International Transport Forum

CPB
Corporate Partnership Board

Mix and MaaS
Data Architecture for Mobility as a Service

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The International Transport Forum

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Camille Combe coordinated the project. Sharon Masterson manages the CPB and Philippe Crist manages CPB projects.

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Glossary

Application programming interface (API)	An API is a set of defined rules and protocols that enables different software applications to communicate with each other. APIs allow developers to access the functionality of an existing application or service, such as retrieving data or performing specific tasks, without having to know how the application is implemented.
Commercially sensitive data	There is no standard definition of what comprises "commercially sensitive data". The commercial sensitivity of data is often described in reference to trade secrets (ITF, 2021c; 2021d) or as data that, if disclosed, would harm a party's commercial interests (Welsh Government, 2021). However, while all confidential data are sensitive, not all sensitive data are confidential (ITF, 2021c; 2021d). Therefore, commercially sensitive data may be shared under specific circumstances and conditions.
Data controller	According to the EU's General Data Protection Regulation (GDPR), a data controller "means the natural or legal person, public authority, agency or other body which, alone or jointly with others, determines the purposes and means of the processing of personal data; where the purposes and means of such processing are determined by Union or Member State law, the controller or the specific criteria for its nomination may be provided for by Union or Member State law". The GDPR distinguishes data controllers from data processors. Yet, in some cases, an organisation may be a data processor and controller simultaneously. (European Commission, 2016)
Data mapping	Data mapping is an iterative process to find correspondence between a source data model and a target model. It can improve data sharing by allowing the identification of the similarities, differences and potential overlaps between data models.
Data portability	Data portability refers to the ability, sometimes construed as a right, for people to either obtain or transfer and delegate the transfer of their personal data from entities that collect and hold it to other entities of their choosing (OECD, 2021b). In the context of MaaS, data portability refers to the ability for travellers to authorise the transfer of their personal data in support of joined-up trips among several mobility operators.
Data processing	Data processing relates to operations performed on data or datasets, regardless of their sensitivity or automation. It comprises operations such as collecting, recording, organising, storing, structuring, adapting, altering, transmitting, disseminating, restricting, erasing or destroying. (European Commission, 2016)

Data sharing	Data sharing refers to the distribution process whereby data is transferred from data holders to data receivers; it does not encompass shared material (e.g. data shared). Thus, data sharing should not be interpreted as "shared data" (Support Centre for Data Sharing, 2022).
Data spaces	A data space is "a decentralised infrastructure for trustworthy data sharing and exchange in data ecosystems based on commonly agreed principles" (Nagel et al., 2021).
Data subject	A data subject refers to a person or an entity that can be identified directly or indirectly using an identifier. According to the GDPR, an identifier can be "a name, an identification number, location data, an online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person" (European Commission, 2016).
Deep link pathway	Deep linking is a link in an interface that redirects the user to another system to complete a purchase or otherwise interact with their systems (ITF, 2021).
General Transit Feed Specification (GTFS)	GTFS is a standardised format describing public transport schedules and services. GTFS data includes information on transit routes, stops, schedules, fares, and geographic information such as stop locations and shapes of transit routes. It allows developers to create applications such as trip planners, real-time arrival predictions, and maps that use the transit data. GTFS has a real-time instance, GTFS-RT, which relates to several observable, but not necessarily publicly available, data points such as service alerts, vehicle positions, and trip updates (Barbeau, 2018).
Informational data	Data containing general information on transport services (e.g. availability, location of stops, schedule, cost, etc.). Informational data allow MaaS providers to plan, create and communicate combined-mobility offers. (ITF, 2021).
Interoperability	Interoperability "refers to the ability of different digital services to work together and communicate with one another" (OECD, 2021b). In the context of MaaS, interoperability constitutes a form of data and system compatibility that enables different operators to deliver a combined service to the user (ITF, 2021).
MaaS providers	MaaS providers aggregate different mobility operators' services into a single offer through an application (MaaS app) or another digital interface (ITF, 2021).
Minimum Interoperability Mechanisms (MIMs)	MIMs "are the minimal but sufficient capabilities needed to achieve interoperability of data, systems, and services between buyers, suppliers and regulators across governance levels around the world" (LI.EU, 2021).
Mobility as a Service (MaaS)	MaaS is a distribution model for mobility services that uses shared data and a digital interface to efficiently source and manage transport-related services into a seamless offer tailored to individual traveller preferences. MaaS is typically delivered via an app or another digital interface combining different transport, information

	and payment services into a smooth and reliable digital customer experience.
Mobility operators	Mobility operators provide a physical mobility service. For example, they could be public transport operators, shared bicycle services, ridesourcing or car-sharing operators.
Operational data	Operational data is data enabling or supporting the operational delivery of mobility services – for example, by enabling gate or turnstile access, unlocking or locking a vehicle, terminating a shared vehicle trip, etc. (ITF, 2021; 2022)
Personal data	Personal data describes any information that can be linked directly or indirectly to a natural person. Personal data may relate to sensitive information (e.g. racial or ethnic origin, political opinions, religious affiliation, health status, etc.), which requires additional care.
Personal Information Management Systems (PIMS)	PIMS are a catch-all term that represents any technical tool that helps to address the imbalance of power and transparency about data use between individuals, and firms collecting their personal data. PIMS is provide users with tools to manage their privacy rights. Thia involves granting and revoking their consent for data processing — at a fine-grained level – with any given data controller, and exercising their legal rights, especially the right to data portability (Art. 20 GDPR) and the right to erasure (Art. 17 GDPR). (Krämer, 2021a)
Public service obligation (PSO)	A PSO refers to "specific requirements that are imposed by public authorities on the provider of the service in order to ensure that certain public interest objectives are met" (European Parliament, 2006). In the context of MaaS, PSO refer to obligations imposed on mobility operators – in particular those imposed on public transport operators.
Re-identification	Re-identification is an intentional isolation technique that enables the identification of an individual in a set of observed or volunteered data that has been anonymised. Article 29 Data Protection Working Party (A29WP) distinguishes two re-identification techniques: linkability and inference (Data Protection Working Party, 2014; Finck and Pallas, 2020). Data inference refers to the possibility of deducing a specific insight from data. Finally, linkability refers to the ability to match two records of the same data subjects.
Transactional data	Transactional data are data related to things a user purchases.
Transport Operator to MaaS Provider - Application Programming Interface (TOMP-API)	The TOMP-API (Transport Operator to MaaS Provider - Application Programming Interface) is a standardised technical interface between MaaS providers and transport operators initiated by the Dutch Ministry of Infrastructure and Water Management in 2018 in support of seven national MaaS pilots. Since 2020, the Transport Operator, MaaS Provider - Working Group (TOMP-WG) has been moved to become an open-source foundation with an international scope (TOMP-API, 2021).

Zero-knowledge proof-based signature	A zero-knowledge proof-based trust signature is a cryptographic technique used to verify the authenticity and integrity of data without revealing any sensitive information about that information or the parties involved in the verification process. This can help establish trust in digital transactions, such as online purchases or identity verification, while protecting the privacy and security of the parties involved.

Executive summary

What we did

Mobility as a Service (MaaS) is a promising, rapidly evolving approach to enabling seamless mobility. MaaS requires extensive data sharing among the actors of such an ecosystem and hence an appropriately adapted data governance framework. This report frames the context for data sharing for MaaS and establishes broad principles for its implementation.

What we found

Data is a form of infrastructure. Although immaterial, it shapes real-world outcomes and can help to achieve public policy objectives or work against them. Unlike material infrastructure, data infrastructure is poorly understood and rarely regulated. However, some public authorities are adopting an infrastructure approach to data governance, for instance, in Switzerland or the European Union.

Road, rail, port and airport infrastructure connects places. Mobility data infrastructure integrates services. MaaS delivers this integration as a user-centric distribution model for mobility services. With MaaS, travellers mix and match services as required. Data sharing allows mobility operators that deliver transport services, MaaS providers that integrate offers and data intermediaries to offer the seamless trips that travellers seek.

Data governance for MaaS must account for multiple data properties: are the data personal? How are the data sourced? What functionality do they support? Who can access it? Personal data requires special safeguards, including consent to sharing them within the MaaS ecosystem. Personal data covers data volunteered by individuals and other data specifically concerning them.

MaaS ecosystems require minimum data sharing obligations for participants. This enables a MaaS operator, for example, to join information regarding available shared bicycles and real-time train schedules and provide travellers with a single payment option and a means to access both services. Innovation and competition in the MaaS ecosystem should be founded on service offers, not on the ability to collect and hold data about travellers and operations. Nonetheless, data sharing should be limited to minimise risks associated with mandatory data sharing, especially concerning the onward sharing of data for purposes not consented to by travellers.

Data in MaaS ecosystems need to be interoperable, meaning that the systems of the different actors can work together. Interoperability requires a shared understanding of terminology and how terms relate.

MaaS ecosystems also require personal data to be portable from one system to another with traveller consent. Portability concerns rights and responsibilities about how and under what conditions data is transferred. A functioning and competitive MaaS ecosystem requires continuous data portability to enable real-time trips – not just ad-hoc data transfers. It is vital for user-centric services and is a precondition of interoperability.

A MaaS ecosystem requires a common data resource for all actors. Centralised data repositories controlled by one actor have been the norm for establishing this data resource in the past. However, this raises questions about trust and impartiality. A more effective approach makes the necessary common data resource accessible on-demand via application programming interfaces (APIs).

APIs enable sharing a subset of mobility operator data to vetted MaaS providers. They also serve to build seamless on-demand trips within the MaaS ecosystem. Furthermore, an API data sharing approach enables secondary and tertiary service markets such as payment processing, route calculation or identity authentication for people and vehicles, which could generate efficiencies and innovation. As that happens, the role of the MaaS provider shifts from integrating mobility offers to orchestrating mobility-linked services.

Most actors in the mobility sector already rely on data to build and run their services. However, the future MaaS ecosystem will require convergence around data standards and new data sharing mechanisms. There is a structural mismatch regarding data management and governance capacity within the public sector and the requirements for MaaS to function at scale. Delivering data infrastructure supporting the common good will require skills and capacity development across all MaaS ecosystem actors, particularly the public sector.

What we recommend

Think of mobility data as infrastructure

More and more actors view and treat data as critical infrastructure. Mobility data plays an essential role in how people live their daily lives, and it should be considered critical transport infrastructure along with roads, rail lines or IT infrastructure. An infrastructure approach to data governance should establish a shared vision of what this infrastructure should deliver and how it should serve societal objectives. This will guide the development of data-driven markets in line with public policy objectives, rather than only addressing market failures.

Develop a cross-sectoral vision for data governance

The challenges regarding data governance are cross-cutting. The finance, health, energy, telecommunications and transport sectors, among others, are all seeking to address similar issues relating to the role of data resources and how to manage data sharing. Public authorities should help establish a consensus-oriented, comprehensive vision for data governance and guiding principles that inform aligned rule-setting in different sectors.

Establish minimum data sharing requirements for actors in MaaS ecosystems

Minimum mandatory data sharing is required to establish the common data resource necessary to deliver social welfare-enhancing MaaS. This data should include volunteered and observed personal data with appropriate and clear consent mechanisms. It should also be made accessible at latencies low enough to support real-time delivery of joined-up trips. Data shared should not include knowledge and inference derived by actors based on raw data analytics. Data sharing obligations should also cover the use, specification and structure of data sharing APIs. This will establish a common base while incentivising appropriate convergence in their design and functionalities.

Link data sharing requirements and incentives to licencing

Licencing terms for mobility operators and MaaS providers should reference basic data sharing requirements and use open standards. They should also encourage the use of standard terminology, compatible data schemas and syntaxes. For efficiency, the licencing terms should also promote the adoption of open and open-source APIs among actors in a MaaS ecosystem. Licensing terms could also be more or less standardised to reduce compliance costs.

Public authorities should provide essential data sharing functionalities

Public authorities are responsible for delivering essential public building blocks to build MaaS data sharing. For example, specifying standards for APIs enabling identity and authentication fosters trust that actors are who they say they are. Beyond that, public authorities can deploy API-enabled pathways for other official information relating to the traveller’s status. This enables MaaS actors to establish traveller rights, such as those concerning fares or disability status.

Improve data skills and digital management capacity within public administration

The skills for managing data infrastructure differ from those needed to govern other infrastructure. Public authorities often struggle with digital transformation as they seek to overcome practices inherited from the analogue era. Targeting recruitment to acquire new skill sets helps to close this gap. Outsourcing data management may help where recruitment remains challenging for the public sector. However, even outsourcing requires knowledgeable contract managers and competent leadership. A focus on in-house up-skilling can help foster essential data governance skills.

Mobility data infrastructure and MaaS

Digitalisation is profoundly impacting how society and markets function. One of these impacts is the shaping of essential infrastructures (Banerjee, Jittrapirom and Dangschat, 2021; Dijck, Poell and Waal, 2018; Kitchin and Dodge, 2011). Physical spaces and networks have become so intertwined with digital elements that networks have become as significant as their physical counterparts (Banerjee, Jittrapirom and Dangschat, 2021). Digital "code/spaces" are increasingly indispensable to the functioning of everyday life. Just as the physical world is increasingly dependent on code, code itself is written (sometimes without human intervention) to produce material spaces, including infrastructure (Kitchin and Dodge, 2011; Nagel et al., 2021). Data as infrastructure is emerging in many domains, such as health, energy and transport. Across these domains, public authorities and other stakeholders will need to make conscious decisions about how to design open and interoperable sector-specific data infrastructures (Dodds and Wells, 2019).

Mobility data as foundational infrastructure

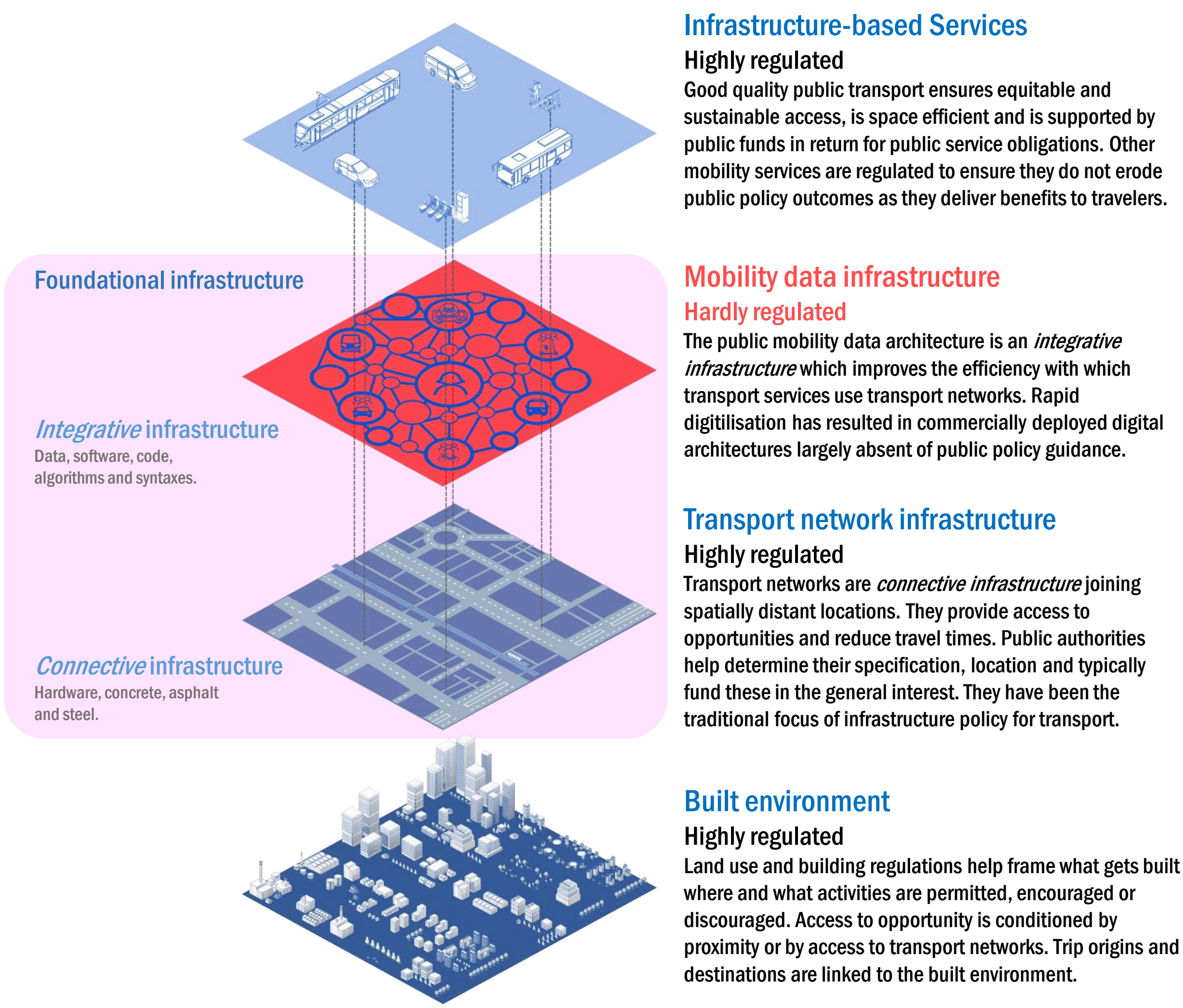
Society depends on infrastructure. It provides essential services that enable society to function. When infrastructure works, people forget about it. When it breaks down, people immediately realise how much everyday life depends on it. When it is managed as a public good, all benefit. When it is not, inequity increases. The term "infrastructure" brings to mind roads, rail, pipes and powerlines, but infrastructure is not only physical. It also comprises non-material but equally essential systems that contribute to general public welfare (Dodds and Wells, 2019).

Digitalisation has given rise to a new set of virtual infrastructure comprised of the architecture – for example, the structure and linkages – of mobility data (Figure 1). This infrastructure layer and its architecture shape how and under which conditions data are created, shared, used, maintained and destroyed. Its real-world impacts are significant – it can help achieve public policy outcomes just as it can work against them if unguided. Yet, unlike the other material layers, this emerging digital layer is poorly understood and hardly regulated. This is because its importance is only starting to become evident and because regulatory models for digital public spaces and digital infrastructure have not yet emerged (Banerjee, Jittrapirom and Dangschat, 2021; Lehrer, 2021; van der Waal et al., 2020; Waag, 2021). This report seeks to address these challenges in the context of data governance, in particular data sharing, relating to Mobility as a Service (MaaS).

The mobility infrastructure stack

Figure 1 illustrates the linkages between the built environment, physical and digital infrastructure layers and infrastructure-based services in the emerging mobility code/space or infrastructure stack. At the base is the *built environment*. Buildings and underlying land-use patterns determine the built environment. These result from countless decisions by individuals, firms and public authorities, each trying to balance their interests. This arbitration risks creating asymmetric outcomes favouring the interests of some over those of others, leaving society worse off. For this reason, authorities typically guide the stock of buildings and land use patterns through building and land use zoning regulations. Together, these regulatory interventions help determine what gets built where and which activities are permitted in which location.

Figure 1. The mobility infrastructure stack and digitalisation



The next layer – *transport network infrastructure* – determines how people gain access to spatially distant activities and opportunities. This infrastructure is *connective* because it physically enables people and goods to travel between spatially distant locations. It is also *foundational* in that it is part of the infrastructure of everyday life and is a pre-condition for the well-being of every citizen (Foundational Economy Collective, 2022a).

Like other forms of foundational infrastructure, transport networks typically benefit from a monopoly over any given area and are designed to provide service to society. They may or may not be publicly owned, but they are managed in the general public interest (Finger and Montero, 2022, Montero and Finger, 2021a; OECD, 2021a;). The connective and foundational infrastructure that underpins transport comprises roads, streets, pavements, rail, stations, ports and airports. A key focus for authorities is the efficient and socially beneficial use of transport network infrastructure. Accordingly, public authorities are deeply involved in the design, specification, siting, funding and financing, regulation and management of these networks and have built considerable in-house expertise and resources to do so.

Infrastructure-based services deliver value to citizens and society at the top of the mobility infrastructure stack. These services are heterogeneous and operated under different access and operational models. They are priced differently, and some must adhere to public service obligations.

A core service derived from foundational transport infrastructure is individual mobility – people walking or using their vehicles to carry out their daily travel. On unpriced or subsidised infrastructure – as in the case of roads and streets – inefficient uses may dominate, generating harmful externalities (e.g. traffic congestion, air pollution, etc.). In these instances, the sum total of individual decision-making generates unsustainable societal burdens (ITF, 2021d; Mattioli et al., 2020).

Transport network infrastructure also enables the provision of publicly or commercially operated infrastructure-based services. These include public transport (by bus or rail operators), taxi and ride-sourcing services (by individual drivers and commercial platform operators) and shared micromobility or carshare services (by community-based or platform operators). These services are almost always the object of specific regulation concerning licensure and other operating permissions. Some of these services whose public utility is demonstrated and valued, even when they may be uneconomic, are subject to much more stringent regulations, fare-setting and operational requirements in return for public subsidy. This is the case for public transport, whose subsidy is conditioned to public service obligations. Transport network infrastructure also enables other services beyond those directly enabling the movement of people. These include emergency and health services, waste removal, postal delivery, urban goods distribution and services linked to construction, plumbing maintenance and other trades.

The mobility infrastructure stack has been characterised by long periods of stability punctuated by short bursts of change. The digitalisation of transport services and other aspects of daily life has triggered such a burst. It has resulted in a new layer in the mobility infrastructure stack – mobility data infrastructure. This data infrastructure comprises four main components:

1. **Algorithms:** central to data processing. They process inputs into outputs according to their design. The move towards artificial intelligence and self-writing algorithms makes these increasingly more opaque to the public, decision makers and even their designers (see also ITF (2019).

2. **Infrastructural platforms:** the foundational physical and code-based platforms that materially enable data collection, transmission, processing and storage. They enable sectoral platforms and ecosystems of platforms.

3. **Sectoral platforms:** platforms that serve specific sectors or markets. They often are connective (two-sided) platforms that bring together supply and demand (e.g. Airbnb, Didi, Uber, Free etc.). They are generally delivered to people via apps.

4. **Ecosystems of platforms:** the web of complementary (and sometimes competing) platforms and services that deliver value to people via the interconnection of systems and the sharing of data among ecosystem actors. The linkages among platforms and services are enabled by application programming interfaces (APIs) and the diffusion of Software Development Kits (SDKs). SDKs enable system, protocol and data linkage and interoperability. (Banerjee, Jittrapirom and Dangschat, 2021; Dijck, Poell and Waal, 2018)

In contrast to the connective nature of the material infrastructure comprising transport network infrastructure, mobility data infrastructure is *integrative*. Rather than connecting physically distant locations, it *digitally integrates* the infrastructure-based services that operate on transport network infrastructure. It could create efficiencies and provide more seamless travel options to people.

Data infrastructure should not be conflated with digital infrastructure comprised of the material technologies that enable data collection, processing, transmission and storage. Just as the built environment and transport networks create public spaces essential to the well-being of citizens and society, data infrastructure is essential to creating digital public spaces that benefit all (Lehrer, 2021; van der Waal et al., 2020; Waag, 2021).

The linkages between the mobility data infrastructure layer and other layers in the mobility infrastructure stack are important. Just as roads help people navigate to destinations, mobility data infrastructure helps people navigate to decisions (Dodds and Wells, 2019). These decisions have real-life repercussions on people's mobility, including when, where and how they travel. This layer also influences the provision and viability of different infrastructure-based services and even the physical layout of the underlying transport network infrastructure and built environment (ITF, 2020).

Regulating mobility data as foundational infrastructure

There is a strong argument that the emerging mobility data layer is not only a new form of infrastructure, but as with other forms of transport infrastructure, it is *foundational*. This means it influences fundamental aspects of everyday life and is a pre-condition for citizens' well-being (Busch, 2021; DETEC, 2022; Dodds and Wells, 2019; Ecoplan, 2019; Finger and Montero, 2022).

Considering mobility data as foundational infrastructure mirrors the *infrastructural* interpretation of data in other sectors, particularly those displaying similar cyber-physical characteristics as in transport (e.g. telecommunications and energy) (Hoffmann and Gonzalez Otero, 2020; Janssen, Chun and Gil-Garcia, 2009; Rahman, 2018; Surblyte, 2016). Such an approach links all the different layers to be analysed to understand factors such as usage, future requirements or usefulness. Foundational characteristics affect how authorities frame this infrastructure's development and regulation. In particular, this framing will influence how authorities address data governance in transport, specifically for MaaS, especially concerning data sharing among MaaS ecosystem actors.

The rapid rise of platform-based and other digital services is one of digitalisation's most consequential and far-reaching results (Dijck, Poell and Waal, 2018; Nash et al., 2017). Digital platforms have emerged in several different areas like information search and acquisition (Google, Bing, Baidu), mapping and geo-referenced content (Google maps, Bing maps, Baidu maps), social media platforms (Facebook, Twitter, Instagram, Tik Tok), shopping (Amazon, Alibaba) and navigation and mobility (Google maps, Uber, Rome2Rio). In all of these areas, digital services and the digital infrastructure on which they depend take on an important and, in some ways, primordial role in people's everyday life. They increasingly extend to fields of activity that are typically managed in the general public interest. They influence consequential decisions that their users make and, at the same time, gradually exclude non-users from accessing central economic and societal infrastructures (Busch, 2021; Durand et al., 2022).

In response, public authorities and civil society are starting to scrutinise digital services. Consequently, they are exploring regulatory frameworks enabling innovative services to develop while guaranteeing that their activity does not erode fundamental rights or desirable public policy outcomes (Cremer, de Montjoye and Schweitzer, 2019; Furman et al., 2019; Lancieri and Sakowski, 2021; Marsden and Podszun, 2020). These efforts focus on addressing the market power of digital platforms and generally propose adjustments to competition law. This, however, may be an insufficient approach as it does not address the emerging and foundational role that these services currently play across many global regions (Busch, 2021; Finger and Montero, 2022; Montero and Finger, 2021a).

The societal and regulatory challenges posed by increased reliance on digital platforms should not only be viewed in light of market competition dynamics. Busch (2021) highlights that platforms "are extending their reach further and further into areas where social participation and the supply of essential services to citizens is at stake. In short, digital platforms have developed into infrastructures of digital services of general interest". For this reason, regulation in this area is not just a question of competition policy but also of infrastructure policy. In practice, this suggests that, just as public authorities regulate other essential public interest infrastructure, authorities must address the "infrastructural function" of digital platforms and ecosystems as part of their responsibilities to citizens (see Box 2) (Busch, 2021; Dijck, Poell and Waal, 2018; Dodds and Wells, 2019; Nash et al., 2017; Soriano et al., 2019).

Similarly, public authorities' responses to regulating the digital infrastructure layer should not be motivated solely by seeking to address market failures. Instead, there is a justification for authorities to play an active role in market creation as with other essential infrastructure investments (Mazzucato, 2015, 2016). This means going beyond just fixing markets and systems or simply de-risking private sector investments but supporting socially beneficial outcomes by creating and shaping entirely new markets that emerging technologies and practices make possible (Mazzucato, 2016). The EU adopts such an approach by articulating public policy "missions" whose outcomes are aligned with societal objectives and public expectations.

Authorities must help shape nascent markets to support these missions (Mazzucato, 2018). This approach seems appropriate to accompany the development of mobility data infrastructure given substantial market capture and lock-in risks and, more generally, the risk that people will lose their ability to assert and realise their fundamental rights in digital public spaces. Public authorities intervene and guide outcomes in the general public interest in all other layers of the mobility infrastructure stack, and so too should they for mobility data infrastructure. This represents a public policy mission for digital spaces and is increasingly shaping public policy.

Mobility data infrastructure is deployed and managed by public and private mobility ecosystem actors, each producing digitally-enabled services. There is no single "mobility platform", but there are emerging platform-based mobility services and actors who could become dominant players in the ecosystem. For this reason and those outlined above, public authorities should consider anticipatory actions aiming to mitigate the risk of market dominance and address the role of mobility data as foundational societal infrastructure. In particular, there is an emerging need to conceptualise public value-centric design for data infrastructure and platform markets (Banerjee, Jittrapirom and Dangschat, 2021; Dijck, Poell and Waal, 2018; UK House of Lords, 2019). In line with that thinking, the 2022 French Presidency of the EU produced a call for digital and data infrastructures to be managed or created as digital commons (European Working Team on Digital Commons, 2022). Such digital commons are "information and knowledge resources that are collectively created and owned or shared between or among a community, and that tend to be non-exclusive [and] are oriented to favour use and reuse, rather than to exchange as a commodity" (Morell, 2014).

Some public authorities are starting to address the infrastructural nature of mobility data and adopt digital commons approaches to this infrastructure. The following address the need to manage and frame mobility data governance for the common good, with some calling for infrastructure-like functionalities:

- France's Framework Transport Law (*Loi d'orientation des mobilitiés* [LOM]).
- The recent reform of the German Passenger Transport Act (*Personenbeförderungsgesetz* [PBefG]).

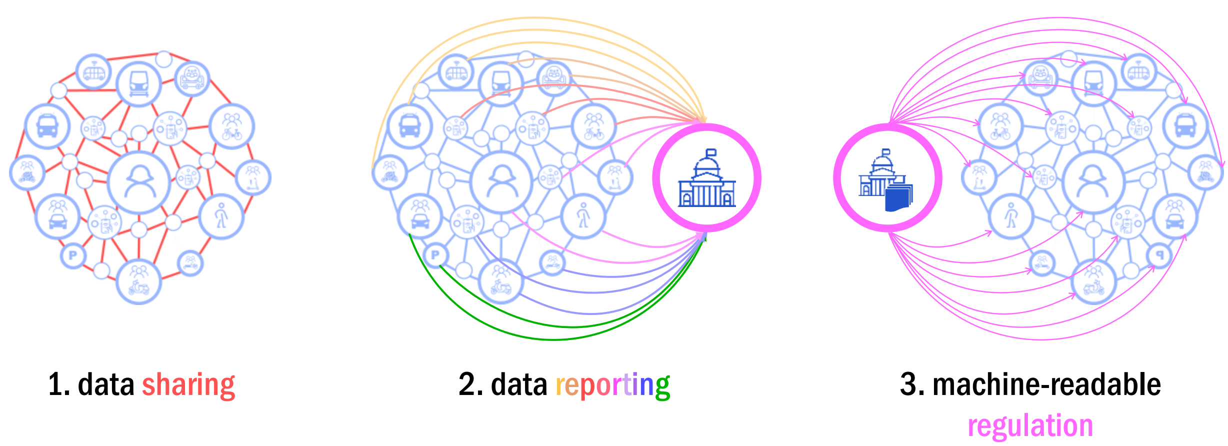
- Legislative efforts underway at the level of the European Union (e.g. regarding multimodal digital mobility services [MDMS] in the context of the revision of Delegated Regulation [EU] 2017/1926 on multimodal travel information services and the ITS Directive 2010/40/EU).
- National Access Points (NAPs) for scheduled transport data in the EU.
- Switzerland's draft federal law concerning mobility data infrastructure (*Loi fédérale concernant l'infrastructure de données sur la mobilité* [LIDMo]).

Switzerland has explicitly recognised the infrastructural nature of mobility data. The draft law – the LIDMo – recognises mobility data infrastructure (MODI in the law) as a third transport infrastructure alongside roads and rail and calls for the Federal Office of Transport to manage and regulate it for the public good (Assemblée fédérale, 2022; DETEC, 2022).

The architecture of mobility data infrastructure

Mobility data infrastructure comprises multiple elements beyond the data (Box 1). It is characterised by an architecture that matters from a conceptual and a regulatory perspective – especially in the context of MaaS. This architecture is organised along three pillars (Figure 2).

Figure 2. The three pillars of mobility data architecture



The first pillar relates to data sharing practices, methods, protocols and syntaxes among public and private market actors. These transfers enable innovation in new, joined-up offers and services. This pillar creates the foundation for MaaS, and as such, it is characterised by a many-to-many exchange of data that has implications for its governance. This first pillar – data sharing among mobility ecosystem actors – is the subject of this report.

The second pillar relates to the reporting of data by ecosystem actors to public authorities. This enables authorities to monitor how, to whom and under which conditions ecosystem actors deliver services. It allows authorities to monitor impacts and understand if, when and how they may need to intervene to ensure the public policy outcomes for which they have mandates. Data reporting involves a many-to-one communication channel, as explored in the ITF report *Reporting Mobility Data: Good Governance Principles and Practices* (ITF, 2021c).

The third pillar relates to public authorities issuing machine-readable regulations and laws, which signals public policy intent to ecosystem actors. This pillar is under development across multiple domains within and outside of transport. Still, it faces challenges as there is no broadly accepted model (or legal tradition) to guide the development of machine-readable and interpretable law. These challenges will likely grow with the uptake of more automated and artificial intelligence-dependent services and technologies. This pillar is characterised by a one-to-many communication channel (ITF, 2018b; 2018a; 2019).

Mobility data infrastructure and MaaS

MaaS is an emerging and evolving concept that can improve transport efficiency and people's everyday mobility (ITF, 2018a; 2021a; 2021b; 2021e;). It promises improvements in the use of transport assets and vehicles and better alignment of transport services with individual desires and needs. Also, it could lead to the emergence of more sustainable travel behaviours and a reduction of the negative impacts linked to solo car use (Arias-Molinares and García-Palomares, 2020; Durand et al., 2018; Jittrapirom et al., 2018; Pangbourne et al., 2018; Lyons, Hammond and Mackay, 2020; Hensher, Ho and Reck, 2021; ITF, 2021e; Schultz, Meda and de Labaca, 2021).

MaaS combines three fundamental concepts:

1. providing transport "as a service" rather than through vehicle ownership – i.e. access to vehicles versus ownership of vehicles
2. joining multiple transport services seamlessly to carry out a trip
3. focusing on the customer and demand side.

The first element is not new – transport services have been around for as long as transport technologies. Modes such as public transport, air, maritime and rail travel are all based on services that allow individuals to travel without owning a vehicle.

The second component – multi-modality and seamlessness across travel modes – is not new either. Multimodality is a long-term policy focus, especially where travel demand is high and space or network capacity is constrained. There are likely some natural limits to multi-modality. Almost all trips are bi-modal, combining walking (for those who can) and another travel mode. Many trips could become multi-modal in different ways in the first, middle and last metres or kilometres. However, it is unclear how much multi-modality people might want and under what conditions they would accept inter-mode transfers (Pickford and Chung, 2019).

Finally, despite the "customer-centricity" maintained, relatively few people use MaaS offers when they are available, and even fewer ask for them when they are not (Alyavina, Nikitas and Njoya, 2022; Hensher, 2022; Hensher, Mulley and Nelson, 2021; Hensher and Xi, 2022; Lyons, Hammond and Mackay, 2020). It is apparent that many people use trip-planning services and combine at least two modes on their own. MaaS services that offer physical accessibility-centric trips are also used more by travellers with specific mobility needs (e.g. travellers with wheelchairs).

MaaS has yet to achieve widespread uptake via successful and durable business models or use cases. There are many reasons for this. Some reasons are structural, like the fact that transport networks and the built environment are not generally created with intermodality in mind. Another reason is that there is no firm consensus on what MaaS is and even less experience on what it could actually deliver (Alyavina, Nikitas and Njoya, 2022; Arias-Molinares and García-Palomares, 2020; Calderón and Miller, 2020; Jittrapirom et al., 2017a; Liimatainen and Mladenović, 2018; Lyons, Hammond and Mackay, 2020; Schultz, Meda and de Labaca, 2021).

Often, the definition of MaaS is conflated with specific MaaS use cases. They confuse what *is deployed* as MaaS with an overall understanding of what MaaS *does*. In these cases, MaaS is treated as a product or an app when in fact, from a delivery-neutral and functional perspective, it is neither.

MaaS is a user-centric distribution model for mobility

From a functional perspective, MaaS is a "distribution model for mobility services that uses shared data and a digital interface to efficiently source and manage transport-related services into a seamless offer tailored to individual traveller preferences" (ITF, 2021a; 2021b; 2021e). MaaS is typically delivered via an app or another digital interface that combines different transport, information and payment services into a smooth and reliable digital customer experience.

MaaS promises to improve traveller convenience by allowing seamless access to a range of mobility services across interconnected trip chains. By removing both physical friction and the cognitive load of switching from one service to another, MaaS solutions would enable better use of existing capacities and service offers as travellers go from A to B. This improved ease would enhance the travel experience of using MaaS compared to experiences provided by single modes – notably cars (but in reality, bicycles and some public transport trips).

Proponents of MaaS believe that well-designed offers would unlock efficiencies and increase the adoption of under-used vehicles. This would result in decreased congestion, improved environmental outcomes and a reduction of other transport externalities. These potential benefits remain untested at scale, and evidence to date has been mixed (Alyavina, Nikitas and Njoya, 2022; Hensher et al., 2020; ITF, 2021e; Storme et al., 2020).

MaaS responds to two efficiency challenges

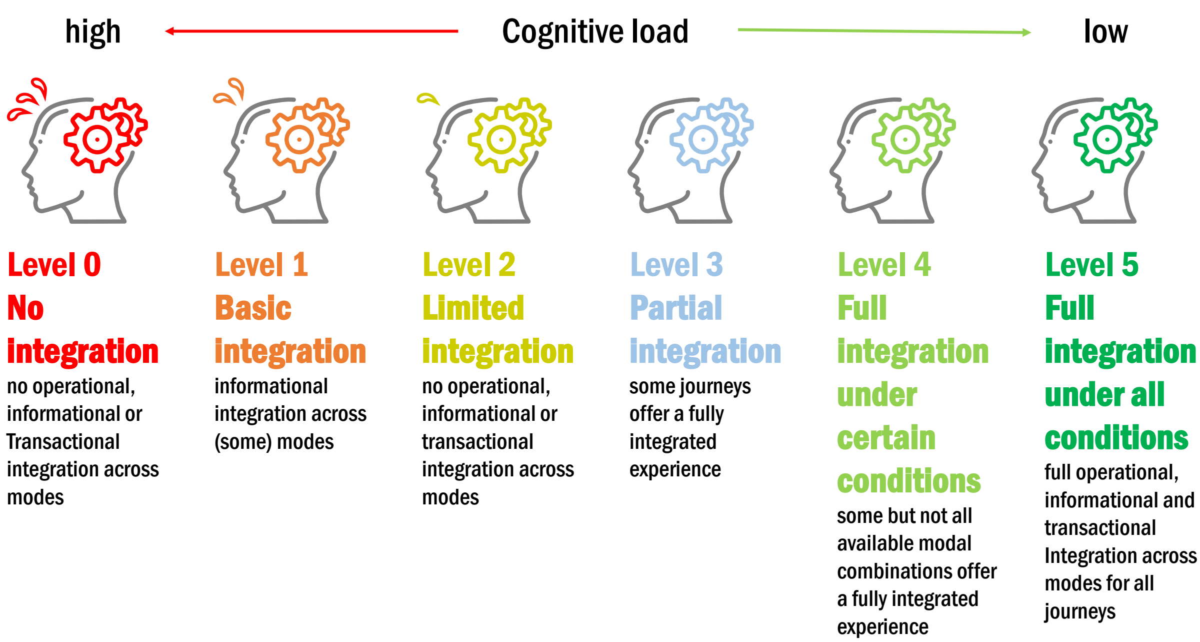
MaaS addresses two crucial efficiency challenges. The first is the physical and material friction travellers face switching from one mode to another. These include inexistent or poorly co-ordinated infrastructure-based mobility services. Frictions also emerge from insufficient or non-existent wayfinding information, physical distance or barriers between interchange points and lack of harmonised design standards regarding access to vehicles, stations and interchange points. In addition, the lack of co-ordinated planning around the configuration of MaaS-relevant parts of the public realm, including kerbside access, sidewalks and parking, can cause friction. Therefore, necessary pre-conditions for the uptake of MaaS include quality mobility services and the infrastructure on which they operate.

The second component comprises the digital interconnections among mobility service providers' wayfinding, operating, scheduling, payment, consumer-facing interfaces and customer information systems. These form part of the data infrastructure that virtually integrates services into a seamless digital travel experience.

Increasing levels of digital integration reduces people's cognitive processing to undertake multi-modal journeys (Figure 3). The less cognitive processing required for intermodal trips, the more compelling these become compared to single-mode journeys (Alonso-González et al., 2020; Durand et al., 2018; Lyons, Hammond and Mackay, 2020). This is true for car trips but potentially also for other types of single-mode travel (e.g. active mobility or public transport). There are limits to how much digital integration can change behaviour. As noted above, better digital integration will not overcome poor-quality mobility services or poorly linked infrastructure.

Similarly, travel behaviours that are ingrained and habitual will likely not be changed via digital integration alone (Alonso-González et al., 2020; Durand et al., 2018). Nonetheless, this layer promises to overcome the siloed nature of different mobility services and create efficiencies by improving the matching of travel demand to the broad range of capacity available to satisfy trip needs. This data infrastructure layer is at the core of the MaaS value proposition.

Figure 3. MaaS behaviour change – the relationship between MaaS integration levels and cognitive load



Source: adapted from Lyons, Hammond and Mackay, 2020.

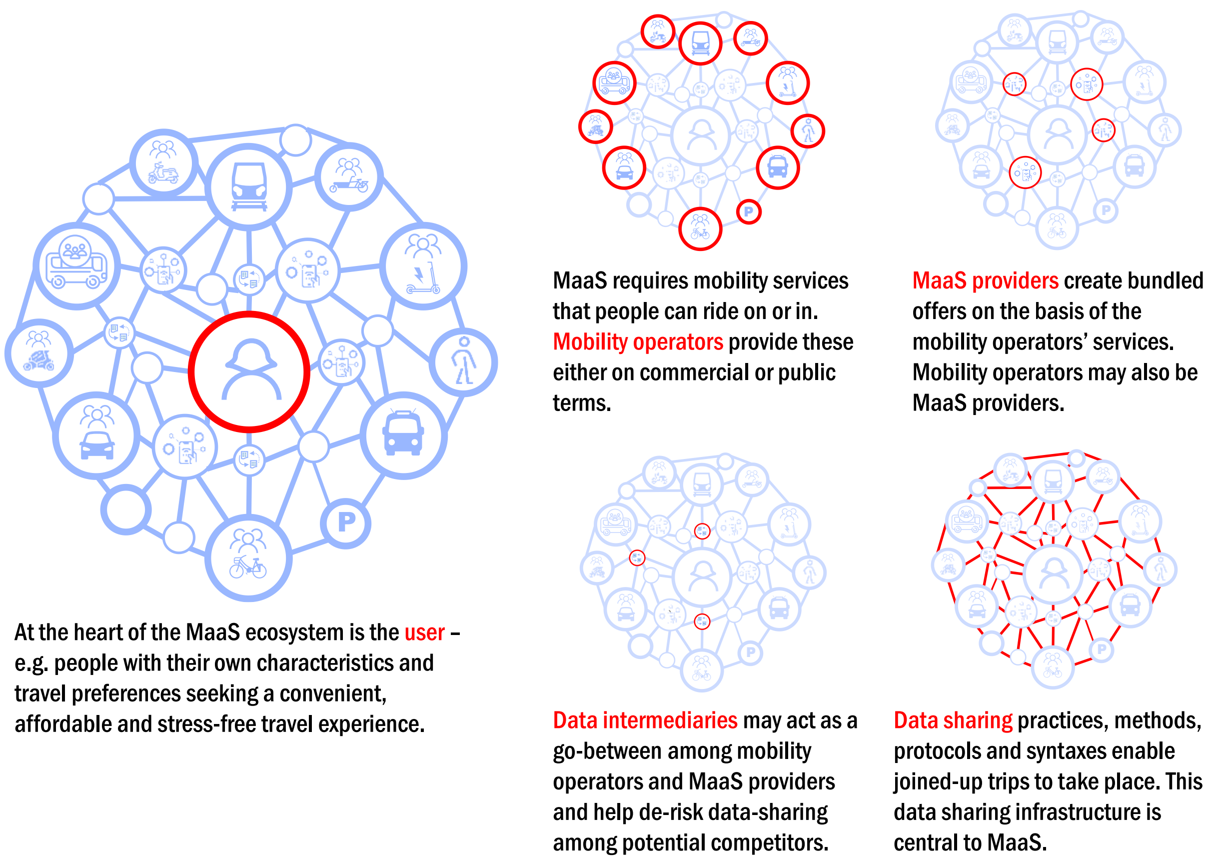
MaaS is delivered via an ecosystem

MaaS emerges from the interactions between actors and infrastructures in a loose ecosystem. The core MaaS ecosystem encompasses four main types of actors operating on one form of infrastructure (Figure 4).

At the centre of the MaaS ecosystem are individual travellers. MaaS offers are meant to cater to travellers' needs, preferences and budgets and are designed so that they find those offers at least as compelling, if not more compelling, as travelling by single modes.

Finding a compelling offer for people is not straightforward because there is no single "traveller". People travelling display a wide range of characteristics (e.g. needs, preferences and budgets) (Alonso-González et al., 2020; Durand et al., 2018; Hensher, 2022; Hensher and Xi, 2022). MaaS offers that are compelling enough to switch some travellers' behaviours may be uneconomic to offer on commercial terms. Conversely, commercial offers from MaaS providers may be unaffordable for many people.

Figure 4. The MaaS ecosystem



Travel behaviour and travel decisions are rarely straightforward; they result from multiple arbitrations among several factors and opportunities or constraints (ITF, 2021e). Individuals' characteristics matter, though they alone do not determine travel choices. How people make decisions also matters. Human decision-making is complex. A lot of human behaviour involves avoiding choosing, and some widely used decision-making models – like rational choice models – often fail at the individual level, even if they function at the aggregate level. People also make decisions based on the costs, constraints and inherent or operational characteristics of different mobility services and modes available to them.

Finally, people make decisions based on what *is*, what *is not* or what *is only difficultly* possible. If the "system of provision" for transport incentivises car use, for example, it will be challenging to get people to choose MaaS offers (Mattioli et al., 2020) unless the ensemble of norms, built environment and practices is adjusted. Individual car use must be de-prioritised where it is most problematic and burdensome, and other transport services must be improved so they become intrinsically more attractive. MaaS is not required for both of these things to happen – indeed, these two strategies have been pursued for decades in many regions. But unless these two strategies are pursued, the attractiveness of MaaS will always pale compared to other alternatives – foremost with individual car use (Hensher, 2022; ITF, 2021d; 2021f).

MaaS requires the mobility services mobility operators provide. These services are offered on commercial terms (like many forms of micromobility, ride-sourcing, car-sharing and ride-pooling), as public transport services where the burden of public service obligations and fare-setting requirements are offset by public subsidy or as different hybrid forms of service delivery (as with taxis in some jurisdictions). Mobility operators must typically obtain a license or permission to operate from local or regional authorities.

MaaS providers – either public or private – create joined-up travel offers based on the services provided by mobility operators. They must therefore have access to certain types of mobility operator data, enabling them to plan, book and deliver seamless multi-modal trips to their clients. MaaS providers may be "pure platform players" in that they only provide MaaS services without direct or exclusive links to the provision of mobility services. Alternatively, they may operate under a hybrid model providing both vehicle-based mobility services and digital MaaS offers. Special provisions may be required to ensure that such an operation does not lead to anti-competitive behaviours or outcomes (ITF, 2021a). MaaS providers should face comparable licensing requirements such as those faced by mobility operators with respect to data sharing. However, these should be light-touch at the outset to enable adequate monitoring without stifling innovation in an untested market where durable business models have yet to emerge (see ITF, 2021a for ITF's guiding principles for MaaS regulation).

Data intermediaries, integrators and other third-party service providers also play a role in the MaaS ecosystem – especially in the absence of compulsory data sharing requirements among ecosystem actors. Data intermediaries help avoid risks linked to sharing potentially commercially sensitive data among ecosystem actors. They act as go-betweens among mobility operators and between mobility operators and MaaS providers and ensure that data sharing in the ecosystem is not prejudicial to the interests of individual ecosystem actors. This de-risking role may become less relevant if, over time, automated, code-based and transactional data processing and intermediation are built into the MaaS data sharing architecture (ITF, 2018a). Data intermediaries might then pivot towards enriching data to the benefit of stakeholders (e.g., working on data quality so that it is more accurate and meaningful to travellers).

The data infrastructure that enables MaaS is also part of the ecosystem. There is no MaaS without data or, more specifically, without data sharing among all MaaS stakeholders. The ease that MaaS promises for travellers via a convenient user experience delivered by a customer-facing user interface builds on a tremendously complex back-office exchange of sometimes sensitive information amongst different actors. Data and the knowledge derived from its collection, processing and analysis have been a necessary component of the delivery of any mobility service. The data collected includes data regarding the location of static and moving assets, the scheduled or real-time operation of services, prices and payment clearing, access rights and customer profiles. What MaaS changes is the need to share this data among other actors in the broader mobility ecosystem to provide joined-up services for travellers.

MaaS requires appropriate data governance by public authorities

Delivering MaaS will require an appropriate data governance framework that guides data sharing in a way that enables remunerative business models, provides a compelling experience for travellers and maximises social welfare outcomes (ITF, 2021a; Pangbourne et al., 2018). Both commercial operators and public authorities are interested in MaaS but do not necessarily share the same motivations for its deployment. Commercial operators hope to establish successful commercial offers, and public authorities hope to leverage MaaS to improve efficiencies and contribute to better transport outcomes. Both have concentrated on what opportunities MaaS represents for them individually. Although MaaS could deliver on both points, this is not a given without purposive design and guidance. As with other foundational infrastructures, public authorities have a role in framing, monitoring and, in some fundamental ways, regulating data sharing for the public good. This report discusses the challenges of doing this and provides guidance and principles to ensure that data sharing for MaaS benefits societal well-being.

The MaaS ecosystem enables a secondary market for mobility services

Mobility operators produce mobility – that is, they produce a service comprised of access to a vehicle for a set distance or amount of time, which enables a customer to get from one point to another. In return, mobility operators are paid by the customer or receive a public subsidy, or a combination of both. Producing this service requires a capital outlay for vehicles and supporting hardware (e.g. IT systems) and, in some cases, infrastructure (e.g. stations, bus stops, shared bicycle docks). It also requires outlays for staff to operate the service and maintain the assets and infrastructure. Combined, all of these enable the *primary market* for mobility service provision, in short, the market for *rides*. It is a market where publicly subsidised and commercially operated services co-exist in various degrees of government oversight and control.

The *integration* of rides by MaaS providers can be seen as a *complimentary*, *secondary* or *aftermarket* of the primary mobility market for rides. It is a market characterised by multiple scales and geographic extents. A public transport operator may have a dominant market position for mobility service provision locally. In contrast, a global search and mapping engine may hold a dominant global position for trip planning and routing. This market also features traditional network industries that are overlaid and merged with emerging features of digital networks. It is also an ecosystem in which third-party service providers may handle MaaS provider services themselves (e.g. establishing and authenticating identity, payment, and route-finding). All of this complicates and, in many instances, limits recourse to traditional market oversight and control mechanisms (Bourreau, Krämer and Buiten, 2022; Cremer, de Montjoye and Schweitzer, 2019; de Streel, Krämer and Senellart, 2021; Montero and Finger, 2021b; OECD, 2021b).

The ongoing effects of digitalisation on primary and secondary mobility markets are still poorly understood – partly because they have not entirely played out as digitalisation continues to generate far-reaching impacts (Cremer, de Montjoye and Schweitzer, 2019; Montero and Finger, 2021b). This uncertainty calls for a cautious but outcome-oriented approach that seeks to ensure that the benefits derived from secondary markets enabled by digitalisation are delivered without eroding public policy outcomes (ITF, 2021a). In the case of MaaS, such an approach should seek to establish and open the secondary market for MaaS provision while ensuring that public authorities retain, or even strengthen, their ability to guide and shape the market to support the mandates citizens have given them.

In what way is MaaS similar to other secondary markets?

Secondary markets in sectors like electricity, telecommunications, banking, health and airline reservations share similarities with MaaS in urban mobility.

Technological and regulatory evolutions

Recent progress in digitalisation across electricity, telecoms, banking, health and other sectors and the availability of connected devices (e.g. smartphones, smart meters) has given rise to secondary markets for new products and services in various sectors. For example, in the banking sector, many countries have implemented reforms and established regulations to limit customer lock-in, actively enhance competition, and develop downstream markets. Open banking reforms (e.g. the Revised Payment Services Directive in Europe, the UK Open Banking framework, the Consumer Data Right regime in Australia and the Dodd-Frank Act in the United States) outline specific and mandatory data sharing and data portability requirements that encourage competition and empower consumers (Borgogno and Colangelo, 2019; de Streel, Krämer and Senellart, 2021; OECD, 2021b).

Data sharing models

Data sharing strategies are implemented as a way to promote innovation, to cope with sectoral challenges or as a remedy to restore competition in digital markets. Just as MaaS cannot exist without data sharing and access between mobility operators and MaaS providers, new payment services cannot exist if banks do not share their data with third-party providers. The air travel industry was a precursor in that it implemented data sharing strategies and data specifications in the 1960s to facilitate multi-leg trips involving other airlines (Teal et al., 2020).

Data sharing and portability regulations

Various regulatory regimes apply for public and private data sharing. In Europe, the Open Data Directive (2019) requires that documents held by public sector bodies that fall under the scope of a public task (e.g. public service operation) “shall be re-usable for commercial and non-commercial purposes” (European Commission, 2019). Other sectoral regulations imposed data sharing rules on market actors. For instance, in Europe, the Revised Payment Service Directive (PSD2) in 2015 for the banking sector or the New Electricity Directive in 2019 introduced provisions to ease access to consumer data (Feasey and de Streel, 2020). At the same time, In Europe, the General Data Protection Regulation (GDPR) applies to any organisation (e.g. public or private) that provides a service or supplies goods to customers or businesses in the EU.

Open market

New digital actors (e.g. micromobility companies, journey planners, Fintechs) have disrupted incumbent actors across many sectors (e.g. banks, electricity producers, public transport). The opportunity to access a service anytime, anywhere, constituted a paradigm shift for once very static and inflexible relationships. At the same time, mobile technology and progress in payment solutions eased the possibility of accessing and paying for these services.

Access to assets

Infrastructure managers historically provided the service linked with infrastructure. Transport infrastructure managers and electricity producers managed the infrastructure (e.g. roads, transport, power plants) and provided a service simultaneously (e.g. energy supply, loan, bank account, transport service). Now, service providers do not necessarily have to own or manage the infrastructure to provide a service in these sectors. Like MaaS services providers, who do not have to own the infrastructure or vehicles, electricity suppliers do not necessarily manage power plants or electricity distribution infrastructure.

Indirect sales channels/resell services

MaaS providers should be able to resell services, such as public transport tickets, as part of their offer (ITF, 2021h). In this context, the MaaS service provider acts as a middleman between the service operator and the customer. The same situation exists in the electricity market, where suppliers buy electricity on the wholesale electricity market from producers. Similarly, Online Travel Agencies (OTAs) acting as MaaS providers allow customers to search for and book various services online in the travel sector. They act as resellers on behalf of the service provider. To that end, OTAs are integrated into a Global Distribution System (GDS), which combines multi-modal offers and those relating to other domains (e.g. lodging, tours).

In what ways is MaaS dissimilar to other secondary markets?

Unlike many other network industries, urban transport – and thus MaaS – is characterised by strong public involvement. This is because poor or lack of access to transport options limits access to amenities such as education, jobs and health facilities (ITF, 2017). Also, given that the most prominent infrastructure in cities is related to transport, a change in transport demand (e.g. number of trips, modal share) will impact the use and allocation of city space (ITF, 2022).

Many public authorities view public transport as essential to reaching public policy objectives, and thus it is subsidised via public service obligation (PSO) arrangements (see glossary). PSO schemes can take many forms: public authorities can impose a certain level of service (e.g. essential services, frequency, minimum hours of service), provide a service in a particular area (e.g. route coverage), introduce special tariffs for specific users (e.g. lower-income population, elderly, disabled people, children). They can be found in many regions, such as the United States, Australia and Europe.

MaaS trip offers have been complex, notably due to the prominent role and status of public transport in urban mobility (Valdani Vicari & Associati, 2019). Part of this complexity arises because public authorities influence the prices of PSO services. In other network industries like electricity or telecoms, the price for a service typically equals the production cost for a service (e.g. all direct and indirect costs) and a reasonable margin. The emerging MaaS ecosystem is a hybrid one in that while all market actors compete for passengers, some of them (e.g. public transport notably) can rely on public support.

The rationale behind the subsidisation of public transport is threefold. First, subsidisation aims to ensure a certain level of service that would typically not be provided by the private sector. Second, it seeks to incentivise public transport use to encourage modal shifts. Finally, it aims to improve social equity and accessibility by enabling vulnerable public and lower-income groups to use public transport (ITF, 2013; O'Callaghan, 2017).

The integration of public and private ticketing services is also complex. Demand-side subsidies (e.g. concessional fares) allow public transport authorities and operators to reduce the price of the service for the customer. Public Transport Authorities (PTAs) historically issue “tickets”, i.e. contracts between passengers and the service provider. Depending on its policy objectives, the PTA applies special tariffs for specific groups or in particular areas (UITP, 2020a). Non-PSO undertakings have limited access to the public ticketing market and face difficulty selling public transport tickets. The price structure for the same service may vary depending on whether the service is subsidised.

A further difference with other “pure player” digital markets is that MaaS (and mobility services more generally) combines a digital layer and physical services (mobility) with real-world impacts. This is unlike many digital platform-based markets where the digital layer is linked to the consumption of digital services (e.g. online posts, likes, streaming content). Arguably, some digital platforms also express such hybrid cyber-physical architectures. A search engine can influence a travel decision with real-world impacts, just as purchasing goods via a digital market platform results in the movement of vehicles in the real world. Nonetheless, digital market regulation typically employs a competition policy lens to focus on first-order “virtual” impacts of transactions occurring in the digital layer. However, in some cases, as with MaaS, it isn't easy to disentangle digital outcomes from those occurring in regulated spaces in the real world. These outcomes can relate to mobility service provision or address transport efficiency, equity and environmental performance.

The coupling of digital and real-world outcomes inherent in MaaS suggests two things. The first is that MaaS alone cannot deliver integration and interoperability. Data sharing gives rise to MaaS, but if that integration is not mirrored in the real world – for example, in terms of the physical ease of connection between different trip leg components – then MaaS will not be adopted by people. The second is that MaaS may impact multiple desired policy outcomes – particularly regarding accessibility and sustainability. But, again, these outcomes should be enabled by the broader regulatory context around mobility. For example, building sustainability nudges into MaaS applications makes little sense if they are not supported by the physical context in which people travel. An in-app push to choose public transport or cycling-based options, for example, will not necessarily translate into more public transport or cycling use if these modes do not match people's needs, expectations or travel experiences.

Data sharing … and sharing data for MaaS

Data sharing refers to the distribution of data resources across multiple actors in a market. Without data sharing, data cannot circulate across market stakeholders. This section discusses why data sharing is crucial for MaaS and how data sharing governance frameworks may be designed to consider the multiple dimensions of mobility data.

The public and private value of data sharing

Evidence shows that non-collusive data sharing between market actors and data reuse contributes to growth opportunities and creates wider societal benefits. Positive impacts of data sharing can be direct (e.g. for those sharing the data), indirect (e.g. for those reusing the information), or induced (e.g. wider impacts) (OECD 2019a). OECD (2019a; 2020) suggests that sharing data can increase value for data users from 10 to 20 times and generate more value for the wider economy (20 to 50 times). Data sharing can act as a lever to generate a net increase in gross domestic product (GDP) between 0.1% and 1.5% of GDP with public-sector data only, between 1% and 2.5%, including private-sector data (OECD, 2019a).

Data sharing enables different types of socio-economic benefits. Among these, data access and sharing improve transparency and empower market actors. Data sharing can also generate market opportunities for companies (e.g. data controllers, data processors, data intermediaries), foster co-operation, and stimulate competition between market actors. In London, Transport for London (TfL) open data benefitted app developers based in London. Annual revenues attributable to TfL open data reuse were estimated between £120 million and £160 million (indirect benefits). At the same time, cost savings (direct benefits) were estimated to be between £0.9 million and £1.725 million per year (Deloitte, 2017). Data sharing agreements with data companies and service providers brought new insights to TfL and allowed it to improve its operations (Carey, 2022).

Understanding data sharing value is complex, given the specificity of different data assets. The value of data sharing is closely linked with the data itself and its characteristics. Similar shared datasets may have different values. According to the International Association of Public Transport (UITP), the value of data sharing depends on five main factors: the object of the dataset (i.e. what it describes), its quantity (i.e. data coverage), quality (i.e. accuracy, validity), granularity (i.e. aggregated or raw), and its access (i.e. open, restricted, file or API) (UITP, 2020b).

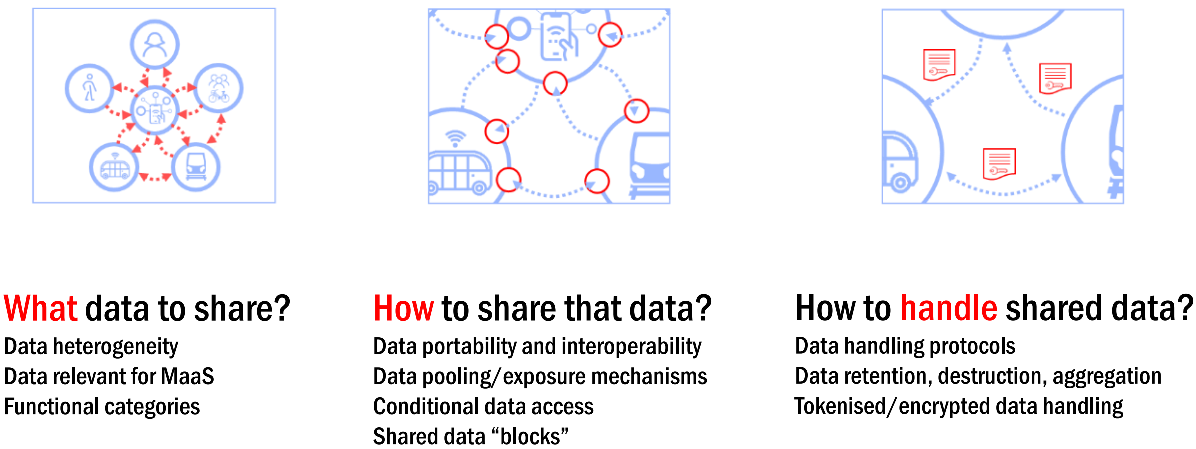
Data sharing valuation methods can provide an appreciation of the different benefits of data sharing. Reducing the uncertainty around data sharing value is crucial to unlocking data sharing and, thus, its full potential. Notably, the value of data sharing will depend on the perspective taken (e.g. from the owner of the data or the data user) and the valuation method used (Infocomm Media Development Authority, 2019; UITP, 2020b).

Sharing data for MaaS

Enabling a purposive, actionable, privacy-preserving and commercially relevant data sharing framework within the MaaS ecosystem requires addressing three key questions (Figure 5):

1. What data to share?
2. How to share that data?
3. How to handle shared data?

Figure 5. Data sharing for MaaS must address three essential questions



Understanding the multiple dimensions of MaaS-relevant data

There are several aspects to consider regarding mobility data when answering these three questions and designing data governance frameworks. In the context of MaaS, these relate to how the data is sourced, the nature of the data, its function or use, who has access to it and under what conditions (Figure 6).

Data sourcing

Data can be sourced from people providing it *directly* and *voluntarily*, via *observation* or as knowledge obtained by *inference* via data analytics (Cremer, de Montjoye and Schweitzer, 2019; Krämer, 2021a).

People explicitly *volunteer* data by directly inputting data pertaining to them into systems. A typical example is when people register for a service or to gain access to rights. Volunteered data requires a specific data capture mechanism (e.g. a form or an interface) and updating from data subjects. Both requirements may introduce friction in data collection efforts and barriers to registration and access rights. Data may no longer be accurate if not updated, and different data controllers may hold other data regarding the same data subject, some of which may be erroneous.

Figure 6. The different facets of mobility data

Source

How is the data sourced?

Volunteered

Data that is explicitly and intentionally revealed by a natural person (e.g. identity or contact details).

Observed

Data that is collected from interaction with a service or a device (e.g. location data , trip history, travel schedule).

Inferred

Knowledge that is derived from combining volunteered and observed data – and other inferred data – and applying analytical processing to it.

Nature

To who or what does the data pertain?

Personal

Data that can be linked directly or indirectly to natural persons –including direct identifiers, location, or other factors.

Non-Personal

Data which is not or cannot be linked to natural persons –either because there is no link or because it has been robustly de-identified.

Commecially sensitive

Data which pertains to the ability for economic agents to compete in markets –e.g. that is commercially valuable, known to limited people, and/or subject to confidentiality agreements.

Function

What purpose does the data serve?

Informational

Data that supports the planning, scheduling or coordination of trips.

Operational

Data supporting the fulfillment of travel services (e.g. vehicle or station access rights, continuity management for multi-leg trips, etc).

Transactional

Data that enable people to book and pay for services and allows revenues to be redistributed among service providers.

Access

Who has access to the data and under what conditions?

Closed

Data that is only available to the data controller parties designated by the data controller.

Restricted

Data that is available to parties other than the data controller under specific conditions.

Open

Data that is available to parties other than the data controller under no set conditions.

Source: based on Cremer, de Montjoye and Schweitzer (2019); ITF (2019; 2021c); Lyons, Hammond and Mackay (2020); OECD (2019a).

Data can be collected by observation, monitoring or logging. Data may be collected from sensors, including embarked global positioning chips in mobile handsets or video data, from logging human-machine interactions or any other observational means. Observed data reveal information about data subjects as they move and interact in the real or virtual world and is often collected unbeknownst to them. These data are richer than volunteered data, and their collection favours actors who have invested in widespread sensing and data-logging networks.

Finally, valuable knowledge can be derived by *inference.* This knowledge is qualitatively different from volunteered and observed data in that it does not exist without active human interpretation or, more likely, algorithmic and increasingly artificial intelligence-based data analytics and processing.

The nature of mobility data

Data may be personal, non-personal or commercially sensitive (Figure 6). Personal and commercially sensitive data bear unique risks and require adapted collection, handling, sharing and storage protocols.

Personal (and sensitive) data

MaaS activities involve sharing a wide array of personal data. This data pertains to customers (e.g. identity, gender, age), travel activity (e.g. geolocation, trip history), and payment details (e.g. information required to complete a transaction). Basic anonymisation techniques (e.g., generalisation and randomisation) do not prevent the re-identification of people and thus do not mitigate personal data risks (ITF, 2015; 2016; 2019; 2020; 2021c). Article 29 Data Protection Working Party (A29WP) states, "identification not only means the possibility of retrieving a person's name and/or address, but also includes potential identifiability by singling out, linkability and inference" (Data Protection Working Party, 2014; Finck and Pallas, 2020). These re-identification techniques constitute a potential risk for individuals. Singling out is an isolation technique to identify an individual in a dataset. Data inference refers to the possibility of deducing a specific insight from data. Finally, linkability refers to the ability to match two records of the same data subjects. Re-identification results from the intentional processing of observed or volunteered data that may relate to an individual or a device they use (ITF, 2021d).

Re-identification represents a significant and consequential risk for personal data, especially in transport with location-based data sharing. Evidence shows that it may be possible to re-identify individuals' travel patterns from anonymised datasets. Thus, there is a need to complement anonymisation with additional mechanisms to protect de-identified information (ITF, 2016; 2019; OECD, 2019a). Establishing independent review bodies to evaluate the adequacy of data security, contractual provisions binding data receivers to security rules and practices, and security audits can constitute strong measures to prevent the re-identification of data.

Moreover, authorities should adopt a prudent approach regarding what constitutes personal data. Where a potential re-identification pathway exists, a precautionary approach would require considering such data as personal, thus requiring extensive privacy protection. Irreversibly de-identified data should not be regarded as personal (ITF, 2021c) and, therefore, should fall outside of the scope of personal data protection regulations (e.g. GDPR) (Recital 26, GDPR) (European Commission, 2016).

Risks associated with breaches of MaaS-related personal data vary in severity and probability. Individuals could lose control over the data they share (e.g. who uses it, how they use it). This risk increases as data are shared across multiple third-party data processors and jurisdictions. Loss of control over data may discourage individuals from sharing their data or using particular digital-related technology (OECD, 2019a). One way to minimise these risks is by designing privacy-preserving data sharing mechanisms, including ensuring that de-identified or non-personal data is used by default for all but the particular cases where personal data is essential. For instance, in response to a data breach of Swiss public transport operator Postbus' TicketControl data platform (The Daily Swig, 2022), researchers recommended that data platforms should, at a minimum, implement authorisation checks and, if necessary, apply a "least-privilege principle" where the system grants authorised users the minimal required functionality to achieve their task (Gegick and Barnum, 2005). Another way is to develop distributed ledger-based approaches to ensure that personal data, even when shared, is never exposed to non-authorised or vetted actors (ITF, 2018a).

Commercially sensitive data

Sharing commercially sensitive data exposes an organisation to digital security threats similar to personal data and privacy risks for individuals (OECD, 2019a). The unintended release of data can also be associated with reputational damage and financial loss for corporate or institutional data holders. The strategic importance of transport for the economy and national security makes the sector a target of cyber-attacks. Evidence suggests that transport organisations are more vulnerable to cyber-security threats as attacks on databases and IT systems increase (Huber, 2022).

Data holders may also be wary that sharing commercially sensitive data will give a cutting-edge competitive advantage to potential competitors in the market. This risk is more acute within uneven competition where certain market actors have data sharing requirements while others do not. In the short term, the risk is that the initial data sharer could lose contracts. In the longer term, data holders may be wary of the potential socio-economic damage data sharing could cause to their business (e.g. fewer contracts and job loss) (Nielsen et al., 2021).

Inaccurate or wrong use of data can cause potential reputation damage to the original data holder. The lack of trust between market actors can exacerbate this type of risk. Data holders can be reluctant to share their data, fearing they could be held responsible for another market actor's improper use of the data they initially shared. Like individuals, market actors can fear losing control over how their data are used once they are shared. Data sharing agreements constitute a good practice for mitigating potential liability risks. This type of contractual agreement can include details on the role of each party (e.g. data sharer, processor, user), the rules associated with data at each stage of the process (e.g. deletion, anonymisation rules), and the type of standard used (Information Commissioner's Office, 2022a).

The function of mobility data

In the context of MaaS, data may relate to planning, routing and co-ordinating trips. It may be necessary for the operational delivery of joined-up trips or be transactional, covering trip booking, payment and revenue aspects (Figure 6).

Informational data

Informational data relates to the availability of mobility services. It covers asset/vehicle identity, location, service type, schedule information or latency in the case of non-scheduled services, for instance. It may also include routing and navigation information for a specific customer-initiated trip request. These data represent the information necessary to select a trip option and are generally not technically challenging to provide (though it is not costless). As it comprises largely publicly available data, sharing informational data is not usually seen as a significant source of commercial risk. However, many mobility operators fear losing a direct relationship with their clients if a MaaS provider initiates requests for informational data.

Operational data

Operational data relates to the physical joining of different mobility operator services in a single trip. This may relate to access rights and the seamless integration of access protocols (e.g. vehicle access and unlocking protocols, gate-based station access versus contactless station access). Poor operational integration leads to greater interchange penalties as travellers must overcome unjoined or poorly linked legs of multi-modal journeys. Operational integration is more complicated to carry out than informational integration. This is primarily because of sunk investments in data systems and associated hardware that must be retrofitted to ensure seamless interoperability. For this reason, mobility operators are often unwilling to pursue operational integration unless they feel they would derive clear benefits from doing so and that these benefits are greater than the investment required. Public authorities have often required sharing operational data or facilitated operational integration among public transport operators, expecting these benefits to generate overall improvements in consumer and societal welfare.

Transactional data

Transactional data relates to trip booking, payment and revenue allocation. Mobility operators see this data as extremely sensitive from a commercial perspective, not only because it may include price information and be used to derive insights into market activity and turnover but also because it enables MaaS providers to enter into and maintain direct relationships with their customers. For this reason, many market actors have been reticent to share these data or to allow broad transactional integration. These data could enable a range of transactional integration. It can go from no integration to reciprocal (or not) deep-linking to other mobility operator booking and payment protocols and, finally, to fully integrated in-app booking and payment for all mobility operator services in MaaS provider interfaces. The current revision of the EU ITS Directive specifically targets obligations to open and share data enabling cross-service booking and payment.

Access to mobility data

Finally, data access rights differ across the MaaS ecosystem (and elsewhere) (Figure 6). Much of the data held by mobility operators, MaaS providers and ticketing service providers are "closed" data – that is, only available to the data controller or parties granted access rights. In some jurisdictions where personal data protection rules are in place, data subjects may also have access and control over data concerning them. This is the case in the European Union, where GDPR defines a data access right for data subjects to their personal data (or a right to designate the transfer of that data to a third party).

Data may be shared under specific restrictions – for example, the data controller will share access to data if the requesting party meets specific conditions and has legal standing to access that data. Such conditional data sharing/access seems well-suited to the MaaS ecosystem, where actors seeking data from other ecosystem participants should have established legal standing to use the data to deliver services.

Finally, data can be open – that is, accessible by all under no or very few conditions. There is a significant move underway for public authorities to provide data unrestrictedly except in clearly defined cases where such data is personal or meets agreed and defined thresholds for commercial sensitivity. Open data policies promote transparency, accountability and value creation but may not be suitable for operational or transactional data sharing and exchange.

"Open" should not be confused with "open source". The former refers to how data access rights are defined, and the latter to the accessibility, transparency and editability of software code and algorithms. The source code of open-source software is public and, depending on its licence, can be freely copied, shared, edited and transformed. Shared data, open data and open source code – especially concerning data syntaxes – are essential elements of *foundational data infrastructure* since they help maximise social welfare outcomes (OECD, 2019b).

Why share what data? The economic and social welfare case

The value of data depends on how it is transformed into meaningful information and knowledge (Figure 7). Raw data are purely *descriptive*. They capture a specific and often context-less state, such as a name, a number or geographical co-ordinates. That data can have *meaning* assigned to it. For example, if the name is associated with access rights or the number is linked to an action or a set of coordinates of a meaningful place. Once processed and interpreted, data generate valuable *knowledge,* like a person's travel behaviour and trip history. Combined with other data, this can provide predictive insight into likely future travel behaviour (de Streel, Krämer and Senellart, 2021).

Volunteered and observed data are raw "inputs" to producing actionable inferred knowledge, which is the source of competitive advantage and value creation in data-intensive digital markets (de Streel, Krämer and Senellart, 2021; OECD, 2021b; Tucker, 2019).

What does this mean regarding mobility data, sharing and the governance of MaaS ecosystems?

There are risks that MaaS markets will foreclose if market actors unduly restrict access to raw data inputs. From an economic perspective, these data are excludable. Data controllers may prevent the sharing of data via technical or legal restrictions. Yet, they are generally understood to be non-rival (meaning, consuming data does not prevent others from consuming the same data). The consumption of non-rival goods typically increases social welfare, so there is an economic and social argument for shared and open access to those data (de Streel, Krämer and Senellart, 2021; Jones and Tonetti, 2019; OECD, 2021b).

Figure 7. From data to knowledge

Source: based on de Streel, Krämer and Senellart (2021).

There are, however, aspects of rivalry relating not to the *consumption* of data but to its *collection* – especially for observed (as opposed to volunteered) data (de Streel, Krämer and Senellart, 2021). These aspects relate to the scale and scope of data collection and favour dominant actors, first movers and those collecting data across markets. They arise from fundamental asymmetries in the amount and breadth of data collected and processed among ecosystem actors. For example, mobility operators collect data regarding where, when and how a person travelled. Though it would be theoretically possible for others to collect that data by observation, doing so would be complicated and costly, especially if the mobility operator is dominant and does not share that data (i.e. the data is excludable).

Similarly, local market actors may face difficulty duplicating observed data collected by a dominant global search platform regarding destination search and travel routing. The status quo favours first movers and those who benefit from substantial network effects within and outside of mobility and beyond local contexts (Bourreau, Krämer and Buiten, 2022; de Streel, Krämer and Senellart, 2021; Hoffmann and Gonzalez Otero, 2020; Kerber and Schweitzer, 2017; Krämer, 2021a; OECD, 2021b; Soriano et al., 2019; Scott Morton et al., 2021).

A fundamental question in the data sharing debate concerning personal data is which of the three sources of data – volunteered, observed or inferred – should be shared? This is a simple question with a complex answer. It relates to how different regulatory regimes interpret what constitutes personal data and what control should be granted to people regarding data pertaining to them. It is also linked to data portability requirements (discussed in the next chapter). A restrictive interpretation is that only volunteered data should be shared (with the data subject's consent). This approach acknowledges, among other things, that data controllers invest in data collection and thus should benefit from their investments. However, if data collection (especially of observed data) is rival, there is an argument for a more expansive interpretation from a social welfare perspective. At the core of a broader interpretation is the recognition that observed data is still *personal data* relating *to a data subject* (de Hert et al., 2018; de Streel, Krämer and Senellart, 2021; Krämer, 2021a; OECD, 2021c). Accordingly, the data subject should have agency to determine to what purposes that data is put and with whom that data is shared.

This expansive interpretation is articulated in the guidance on personal data portability in the context of the GDPR issued by the independent European advisory body on data protection and privacy. Article 29 Working Party (Art. 29 WP) states: "[data portability requirements] should also include the personal data that are observed from activities of users such as raw data processed by a smart meter or other types of connected objects, activity logs, history of website usage or search activities" (Art. 29 WP, 2016). De Hert et al. (2018) note that volunteered or observed data – including location data – that a data controller has not processed should be shared (with data subject consent). These views reflect discussions around a specific form of personal data sharing (i.e. personal data portability under the EU GDPR). Still, they reflect an increasingly convergent view of what constitutes personal data and how it should be shared with user consent and agency in digital markets (Krämer, 2021a).

The economic and social welfare case for a more expansive interpretation of which data to share in digital markets, including MaaS, is linked to where value is created for market actors. De Streel, Krämer, and Senellart (2021) note that as raw data (e.g. volunteered but especially observed data) becomes more shared, "the focus of competition is likely to move more from collection to analytics, which likely stimulates innovation rather than stifling it. Indeed, as data collection is inherently concentrated and the services through which (observed) data is collected usually exhibit strong network effects, a stronger competition at the data analytics level (based on knowledge) seems much more feasible and desirable than competition at the data collection level."

Furthermore, fostering greater access to more data (volunteered and observed) improves the quality of inferred data and, thus, its ability to contribute to value creation (Krämer, 2021a). From an overall welfare perspective, shifting competition away from data collection and towards data analytics favours consumer-centred innovation, particularly in the case of platform-mediated markets (de Streel, Krämer and Senellart, 2021; Florez Ramos and Blind, 2020; Gal and Rubinfeld, 2019; OECD, 2021b). Ensuring broad access to volunteered and observed data (via open data exposure mechanisms, portability requirements and converging interoperability) is a cornerstone of foundational mobility data infrastructure.

Mandatory data sharing does incur specific risks. These relate to actors potentially removing incentives to collect data in the first place and the costs associated with putting data sharing mechanisms in place. There is also the challenge for mobility operators, third-party data analytic firms and MaaS providers to develop viable business models that generate value from data analytics, in contrast to simply extracting rents from monopolies on data collection (de Streel, Krämer and Senellart, 2021; Florez Ramos and Blind, 2020; Gal and Rubinfeld, 2019; OECD, 2019b, 2021b).

Another possibility is that data sharing – especially mandatory data sharing – will pose an asymmetric risk to smaller actors and market entrants as opposed to larger and dominant market actors (de Hert et al., 2018; de Streel, Krämer and Senellart, 2021; Krämer, 2021a). Requiring smaller actors to expose their data to larger actors may enable large actors to mobilise their greater network effects, resources and dominant market position to the detriment of smaller actors. It is this risk that leads regulatory initiatives like the EU's Digital Markets Act to target dominant market players and market "gatekeepers" with asymmetric data sharing requirements (EU, 2022b) or to pair mandatory data sharing with regulatory oversight mechanisms as with the EU Payment Services Directive (PSD2).

Data sharing should not be expansive in light of these risks. Rather, it should be limited and purposeful, such as being linked to specific desired and transparently communicated outcomes as specified, for example, in the EU GDPR. A two-tiered approach to mobility data sharing would help to address these risks. This means all actors would share a core set of data to enable trip planning and fulfilment. Other supplementary data that could add value but are not necessary to deliver inter-modal trips would be shared on a negotiated and voluntary basis. Establishing public authority responsibility (either directly or delegated to a neutral third party) for monitoring and tracking data sharing outcomes in the MaaS market can also help assess if data sharing requirements deliver on desired policy outcomes.

What data to share for MaaS?

From a traveller's perspective, getting from one point to another is straightforward when only considering walking and one additional transport mode. From a transport service provider or public authority perspective, the task is more complicated, and decisions must be made over the long-term (investment), medium-term (schedules and latency) and short-term (vehicle availability and access). This complexity significantly increases when planning, organising and delivering the multi-leg and multi-modal trips at the heart of the MaaS value proposition. The complexity arises from the need to co-ordinate physical services in response to travellers' requests and, especially, to co-ordinate the multi-dimensional data flows necessary for trip fulfilment. Supporting each phase of the trip cycle and delivering a seamless travel experience for travellers requires access to a core set of essential data elements (Transportation Research Board, 2020).

The functional blocks that make up MaaS

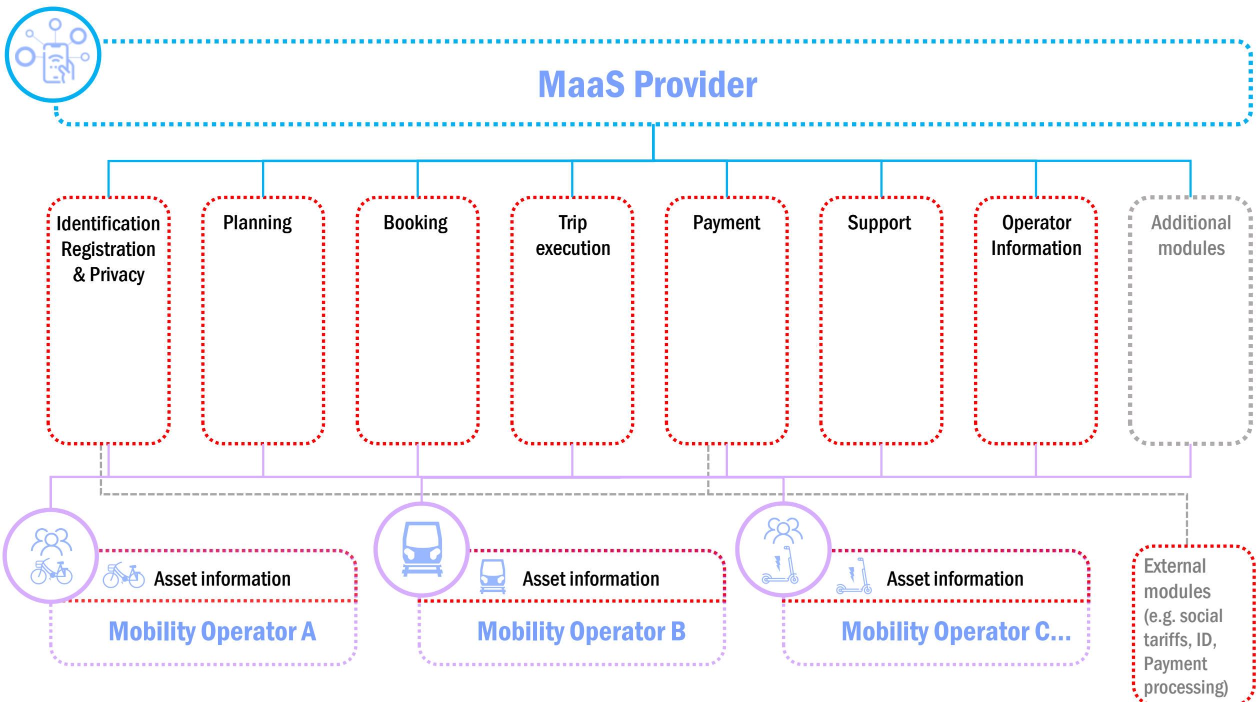
Breaking down complex data flows into functional blocks helps understand what data must be shared for which purpose and by whom. This approach is necessary to organise the digital interactions that enable MaaS trips. Such a functional breakdown is inherent in any framework for interactions between mobility operators and MaaS providers and is at the heart of many public or commercial MaaS platforms.

The MaaS Alliance identifies six core MaaS functionalities: register, plan, book, pay, travel and after sales (MaaS Alliance, 2021). Many operator and mode-specific data schemas and syntaxes exist (e.g. for public transport, micromobility, carshare, parking), each handling these functionalities in their own ways – sometimes calling on standardised approaches but often not. For MaaS to function well, a solid case must be made that such a functional breakdown should be open, aligned and integrated across *all* MaaS market actors.

The Transport Operator to MaaS Provider - Application Programming Interface (TOMP-API) (see Glossary and Figure 8) is an example of a reference architecture that illustrates the types of functional blocks inherent in the design of any MaaS system. TOMP-API, as its name suggests, is designed principally to enable data sharing between transport operators and MaaS providers to carry out joined-up trips. In this way, it is different from other syntaxes, which are designed to report data to authorities (e.g. the Mobility Data Specification) or to share information about the state of services without supporting on-trip operational linkages between operators and with MaaS providers (e.g. The General Transit Feed Specification [GTFS]).

Core functional blocks, such as those comprising TOMP-API (e.g. identification/registration, planning, asset information, booking, trip execution, payment, support, operator information and potential external modules), are distinct. Each block handles a specific outcome covering necessary sub-routines and data flows. The architecture is modular, so changes in one block only require minimal, if any, changes in other blocks. TOMP-API's architecture provides an example of the type of data exchanges which enable or support MaaS. Such modular architecture enables flexibility and extendibility and, in principle, allows external (to the MaaS provider or mobility operator) service providers to fulfil these functionalities.

Figure 8. TOMP-API functional blocks for MaaS



Source: based on TOMP API (2020).

From functional blocks to microservices

The functional blocks described above encompass specific processes that must be linked to others to deliver MaaS. They describe stand-alone processes that require data inputs from multiple MaaS ecosystem actors and generate data outputs for their use. There are two broad approaches to structuring these blocks.

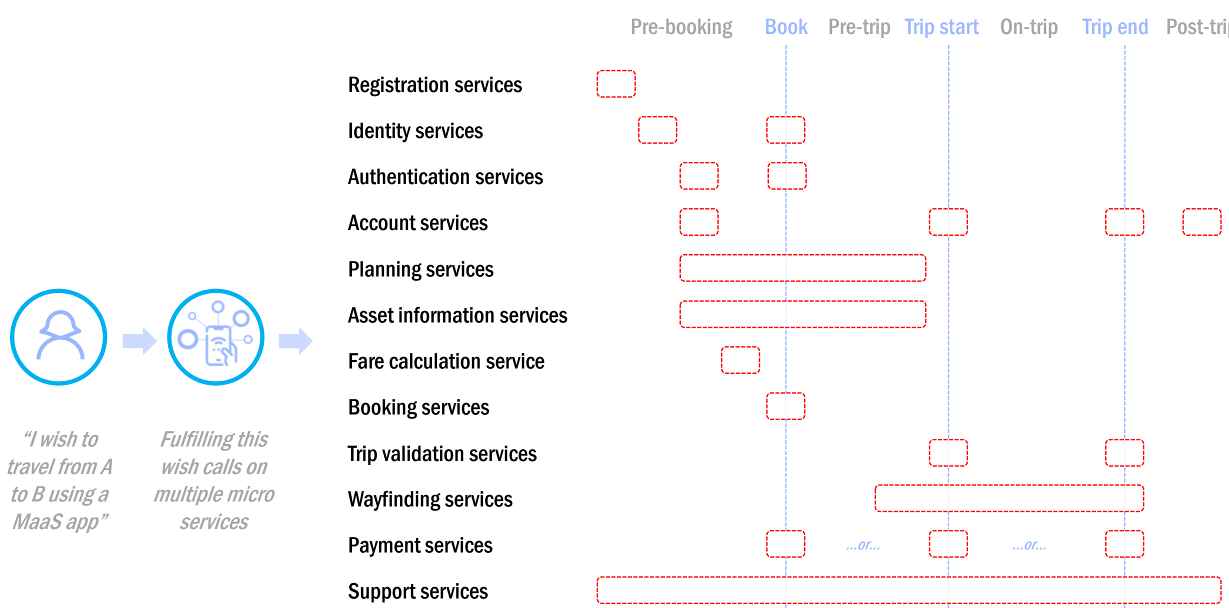
The first is to shape them as part of a unitary code base within a single software environment. The advantage is that it is less complex to design and does not require a broader regulatory framework governing market access and participation by various secondary service providers. However, it requires multiple teams coding across an ever-growing code base that increases in complexity as it grows in functionality. It also increases the risk of single points of failure due to the sharply intertwined nature of the monolithic code (Karabey Aksakalli et al., 2021).

The second approach is to leverage functional block architecture to establish a series of "microservices". These are self-contained, linked to other microservices and open to being designed, implemented and managed by either mobility operators, MaaS providers or third-party service providers. The microservice architectural approach disintermediates MaaS itself and establishes a series of secondary and tertiary MaaS-supportive service-based markets that can generate efficiencies and innovation. Under this approach, the role of the MaaS provider shifts from the strict *integration* of mobility offers to the *orchestration* of MaaS-related microservices, some of which the MaaS provider may offer themselves. Key to this microservice architectural model are the communication protocols used to communicate the status of processes, transactions and states from one microservice to another (Callegati et al., 2017; ITF, 2019; Karabey Aksakalli et al., 2021). More fundamentally, the decomposition of MaaS processes into constitutive microservices helps map out the types of data sharing necessary to enable MaaS.

Microservice-based MaaS

Figure 9 illustrates the breakdown and sequential timing of the microservices that underpin MaaS. It shows the data types that must be shared among microservices and, potentially, by different MaaS actors. It is agnostic as to who is responsible for implementing and delivering each microservice – a single actor could manage all or a subset of these microservices. Alternatively, multiple actors could offer these services in a thriving secondary or tertiary market for MaaS-related services. The functionalities of the microservices and the kinds of data sharing they require are described below.

Figure 9. Microservices underpinning MaaS and their sequential timing



Source: based on F. Burgersdijk, 2022, personal communication.

Registration, identification and authentication services

These services establish the identity of users and service providers and authenticate this information during MaaS transactions. Registration allows users to create and sign in to their MaaS account or authorise the MaaS provider to access users' mobility operator accounts on their behalf. It also allows service providers to establish their legal identity and rights to deliver services. Identity data must be authenticated and used as the basis for gaining authorisation to access resources or act on behalf of a natural person. Identity, authentication and authorisation are separate but linked processes.

Identification and registration microservices may require other information, including information on a traveller's specific needs, characteristics or preferences. Data regarding disabilities and other trip-relevant characteristics would be covered here, as well as information relating to travellers' preferences (e.g. shared modes, maximum distance by foot, maximum number of transfers).

Identity and registration data are personal data, and some potentially included in this block are also sensitive (data on disabilities or qualification for social fares). Further, linking natural persons to their travel characteristics and preferences has commercial value. There is a strong imperative, therefore, to share these data only with the consent of the data subject (in some contexts, like in the EU under GDPR, this is a legal requirement).

There is also an imperative to ensure that the benefits of sharing commercially sensitive data outweigh potential adverse outcomes. There are technical means to ensure that the outcomes of sharing identity-related data are met without sharing personal or commercially sensitive data among MaaS ecosystem actors. These are discussed in the next chapter.

Account services

Account services determine how information for a specific account is updated, stored and shared to reflect changes in the traveller's status, their account or activity history and the rights conferred to them. It also relates to how travellers can see and track their activity history. Because account services may have access to detailed usage data (including trip histories), they also handle personal data.

Planning and asset information services

Trip-planning microservices enable travellers to explore trip options before they commit to one. It integrates desired destinations, user characteristics, and preferences from other microservices. Trip planning information includes estimated travel time, cost, and location of mobility services (e.g. stop, vehicles, infrastructure). This information combines scheduled and estimated service availability with real-time routing, service schedule and latency data. Trip planning services can be "in-house", meaning the MaaS platform provides them, or third-party microservice providers can provide them.

Trip planning differs from booking. Planning refers to rapid search (e.g. when there is no intent yet to book a trip). To that end, it does not require strict accuracy but only suggests options and rapidly estimates relative travel times, costs and conformity with traveller preferences. This stage does not entail the creation of a mobility offer, but in some cases, the information returned by a planning query may contain "ready-to-book" options.

Trip planning microservices are linked to asset information microservices that describe the location of assets (e.g. vehicle, service, infrastructure) and their ability to fulfil a trip at a given instant, for a given amount of time (e.g. duration of the trip), and under given conditions (e.g. destination, number of passengers). Asset availability may refer to the state of a device (e.g. functioning, not functioning, state of charge) or the number or type of available seats (e.g. shared taxis, on-demand shuttles, accessibility for the disabled). This microservice can also provide additional information on the service (e.g. type of vehicle, equipment, etc.).

Both trip planning and asset information data are essential inputs to the planning and booking phase of trip lifecycles. Thus, they form part of the core information (either in the form of data or verified status messages) that all mobility operators should expose.

Fare calculation service

Fare calculation runs alongside the trip planning service and allows the MaaS provider to display the cost of travel options offered to travellers. Fare calculation for multi-legged trips requires accessing information from multiple "tariff owners" (those who set the prices for their services) and applying composite fare calculation methods (e.g. based on traveller characteristics such as age or income, subscriptions, rules based on geography). Some fares are open to the public and are detailed alongside service descriptions, while others must be adjusted for several factors.

Fare calculation is typically embedded in each mobility operator's fare collection or ticketing platform. However, standalone third-party fare calculation services can also deliver this service – perhaps even more efficiently in multi-operator MaaS trips. Such an approach has been adopted in Switzerland for all public transport journeys. The NOVA platform acts as a separate fare calculation module servicing all public transport trips in the country (Eichhorn, 2020; Hansel, 2019).

Booking service

The booking microservice commits travellers to a specific option offered by the MaaS provider. A booking can flow from the planning microservice or may be initiated directly when the traveller already has a preferred option in mind. Booking is a more complex process than planning a trip and requires greater accuracy alongside service delivery commitments from mobility operators.

The booking microservice creates a unique booking identifier to be used with mobility operators and to confirm the real-time availability of assets. If requested assets are available according to trip- and user-specific requirements, the booking service initiates a booking request which temporarily locks in assets pending confirmation from the mobility operator. Before finalising confirmation, the mobility operator may require user ID authentication, which, if successful, confirms the booking and commits the mobility operator to deliver the requested trip leg. This happens under the condition that all other mobility operators operating other linked trip segments also confirm their specific bookings initiated by the booking service provider.

Booking requires a commitment by the user or the MaaS provider acting on the user's behalf to purchase the trip. Purchasing differs from payment as it does not include any financial transfer but pre-commits the user to pay.

The flow of data and the processes enabling the booking of trips are essential for MaaS to function, so data exposure enabling booking and processes guaranteeing bookings form part of the minimal data to be shared by MaaS ecosystem participants.

Validation services

Validation services grant travellers specific vehicle or service access authorisations once a trip commitment has been made via a booking. Proof of booking (from the booking service) is then used to validate the traveller as being the rightful user of the committed service.

In practice, a digital token or unique identifier is recognised by the mobility operator, and authorisation is granted to the traveller to use the mobility service. This interaction is required at the start of the journey. During the trip, the validation can be checked automatically or manually. At the end of the trip, the specific right to consume the mobility service offer expires and this closure must be validated as authentic. End-of-trip confirmation is linked to other microservices, including account and payment services.

MaaS offers cannot function without trip status messages; thus, these form part of the information that mobility operators and MaaS providers must expose. TOMP-API, for example, identifies five linked trip execution states (TOMP-API, 2022):

1. *Trip in preparation*: This state refers to a trip that has been booked and committed but where the asset is being prepared for use (e.g. a taxi making its way to a user or while a rental car is being prepped and cleaned before being released to a user). The trip preparation state is also when access and location data are sent to the user.
2. *Trip is underway (in use)*: The in-use state is triggered when a user has commenced travel. Acknowledgement of this state can be communicated either by the mobility operator or the MaaS

provider depending on the kind of booking, type of asset and trip initiation protocol (e.g. getting on a bus vs unlocking a bicycle and starting to ride).

3. *Trip is paused*: Users or mobility operators may need to indicate that an ongoing trip has been paused. It may be necessary to apply different rates (e.g. for a parked vs a moving car).
4. *Trip is finishing*: This state reflects when an asset is no longer being used but before final clearance has been processed. For example, this state would apply as the mobility operator verifies the state of the vehicle or processes the final payment after the user has indicated the trip is complete. If the trip execution requires closing an asset (e.g. dock a bike, return a car), the user should indicate that they are stopping their trip. This message is transmitted directly to the MaaS provider or the transport operator (with notification to the MaaS provider). In return, the user receives trip end or lock instructions. Once the asset is closed (e.g. bike docked), the user app generates a trip-end confirmation message which is transmitted to the MaaS provider and mobility operator.
5. *Trip is finished*: This state reflects a definitive finding by the mobility operator that the trip leg has been completed, and no further processing or communication regarding the trip execution is necessary. The MaaS provider can confirm a multi-leg trip has been completed when all mobility operators have confirmed that each trip leg for which they had responsibility has been completed. Once the final clearance process is over, the user should no longer be able to use the asset.

Wayfinding services

These services provide information to accompany travellers on-trip, including how to physically access different services during the trip. They are typically map-based but may also include specific text or aural cues. They communicate trip progression and trip status messages to travellers and can provide alternative routing in response to trip disruptions and incidents while it is underway. Sometimes, wayfinding services serve a secondary function as a conduit for communicating relevant wayposts along a traveller's journey back to service providers. Time-stamped location, for instance, can enable a service provider to ensure that a trip occurs in a specific geographic area or within a determined time window.

Wayfinding services may require input from identification and account data to establish if specific needs or preferences must be accounted for in the wayfinding cues given to the traveller. These cues may relate, for example, to wheelchair-accessible routes and vehicle access instructions or routes that fit a preference for cycling on residential streets versus on dedicated infrastructure. Wayfinding services may also be linked to trip planning, asset availability and booking services. Wayfinding data must be treated as personal data when it comprises privacy-sensitive time-stamped location data or traveller characteristics.

Payment services

From a customer perspective, payment should allow one seamless payment for the entire trip, even if it includes different transport services. The user should be able to use various payment types (e.g. subscription, pay-as-you-go, deposit). The mode of payment can later serve as means of access (e.g. payment card) for the different legs of the trip. Payment may occur pre- or post-trip. The MaaS provider, either directly or as an orchestrator of other trip-related microservices, acts as a *payment service initiator* – the party that notifies when payment should occur.

The payment microservice communicates the status of prepayment for the different portions of the trip (e.g. deposit, subscription) and the status of post-payments related to the trip (e.g. fines, penalties, damages, refunds). Some businesses may use both the pre and post-payment model at the same time. Mobility operators may request a deposit before the user books a valuable asset. In this case, if initially agreed conditions are met (e.g. no damage, full battery or tank), these should be refunded via the MaaS provider.

Sharing data on payment status is essential to confirm bookings and allow joined-up trips. As such, data relating to these should be part of the minimal shared data allowing MaaS to function. Payment processing is a related but separate task. Payment processing data (bank account balance, payment methods, identity, etc.) should not form part of the scope of shared data and should remain with payment processors. However, it should be noted that payment processors may need, or have a right, to access individuals' account data from banks and financial institutions (as in the case of EU financial institutions under the Second Payment Services Directive – PSD2). Though, this falls outside of the scope of MaaS data sharing.

Support services

Support is a transversal function delivering technical assistance to users anytime during a trip, for example, in response to incidents occurring in other functional blocks. The assistance process starts with the user's request for support, or an update is generated regarding the trip. The request may be handled directly by the MaaS provider or the mobility operator or by an external microservice provider who then manages the incident and ensuing data flow between MaaS provider, mobility operator and traveller.

The issue may imply modifications to the initial trip. To that end, the support microservice may include links to other microservices (e.g. planning, booking, payment and trip validation). Some support may be necessary after a trip has been completed. After-sales processes may imply refunds from the mobility operator to the user. In this case, it is linked to the payment and account microservices. After-sales support may include warranty services (e.g. damage on a shared vehicle), information on how to use a device (e.g. code of conduct), or surveys. After-sales data reporting requirements may extend beyond trip support, covering enforcement actions and gathering statistical data as outlined in the French Mobility Bill (French Government, 2021).

Minimal data sharing

There are few incentives for first movers to provide access to and share their data if other MaaS ecosystem actors do not do so themselves. This suggests a need to impose minimal data sharing requirements, so all vetted actors have equal access to the data necessary to deliver MaaS offers.

Minimal data sharing requirements should cover the type of travel agreement, including the service description (type of transport in space and time), asset and service availability, compensation (price) duration, terms and conditions; and information regarding the status of trips (e.g. booked, confirmed, validated, concluded, paid).

As noted previously, minimum data sharing obligations also help address the rivalry of data collection (as opposed to data consumption) and have a pro-competitive effect if appropriate safeguards are in place. Common data sharing requirements generate benefits but impose costs that not all actors can absorb easily or at all.

In this respect, the *design* of data sharing mechanisms – particularly interoperability and data portability requirements – is essential to minimising these costs.

How to share MaaS-relevant data?

Data sharing enables the MaaS ecosystem to generate value for all actors. Sharing data is both an aspiration – what mobility data governance should enable – and an outcome – what happens when a specific set of policies, agreements and measures are implemented. From a policy perspective, it is essential to address data access rights and sharing responsibilities and consider how data interoperability and portability are enacted (Hoffmann and Gonzalez Otero, 2020). The potential for data sharing to deliver broad benefits is tied to several technical mechanisms that enable essential data to be shared in a privacy-preserving, pro-competitive and secure way among market actors. This section addresses these mechanisms.

Ensuring technical interoperability of cross-actor systems is a crucial concern for data sharing in support of MaaS. This is the focus of this section, but it is not the only interoperability concern. How well actors work together and the mechanisms they or others establish are also critical enablers of MaaS.

Technical aspects of integration, compatibility and data sharing

The technical mechanisms supporting data sharing relate to connectivity, data interoperability and data portability (Figure 10).

Connectivity

Data can be shared in many ways. A letter, an email, a PDF file, a book and an API are all mechanisms for sharing data, but they are not equally shareable across multiple media and platforms. In the context of MaaS, and more broadly with all digital services, data will likely be shared in digital formats. This presupposes that different MaaS ecosystem actors can physically connect to each other's systems – that is, the bits and bytes comprising data and information can flow from one system to another. This connection may be enabled through fibre-optic cables, WiFi or cellular networks. Without this connection, systems are offline and can only asynchronously interact until connectivity is re-established. Connectivity is generally not a significant concern, especially in urban areas, as cellular and other networks are ubiquitous and generally reliable. In some rural areas, this may not be the case. Thus, the pre-condition of network and system connectivity may be a barrier to MaaS in those contexts (Banerjee, Jittrapirom and Dangschat, 2021; Durand et al., 2022; Rudolph, 2019).

Figure 10. Technical aspects of data sharing: Connectivity, interoperability and portability

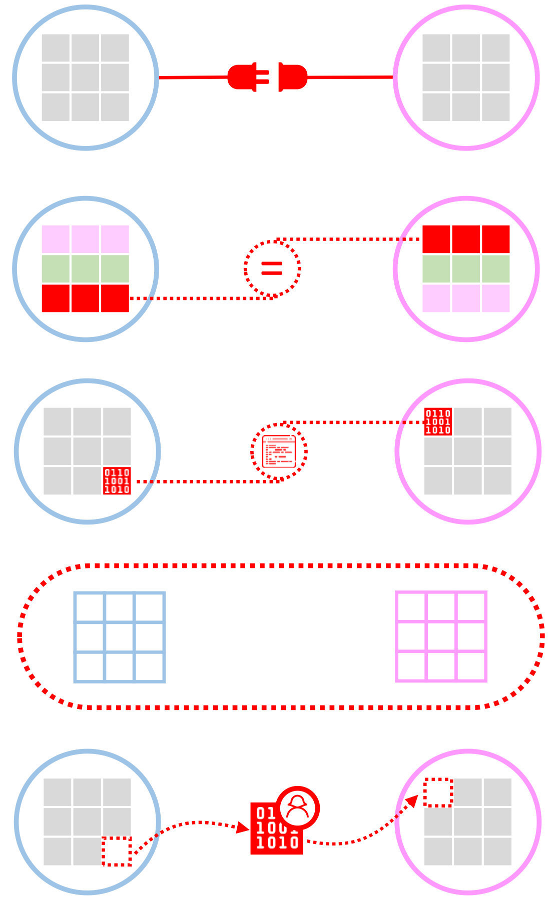
System connectivity
Are systems materially able to connect with each other? Does this connectivity ensure low-latency interaction among systems? Are people able to connect to systems? Do they face challenges in doing so?

Protocol (schema) interoperability
Are systems able to interact with each other without undue friction from incompatibilities - are schemas and data structures mappable between systems?

Data (syntaxical) interoperability
Can data generated and used in one system be relatively frictionlessly ingested and used by another system? Do systems share common semantical meanings and are syntaxes shared or compatible amongst systems?

Full (native) interoperability
Do standards, hardware and systems interact "natively" and seamlessly amongst different systems? Can users of one system use features of other systems, and vice-versa, without any additional prompting or learning on their part?

Data portability
Do data controllers allow data subjects to access data pertaining to them or to designate third parties who should have access to this data? Is this data transfer made on a one-off or continuous basis?



Source: based on Bourreau, Krämer and Buiten (2022); Cremer, de Montjoye and Schweitzer (2019); de Streel, Krämer and Senellart (2021); ITF (2021c); Krämer (2021a); OECD (2021b).

Interoperability

Interoperability and data portability questions arise once systems physically connect. Interoperability broadly refers to how well systems can "work together" (Bourreau, Krämer and Buiten, 2022). In digital markets, interoperability allows "system, product or service to function with other, technically different systems, products or services" (Kerber and Schweitzer, 2017). Interoperability, and the lack of it, is often at the heart of many competition policy discussions regarding market capture or openness (Borgogno and Colangelo, 2019; Bourreau, Krämer and Buiten, 2022; OECD, 2021b; Scott Morton et al., 2021).

Improving interoperability and imposing personal data portability are often offered as solutions to avoid consumer lock-in or excessive market power. Interoperability and data portability, however, are two related but distinct mechanisms. Interoperability enables data to flow between and be ingested by different systems to deliver joined outcomes. It is about the *ability* for data to be shared and systems to work together. Data portability is about *what* data is carried or allowed to flow from one system to another and under what conditions this occurs – it is about *rights* and *responsibilities*.

Closed or proprietary mechanisms may ensure interoperability, but this may concentrate power on the "owner" of the interoperability mechanism and may lock users in at the expense of continued innovation.

In contrast, open interoperability mechanisms, for example, those developed transparently via open participation and governance frameworks and which produce open source and documented code, counter these risks (Bourreau, Krämer, and Buiten 2022; Heuser et al. 2017; Hoffmann and Gonzalez Otero 2020; Kerber and Schweitzer 2017; OECD 2021a; Scott Morton et al. 2021). Social value-maximising interoperability leverages open standards, is vendor agnostic, avoids prescriptive solutions or technologies, is modular, can be developed incrementally and focuses on concrete and identified outcomes (Heuser et al., 2017; MAAS Alliance, 2021).

Interoperability – and the data sharing it requires – should be equitable, but that does not mean that systems should be open to all or that all data should be shared with all. Equitable interoperability in the context of MaaS means that actors can join the MaaS ecosystem freely and participate in qualitatively equivalent terms (Scott Morton et al., 2021). Interoperability, and the data sharing it requires, should not favour dominant actors over others, especially when that actor deploys services that compete with those of other actors. Interoperability may be achieved at different levels, but the choice of *where to focus* interoperability efforts will matter regarding how equitable that interoperability is and how well it aligns with other societal objectives. The choice and design of interoperability and data sharing mechanisms also matter as these open or constrain data access.

Interoperability can be split into three levels: protocol interoperability, data interoperability and full interoperability.

Protocol interoperability

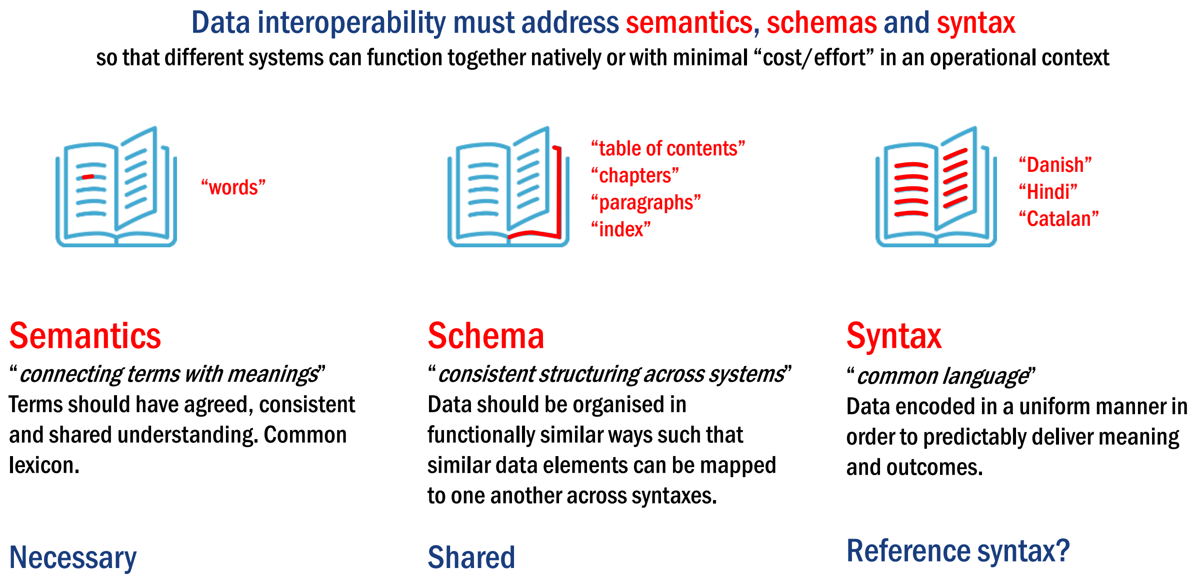
Protocol interoperability refers to how systems work together. Are data transfer protocols of one system compatible with those of another system? Do the systems operate on the same core software encoding standards? Are the respective code bases of each system organised along the same schemas and architectures? Is the code well-referenced, documented and conforming to open and shared coding standards? The more the systems can be mapped from one to another and interact without major (and costly) re-interpretation and adaptation, the more interoperable they are.

Data interoperability

Data interoperability refers to the ability for data generated in one system to be frictionlessly (ideally in real-time) ingested, processed and used in another system (and vice-versa). Data interoperability is at the core of MaaS and yet is an area where little convergence has occurred. This is due to several factors, including the diversity of MaaS ecosystem actors and accompanying data standards, a reluctance among actors to adopt data standards they feel they have little or no control over, the use of closed data syntaxes by some market actors to foreclose competition and the costs of re-coding internal systems to data standards which may not prove durable or aligned with their perceived best interests.

Data interoperability has three core building blocks: semantics, schemas and syntax (Figure 11).

Figure 11. Building blocks of data interoperability: Data semantics, schemas and syntax



Data semantics

Like human language, digital systems build on a shared understanding of the semantical building blocks of language – words and terms. However, unlike human language, which is often open to nuance and interpretation, digital systems using machine language require clear, consistent and unequivocal definitions of terms and meanings. The MaaS ecosystem cannot function effectively if mobility operators, MaaS providers and other MaaS ecosystem actors understand terms like "trip started", "bus stop" or "vehicle available" in different and sometimes incompatible ways.

Establishing common and documented meanings to terms used in digital exchanges is a prerequisite for data interoperability. Accepted semantic models exist for established mobility services but are still lacking for many new ones. Mode-specific semantical models are more likely to exist for public transport and serve as the basis for the data syntaxes used to promote interoperability and reporting within those services. In contrast, little semantical harmonisation has taken place among new mobility operators. Thus multiple definitions may exist for such basic information as "is an asset available?" or "has a trip ended?". Some progress in remedying this is underway, as in the case of mapping General Bike Feed Specification (GBFS) to the Network Timetable Exchange technical standard (NeTex) and the Service Interface for Real Time Information protocol (SIRI) (DATA4PT and MobilityData, 2022).

Common semantical lexicons should be developed at the highest level possible to ensure their widespread adoption (for examples of MaaS-relevant semantical lexicons, see ITF [2021c] and MaaS Alliance [2021]). Linking these building blocks to contracts and existing mechanisms or aligning them via canonical mapping to other current or converging standards will facilitate their uptake.

Deployment should be voluntary and incentivised via traditional standard-setting processes, which will take time and there is, at present, no well-defined broad initiative to do this. In the meantime, market actors and authorities can incentivise the adoption of emerging semantical lexicons that provide some form of convergence around the meaning of terms. More importantly, authorities can incentivise or require (in the terms of the licenses they grant) actors to adopt common semantic operations and logics when mapping one term to another in different data syntaxes. For example, suppose "unavailable vehicle" in one syntax could be interpreted in one of two (or more) ways in another syntax. In that case, authorities could incentivise one consistent interpretation across all ecosystem actors.

Data models and schemas

Establishing common or broadly compatible data schemas can bridge the gap between a MaaS ecosystem characterised by multiple bespoke data syntaxes and one in which a single harmonised data syntax prevails.

Data schemas are high-level architecture models relating to data structuring within each syntax. A data schema is roughly analogous to the structure of a book. A book has a cover and a back, it may have a table of contents and chapters, the text is organised into paragraphs, and each page is assigned a referenceable number. All of these mean that very different books are useable in the same way despite differences in content and language. Data should be consistently structured and organised functionally so that similar data elements can be mapped to one another across otherwise different syntaxes.

A number of mobility data schemas exist or are emerging (see Chevalier et al., 2021; ITF, 2021c; MAAS Alliance, 2021). A MaaS-supportive data schema should ideally be structured in line with the functional domains necessary for mobility operators and MaaS providers to deliver co-ordinated and joined-up trips. In this respect, the functional microservice-oriented breakdown outlined in the previous section serves as a model for structuring a common MaaS data schema. Beyond the data structuring, appropriate meta-data and built-in model referencing and documentation help describe how the data structure is linked to specific data elements across different data syntaxes.

Data Syntaxes

If the semantical basis for mobility data is analogous to words in human language, the digital data syntaxes deployed to support mobility data sharing are akin to grammar rules. They provide the structure in which the building blocks of language are organised to communicate meaning and generate understanding. As noted above, there is little room for interpretation in machine language. Therefore, specifying a data syntax that enables communication, or finding an efficient way to translate meaning from one syntax to another, is a core concern in deploying digital services.

The strongest level of data interoperability stems from the broad use of accepted (or imposed) data sharing syntaxes. These may be set by standard-setting bodies or de facto standards established by a dominant actor or collaboratively built by consortia of market actors. At present, however, there is no universal mobility data sharing syntax. Public transport operators use industry-standard data syntaxes for sharing information (e.g. in Europe, NeTEx and SIRI based on the Transmodel model, DATEX II, or, globally, the General Transit Feed Specification [GTFS] for static information). Shared bicycle, shared micromobility, and carsharing operators may use the GBFS to communicate with other systems. Other mobility operators or services, like carpooling services or taxis, may use emerging syntaxes like General On-Demand Feed Specification (GOFS) or their own bespoke standards. Shared micromobility operators can also report data using the Mobility Data Specification (MDS), which incorporates elements of GBFS (for an overview of these syntaxes, see Chevalier et al., 2022; ITF, 2021c; MAAS Alliance, 2021).

Multiple, poorly aligned, or incompatible data syntaxes hamper the uptake of integrated mobility services. They may also give rise to market power asymmetries if adopted data sharing syntaxes favour certain operators over others, whether by design or in practice. The deployment and uptake of open and mode-agnostic data syntaxes mitigate this risk. There is also a risk that forcing the MaaS ecosystem to adopt a specific data sharing syntax, even if it is flexible and evolutionary, may foreclose innovation and impose costs related to complying with the syntax. This especially applies to small- and medium-sized operators who already have built their data architecture around another syntax.

A less restrictive approach may be to ensure broad functional alignment between the different standards used by MaaS ecosystem actors. This functional interoperability may be delivered by market actors agreeing to (or being required to) conform to a common data *schema* rather than a specific syntax (ITF, 2021a). This path is taken by DATA4PT (Transmodel) and MobilityData (GxFS) based on a canonical mapping between the standards. The idea is to recognise that different standards meet different needs and use cases and ensure that a simple conversion tool can be built for better interoperability. Regarding the book analogy, the mapping would be like bilingual dictionaries.

Another less-restrictive approach to interoperability would be to establish semantically-aligned, validated and authoritative meta-data statements concerning the status of a transaction or process. Exchanging commonly understood and trusted status messages such as “confirmed”, “validated”, “concluded”, “paused”, “paid” would serve as a proxy for the kind of outcomes data interoperability seeks to achieve. Such a trust-based approach would require auditability, control and enforcement mechanisms. It could leverage zero-knowledge proof-based trust signatures (see glossary) and distributed ledgers.

Full interoperability

Full interoperability refers to systems designed to be fully interoperable from the outset – that is, interoperability is a built-in design feature. Fully interoperable systems are characterised by but go beyond deep protocol and data interoperability. They allow substitute services, deployed by different MaaS actors, to interoperate – for example, public transport, taxi and micromobility services, which are natively and interchangeably bookable, payable and accessible from mobility operator apps. Fully interoperable services allow competitors to access their rivals’ user base, thus sharing network effects and enabling a more level playing field (Bourreau, Krämer and Buiten, 2022).

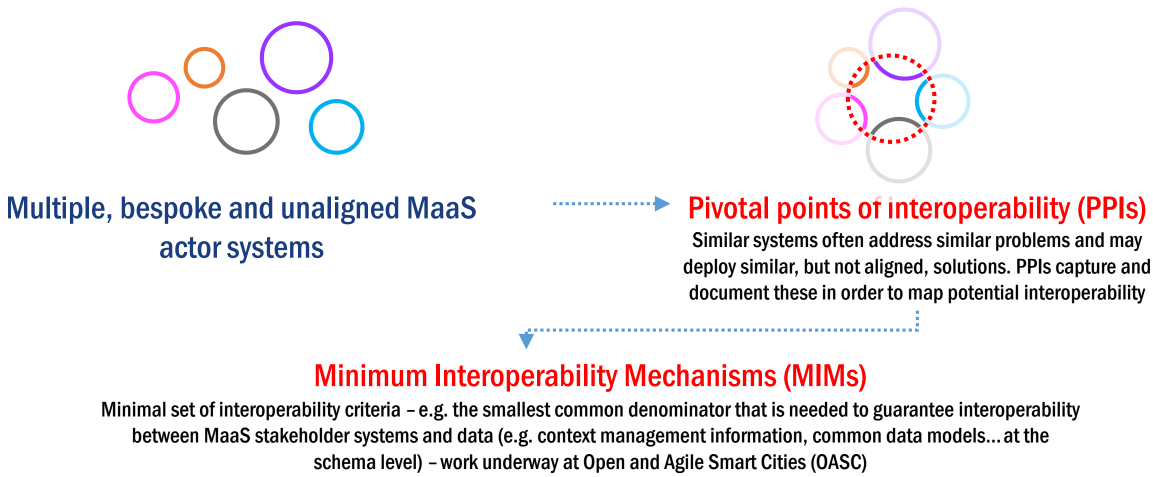
Strategies for enhancing interoperability

Interoperability should be understood as a means to an end, not as an end in itself (Hoffmann and Gonzalez Otero, 2020). In MaaS, interoperability allows people to easily understand and undertake seamless, joined-up trips using different mobility operator services. Achieving that objective will require interoperability, but that interoperability must be balanced and aligned with other important objectives. These include minimising the cost associated with enhancing interoperability, addressing potential competition and other market impacts, accounting for the technical feasibility of introducing and maintaining interoperable systems and ensuring that interoperability contributes to innovation, value creation for users and achieving broader policy objectives.

Those last points underscore a fundamental trade-off: standardising everything forecloses innovation, whereas standardising nothing results in non-interoperable silos (IES-City, 2018). Neither of these is a good option.

At this early stage in the deployment of MaaS, it makes little sense to lock in a single mobility data sharing syntax – these are likely to change as MaaS matures and experience grows and needs evolve. There is also the risk that locking in one solution would also intentionally or unintentionally confer market power to a single or a small set of actors. In this context, a preferable response would be to seek ways to identify and accommodate minimum effective interoperability frameworks across the MaaS ecosystem. *Pivotal points of interoperability* and *minimum interoperability mechanisms* are two promising linked strategies to do this (Figure 12) (Heuser et al., 2017; IES-City, 2018; ITF, 2021c; LI.EU, 2021; MaaS Alliance, 2021; OASC, 2021).

Figure 12. Establishing minimum interoperability between mobility data syntaxes



Source: based on MaaS Alliance (2021).

Pivotal Points of Interoperability

Independent teams facing analogous problems often develop similar concepts and approaches regarding standards, specifications, architectures, frameworks, conceptual models, platforms, protocols, and environments (IES-City, 2018). They develop these in response to common concerns and goals. For example, how can information be shared about available transport assets? How can travellers and assets be located in a timely and consistent manner? How can travellers book and pay for assets within and across mobility operator systems?

These concerns are tied to technical choices, such as communication protocols, data ontologies, chronological synchronisation, localisation, asset identification and tracking. Identifying the set of common, similar or compatible solutions to these concerns reveals potential Pivotal Points of Interoperability (PPI). These include features in different systems that are functionally aligned and compatible and can serve as a basis for interoperability.

PPI is both a process and an outcome that charts a middle way between a single standard or system and multiple incompatible standards or systems. It seeks to surface common concerns and desired outcomes, link these to technical design and features in each syntax or system, and map these across systems to identify where interoperability can naturally emerge. The process has been documented in several instances, notably by the Internet-of-Things-enabled Smart City Framework working group – an open international initiative housed by the US National Institute of Standards and Technology (IES-City, 2018) and by the European Innovation Partnership on Smart Cities and Communities (Heuser et al., 2017). The difference between those initiatives and the application of PPIs for MaaS is that the former addresses widely divergent systems in the context of smart city cyber-physical systems. Those Internet-of-Things systems display fundamentally different designs, functionalities and technical characteristics (e.g. urban lighting, water management systems, central heating and transport). This is less the case within the MaaS ecosystem. As noted earlier, the basic micro-service-oriented functionalities outlined in the previous section will likely be found across most mobility operators' systems, facilitating the discovery and mapping of PPIs.

Minimum Interoperability Mechanisms

Once points of interoperability have been identified, specific measures and capabilities must be developed and implemented across systems and syntaxes to render them interoperable. The Minimum Interoperability Mechanism (MIM) framework developed by the Open and Agile Smart Cities network addresses this challenge (1001 Lakes Oy et al., 2021; LI.EU, 2021; MAAS Alliance, 2021; OASC, 2021). If PPIs are *where* interoperability can occur across different syntaxes and systems, MIMs define the interoperability "hooks" – that is, *how* interoperability is established.

MIMs are "the minimal but sufficient capabilities needed to achieve interoperability of data, systems, and services between buyers, suppliers and regulators across governance levels around the world" (LI.EU, 2021). The most current version (v 5.0 – also referred to as MIMs Plus) sets out a comprehensive vision for an open, technology agnostic and vendor-neutral data schema that, if implemented, would enable all of the stakeholders in the data ecosystem to achieve interoperability, building on existing and bespoke data syntaxes and standards. In particular, MIMS Plus enables modular, flexible and scalable solutions to allow for bespoke adoption by all kinds of actors and in different contexts, adopting global, standard-based open application programming interfaces (APIs) to enable broad interoperability and ensure data harmonisation and global standards based on semantic interoperability through the adoption of common, linked data models (LI.EU, 2021).

MIMs have the potential to serve as the blueprint for mobility data infrastructure (Figure 1) in that not only do they open a pathway to link different data syntaxes and systems presently operating in that space, but also they are designed to enable broader societal goals to be built into the technical systems that collect and process data. MIMs Plus compliance, for example, would ensure that data-reporting processes are privacy-preserving by default. The schema also seeks to provide a flexible and scalable framework that enables data-governance frameworks to account for new forms of data and processing (SynchroniCity, 2020; LI.EU, 2021; OASC, 2021).

The MIMs framework is implemented in several Smart City and data governance initiatives, including the MyData framework (See Box 8). MyData is a Finnish-initiated, open global personal data management framework that empowers people to use their personal data according to their preferences and securely authorise sharing that data on their own terms (MyData, 2018; Poikola et al., 2020). MyData serves as a reference architecture for personal data management in MIMS Plus, where it outlines mechanisms giving people meaningful access and control to data on and produced by them across multiple systems and encoded in various syntaxes (for more information on MyData, see 1001 Lakes Oy et al. 2021; ITF 2021c; Poikola et al. 2020).

MyData's API-based architecture establishes data subject agency and assigns data access rights and responsibilities. As such, it can frame data sharing of personal information within the MaaS ecosystem. Beyond that, it is an example of how different modular units – "building blocks" – carrying out essential data sharing functions can serve as a basis for mobility data sharing infrastructure, especially when fulfilling continuous personal data portability in the MaaS ecosystem (Langford et al., 2022).

Data portability

Data portability refers to individual rights and market actor obligations enabling people to access data about them or designate to whom and under what conditions market actors should transmit their personal data. OECD (2021b) defines data portability as "the ability (sometimes described as a right) of a natural or legal person to request that a data holder transfer to the person, or to a specific third party, data concerning that person in a structured, commonly used and machine-readable format on an ad-hoc or continuous basis" (OECD, 2021c). If interoperability *enables* data to be shared and used across market actors and systems, data portability addresses *what* data should be shared, by whom and under what conditions.

Data portability is an essential tool enabling people to control and manage the sharing of their personal data. Data portability reduces the risk of consumer lock-in by enabling multi-homing (i.e. customers using multiple platforms to access the same or comparable services) and reducing the friction of moving from one service provider to another. Data portability, in theory, if not in practice, enables people to share their personal data in real-time to create services that cut across different operators – as in the case of MaaS.

Data portability requirements are enacted in numerous jurisdictions and sectors but vary in their purpose, scope and degree of operational specification. Data portability is almost always motivated by its pro-competitive effect in data-intensive markets. However, in some jurisdictions – in the European Union, in particular – data portability is also associated with a fundamental right for people to have access to and control the use of their personal data. Despite their diversity, data portability initiatives can be broadly characterised across five key dimensions (OECD, 2021c) – all relevant to MaaS.

1. Sectoral scope

Some data portability measures are cross-sectoral (e.g. GDPR in Europe, the California Consumer Privacy Act or the California Privacy Rights Act), while others are sector-specific (e.g. The 2nd EU Payment Services Directive or The EU Regulation on Motor Vehicles). Sector-specific approaches typically target infrastructural sectors (e.g. telecommunications, energy, banking and health) (OECD, 2021c). Where data portability requirements exist on a general level (as in Europe with GDPR), these should be implemented within the MaaS ecosystem. Where such general frameworks do not exist, sectoral approaches for MaaS (and for mobility services more generally) would be appropriate.

2. Beneficiaries

People are typically the focus of data portability initiatives, especially when data portability is conferred as a right (e.g. in Europe and California). This reflects the focus of many of these initiatives on enabling people to better control data pertaining to them. Data portability for MaaS should focus on rights conferred to individuals since this fosters greater user-centricity in the MaaS ecosystem.

3. Data type

Which data are covered by personal data portability initiatives depends on how different jurisdictions define "personal data". As noted previously, there is a case to adopt a more expansive understanding of personal data covering both volunteered and observed data, but not inferred data. There is growing regulatory convergence towards this understanding in several jurisdictions, particularly in the EU (de Streel, Krämer and Senellart, 2021; Krämer, 2021a; OECD, 2021c).

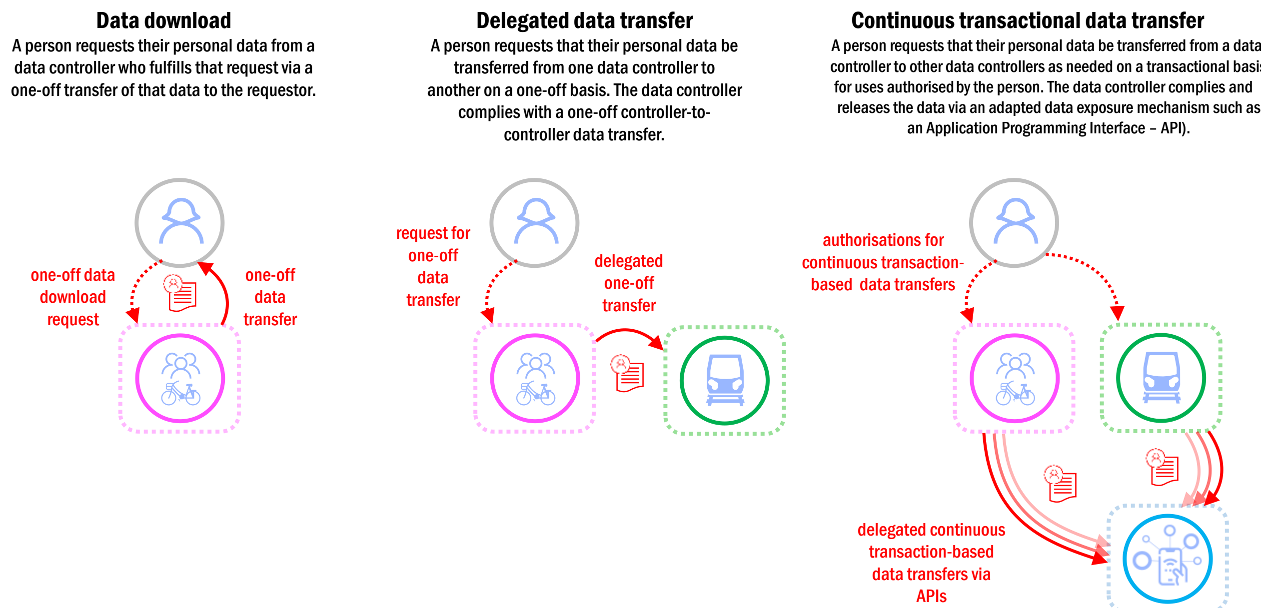
4. Legal frameworks, obligations and enforcement

The imposition of data portability obligations may result either from regulation or in response to specific prior adjudication of competition enforcement actions. The difference between the two matters. When it results from regulation, it establishes and specifies data portability requirements for all market actors. In contrast, when it comes from prior adjudication, it is only triggered by competition enforcement proceedings and thus occurs on an ad-hoc basis to address specific harms. Many data portability frameworks are not backed by strong implementation guidance. Beyond establishing data portability responsibilities or rights, they typically give little practical guidance on the mechanisms and methods to be used to carry out portability and rarely link them to broader interoperability frameworks (Article 29 WP, 2016; de Hert et al., 2018; de Streel, Krämer and Senellart, 2021; Krämer, 2021a; OECD, 2021c).

5. Data portability model

Personal data portability may be enacted in several ways (see Figure 13).

Figure 13. Data portability models



Source: based on de Streel, Krämer and Senellart (2021); OECD (2021c).

Data portability may entail allowing a person to download their personal data on an ad-hoc basis from a data controller in a structured, commonly used, machine-readable format. The data subject can then access or transmit this data to another data controller as they migrate to a new service. Data portability is typically asynchronous in this model – there is a delay between the request for the data and its transfer (de Streel, Krämer and Senellart, 2021; OECD, 2021c).

Data portability frameworks may also require data controllers to transmit personal data they hold to another data controller when asked to do so by the data subject. In this instance, the data subject directs the data controller to initiate the transfer. The delegated transfer may be conditioned by the technical feasibility of enacting controller-to-controller transfers, as with GDPR.

Both the direct download and delegated data transfer models comprise a one-off or ad-hoc transfer of personal data at the data subject's request. They are meant to reduce switching costs when changing from one service provider to another and enable multi-homing. The direct download model may involve some delay (and human intervention from the data controller). On the other hand, delegated data transfers are typically initiated as an immediate response to a request by the data subject (e.g. on a *pull*-basis where the receiving data controller "pulls" the data from the originating data controller).

Because the delegated data transfer entails interoperability between data controllers, the transfer is generally handled via an Application Programming Interface (API). The receiving data controller is the client of the originating data controller API to whom they provide valid authorisation for initiating the transfer (typically a token). API-managed data portability requires mapping the data schema of the originating data controller to the receiving data controller (Borgogno and Colangelo, 2019; de Streel, Krämer and Senellart, 2021)

A third data portability model seeks the same outcomes but targets very low latency – in some cases on-demand or real-time – transfers of personal data among market actors with the data subject's consent. Such "continuous data portability" enhances interoperability and is triggered as necessary in a transactional context. A requirement to ensure continuous and consent-based personal data portability is expressly set out in the proposed EU Data Act subject to its "technical feasibility" (EU, 2022a).

Continuous data portability fosters new services and innovations but requires adapted technical mechanisms – notably APIs that can handle data transfer requests with extremely low latencies or in real-time. As with delegated ad-hoc controller-to-controller data transfers, the receiving data controller acts as a client to the originating data controller and must provide valid, token-based authorisation for the transfer request to the originating data controller. Data schemas of originating data controllers must also be mapped to receiving data controllers.

Continuous data portability also comes with risks that must be managed (de Hert et al., 2018; de Streel, Krämer and Senellart, 2021; Krämer, 2021a; OECD, 2021c). One variant of the continuous data portability model involves the delegated transfer of data from a data controller to a third party, such as a Personal Information Management System (PIMS), entrusted to handle transfers of personal data on behalf of the data subject (Krämer, 2021a). This third party then acts as the client of the originating data controller (with pull/read rights) and the receiving data controller (with push/write rights).

Data portability and MaaS

Personal data portability plays three essential roles in MaaS data architecture:

1. it plays a pivotal role in enhancing the user-centricity of MaaS
2. it is a necessary (but insufficient) enabler of interoperability
3. it is required to authenticate the identity of travellers and allows mobility operators, via MaaS providers, to grant authorisation to access their services, vehicles and fares.

MaaS involves a degree of personalisation and customisation which requires insight into travel choices and preferences that cannot be derived from volunteered data alone. A broad understanding of what comprises "personal data", including observed data, provides the basis for crafting customised and compelling MaaS offers. Therefore, user consent-based data portability frameworks covering both volunteered *and* observed data enable greater user-centricity.

Where general personal data portability frameworks exist, their specific application in MaaS should be addressed by public authorities and supported by MaaS-specific implementation guidelines. Where cross-sectoral data portability frameworks are absent, there is a case for seeking to implement data portability commitments or requirements in support of MaaS either through a code of conduct or by conditioning licensure of mobility operators and MaaS providers to adhere to them.

Ad-hoc data transfers may enable people to switch services or multi-home. Still, they are insufficient to allow the type of low latency or real-time transfers of personal data that enable MaaS ecosystem actors to deliver joined-up, multi-operator trips. Simply specifying data sharing obligations or portability rights without defining the mechanisms on which they are enacted only partially addresses the core challenge. Worse still, it increases transaction costs for users and thus erodes the attractiveness of MaaS-based offers in relation to other travel options. Data portability is thus a necessary but insufficient enabler of the level of interoperability that MaaS requires (Hoffmann and Gonzalez Otero, 2020).

In the specific context of MaaS, leveraging data portability to achieve user-centric interoperability suggests three things.

The first is that personal data portability frameworks should cover not only ad-hoc data transfers but include a form of continuous and transaction-based personal data transfers. J. Krämer (2021a) notes that "a right to port personal data continuously and in real-time would be necessary to truly empower consumers in the context of the digital platform economy", and MaaS is no exception. As noted, this approach is adopted by the EU Data Act (passed in May 2022), potentially serving as a precedent for other EU approaches (EU, 2022a).

The second implication of moving beyond data portability to greater interoperability is that it will require commonly accepted interoperability mechanisms and, in some cases, convergence on data standards. Both continuous and ad-hoc data transfers between two data controllers require both controllers to agree on a common semantical lexicon (or inter-lexicon translation logic) and adopt broadly aligned data schemas that enable one controller's data to be easily onboarded by the other and vice-versa. Ideally, both would share a common syntax and a common data exchange API architecture.

The third point is that adopting an expansive view of what constitutes "personal data" and granting people the ability or right to delegate the transfer of that data from one data controller to another implies a robust framework for signifying, granting and managing the consent of data subjects regarding the use of their data. Consent regarding the sharing and use of personal data is essential not only on a fundamental rights basis (especially where that right is enshrined in law) but also to increase trust on the part of data subjects that the use and sharing of their data delivers tangible value to them.

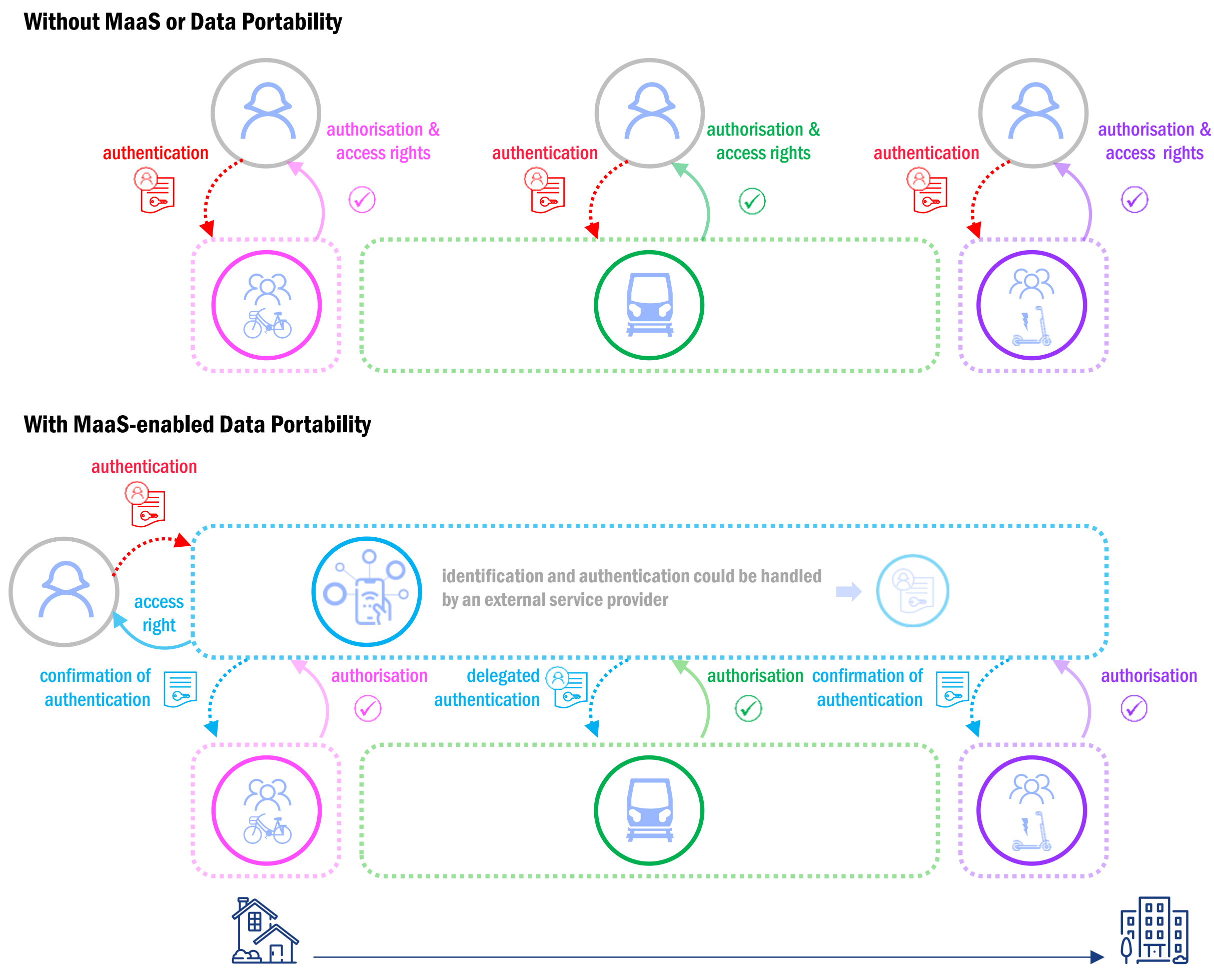
The MaaS data governance framework must balance telling data subjects the potential uses to which their data will be put and acquiring their consent, and minimising barriers to adopting innovative services using that data. Achieving that balance may mean moving away from transaction-based consent frameworks to higher-level consent-management frameworks. Transaction-based consent frameworks are based on gaining consent for every new transfer of personal data. Higher-level consent-management frameworks focus on providing mechanisms for handling general preferences about the use of personal data and establishing upstream mechanisms to manage consent. PIMS are one way of establishing such consent management frameworks, and MyData is a good example of a concrete model and operational means to do so.

Another strategy to improve the consent framework for MaaS is establishing and adopting common consent language across the MaaS ecosystem. This could include signifying that "personal data" consists of both volunteered and observed data, or that consent is being given to initiate continuous – but time-bound – personal data transfers in the context of delivering a MaaS offer for a trip undertaken by the data subject). Public authorities could condition licensure of both mobility operators and MaaS providers to the adoption of agreed consent language or could incentivise the use of such clauses by fast-tracking the applications of those actors who adopt it (since a more detailed review of their data policies would not be required). In any case, developing agreed consent terms will require input from, and consideration of the needs of, all MaaS ecosystem actors. Thus, there is a need to establish an open and transparent process with which to do so.

A final point to consider regarding personal data portability in the MaaS ecosystem concerns how personal data is used for two essential MaaS functions: authenticating identity and granting related authorisations.

Authentication and authorisation are two distinct but related processes. Authentication refers to establishing and validating the identity of a user or a service, whereas authorisation involves verifying identity and granting related access or usage rights. In the context of MaaS, authenticated identity serves as a basis for obtaining access to services offered by mobility operators (e.g. boarding a tram) or MaaS providers (e.g. accessing a subscription package). How and how frequently users must provide their personal data to establish their identity and access services changes with the introduction of the MaaS provider. How *exactly* this will change depends on how personal data portability is managed within the MaaS ecosystem (Figure 14 provides one example).

Figure 14. MaaS: Authentication, authorisation and personal data portability



Without a MaaS provider (and without personal data portability), a person undertaking a three-segment trip from home to work (Figure 14) must provide personal data establishing their identity to all three operators, who, in turn, must validate that identity. For some forms of travel, validated identity is not really an issue – travellers bearing a valid but anonymous ticket can, for example, board a bus, subway or tram. However, identity authentication (including certain types of personal characteristics, e.g. if the traveller has a valid license to operate the vehicle they want to access) is necessary where access rights are nominative or account-based. Establishing identity is usually a one-off process that occurs during onboarding. Authentication of identity, however, occurs for each trip. In the case of a trip without a MaaS provider or personal data portability, each mobility operator must authenticate the user's identity (using their own validation processes) for each trip. Each operator then must communicate to the user access authorisations associated with that identity.

Authentication and authorisation pathways change in the presence of a MaaS provider and with personal data portability. For example, a user establishes their identity with the MaaS provider – or a third-party authentication service – who authenticates it. Some mobility operators may accept the MaaS provider's or the third party's confirmation of authentication (without seeing the user's identity or other data). Others may require personal data to confirm the user's identity. In the latter case, the user grants the MaaS provider or the identification/authentication microservice provider delegated authority to provide the mobility operator with their personal data. Once the user's identity is established and authenticated, the mobility operator communicates authorisations to the MaaS provider, who, in turn, transmits access rights to the traveller.

The example above describes one of several possible ways to manage authentication and authorisation. Still, it highlights what is important from the traveller's perspective (single sign-on and transacting via a single or unified interface) and what is important to other MaaS ecosystem actors (robust and persistent identity authentication and clear mechanisms for associating and granting rights to validated users).

Authentication and authorisation functions can be handled by mobility operators themselves or by third parties. The MyData framework and principles described earlier set a vision for ensuring that third parties operate in a way that contributes to improved social welfare and the protection of individual rights. In the logistics sector, the Dutch iShare scheme seeks to do the same (iSHARE, 2021). Other open identity management and validation standards such as OpenID, the EU Digital ID framework (eIDAS) or delegated authorisation standards like OAuth2 also create harmonised and uniform methods for addressing authentication and authorisation independent of any actor's own methods. Beyond improving interoperability, these approaches underscore that developing a data architecture around trusted task-based modules helps ensure resilience. If a better, more secure or innovative way of accomplishing a task comes along, the module can be updated or replaced without fundamentally re-coding the entire system.

Some transport fares are conditioned to income, age, employment or other sensitive personal information. These require travellers to demonstrate to mobility operators, MaaS providers or fare calculation microservice providers that they qualify for those fares. To do so, they must provide a certificate from an appropriate public authority or the raw data (e.g. an income tax declaration) indicating that they meet the required threshold. The operators must authenticate these documents before authorising travellers to access the reduced fare. In France, the Inter-Ministerial Office for Digital Affairs (DINUM) and the National Association of Mobility Authorities (GART) have organised a whole-of-government initiative implementing public service APIs allowing mobility operators to directly authenticate the status of travellers regarding multiple endpoints like age, income, disability, household characteristics, employment and drivers licence holding. A user only has to provide their official e-identifier to the mobility operator or MaaS provider, who then can access relevant APIs and receive confirmation (or not) that the traveller has the right to access a service or social fare (DINUM, 2022).

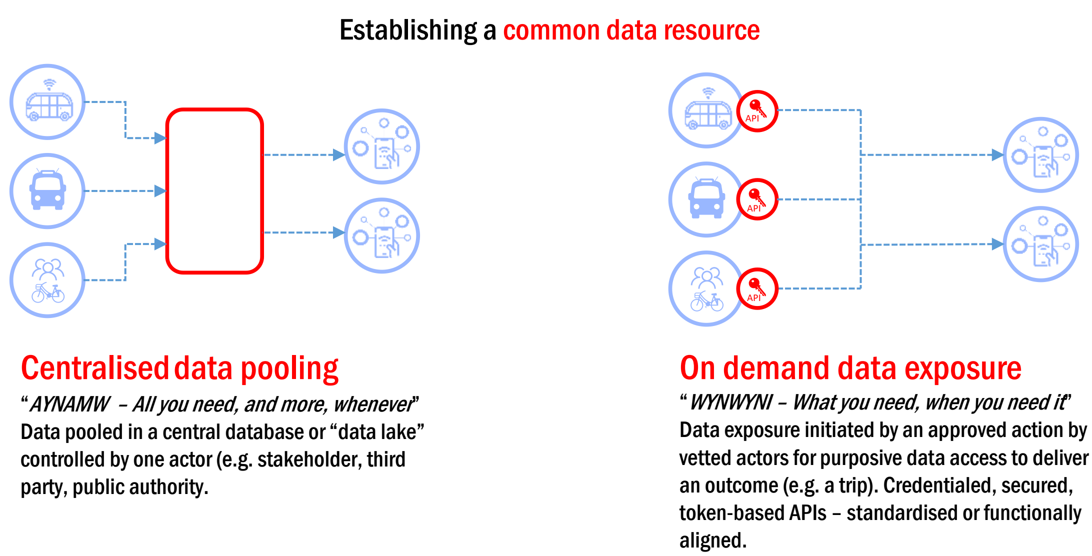
Beyond discussions relating to personal data portability, there is the broader issue of non-personal data portability and reuse among MaaS ecosystem actors. This type of data transfer falls under the scope of business-to-business data sharing. As discussed earlier, it should be addressed for minimal data sharing, which should be incentivised or required to establish a functioning MaaS ecosystem.

Data sharing mechanisms for MaaS: The role of APIs

Data sharing mechanisms enable the creation of the shared data resource required to allow for end-to-end trips across multiple mobility operator services. However, not all data sharing mechanisms equally build trust in the MaaS ecosystem or foster limited, purposive and efficient data sharing in support of MaaS.

Data sharing mechanisms for MaaS broadly fall into one of two categories. The first is a centralised data resource under the control of one actor, and the second is an "on-demand" data resource accessed via limited, real-time and vetted access data exposure mechanisms such as application programming interfaces (APIs – see Figure 15). This is admittedly a generalisation; access to centralised data resources can be achieved via APIs. However, it underscores two fundamentally different strategies: centralising data or creating distributed on-call data exposure mechanisms where the data is housed.

Figure 15. How to share data? Centralised data pooling versus on-demand data exposure



Much of the "historic" focus on MaaS data sharing mechanisms has centred on centralised data collection and management by a back-end, data platform-operating entity (Arias-Molinares and García-Palomares, 2020; Audouin and Finger, 2019; Banerjee, Jittrapirom and Dangschat, 2021; Crozet and Coldefy, 2021; Jittrapirom et al., 2017a; Kamargianni and Matyas, 2017; Longo, Zappatore and Navathe, 2019; Pagoni et al., 2022; Polydoropoulou et al., 2020; van den Berg, Meurs and Verhoef, 2022). This entity could be a commercial, public or mixed-platform operator. But, in all cases, data flows into a centralised entity's database or "data lake" under this model. The approach assumes that market actors provide data to the platform and that the platform operator manages access to the data as necessary and as required to carry out integrated trip offers. This model raises questions regarding trust that the back-end data platform operator would act in a neutral capacity regarding its gatekeeping and governance functions. There is also the risk that centralised data collection may lead to data leakages or other unwanted outcomes (ITF, 2021a).

One way to address these risks is to adopt a more agile data sharing mechanism based on permissioned and conditional data exposure via specific APIs. APIs are code-based and documented sets of rules establishing an interface that enable two different computer systems, applications or software to communicate and transfer data between each other in a way that allows the data to be used without further transformation. Accessing data from one system, or exposing data to another system, does not require any knowledge of how the API is implemented – all that is needed is to use the interface (IBM, 2022). APIs are and will continue to play a pivotal role in ensuring interoperability, not just in the MaaS ecosystem but more generally across all levels of digital interoperability.

APIs enable two essential MaaS data sharing outcomes. They establish a technical means to expose and meter a subset of mobility operator data to authenticated and vetted MaaS providers. They also serve as modular building blocks to build on-demand joined-up trips within the MaaS ecosystem (Borgogno and Colangelo, 2019; Hoffmann and Gonzalez Otero, 2020).

In a practical example, when a MaaS provider wishes to create or initiate a trip request on a traveller's behalf, APIs are called to establish the traveller's identity and that of the MaaS provider. Identity authentication is then linked to authorisation to access specific data held by mobility operators via an API (Figure 14). A token (or another secure and unique identifier) confirming identity and authorisation is then used to gain access to data via APIs housed by mobility operators. This would, at a minimum, include informational and operational data and, if contractually agreed by the transacting parties, data and access to systems enabling booking and payment. Alternatively, the API could provide a deep link pathway (see glossary) to the mobility operator's own booking and payment service. Tokens can also be used to deliver time-bound authorisation for certain actions and transactions via a data sharing API. The validated authentication and conditional authorisation functions provided by the token-API architecture limit over-broad data sharing risks and address potential anti-competitive behaviour via auditability and traceability. They also have the advantage of building on well-known protocols (Borgogno and Colangelo, 2019; ITF, 2021a; MaaS Alliance, 2021).

APIs can be internal or external-facing. Internal-facing APIs are deployed within a firm and support inter-firm functions. They support internal processes (e.g. micro-services) within a closed environment but may also be re-purposed to serve external requests. External-facing APIs may be open or restricted. Open APIs can be accessed by any entity, under any circumstances, with few, if any, restrictions (which may be limited to data transfer rates, for example). Restricted APIs are accessible only to vetted and authenticated entities. Authentication and access to restricted APIs are typically managed through trusted tokens.

External-facing APIs (both open and restricted) may be based on proprietary code or open-source standards. The technical specification and access rules of proprietary APIs remain entirely under the control of the hosting (and data-holding) entity. In contrast, the specification and implementation of APIs based on open-source standards follow open and consensus-based governance models.

External-facing APIs require accessible and up-to-date documentation allowing those requiring access to it to invoke API functionalities correctly. Open APIs provide API documentation and metadata by default (via code-hosting sites such as GitHub). This is not necessarily true for proprietary external-facing APIs, which may condition or restrict access to documentation based on trade secret clauses (Borgogno and Colangelo, 2019; Hoffmann and Gonzalez Otero, 2020).

External-facing but proprietary APIs enable the hosting entity to innovate in the extent to which it exposes its data. There is, however, an inherent risk that unilateral control over the configuration of the API allows the API host to intentionally or inadvertently degrade or eliminate API functionality for all or a subset of those accessing it (Hoffmann and Gonzalez Otero, 2020; van Arsdale and Venzke, 2015). The API host may also intentionally throttle API access to certain actors while retaining or improving data transfer rates to others. These risks are inherent in deploying external-facing proprietary APIs. Where these APIs contribute to or enable public outcomes in MaaS (and elsewhere), appropriate monitoring and redress mechanisms must be built into the data governance framework.

Architectural guidelines on APIs as mobility data infrastructure

APIs play a crucial and fundamental role as the principal enablers of data portability and interoperability within mobility data infrastructure. As with other types of infrastructure, APIs supporting MaaS will mix private and public ownership and governance. However, as with other essential *foundational* infrastructure, the architecture of that web of data sharing APIs, and in some cases, of the APIs themselves, should be aligned with public policy outcomes and framed by a consensus-based vision of what and how they should contribute to mobility generally, and MaaS in particular.

That vision – of what outcomes MaaS ecosystem APIs should support and especially how they should do so – is not settled, given that the concept of MaaS is still maturing. However, a few broad architectural guidelines can already be outlined based on the previous discussion. These architectural guidelines are *in principle* only. They do not reflect the diversity of specific legal contexts in which they would be implemented. Still, they sketch an aspirational blueprint of a MaaS data sharing framework that balances user-centricity, public value, innovation and commercial opportunity. As such, they outline a possible end-point and indicate a trajectory towards establishing foundational mobility data infrastructure encompassing MaaS.

Obligation to share data

The MaaS ecosystem requires a shared data resource to function. This common resource should be built on an obligation to share minimum but sufficient data to create cross-operator MaaS offers. This data should include non-personal data necessary to support the planning and operational delivery of MaaS offers. It should also include access to payment mechanisms that, at a minimum, allow MaaS providers to access the same booking and payment functionalities available to the individual travellers they represent.

Personal data (including volunteered and observed data) should also be shared with the express consent of the data subject. Travellers should be able to receive their data or delegate the continuous transfer of that data from data controllers who hold their personal data to other data controllers of their choosing in the context of accessing MaaS services. This transfer should be mandatory if invoked by the data subject. Such regulatory requirements imply monitoring and enforcement mechanisms. Establishing licensure for MaaS providers and adapting mobility operator licenses to reflect these obligations accomplishes this.

The obligation to share data should also be linked to quality requirements for that data. Sharing poor or incorrect data limits the value of data sharing and erodes trust in how those data are used. Quality assurance is a crucial enabler of value. A good example of quality assurance for shared data is the UK Bus Open Data Services (BODS), which supports trip planning and increases bus patronage. The critical success factor of BODS was tightly coupling data sharing to data quality standards (UK Department for Transport, 2022).

Obligation to house data sharing APIs open to vetted ecosystem actors

Data sharing should go beyond the definition of rights and responsibilities. Operationalising cost-effective and welfare-improving data sharing and portability implies outlining the mechanisms to deliver these outcomes. MaaS ecosystem stakeholders should be obligated to implement adapted data exposure pathways via APIs that are open to vetted actors holding valid licenses. This obligation should be included in the licensure for mobility operators and MaaS providers and should cover exposure of minimum but sufficient data to enable the creation and sale of joined-up trip offers.

Free but incentivised choice of APIs

Interoperability is facilitated by: (1) the alignment of different systems or (2) functionally mapping one system to another. The first option provides the greatest interoperability, especially if it is delivered by adopting a single harmonised set of APIs. However, it potentially imposes high costs for some actors and may foreclose innovation emerging from competing (but hopefully compatible) API standards. More fundamentally, the MaaS ecosystem is not yet mature enough to require convergence towards one set of APIs. In this context, public authorities and MaaS ecosystem actors could define a "reference" set of APIs that deliver certain measurable benchmark outcomes. Ecosystem actors can select these reference APIs or adopt another set of APIs. In the second case, those adopting (or those developing) non-reference APIs should establish that those APIs deliver the target performance outcomes as well or better than reference APIs. This requires establishing target benchmark outcomes for API-based data sharing.

Adoption of restricted APIs

Access to MaaS APIs should not be open (to all) but limited to vetted (licensed) MaaS ecosystem actors. Licensure establishes vetting and commits actors to respect data handling and data sharing requirements and protocols.

Incentivised open-source APIs and their standards

Open-source APIs (e.g. those with open, documented and transparent governance) are preferable to proprietary APIs. Additionally, APIs conforming to open API standards (e.g. OpenAPI architecture) are preferable to those adopting proprietary architectures. The OpenAPI Specification (OAS) "defines a standard, programming language-agnostic interface description for HTTP APIs, which allows both humans and computers to discover and understand the capabilities of a service without requiring access to source code, additional documentation, or inspection of network traffic" (OpenAPI, 2022).

MaaS ecosystem actors adopting both open-source APIs and open API architectures could be granted fast-track licensure. Actors retaining proprietary APIs or architectures would then be subject to robust and ongoing documentation requirements (to mirror the transparency in open-source APIs). As noted above, authorities or other public-private governance bodies should detail the core functionalities that APIs must deliver. Changes in proprietary API architectures that impact the ability of the API to deliver on those functionalities should be logged, documented and notified to actors and authorities. An explanation should be provided on how those functionalities have been affected. Authorities would reserve the right to re-assess licensure if desired functionalities are degraded or removed.

Incentivised convergence mechanisms

Licensure should reference a common and agreed semantical lexicon (or common logical operations to translate terms). It should also encourage alignment towards common and compatible data schemas. Likewise, common consent language should be incentivised. This could include an expansive interpretation of "personal data" (if this is not otherwise established) or the acceptance of continuous, transaction-based personal data portability. One example of such a principle-based convergence mechanism is the Mobility Data Interoperable Principles (MDIP) (MDIP, 2022). Adopting vetted or recognised interoperability and data portability mechanisms could fast-track licensure. Not adopting them would be accompanied by an assessment of how targeted functionalities and outcomes would be impacted.

Public authority oversight and capacity development

Authorities must deploy active oversight mechanisms to ensure the intended function of MaaS data architecture (including APIs). This entails upskilling and acquiring the technical capacity to carry out these reviewing and monitoring tasks or overseeing third parties to whom public authorities delegate these tasks.

How to handle and process shared data?

Market actors have responsibilities when handling and processing shared mobility data alongside the data access rights granted to them. These responsibilities may vary depending on the type of data (e.g. non-personal, personal, and commercially sensitive). This section underlines the role of data-handling processes in creating trust among market actors. Then, it describes effective data handling and processing protocols.

Data handling protocols and processes

Adopting adapted data handling protocols can reduce data sharing risks and market actors' perceptions of these risks. These risks are associated with the sensitive or personal nature of some data collected by market actors. In democratic societies, open, transparent, and participatory governance processes that limit public authorities' potential for overreach and abuse generally mitigate these risks. These powers may be unchecked in less democratic or authoritarian regimes. Misuse, abuse, or careless handling of personal or sensitive data shared between stakeholders can result in significant harm in both cases.

Establishing transparent, proportionate, and adequate data handling protocols and processes should prevent risks related to sharing personal and commercially sensitive data. Personal data handling should trigger additional protocols to ensure its safe processing. These protocols should be based on guidelines ensuring data sharing-related risks are identified and mitigated by default. Several data governance frameworks and principles have been proposed. Some integrate data handling protocols and processes. ITF (2021c) lists some of the most recent proposed data sharing governance frameworks and principles from various organisations (i.e. NUMO, 2021; OECD, 2021; SuM4All, 2021; WBCSD, 2020).

Data handling protocols and processes are crucial to building trust among market actors. According to WBCSD (2020), public authorities can establish governance structures and privacy regulations to reinforce trust between market actors. Additionally, public authorities can clearly establish roles and responsibilities for supervising and managing data handling protocols to allow data sharing frameworks to be effective. SuM4All (2021) notes that establishing an independent function responsible for overseeing data use can ensure the ethical handling and processing of data. Emerging tools such as data review boards (DRB) (IAPP, 2020) can help companies make responsible decisions regarding data processing.

MaaS ecosystem stakeholders (e.g. MaaS providers and transport operators) should also establish two essential functions: data stewardship and custodianship.

Data stewards oversee all institutional data requirements, quality and fitness for data assets. They are primarily concerned with data content and context. They are responsible for collecting, merging, logging meta-data and addressing issues and problems with data. They ensure compliance with all applicable legal and policy obligations and ensure that data collected and processed can meet the defined purposes for which they were collected and achieve desired outcomes (Plotkin, 2021).

Data custodianship functions relate to the handling of data. Data custodians manage how data are stored, processed and transmitted internally and externally. They are also responsible for deploying physical and technical safeguards to protect the integrity, confidentiality, security and availability of data necessary to enable the MaaS market (Carnegie Mellon University, 2021).

Both data stewardship and data custodianship roles should be clearly defined within stakeholders' organisations that process shared mobility data (e.g. service providers and public agencies).

Data retention, destruction and aggregation

Mobility data should circulate between market actors lawfully and appropriately to mitigate risks for individuals and companies. This requires a coherent and principle-led data sharing framework. The EU's GDPR Article 5 outlines three principles that capture the essence of that framework.

1. Transparency and purposive process

Data processing results should be aligned with the purposes for which it was designed. A cornerstone of most data-privacy frameworks is the meaningful consent given by data subjects for collecting and processing data concerning them. Data subjects should also give their consent to the onward collection and processing of data by MaaS stakeholders. The notion of consent should be clearly addressed and enacted in data sharing frameworks. As much as legally possible, data subjects should be informed of onward processing by market actors in clear and easy-to-understand terms and express their consent via simple and easily actionable consent mechanisms. The outcome of processing should be aligned with the purposes for which it was collected.

2. Limited data sharing

The sharing of personal and sensitive data (if consented to) should only be done by the necessary parties to achieve the purpose of its collection. MaaS stakeholders should clearly identify to whom data will be transmitted (if at all). These parties may include other service providers, public agencies and third parties. In all cases, data transmission should be demonstrably linked to achieving the purpose for which it was collected. Onward transmission of personal data should be avoided by default and limited to the minimal number of parties required. Consent for this transmission should be obtained when the data was originally collected from data subjects.

Data custodians should enact strong and conditional access controls for personal and other sensitive data. These controls should minimise security risks and prevent unwanted data access and processing.

MaaS ecosystem actors should also develop privacy risk assessments and establish data privacy policies. Commercial MaaS operator Whim's privacy policy specifies data sharing limits and the conditions under which users' personal data may be disclosed. For example, personal data might be shared with third-party service providers: "we could, for example, share your name and contact details with a service provider […] so that the service provider knows you will be using their services and will be able to contact you directly, for example, in case there is a problem in the service" (Whim, 2021). As privacy risks evolve, privacy risk assessments should be held frequently.

3. Appropriate data retention and deletion

Clear data retention, transformation and destruction policies build confidence that sensitive data will only be retained as long as strictly necessary. Data should be retained and stored securely in line with their sensitivity. Data custodians should ensure that data are protected and secure throughout their lifetime. This is especially the case for personal and other sensitive data.

Data should only be retained for as long as necessary to fulfil the purpose of their collection. Data retention may be permanent for aggregated and anonymised data collected for planning purposes, as this provides valuable time-series data. However, retention periods for personal or other sensitive data should be strictly minimised to the time necessary to carry out the purpose of their collection. Public authorities may require extended retention of certain types of data. For example, data processors may be required to securely store payment data for tax purposes. In Vienna, Wiener Linien indicates that “purchase and/or order data derived in connection with services of Wiener Linien will be deleted at the end of a period of 7 years due to legal obligations for retaining data for tax purposes” (Wiener Linien, 2021).

The data processor should specify retention rules. Additionally, if a data or dataset is not further processed, the data processor should indicate the reason for retention. Post-processing protocols will depend on the type of data (e.g. commercially sensitive, personal or non-personal). Data retention periods may be different depending on existing regulations. For personal data, data processors should open the possibility for the user to request the immediate deletion of their data. In Paris, RATP (2021) maps different types of personal data to adapted retention and deletion rules.

Protocols for safe deprecation or irreversible de-identification of personal data should be specified. If personal data are collected, they should be processed and transformed once the purpose for their collection is attained so that they no longer represent a privacy risk. Specific and documented protocols for irreversibly de-identifying personal data should be adopted, communicated and applied. Once de-identified, original data should be irreversibly destroyed. Before this destruction, data processors may wish to log and archive meta-data for onward use in planning and evaluation.

In its guidance for private hire operators, TfL follows Information Commissioner’s Office (2022b) recommendation regarding storage limitation. It indicates that operators “must not keep personal information for any longer than is ‘necessary’’’. Privacy policies should clarify what “data erasure” means. Erasure can refer to the permanent and secured deletion of the data or de-identification protocols (e.g. noise or aggregation). In its privacy and data protection guidance for private hire operators, TfL (2019) states that “deletion” refers “to permanently and securely destroying that information at the end of its retention period”. TfL further specifies that private hire operators should not “archive or move it so it can be retrieved in the future”. This type of provision implies the deletion of electronic and any physical formats where data are stored (e.g. paper, hard drives).

Retention periods and deletion rules may change with the evolution of legal provisions. In France, Article R1115-16 (2021) requires MaaS providers to implement specific handling and deletion protocols before transmitting statistical data to MaaS ecosystem stakeholders (e.g. transport operators and public authorities). MaaS providers must commit to sharing a minimal amount of data with transport operators and the transport authorities to improve the interoperability of transport services.

To that end, MaaS providers must use several protocols:

- Before sharing data, MaaS providers must anonymise data. They must use robust protocols that avoid potential re-identification of users.
- Once anonymised, the MaaS provider aggregates the data.
- The MaaS provider shares the aggregated data and deletes non-anonymised and non-aggregated data.

For non-personal data, Article 32 of the *Loi d'orientation Des Mobilités* (2019) states that relevant *data from* connected vehicles must be aggregated before being shared with infrastructure managers and public transport authorities. These data are considered necessary to improve traffic, knowledge and emergency interventions. The only exception is for data when the aggregation makes their use impossible.

MaaS data sharing: State of play

There is a gap between potential future data sharing models in the MaaS ecosystem and current practice. While most ecosystem actors rely on data to build and operate their transport services, the circulation of data is more complex because of issues related to competition (e.g. perceived risks) and lack of existing solutions (e.g. low standardisation and lack of guidelines). MaaS data sharing also entails a new relationship between market actors beyond simple competition. It constitutes a fundamental paradigm shift for most MaaS ecosystem actors.

Efforts to promote more discussion between market actors are underway. Yet, it will take time to reach consensus on answers to questions like “how and what data to share” or “how to manage data sharing”. Several initiatives aim to promote more effective data sharing across MaaS market actors. This section explores current efforts to improve data sharing in the context of a MaaS and identifies what solutions and risks may emerge in the years to come.

Current efforts to improve data sharing

Mobility is a highly standardised sector where different initiatives have led to the development of multiple data standards for real-time or static data regarding public transport, micromobility services and road traffic management. These mechanisms may share similarities, but their differences make them unique and often incompatible. For example, a “stop” is not represented in GTFS as in GBFS based on inherent differences between public transport and micromobility operations. A public transport stop can be defined in point co-ordinates, whereas free-floating micromobility may reference a “stop” as a geofenced area.

The emergence of new mobility services (e.g. shared mobility services) and regulatory requirements (e.g. the EU requiring the use of Europe’s Committee for Standardization’s [CEN] transmodel standards for public transport data reporting) have driven the growth in the number of standardisation initiatives. Standards may refer to data categories previously not (efficiently) covered by existing standards (e.g. GBFS as a standard to allow data sharing on shared vehicles between market actors).

Within this complex landscape, data standardisation constitutes a partial answer to enabling data sharing between the increasing number and types of mobility stakeholders. Yet, standardisation is a challenging and tedious process that requires identifying the existing data sharing standards (e.g. mapping), promoting standardisation results and reaching a consensus on the standard to use (MaaS Alliance, 2021)

Mapping data sharing ecology

There is no one-size-fits-all approach when it comes to data sharing. A taxonomy can help assess and understand the complex landscape of existing data sharing mechanisms between market actors. In the mobility sector, several ongoing projects seek to index standards and APIs to understand the complex ecology of mobility data sharing.

For data standards, the Open Data Standards Directory provides an inventory of commonly used standards in mobility, among other sectors. Chevallier et al. (2021) provided a state-of-the-art review of mobility data standards as part of the MobiDataLab H2020 project. MobiDataLab taxonomy gathers standards from various mobility domains (e.g. public transport, road traffic, micromobility and infrastructure). It also considers ticketing and MaaS-related standards.

This work constitutes one stage of a two-part standardisation roadmap that aims to integrate existing data standards and promote standardisation among data sharing mechanisms. MobiDataLab will provide guidance and suggestions to improve mobility data sharing in a subsequent publication outlining how existing standards might evolve and what new standards may be needed (Chevallier et al., 2021).

France-based *Fabrique des Mobilités* (2021) published a collaborative and open-source inventory of APIs for mobility services and MaaS. APIs differ depending on the type of transport considered (e.g. carsharing, public transport or micromobility).

Promoting standardisation results

Data mapping constitutes the first stage for promoting standardisation results. It presents three main capabilities:

First, a quick mapping can help to establish the boundaries and overlaps between data standards.

Characterising an overlap between two data models requires a precise comparison between two data models. Data overlapping occurs when models A and B are considered semantically equivalent and when an attribute in B can replace an attribute in A without losing information. This type of mapping is relevant when considering using specific data models to represent data elements (e.g. a reference model). If there is no overlap between data models, A and B have different scopes. Therefore, the target model may not be a contributing model. These mapping exercises require extensive knowledge of the various data models. Several initiatives have noted overlaps between data models.

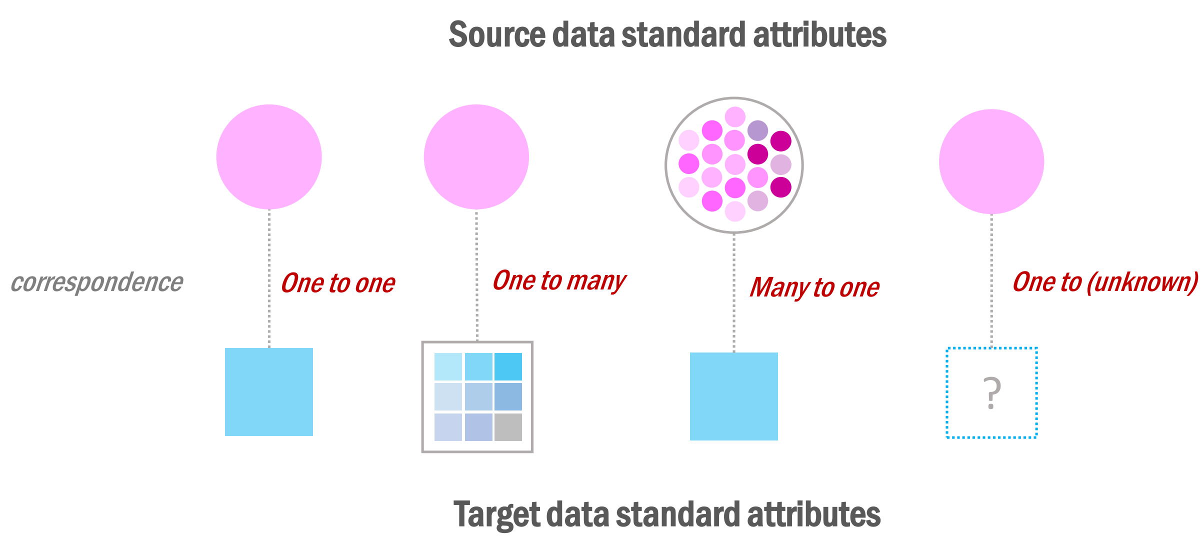
In 2019, a report published by the European Commission’s Joint Research Committee provided recommendations to address overlaps and gaps existing in the data standards used for data sharing of mobility information under Commission Delegated Regulation (EU) 2017/1926 concerning the provision of EU-wide multimodal travel information services (MMTIS) (Bourée et al., 2019). The mapping analysis showed that NeTEx, SIRI, and INSPIRE standards were sufficient to implement the regulation. The study defined each data category listed in the Commission Delegated Regulation (EU) 2017/1926's annexe and specified a reference standard and one or more contributing standards for each category. The study concluded that several MMTIS data categories lacked a reference standard. There are two main obstacles explaining this. First, the existence of gaps in standardisation (e.g. when the standard exists but is not yet published or when there is no standard). Second, the absence of a reference standard (e.g. when two or more standards efficiently contribute to a data category). The recommendations emphasised the need for further developments to address these data interoperability gaps across the different standards.

Second, a more comprehensive data mapping allows for finding correspondences, thus contributing to integrating different data models.

Since 2020, the DATA4PT project has supported the development of mobility data standards and models to improve multimodal data sharing. As part of the project, the DATA4PT consortium and MobilityData worked on a canonical mapping between GBFS to NeTEx and SIRI. The mapping aimed to prepare the addition of micromobility modes to NeTEx by finding semantical equivalence between elements and attributes in each standard. The conclusions of this work were published as part of NeTEx Part 5 specifications.

Mapping two separate models like GBFS, NeTEx and SIRI standards is not straightforward and can be complex. In most cases, the mapping will require connecting attributes of two standards after ensuring their definition and semantics (see Figure 16). Correspondences between attributes belonging to different data models can be one-to-one. This means that for an attribute in the source model, there is one attribute with the same semantics in the target model (e.g. GBFS "System Region" and NeTEx's "TOPOGRAPHIC PLACE"). However, in other cases, a group of attributes in the source model may correspond to one attribute in the target model. Conversely, one attribute in the source model can correspond to several attributes in the target model. Finally, there may be no corresponding attribute in the target model.

Figure 16. Correspondence type when mapping two standards



Source: based on Bourée (2021).

Third, a fully detailed mapping can create automated data converters – tools that convert data between two formats automatically (DATA4PT, 2019).

Creating such a complete mapping is a resource-intensive and time-consuming process that requires an extensive understanding of the various data models. Already completed or ongoing mapping initiatives (e.g. DATA4PT) constitute a knowledge base that can be used to build conversion tools – for example, converting GTFS to NeTEx.

Future data mapping initiatives should use or build upon existing and proven methods. In 2020, DATA4PT published a stepwise methodology to compare different data standards (DATA4PT, 2020). The first step consists of mapping at the data category level. This exercise identifies potential overlaps and provides a rough correspondence between the main data categories. Equivalences can be recorded in a mapping table. Linkages can be found by looking at similarities or equivalences between attributes' terminologies (e.g. fare/price, schedule/timetable). The second step consists of the systematic comparison at the level of concepts. At this stage, the semantics of the concepts are considered. Additional considerations regarding the scope of the compared data models also occur at this stage. When comparing GTFS and

NeTEx, this step reveals that NeTEx uses more layers (e.g. reuse of routes, timing patterns and service patterns) than GTFS. Finally, the third step compares the attribute level and their relationships.

APIs handle data sharing and interoperability in MaaS and elsewhere. APIs are particularly effective at these tasks for all of the reasons outlined in the previous sections, but they are not the only conceivable way to accomplish them. Whichever architectures are adopted for MaaS data sharing (or data sharing more generally), they should anticipate a post-API world – that is, a world in which other data sharing and system interfaces emerge. Using APIs to modularise and task out essential functions already goes a long way to anticipating new ways of establishing linkages between different systems. Beyond that, all ecosystem actors should monitor and be aware of new mechanisms that may emerge to handle tasks APIs handle today. Public authorities should ensure that the regulatory frameworks they develop for data sharing allow room for adopting new mechanisms by MaaS ecosystem actors.

MaaS data sharing: A way forward

Facilitating more seamless intermodal travel is a fundamental and long-standing focus of mobility policy – especially where infrastructure is saturated or, conversely, where vehicle capacity is poorly used. MaaS is one strategy to address this paradox. It is a more recent concept placing the individual in the centre of the mobility equation and empowering them to mix and match services according to their needs. However, it is a concept that is still maturing, continuously evolving and seeking to find successful and scalable implementations. What, then, can be said about charting a way forward so MaaS delivers value to people, contributes to public policy objectives and ensures commercial opportunities when very little is currently settled about MaaS?

At the outset, much of what will be required for MaaS to function, let alone scale, concerns data governance in the MaaS ecosystem (and beyond). This is especially true for data sharing among ecosystem actors – particularly between mobility operators and MaaS providers. As noted at the outset of this report, mobility data, the mechanisms that produce and enable it to be shared and how data sharing is governed constitute a new and evolving layer of foundational infrastructure. The central task – and challenge – for both public and private sector actors is to think about how to structure and deploy that infrastructure to improve people's everyday lives.

Articulate a vision

Describing what mobility data infrastructure should look like at this early stage is perhaps less important than articulating what that infrastructure should deliver. These outcomes include user-centricity, personal privacy protection, public services meeting needs, value-creating markets framed by public authority oversight and alignment with public policy objectives. These constitute a vision framing for what mobility data infrastructure should *enable* rather than what it *is*. In the context of MaaS, this vision should emerge from consensus-focused discussions among all ecosystem actors. But, in the end, it should be arbitrated by public authorities who have a responsibility to deliver on their mandates to their constituents.

The vision framing data as infrastructure extends far beyond MaaS and mobility. The financial, health, energy and telecommunications sectors are also seeking to address similar challenges concerning data as infrastructure, the role of platforms and how to manage data sharing, etc. The vision developed for MaaS and mobility data should adopt the same top-level principles guiding the same discussions in other sectors. Public authorities should establish these visions at the highest level – sometimes even at the supra-national level, as in the EU's Data Strategy (European Commission, 2022).

Address uncertainty and early lock-in

Mobility data infrastructure is dissimilar to physical infrastructure as it is primarily virtual, relates to concepts, models and code and can change rapidly. In contrast, physical infrastructure is built with concrete, asphalt and iron, changes slowly (if at all) and lasts decades. The risk for lock-in due to sunken investment is acute in the case of physical infrastructure but much less for data infrastructure.

Nonetheless, lock-in risks exist for data infrastructure, especially regarding the adoption of specific syntaxes, vendor-provided services or restrictive governance rules, which may hamper innovation.

Public authorities are responsible for actively shaping and guiding this infrastructure's development. Still, given the uncertainties involved, this should occur mainly at the level of specifying key outcomes the infrastructure should enable and measuring the performance of the MaaS ecosystem in achieving those outcomes. This will require a mix of compulsion (e.g. requiring data sharing by MaaS ecosystem actors and that it be linked to specific actionable interoperability mechanisms), incentivisation and innovation (e.g. favouring the adoption of certain solutions while enabling more innovative solutions to emerge). For example, work to this effect is underway in Europe with the multimodal digital mobility services (MDMS) initiative. MDMS is defined as services “providing information on traffic and travel data such as location of transport facilities, schedules, availability or fares for more than one transport mode, which may include features enabling the making of reservations, bookings or payments or the issuing of tickets” covering both urban and inter-urban travel. Work is underway to establish a robust legal framework for this initiative (DG MOVE, 2021; 2022).

Leverage “data spaces” to shape data infrastructure around interoperability and trust mechanisms

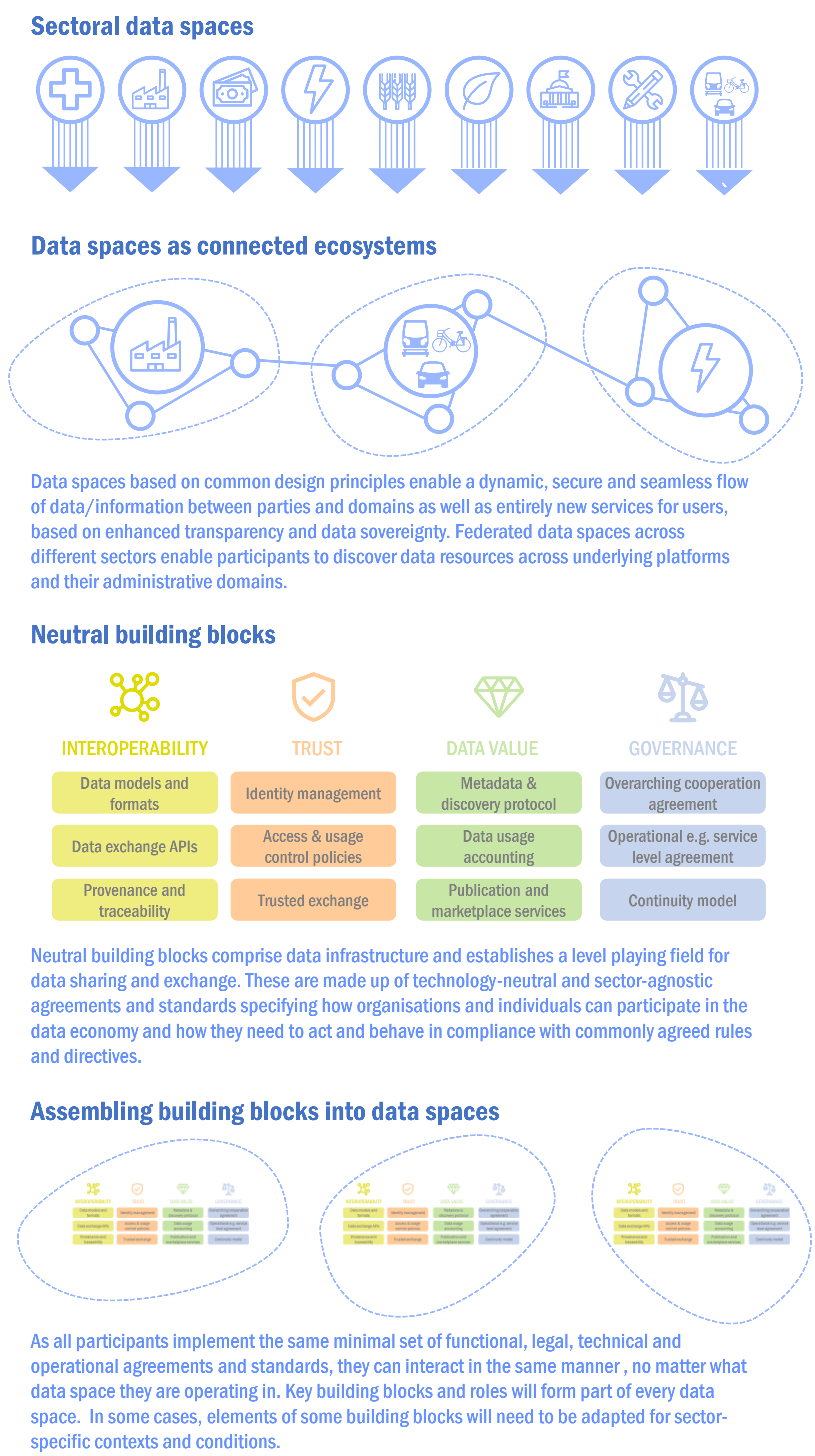
One way to incorporate strong interoperability and trust mechanisms by design and by default in mobility data infrastructure is to establish “data spaces”. These encompass all data-producing and consuming actors, processes and outcomes under a common set of principles, conditions and interoperability features that deliver social value while balancing private and public interests (Nagel et al., 2021). A data space is “a decentralised infrastructure for trustworthy data sharing and exchange in data ecosystems based on commonly agreed principles” (Nagel et al., 2021).

By comparison, physical public spaces are operated under principles, common practices and rules that have emerged over centuries of human interactions in those spaces. These norms determine what can or cannot happen on streets, pavements and other public spaces. This is also the case for buildings and the built environment where public values shape, guide and sometimes constrain private actions. In contrast with physical public spaces, digital public spaces have rapidly developed under rules, practices and conditions that favour private outcomes, sometimes at the expense of public outcomes (ITF, 2021c; van der Waal et al., 2020). Data spaces seek to re-balance these interactions and to ensure that a common approach to data governance built on guiding principles, public value outcomes and interoperability is established across all sectors of the economy (Nagel et al., 2021).

The International Data Spaces Association-led OPEN DEI task force notes that “from a technical perspective, a data space can be seen as a data integration concept which does not require common database schemas and physical data integration, but is rather based on distributed data stores and integration on an ‘as needed’ basis on a semantic level” (Nagel et al., 2021). Data spaces build on a core set of building blocks common to all data spaces but tailored to specific contexts where necessary. These building blocks establish for each sector, and across all sectors, common functional, legal, operational and technical norms and standards guiding data ecosystem interactions. Data infrastructure comprises these components, and because they are similarly structured within and across sectors, data interoperability and trust are maximised (Figure 17).

The concept of multi-sectoral, linked data spaces has progressed most in Europe, forming an integral part of the European Commission’s European Strategy for Data (European Commission, 2020). The Commission has identified nine initial domains to develop these federated data spaces – industry, health, energy, agriculture, Green Deal, finance, public administration, skills and mobility.

Figure 17. Data space ecosystems and building blocks



Source: adapted from Nagel et al. (2021).

The European Commission is currently establishing the basis for the EU-wide mobility data space by convening discussions around its structure, foundational norms and extent (European Commission, 2021a; 2021b). The approach is relevant for many existing data governance initiatives (e.g. the German Mobility Data Space, the Netherlands-initiated iSHARE, MyData) and will also, when established, encompass the MaaS ecosystem.

Deliver essential public data sharing building blocks

Public authorities have a role in developing or shaping many of the building blocks that underpin public value-oriented data spaces – including for MaaS within a broader mobility data space. These building blocks facilitate data sharing within the MaaS ecosystem and beyond.

First among these facilitators is secure official electronic identifiers for individuals. This, of course, can be handled by other non-public actors but will always reference official identity data. Public authorities can close the loop by providing official and secure e-identity APIs.

A second facilitator relates to the third pillar of mobility data architecture – crafting machine-readable regulations and authentication pathways (Figure 2). Examples include the FranceConnect APIs that MaaS ecosystem actors can access to establish identity and rights.

A third facilitator relates to public guidance on API architecture and functionalities oriented to ensure strong interoperability and effective, privacy-preserving data portability.

Improve public administration capacity

From a human resources perspective, talents and skills are central to a mature data sharing ecosystem. For MaaS ecosystem actors, managing external data sources will require additional capacity (e.g. skilled human resources, knowledge and data culture). According to the UITP, many public transport operators have gaps in their data management capacities (UITP, 2020c). Among the most cited gaps was the lack of dedicated and skilled staff to analyse and manage data sharing initiatives along with difficulty valuing data sharing and monitoring risks.

Managing mobility data infrastructure

Like other infrastructural layers (e.g. the built environment and transport network), managing mobility data infrastructure will require skilled and dedicated resources. Currently, there is a structural mismatch regarding data management capacity within the public sector. This problem is acute within the transport sector, characterised by low margins, where additional costs related to data management capacity constitute a barrier for organisations.

The public sector does not govern, value, and manage mobility data infrastructure like other foundational infrastructure for now (e.g. the built environment and transport network) (OECD, 2019c). Public organisations often struggle with digital transformation due to legacy issues caused by approaches and methods inherited from the analogue era. New challenges have also arisen with the growth in data sharing and opportunities and require adapted policy actions. Addressing these challenges requires greater comprehension and organisation.

Conversely, many private sector actors already address this skill capacity issue. New market actors (e.g. micromobility) place data at the centre of their strategy. From a market-wide perspective, this creates an asymmetric situation where public sector organisations lag behind private market actors in terms of comprehension and culture regarding data. Deloitte (2015) indicated that 69% of the public sector respondents to a survey felt that their digital strategy was lagging behind that of the private sector. This structural mismatch is simultaneously a cause and a consequence of the public sector's lack of attractiveness for data-related jobs compared to the private sector. The public sector lags behind the private sector, making it less attractive for talent than the private sector.

Capacity is not only about doing but also about understanding. From a policy perspective, inefficient situations can arise from a skill mismatch between the public and private sectors. Public sector organisations lack of comprehension can often hinder their ability to reach policy objectives. The lack of knowledge and understanding may result in inefficient management of mobility data infrastructure. This situation can be witnessed in other foundational infrastructure management. Addressing skills and talent asymmetry is crucial to overcoming such negative market externalities.

Improving capacity: Recruit, upskill and reskill

Improving capacity is also crucial to cope with the impact of digitalisation on the public sector workforce (OECD, 2021e). As the transport market becomes increasingly digitalised, public organisations can implement various actions to close the skills gaps. Improvement of recruitment practices can help cope with eventual internal skills shortages. Market actors who cannot internally recruit dedicated and skilled human resources can improve their data management capacity by outsourcing data management actions to the private sector. They can also take advantage of existing tools and solutions developed by other market actors that provide access to data management expertise.

Technical assistance centres supported by local, regional or national public authorities could also help close the skills gap. Such centres could:

- provide knowledge to the public sector regarding the use of existing standards
- support the drafting of harmonised regulations concerning data
- be involved in harmonisation initiatives amongst existing standards
- ensure the quality of data shared for MaaS and that it is compliant with local privacy regulations.

Finally, new approaches towards public-private partnerships (PPP) for skills development can address skill shortages in the public sector. According to European Training Foundation (2020), PPP for skills development can be a response in markets with a skills mismatch. This form of partnership has a long history in Europe, where governments, public organisations and businesses often developed PPP for skills. PPP for skills requires a common understanding of the role of data management skills. It further indicates that skill may become a new area for social dialogue between public and private actors (European Training Foundation, 2020).

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Mix and MaaS
Data Architecture for Mobility as a Service

This report develops a framework for data sharing between transport operators that enables them to better integrate transport services and move towards the creation of Mobility as a Service (MaaS) platforms. The report also identifies the risks that come along with data sharing and how they can be minimised. It complements the ITF Corporate Partnership Board project “Reporting Mobility Data: Good Governance Principles and Practices”, which focuses on the issues public authorities must address when establishing data reporting policies by mobility operators to public authorities.

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