	Standards	Guidance/Open Source	Case Studies / Examples
Trip Discovery	EN 12896: Public Transport Reference Data Model: https://www.en-standard.eu/csn-en-12896-1-public-transport-reference-data-model-part-1-common-concepts/ EN 15531: https://www.en-standard.eu/csn-en-15531-2-public-transport-service-interface-for-real-time-information-relating-to-public-transport-operations-part-2-communications/	General Transit Feed Specification (GTFS): https://gtfs.org/ Caltrans – California Minimum GTFS Guidelines: https://dot.ca.gov/cal-itp/california-minimum-general-transit-feed-specification-gtfs-guidelines-v2_0 Schweiger, C., O'Reilly, K., Chang, A., Guan, A., Okunieff, P. E., Neelakantan, R., . . . Peck, C. (2019). Forward-Looking Assessment White Paper: Multimodal and Accessible Travel Standards Assessment – Task 2. Retrieved from https://rosap.ntl.bts.gov/view/dot/53933 MaaS Alliance: Interoperability for Mobility, Data Models, and API: https://maas-alliance.eu/wp-content/uploads/2021/11/20211120-Def-Version-Interoperaability-for-Mobility.-Data-Models-and-API-_-FINAL.pdf	Bristol One City, United Kingdom: https://opendata.bristol.gov.uk/ King County, WA: https://kingcounty.gov/depts/transportation/metro/travel-options/bus/app-center.aspx
Payment	ISO 24014-1:2021 https://www.iso.org/standard/72507.html ISO/TR 21724-1:2020 https://www.iso.org/standard/71511.html	General Transit Feed Specification (GTFS) – Fares v2: https://gtfs.org/schedule/examples/fares-v2/	iMOVE Sydney MaaS Trial, Sydney, Australia: https://imoveaustralia.com/wp-content/uploads/2021/04/iMOVE-Sydney-MaaS-Trial-Final-Report-March-2021.pdf Regional Transportation District (RTD), Uber, Masabi-Denver, Colorado: https://www.rtd-denver.com/projects/uber-collaboration Transit app: https://resources.transitapp.com/article/396-mobile-ticketing-api-guidelines

	Standards	Guidance/Open Source	Case Studies / Examples
Operations	EN 12896: Public Transport Reference Data Model: https://www.en-standard.eu/csn-en-12896-1-public-transport-reference-data-model-part-1-common-concepts/ APTA TCIP-S-001: https://www.apta.com/research-technical-resources/standards/technology/apta-tcip-s-001-4-1-1/	General Transit Feed Specification (GTFS) – Realtime: https://gtfs.org/realtime/ Mobility Data Specification (MDS): https://www.openmobilityfoundation.org/about-mds/ TransitCenter, The Data Transit Riders Want: https://transitcenter.org/wp-content/uploads/2018/12/TC_TransitData_Final_FullLayout_121718-1.pdf Schweiger, C., O'Reilly, K., Chang, A., Guan, A., Okunieff, P. E., Neelakantan, R., . . . Peck, C. (2019). Forward-Looking Assessment White Paper: Multimodal and Accessible Travel Standards Assessment – Task 2. Retrieved from https://rosap.ntl.bts.gov/view/dot/53933 Operational Data Standards (Personnel and Deadheads): https://docs.calitp.org/operational-data-standard/	iMOVE Sydney MaaS Trial, Sydney, Australia: https://imoveaustralia.com/wp-content/uploads/2021/04/iMOVE-Sydney-MaaS-Trial-Final-Report-March-2021.pdf Smart Columbus, OH: https://d2rfd3nxvhnf29.cloudfront.net/2021-06/SCC-J-Program-Final%20Report-Final-V2_0.pdf Transit App: https://resources.transitapp.com/article/404-fixed-route-transit-information

Table H-6. *Mode-Specific Guidance: Flexible Route Bus*

	Standards	Guidance/Open Source	Case Studies / Examples
Trip Discovery	EN 12896: Public Transport Reference Data Model: https://www.en-standard.eu/csn-en-12896-1-public-transport-reference-data-model-part-1-common-concepts/ EN 15531: https://www.en-standard.eu/csn-en-15531-2-public-transport-service-interface-for-real-time-information-relating-to-public-transport-operations-part-2-communications/	General Transit Feed Specification (GTFS): https://gtfs.org/ Caltrans– California Minimum GTFS guidelines: https://dot.ca.gov/cal-itp/california-minimum-general-transit-feed-specification-gtfs-guidelines-v2_0 Schweiger, C., O'Reilly, K., Chang, A., Guan, A., Okunieff, P. E., Neelakantan, R., . . . Peck, C. (2019). Forward-Looking Assessment White Paper: Multimodal and Accessible Travel Standards Assessment – Task 2. Retrieved from https://rosap.ntl.bts.gov/view/dot/53933 MaaS Alliance: Interoperability for Mobility, Data Models, and API: https://maas-alliance.eu/wp-content/uploads/2021/11/20211120-Def-Version-Interoperaability-for-Mobility.-Data-Models-and-API-_-FINAL.pdf	Craig, T., & Shippy, W. (2020). GTFS Flex – What Is It and How Is It Used? Retrieved from https://n-catt.org/wp-content/uploads/2020/12/GTFS-Flex_WhitePaper_Final.pdf OpenTripPlanner: http://docs.opentripplanner.org/en/v1.5.0/Flex/#gtfs-flex-routing Fiscal Year 2016 Mobility on Demand (MOD) Sandbox Program Projects: https://www.transit.dot.gov/research-innovation/fiscal-year-2016-mobility-demand-mod-sandbox-program-projects

	Standards	Guidance/Open Source	Case Studies / Examples
Payment	ISO 24014-1:2021 https://www.iso.org/standard/72507.html ISO/TR 21724-1:2020 https://www.iso.org/standard/71511.html	General Transit Feed Specification (GTFS) – Fares v2: https://gtfs.org/schedule/examples/fares-v2/	Fiscal Year 2016 Mobility on Demand (MOD) Sandbox Program Projects: https://www.transit.dot.gov/research-innovation/fiscal-year-2016-mobility-demand-mod-sandbox-program-projects
Operations	EN 12896: Public Transport Reference Data Model: https://www.en-standard.eu/csn-en-12896-1-public-transport-reference-data-model-part-1-common-concepts/	General Transit Feed Specification (GTFS) – Realtime: https://gtfs.org/realtime/ General Transit Feed Specification (GTFS) – Flex v2: https://github.com/MobilityData/gtfs-flex Mobility Data Specification (MDS): https://www.openmobilityfoundation.org/about-mds/ TransitCenter, The Data Transit Riders Want: https://transitcenter.org/wp-content/uploads/2018/12/TC_TransitData_Final_FullLayout_121718-1.pdf Schweiger, C., O'Reilly, K., Chang, A., Guan, A., Okunieff, P. E., Neelakantan, R., . . . Peck, C. (2019). Forward-Looking Assessment White Paper: Multimodal and Accessible Travel Standards Assessment – Task 2. Retrieved from https://rosap.ntl.bts.gov/view/dot/53933 Transactional Data Specification (TDS): https://sharedusemobilitycenter.org/the-transactional-data-specification-a-building-block-for-equitable-mobility-as-a-service/	Fiscal Year 2016 Mobility on Demand (MOD) Sandbox Program Projects: https://www.transit.dot.gov/research-innovation/fiscal-year-2016-mobility-demand-mod-sandbox-program-projects

Table H-7. *Mode-Specific Guidance: On-Demand/Microtransit*

	Standards	Guidance/Open Source	Case Studies / Examples
Trip Discovery		General On-demand Feed Specification (GOFS)-lite: https://github.com/GOFS-lite/GOFS-lite General On-demand Feed Specification (GOFS): https://share.mobilitydata.org/gtfs-ondemand; https://mobilitydata.org/why-on-demand-transportation-needs-to-be-standardized/ General Transit Feed Specification (GTFS) – Flex v2: https://github.com/MobilityData/gtfs-flex	Smart Columbus, OH: https://d2rfd3nxvhnf29.cloudfront.net/2021-06/SCC-J-Program-Final%20Report-Final-V2_0.pdf King County, WA: https://kingcounty.gov/depts/transportation/metro/travel-options/bus/app-center.aspx Regional Transportation District (RTD), Uber, Masabi-Denver, Colorado: https://www.rtd-denver.com/projects/uber-collaboration Patel, R., Etminani-Ghasrodashti, R., Kermanshachi, S., Rosenberger, J. M., Foss, A. (2022). Mobility-on-demand (MOD) Projects: A study of the best practices adopted in United States. https://www.sciencedirect.com/science/article/pii/S259019822200063X
Payment	ISO 24014-1:2021 https://www.iso.org/standard/72507.html ISO/TR 21724-1:2020 https://www.iso.org/standard/71511.html	General Transit Feed Specification (GTFS) – Fares v2: https://gtfs.org/schedule/examples/fares-v2/	Regional Transportation District (RTD), Uber, Masabi-Denver, Colorado: https://www.rtd-denver.com/projects/uber-collaboration

	Standards	Guidance/Open Source	Case Studies / Examples
Operations		General On-demand Feed Specification (GOFS)-lite: https://github.com/GOFS-lite/GOFS-lite General On-demand Feed Specification (GOFS): https://share.mobilitydata.org/gtfs-ondemand; https://mobilitydata.org/why-on-demand-transportation-needs-to-be-standardized/ General Transit Feed Specification (GTFS) – Flex v2: https://github.com/MobilityData/gtfs-flex Mobility Data Specification (MDS): https://www.openmobilityfoundation.org/about-mds/ SUTI: https://trid.trb.org/view/1494371 Transactional Data Specification (TDS): https://sharedusemobilitycenter.org/the-transactional-data-specification-a-building-block-for-equitable-mobility-as-a-service/	Transit App: https://resources.transitapp.com/article/401-on-demand-transit#gofs iMOVE Sydney MaaS Trial, Sydney, Australia: https://imoveaustralia.com/wp-content/uploads/2021/04/iMOVE-Sydney-MaaS-Trial-Final-Report-March-2021.pdf Smart Columbus, OH: https://d2rfd3nxvhnf29.cloudfront.net/2021-06/SCC-J-Program-Final%20Report-Final-V2_0.pdf

Table H-8. *Mode-Specific Guidance: Paratransit ADA*

	Standards	Guidance/Open Source	Case Studies / Examples
Trip Discovery	EN 12896: Public Transport Reference Data Model: https://www.en-standard.eu/csn-en-12896-1-public-transport-reference-data-model-part-1-common-concepts/	General Transit Feed Specification (GTFS): https://gtfs.org/ General Transit Feed Specification (GTFS) – Pathways/ PathwayUpdates: https://gtfs.org/extensions/	Accessmaps, Seattle WA: https://www.accessmap.io/ Mobility on Demand (MOD) Sandbox Demonstration: Pinellas Suncoast Transit Authority (PSTA) Public-Private-Partnership for Paratransit Evaluation Report: https://www.transit.dot.gov/sites/fta.dot.gov/files/2022-04/FTA-Report-No-0213_0.pdf Mobility on Demand (MOD) Sandbox Demonstration: Dallas Area Rapid Transit (DART) First and Last Mile Solution: https://www.transit.dot.gov/sites/fta.dot.gov/files/2021-06/FTA-Report-No-0195.pdf Mobility On-Demand Every Day Program – Santa Monica, California: https://www.bigbluebus.com/Rider-Info/Mobility-On-Demand-Every-Day-Program.aspx
Payment	ISO 24014-1:2021 https://www.iso.org/standard/72507.html ISO/TR 21724-1:2020 https://www.iso.org/standard/71511.html	General Transit Feed Specification (GTFS) – Fares v2: https://gtfs.org/schedule/examples/fares-v2/	Fiscal Year 2016 Mobility on Demand (MOD) Sandbox Program Projects: https://www.transit.dot.gov/research-innovation/fiscal-year-2016-mobility-demand-mod-sandbox-program-projects

	Standards	Guidance/Open Source	Case Studies / Examples
Operations	National RTAP – General Requirements for All Service Types: https://www.nationalrtap.org/Toolkits/ADA-Toolkit/Service-Type-Requirements/General-Requirements-Common-to-All-Service-Types 2010 ADA Standards for Accessible Design. https://www.ada.gov/regs2010/2010ADAStandards/2010ADAstandards.htm Public Right-of-Way Accessibility Guidelines (PROWAG): https://www.access-board.gov/files/prowag/PROW-SUP-SNPRM-2013.pdf SAE J3171_201911: https://www.sae.org/standards/content/j3171_201911/ ISO 10865-1/2: https://www.iso.org/standard/46214.html; https://www.iso.org/standard/46215.html	General Transit Feed Specification (GTFS) – Pathways/PathwayUpdates: https://gtfs.org/extensions/ Okunieff, P. E., Brown, L., Heggedal, K., O'Reilly, K., Weisenberger, T., Guan, A., . . . Schweiger, C. (2020). Multimodal and Accessible Travel Standards Assessment – Outreach Report. Retrieved from https://rosap.ntl.bts.gov/view/dot/55242 Chang, A., Guan, A., Okunieff, P. E., Heggedal, K., Brown, L., Schweiger, C., & O'Reilly, K. (2019). Multimodal and Accessible Travel Standards Assessment [Survey of Standards and Emerging Standards White Paper]. Retrieved from https://rosap.ntl.bts.gov/view/dot/43633 Transactional Data Specification (TDS): https://sharedusemobilitycenter.org/the-transactional-data-specification-a-building-block-for-equitable-mobility-as-a-service/	Mobility on Demand (MOD) Sandbox Demonstration: Pinellas Suncoast Transit Authority (PSTA) Public-Private-Partnership for Paratransit Evaluation Report: https://www.transit.dot.gov/sites/fta.dot.gov/files/2022-04/FTA-Report-No-0213_0.pdf Mobility on Demand (MOD) Sandbox Demonstration: Dallas Area Rapid Transit (DART) First and Last Mile Solution: https://www.transit.dot.gov/sites/fta.dot.gov/files/2021-06/FTA-Report-No-0195.pdf Mobility on Demand Every Day Program-Santa Monica, California: https://www.bigbluebus.com/Rider-Info/Mobility-On-Demand-Every-Day-Program.aspx

Table H-9. *Mode-Specific Guidance: Transportation Network Companies/Taxis/Sharing*

	Standards	Guidance/Open Source	Case Studies / Examples
Trip Discovery		Legislation Regulating Transportation Network Companies (TNC), Texas, 2017: https://learn.sharedusemobilitycenter.org/wp-content/uploads/policy-documents-2/HB00100F.pdf General On-demand Feed Specification (GOFS): https://share.mobilitydata.org/gtfs-ondemand; https://mobilitydata.org/why-on-demand-transportation-needs-to-be-standardized/ Transit, Ridehail and Taxi: https://resources.transitapp.com/article/403-ridehail-and-taxi Transport Operator Mobility-as-a-service Provider (TOMP): https://github.com/TOMP-WG/TOMP-API	Regional Transportation District (RTD), Uber, Masabi-Denver, Colorado: https://www.rtd-denver.com/projects/uber-collaboration Fiscal Year 2016 Mobility on Demand (MOD) Sandbox Program Projects: https://www.transit.dot.gov/research-innovation/fiscal-year-2016-mobility-demand-mod-sandbox-program-projects Uber API: https://developer.uber.com/docs/riders/ride-requests/introduction
Payment		Transport Operator Mobility-as-a-service Provider (TOMP): https://github.com/TOMP-WG/TOMP-API	Fiscal Year 2016 Mobility on Demand (MOD) Sandbox Program Projects: https://www.transit.dot.gov/research-innovation/fiscal-year-2016-mobility-demand-mod-sandbox-program-projects Regional Transportation District (RTD), Uber, Masabi-Denver, Colorado: https://www.rtd-denver.com/projects/uber-collaboration

	Standards	Guidance/Open Source	Case Studies / Examples
Operations	ISO 22085 – 1 through 3: https://www.iso.org/standard/75366.html	Transportation Research Board. (2019). TCRP Research Report 204: Partnerships Between Transit Agencies and Transportation Network Companies. Washington, DC: The National Academies Press. Available at: https://nap.nationalacademies.org/read/25576/chapter/1 General On-Demand Feed Specification (GOFS): https://share.mobilitydata.org/gtfs-ondemand; https://mobilitydata.org/why-on-demand-transportation-needs-to-be-standardized/ Mobility Data Specification (MDS): https://www.openmobilityfoundation.org/about-mds/ Shared Mobility: Current Practices and Guiding Principles: https://ops.fhwa.dot.gov/publications/fhwahop16022/ch5.htm State Legislation for TNCs: https://policy.tti.tamu.edu/technology/tnc-legislation/	Fiscal Year 2016 Mobility on Demand (MOD) Sandbox Program Projects: https://www.transit.dot.gov/research-innovation/fiscal-year-2016-mobility-demand-mod-sandbox-program-projects Shared-Use Mobility Center. (2019). Objective-Driven Data Sharing for Transit Agencies in Mobility Partnerships, White Paper: https://sharedusemobilitycenter.org/wp-content/uploads/2020/04/SUMC_IKA_DataSharingforTransitAgencies.pdf

Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ADA	Americans with Disabilities Act
ANSI	American National Standards Institute
API	Application Programming Interface
APTA	American Public Transportation Association
ATU	Amalgamated Transit Union
BART	Bay Area Rapid Transit
Cal-ITP	California Integrated Travel Project
CDS-M	City Data Standard for Mobility
CTA	Chicago Transit Authority
CTAA	Community Transportation Association of America
CUTR	Center for Urban Transportation Research
DART	Dallas Area Rapid Transit
DIDs	Decentralized Identifiers
DRT	Demand Responsive Transportation
DSRC	Dedicated Short-Range Communication
EU	European Union
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GAO	Government Accountability Office
GBFS	General Bikeshare Feed Specification
GOFS	General On-Demand Feed Specification
GTFS	General Transit Feed Specification
ISO	International Organization for Standardization
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
ITSJPO	USDOT Intelligent Transportation Systems Joint Program Office
LA Metro	Los Angeles County Metropolitan Transportation Authority
MaaS	Mobility as a Service
MARTA	Metropolitan Atlanta Rapid Transit Authority
MATSA	Multimodal and Accessible Travel Standardization Assessment
MBP	Mobility Blockchain Platform
MBTA	Massachusetts Bay Transportation Authority
MDS	Mobility Data Specification
MnDOT	Minnesota Department of Transportation
MOBI	Mobility Open Blockchain Initiative
MOD	Mobility on Demand

MSGR	Mobility Standards and Guidelines Resource Tool
NABSA	North American Bikeshare & Scootershare Association
NCDOT	North Carolina Department of Transportation
NGO	Non-governmental Organization
NYCT	New York City Transit
ODS	Operational Data Standard
OEM	Original Equipment Manufacturer
PCI	Payment Card Industry
PHI	Protected Health Information
PII	Personally Identifiable Information
PSTA	Pinellas Suncoast Transit Authority
ROW	Right-of-Way
RTAP	Rural Transit Assistance Program
RTD	Denver Regional Transportation District
SCOS	Smart Columbus Operating System
SDO	Standards Development Organization
SEPTA	Southeastern Pennsylvania Transportation Authority
SDP	Standards Development Program
TCIP	Transit Communications Interface Profiles
TDS	Transactional Data Specification
TNC	Transportation Network Company
TOMP	Transport Operator to MaaS Provider
TRB	Transportation Research Board
TriMet	Tri-County Metropolitan Transportation District of Oregon
USDOT	United States Department of Transportation
USF	University of South Florida
UTFS	Universal Transit Fare System
WMATA	Washington Metropolitan Area Transit Authority

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