Mobility Profiles: A Taxonomy for the Standardisation of Mobility Data Spaces*

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Abstract
Mobility Data Spaces have recently taken the spotlight as a practical approach towards the improved interoperability required to develop Multimodal Digital Mobility Services (MDMS). Although there exists design principles towards setting up a data space to be interoperable, there is no domain-specific approach to standardising data spaces. To prevent the development of silo-ed Mobility Data Spaces, this paper proposes a taxonomy for defining Mobility Profiles that standardises the entry of operators into a data space. Through the analysis of existing data standards and exchange methods, five core layers were defined for the taxonomy: Planning, Drivers, Booking, Ticketing, and Payment. Each layer consists of distinct cases of operations which, when put together, encompass a complete operator's data profile required to move a passenger from A to B. Through an example, we define how Mobility Profiles can be derived from the developed taxonomy and used to specify data standards, exchange formats, API specifications, and access rules. The development of these Mobility Profiles provide a structured framework for standardising data spaces but also enable the identification of vertical and horizontal gaps in interoperability across these profiles. If proven to be efficient, this approach can set a baseline for the standardisation of data spaces for other domains.

Keywords
Mobility Data Spaces, Mobility as a Service, MaaS, Data Interoperability, MDMS

1. Introduction

The advancement of Multimodal Digital Mobility Services (MDMS) and the need for improved interoperability have increased interest in Mobility Data Spaces as a solution. A data space is defined as *"a decentralised infrastructure for trustworthy data sharing and exchange in ecosystems based on commonly agreed principles"* [1]. These data spaces offer a practical approach to address the challenges of integrating the data of diverse mobility services. As they stand, these data spaces are constructed through Mobility as a Service (MaaS) stakeholders forming an entity which would be responsible for establishing the governance and set up of the data space [2]. Although this is ideal within a city or a confined geographical region working on a single

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solution, it presents an interoperability challenge as these data spaces are set up independently. The MaaS Alliance emphasized that the development of interoperability solutions should be conducted on a global scale as an increasing number of operators deploy their services across borders [3].

This paper proposes a solution to prevent the development of silo-ed data ecosystems within the realm of mobility. Through an analysis of existing data standards and exchange specifications, a taxonomy classifying the different types of operations of a mobility service is derived. The classification is a high-level breakdown of the distinct types of offers that build up an operator's data profile required to move a passenger from their origin to their destination.

The paper will first present a background explaining the reasoning behind the development of the taxonomy and a justification for its scope. This is followed by a brief description of the data standards considered and an overview of their analysis. The paper then presents the layers derived from the analysis and illustrates them into a concise taxonomy. Finally, an example of how a Mobility Profile can be derived from the taxonomy and used to standardise entry of a mobility operator is discussed.

2. Background

The field of transportation data interoperability and API development has undergone extensive exploration and investigation, with numerous studies and scholarly works focusing on the intricacies of integrating data models and establishing seamless connectivity.

In a significant contribution, the MaaS Alliance Working Group presented a position paper [3] that provided a comprehensive overview of the state of data exchange processes in Mobility-as-a-Service (MaaS). This paper aimed to compare different existing data models, formats, and API specifications at a high level. The ultimate goal was to identify a minimal set of common elements among these specifications, enabling the development of a versatile API for MaaS. Contrary to the expectation of the need for a new standard for MaaS, the comparison in the paper concluded that the focus should be on aligning existing standards to achieve interoperability. The research highlighted that this alignment and mapping process is challenging and would require a significant amount of time and detailed knowledge about each standard. Considering the extensive number of stakeholders and complexity within the industry, the establishment of robust open standards and rules of engagement becomes essential.

To guide the comparison of standards, the paper proposed a shift in perspective, emphasizing a focus on where the individual wants to go rather than simply tracking the vehicle's movements. Accordingly, the paper identified several stages in a journey where data flows between the operator and the user, including user registration, planning, booking, traveling, fare collection, payment, support, and after-sales services.

Additionally, the paper highlighted the importance of global standardization rather than local approaches. As an increasing number of operators deploy their services across different countries, adopting a global perspective becomes crucial to ensure harmonization and interoperability.

The European Commission has put together a new initiative to regulate Multimodal Digital Mobility Services (MDMS). These services can be defined as "systems providing information about, inter alia, the location of transport facilities, schedules, availability and fares, of more than one transport provider, with or without facilities to make reservations, payments or issue tickets" (e.g. route-planners, Mobility as a Service, online ticket vendors, ticket intermediaries) [4]. The objectives of this initiative are outlined below:

1. "Provide certainty and transparency for business-to-business commercial agreements for services reselling mobility products for land-based modes, waterborne and maritime transport, as well as for agreements on journey continuation."
2. "Prevent harmful market effects which may arise from discriminatory behaviour of MDMS against operators, and ensure that the deployment of MDMS is not hampered by discriminatory practices."
3. "Ensure that MDMS enhance the efficiency and sustainability of the transport system."

The commission opened the initiative for feedback in 2021 and conducted public consultation in 2022. The adoption of the initiative is planned for 2023.

The MaaS Alliance recently published a White Paper on Mobility Data Spaces [2]. Mobility Data Spaces are built on top of the International Data Spaces (IDS), established in 2019, which sets a Reference Architectural Model built on Open Standards. It specifies the terms and conditions in the European data economy, promoting FAIR (findability, accessibility, interoperability, and reusability) principles [1]. The IDS Association (IDSA) put together a position paper to define the design principles of an IDS which include a) Data sovereignty, b) Data level playing field, c) Decentralised soft infrastructure, d) Public-private governance [5]. Building on IDS, Mobility Data Spaces would act as a trusted aggregator of mobility data between a set of mobility stakeholders. An example of a Mobility Data Space Topology is shown in Figure 1.

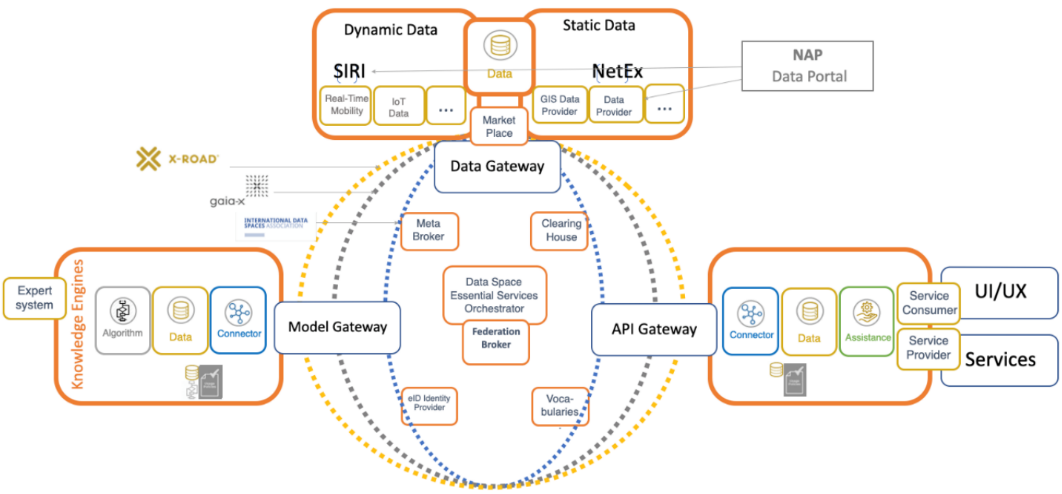

Figure 1: Example Topology of a Mobility Data Space [6]

In order to establish a Mobility Data Space, a collaborative entity is formed by the stakeholders with the following objectives [2]:

- Formulate and establish participation rules.

- Define a shared set of policies.
- Develop a trust model and serve as a trusted authority.

This entity assumes responsibility for the registration and onboarding process of new members into the Mobility Data Space. Some of the subsequent steps involve creating a comprehensive list of data sources, constructing a federated catalogue of services for data users, defining a description and semantic integration of datasets, a common ontology, and a reference semantics to be adopted by all members, among others.

Although there are design principles in place for setting up a data space [5], the principles are not domain-specific. There is an emphasis on standardisation, but there are no specifications set out for each domain. As a consequence, independently developed data spaces may lack interoperability as there is no global specification for data models. To address this challenge, the MaaS Alliance recommends the use of Transmodel as the reference semantics for any mobility data space [2]. Transmodel[1] is a public transport reference data model which provides a description of a variety of data elements required in the operation of public transport including timetable planning, definition of stops, among others. However, it is difficult to impose a specific standard on operators, especially if they already adhere to a different standard, such as GTFS [2].

This paper proposes a taxonomy upon which mobility profiles can be created to define the different possible types of operations. These mobility profiles would serve as a specification for entry to a mobility data space. The development of the taxonomy is outlined in the next section.

3. Taxonomy Development

To develop mobility profiles that cover the different types of operations, a high-level analysis of existing data standards was conducted to identify the different core layers that build up an operator's data.

The scope of the analysis is limited to the data required to move a passenger from their origin to their destination within the context of Mobility as a Service. The layers to build up a profile are distinguished from each other if they would require a different data model within an operator's database, for instance, fixed schedules and dynamic schedules. The taxonomy does not cover factors that affect a journey's recommendation to the user such as transfers between modes or accessibility of the journey, as well as, layers that would not vary in their data model across any type of mobility profile such as metadata.

Through the analysis, the different phases of a journey which require an exchange of data between a user and an operator were investigated. These phases set the themes for the taxonomy's core layers. Under each layer, the possible distinct operation models were defined. These definitions were then validated against existing mobility services to examine whether the taxonomy has discounted any further operation models.

This section will first discuss some of the data standards analysed, drawing up the user-operator data exchange phases and defining the core layers of the taxonomy. The taxonomy is then presented with a brief discussion on its validation.

[1]https://www.transmodel-cen.eu/
[2]https://developers.google.com/transit/gtfs

3.1. Analysis of Data Standards

A select set of data standards were analysed which focused on the most commonly used standards within the MaaS ecosystem. The sections below present a brief discussion on the results of the analysis for each.

3.1.1. General Transit Feed Specification (GTFS) *static*

GTFS *static* is designed for transit agencies with generally fixed routes and timetables. The standard provides a description for a set of CSV files which define how such agencies would model their data. The standard covers the data elements described in Table 1.

Table 1
Analysis of data elements in GTFS

Data Element	Description	Journey Phase
agency.txt, feed_info.txt, attributions.txt, translations.txt	Metadata / Identification	None / All
stops.txt, routes.txt, trips.txt, shapes.txt	Fixed routes	Planning
calendar.txt, calendar_dates.txt, frequencies.txt	Fixed schedules	Planning
fare_attributes.txt, fare_rules.txt	Fare information	Payment
transfers.txt, pathways.txt, levels.txt	Factors affecting the journey and user preferences	Planning

3.1.2. GTFS *realtime*

GTFS realtime [3] supports the publishing of realtime data by transit agencies. The standard includes models for three types of feeds: **(a) Trip Updates** - represent fluctuations in the timetable e.g. *"Bus X is delayed by 5 minutes"*, **(b) Service Alerts** - represent a problem with a particular entity in the form of a textual description e.g. *"Station Y is closed due to construction"*, and **(c) Vehicle Positions** - represent basic information about a specific vehicle within the network.

3.1.3. General Bikeshare Feed Specification (GBFS)

GBFS [4] is a data standard designed for shared mobility. The standard provides a description for a set of JSON files which define how shared mobility operators can share the status of their system in a given moment. The feed is expected to be republished by the operator at a reasonable frequency (in seconds) to provide realtime visibility of the service for planning. The JSON files are described in Table 2.

[3] https://developers.google.com/transit/gtfs-realtime
[4] https://github.com/MobilityData/gbfs

Table 2
Analysis of data elements in GBFS

Data Element	Description	Journey Phase
gbfs.json, gbfs_versions.json, system_information.json	Metadata / Identification	None / All
station_information.json, station_status.json	Station-based services	Planning
free_bike_status.json	Dockless services	Planning
system_hours.json, system_calendar.json	On-demand services	Planning
system_pricing_plans.json	Fare information	Payment
vehicle_types.json, system_regions.json, system_alerts.json, geofencing_zones.json	Factors affecting the journey and user preferences	Planning

3.1.4. Transmodel

Short for the European Standard "Public Transport Reference Data Model", Transmodel was also developed to provide a common language for public transport. The standard is a conceptual model divided into 8 parts as described in Figure 2. In comparison to other data standards, Transmodel is considered very rich with over 1500 concepts covering different modes of transportation and various functional domains.

In addition to the parts presented in Figure 2, an additional part was added in 2021 to cover alternative modes of transport. With this update, Transmodel caters for operations of fixed routes and schedules but also for demand-based operations by managing vehicle meeting points in cases such as vehicle sharing or carpooling. The parts of transmodel allow for standardisation of data beyond what needs to be shared with a public user, such as driver rosters. Based on Transmodel, a data exchange standard, Network Timetable Exchange (NeTEx) [5], was developed which inherits the concepts of Transmodel.

3.1.5. The TOMP-API

Although the TOMP API [6] is an API specification, it plays a major role in shaping the data exchange in the MaaS ecosystem. In the term TOMP, TO stands for Transport Operators, and MP stands for MaaS Providers. The API specification standardises how data is exchanged betweeen operators and MaaS providers according to the different phases of a journey as shown in Figure 3

3.1.6. Results of the Analysis

Through the analysis of the data standards presented above, the phases of a journey and the corresponding variation in operator data profiles were derived.

[5] http://netex-cen.eu/
[6] https://github.com/TOMP-WG/TOMP-API

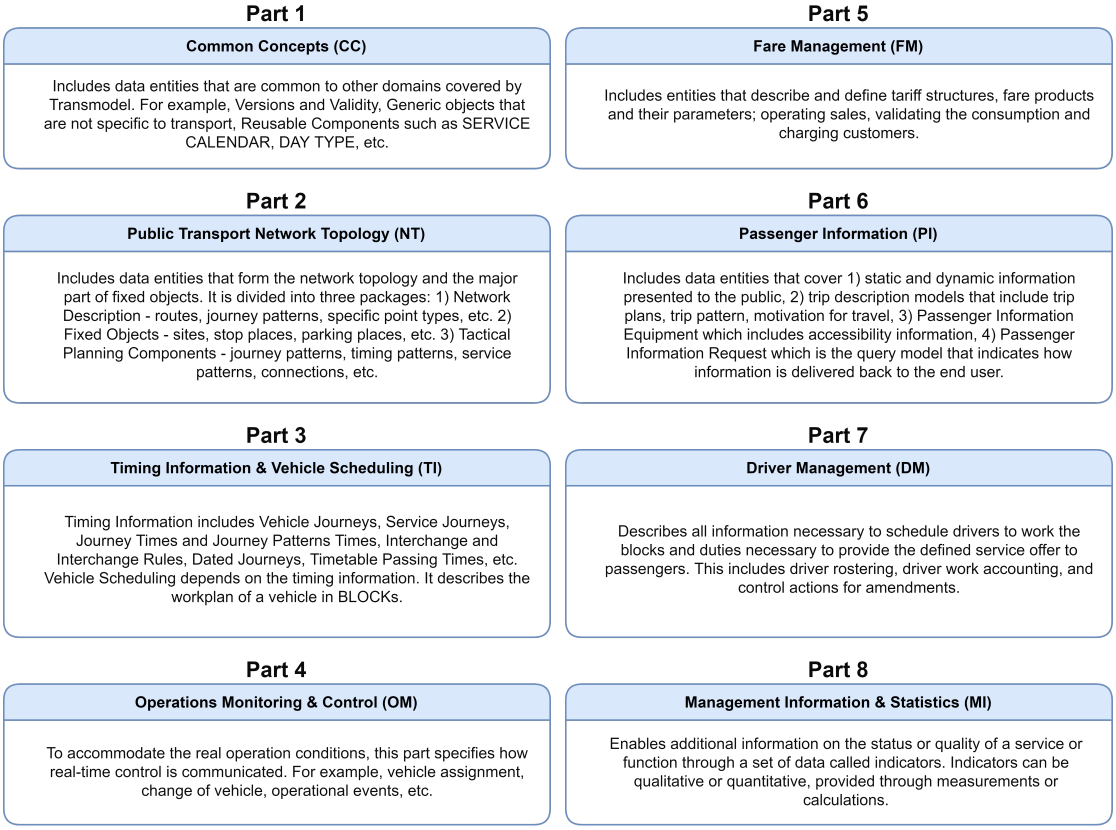

Figure 2: Summary of the 8 parts of Transmodel

Although there are a number of other standards within the realm of Mobility such as Mobility Data Specification (MDS) [7] or Open Standard for Linked Organisations (OSLO) [8], they did not add to the cases of operations already derived from the standards above. Other standards covering mobility domains that affect a journey, such as DATEX II [9], were not considered as the scope of the taxonomy did not include such factors.

A breakdown of the phases of the journey derived through the analysis is shown in Table 3. The table shows the data request by a user in each phase and the corresponding variations on the operator's side. This breakdown will form the core layers of the taxonomy.

In addition to Planning, Booking, Ticketing / Access, and Payment, a journey of a passenger on a service would include the following phases, however, these were not considered in the taxonomy for the reasons listed below:

- USER REGISTRATION - The profile of a user and the data required to be shared with an operator would vary significantly between different types of services. This is due to

[7]https://github.com/openmobilityfoundation/mobility-data-specification
[8]https://data.vlaanderen.be/ns/
[9]https://www.datex2.eu/datex2/

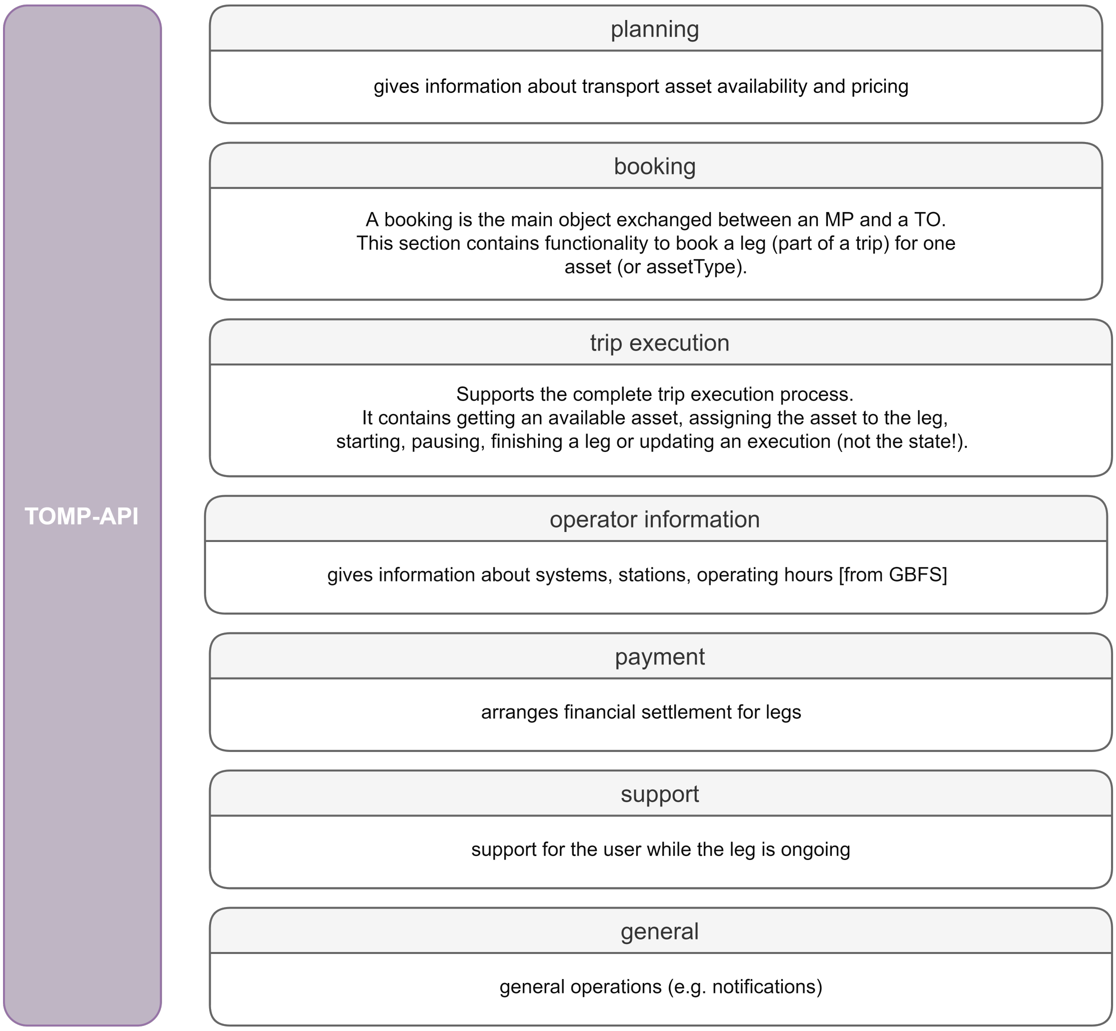

Figure 3: Summary of TOMP-API endpoint categories. For the full API documentation, refer to https://app.swaggerhub.com/apis-docs/TOMP-API-WG/transport-operator_maas_provider_api/1.4.0

different reasons such as safety, liability, accessibility, preferences, among others. It is therefore recommended to develop a similar taxonomy to breakdown, at a high-level, the building components of a user profile. This would then allow the standardisation of user data and can be used for automating and regulating the exchange of user data and account registration across different services.

- TRAVELING - This phase represents data updates during the journey. It was excluded based on the assumption that this would include realtime data on the service that would not vary significantly amongst the different types of operations. This is likely to include the location of the vehicle, changes to the Estimated Time of Arrival (ETA), disruption updates, etc. It is assumed that the data model for such information wouldn't vary between fixed and flexible services and commonly fall under the same data model describing the

Table 3
Breakdown of the Phases in a Journey Illustrating the Data Interaction Required Between a User and an Operator

PLANNING	
User	**Operator**
I need to know where to start and to end	I need to specify available start and end locations: *Fixed locations* *Flexible / demand-based locations*
I need to know what time to start and to end	I need to specify available timings of my service: *Fixed schedule / frequency* *On-demand timings*
BOOKING	
User	**Operator**
I need to know if I can get a place on the service	I need to specify how the user can guarantee a place on my service: *No Booking* *Booking in advance* *Booking on demand*
TICKETING / ACCESS	
User	**Operator**
I need to access the service	I need to specify how the user can access my service: *Non-electronic* *Contactless Ticketing* *Biometric Ticketing*
PAYMENT	
User	**Operator**
I need to know how can I pay for my journey	I need to specify the payment instrument options that can pay for my service: *Methods that require users' personal data* *Methods that do not require users' personal data*
I need to know the pricing and fare rules	I need to specify the prices and fare rules for my service: *Pay-as-you-go* *Subscription*

data for the Planning phase.

- SUPPORT and AFTER SALES - These phases are considered to not vary between operators as it revolves around customer support information and operations like refunds which can be linked to the payment layer defined in the operator's Mobility Profile.

In addition to the journey phases, two other areas of variation were important to consider as they can affect the operation model. These two layers are listed in Table 4.

Table 4
Breakdown of Additional Layers of Operator data

DRIVERS
I need to specify drivers data for my service *Autonomous / No Driver* *Employed Driver / Fixed Shifts and Pay* *Ride Coordination / Flexible Shifts and Pay*
SERVICE OWNERSHIP
I need to specify the type of ownership of the service: *Public Service* *Private Service* *Public-Private Partnership* *Individual Service*

The DRIVERS layer was included as it may specify data that need to be shared in the case of products resale, especially in the case of ride coordination (services like Uber) where the drivers' data is required for the PLANNING phase.

The SERVICE OWNERSHIP aspect needs to be included as it affects the liabilities associated with the operation. The Mobility Profiles taxonomy is foreseen to be useful for automating contracts and data access regulation which may be heavily dependent on the type of ownership of the service. However, this was deemed unnecessary to have as an independent layer but instead as part of the metadata associated with the profile.

The 4 Journey phases and the DRIVERS layer serve as the core layers of a Mobility Profile. The next section will describe how these layers fit together to develop a profile, in addition to any hierarchical or exclusive relationships between / within these layers.

4. The Mobility Profiles Taxonomy

The taxonomy of the Mobility Profiles consists of 5 layers. The function of a layer is to:

- **Define the case** for the operator within the context of that layer.
- **Identify the standard data models or API specifications** that can be used based on the chosen case.
- **Link between the case and its access rules** defined by a data ecosystem.

This section will discuss the 5 layers and the cases that fall under each.

4.1. PLANNING Layer

The first layer is the **PLANNING** Layer. This layer sits at the root of the profile and has exclusivity over its cases. This means that a Mobility Profile can only include one of the case options to identify how its service can be planned. The layer is split by temporal and spatial variations as shown in Figure 4.

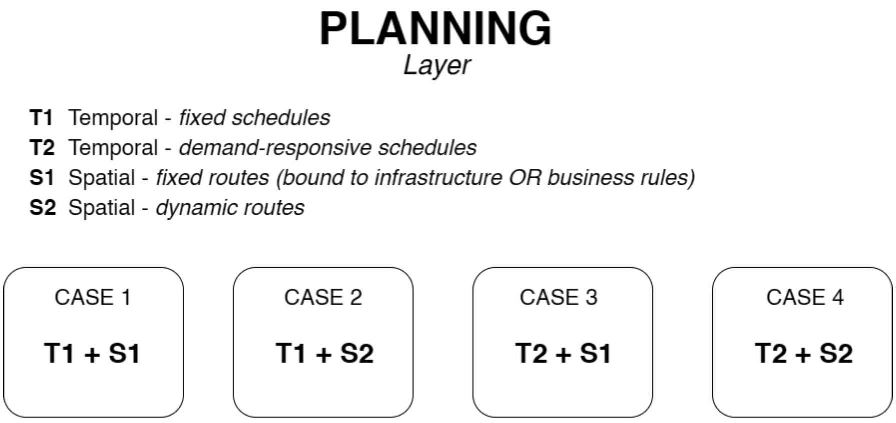

Figure 4: Illustration of the profile cases within the PLANNING layer

4.2. DRIVERS Layer

Closely linked to the PLANNING layer, the DRIVERS layer serves as the second layer in the hierarchy of a profile which also has an exclusive relationship between its cases. A Mobility Profile can either be *Autonomous* (**D0**), have *Employed Drivers*(**D1**), or run on *Ride Coordination* (**D2**). The profile **does not need to include this layer** to accommodate cases where the users of a service are its drivers.

4.3. BOOKING, TICKETING, and PAYMENT Layers

The BOOKING, TICKETING, and PAYMENT layers do not have exclusivity over their cases and a profile can operate more than one variation under these layers. There is no hierarchy among these layers.

The BOOKING layer defines whether the service can be booked. Booking here means that the user can guarantee themselves a spot on the mode of transport. If the service is bookable, the operator defines whether users can book in advance and / or on demand.

The TICKETING layer defines how a user can access the vehicle. The cases were defined based on the type of data required by an operator. Non Electronic (NE) ticketing refers to methods of access that do not have an electronic transaction such as cash, keys, tokens, etc. Contacless Ticketing (CT) refers to access methods such as card-based access, QR code scanners, Bluetooth, or other types of readers. Biometric Ticketing (BT) was classified separately as it requires the collection and verification of biometric data.

Under the PAYMENT layer, the fare rules sit at the top of the layer, which are split into Pay as You Go (PAYG) and Subscriptions (SUBC). Under each type of fare rule, the payment method either does or does not requires the provision of personal data. For example, any method that requires creating an account will necessitate the processing of user data.

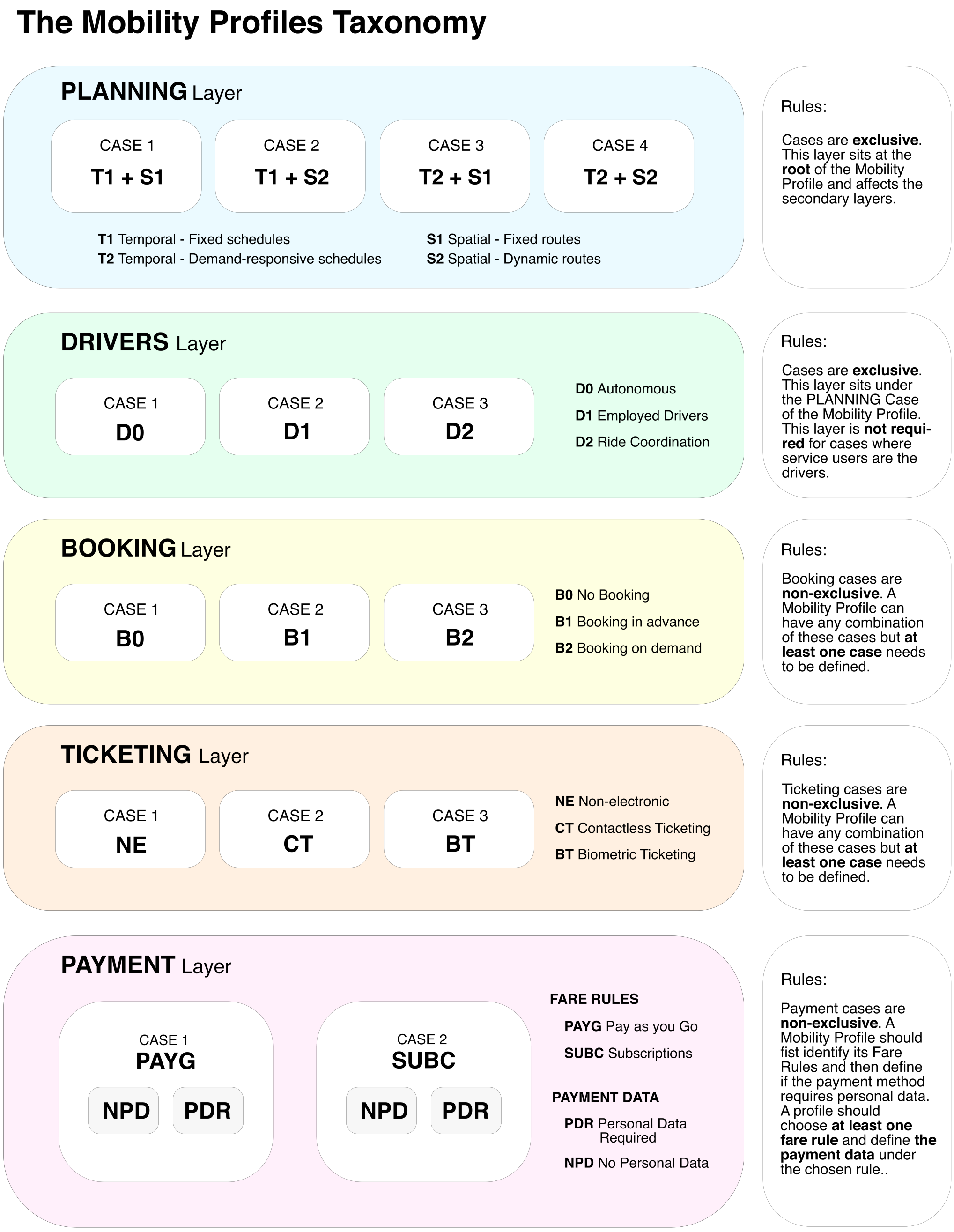

Figure 5: Illustration of the Mobility Profiles Taxonomy

The taxonomy is presented in Figure 5. A Mobility Profile should define the standards and regulations for services that fall under that profile. In that sense, a profile will enable the standardisation of entry to a Mobility Data Space by specifying the data models, API specifications, and exchange formats that are supported for each profile. An operator would then identify which profile fits its service best and provide its data according to the rules of the Mobility Profile. An example of how a Mobility Profile can be set up and used as an entry specification to a Mobility Data Space is shown in Figure 6. This allows the data space to be more flexible, although, it would require the development of verified alignments and interoperability solutions to allow the integration of various standards supported by a profile as well as interoperability across profiles.

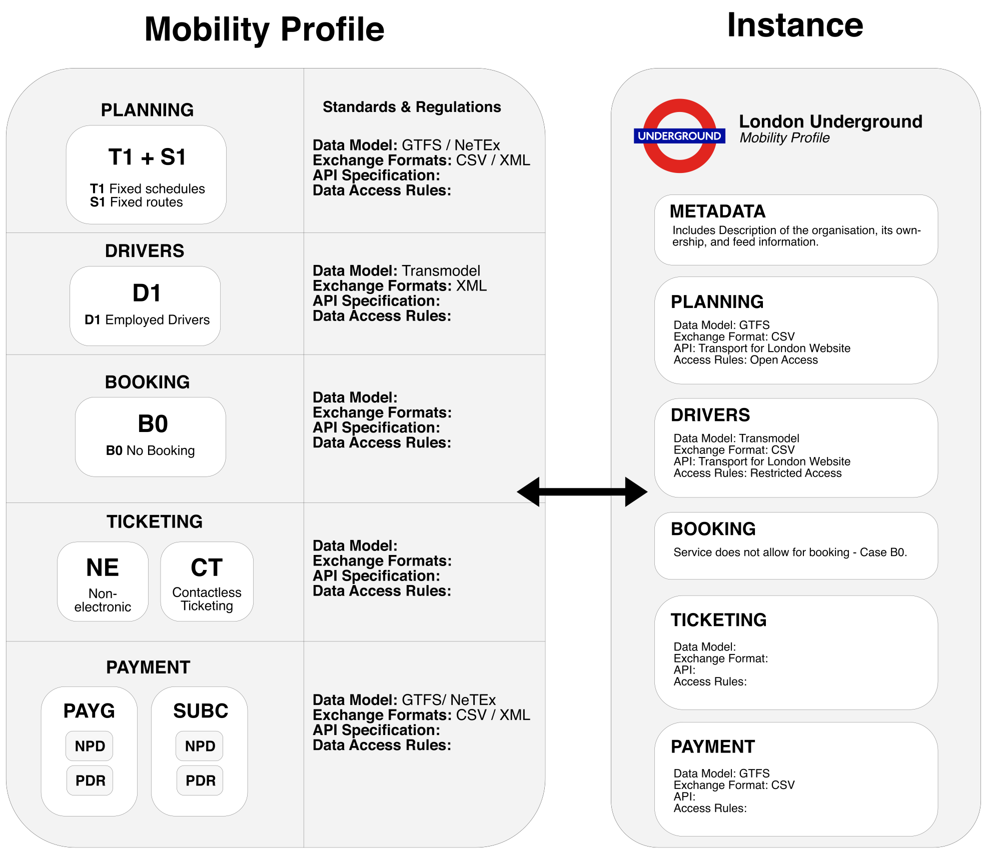

Figure 6: Example of how a Mobility Profile and an instance of the profile would be set up - The details in this figure are just an example and are not the actual standards used by the London Underground

4.4. Taxonomy Validation

To check whether the layers in the taxonomy comprehensively cover the different types and elements that build up an operator's dataset required for moving passengers, a list of services in Moscow are reviewed against the taxonomy layers as shown in Table 5. For each service, the taxonomy is validated by checking whether a case from each layer is applicable to the service.

4.5. Comparison with other Taxonomies

With the proliferation of shared mobility services and the development of various types of operations, establishing policies and regulations around these services have become a focal point. In the endeavor of regulating these service, a few taxonomies have emerged. Cledou et al. [7] presented a taxonomy for planning and designing smart mobility services. The taxonomy is made of 8 dimensions: type of services, maturity level, users, applied technologies, delivery channels, benefits, beneficiaries, and common functionality. Under each dimension, the authors define common concepts providing a vocabulary to guide discussions and information sharing around smart mobility services. The taxonomy gives definitions for different types of services such as journey planners, parking, transport monitoring, and payment, to name a few. In contrast, the Mobility Profiles taxonomy is geared towards categorizing the data essential for efficiently moving a passenger from origin to destination across diverse transportation services. This taxonomy transcends the confines of smart mobility, focusing solely on dimensions pertinent to data exchange for passenger movement. Unlike Cledou et al.'s[7] taxonomy, which caters to a broader planning and developmental context, the Mobility Profiles hone in on the specific requirements for passenger mobility. Therefore, while Cledou et al.'s[7] taxonomy serves a distinct purpose, primed for policy-makers and mobility solution developers to align their understanding, it does not encompass the intricate operational distinctions that the Mobility Profiles taxonomy seeks to define.

Another taxonomy contributing to the field of Mobility as a Service is the 'Levels of MaaS Integration (LMI) taxonomy' by Lyons et al. [8]. The taxonomy covers levels of integration within and between mobility services beyond the private car emulating 0–5 SAE taxonomy for automation of road vehicles. Similar to Sochor et al. [9], this taxonomy defines 5 levels of integration for MaaS services. This taxonomy can complement the Mobility Profiles where different policies are applied through the Mobility Profiles depending on the level of integration of the operator. In parallel, the SAE taxonomy introduced by SAE International [10] offers a classification system for diverse automation levels, aligning with concepts closely related to the DRIVERS layer established within the Mobility Profiles. It's important, however, to appreciate the nuanced distinctions between these taxonomies. The DRIVERS layer primarily serves to identify the driving model associated with a given operational type, guiding the requisite data provisioning for operators. In contrast, the SAE taxonomy delves deeper, concentrating on a hierarchical classification of automation levels, albeit with a narrower focus limited to road vehicles exclusively.

More taxonomies relevant to the mobility field have been found in previous studies. For instance, Solmaz and Turgut [11] introduced a taxonomy classifying different human mobility models which defines four classes that differentiate between how people move including Class1: Pedestrian walk models and Class 3: Vehicular models. Hyland and Mahmassani [12] put forward a taxonomy that classifies vehicle fleet management problems to inform future research on autonomous vehicle fleets. The layers of the taxonomy dive into various factors that affect the operation of a fleet such as pickup and delivery, size of vehicle fleet, pricing structures,

Table 5
Validation of Mobility Profiles against Mobility Services in Moscow

Service	Description	PLANNING	DRIVERS	BOOKING	TICKETING	PAYMENT - PAYG	PAYMENT - SUBC
Metro	Railway service	T1+S1	D1	B0	CT, BT	PDR, NPD	PDR, NPD
Moscow Central Circle (MCC)	Railway service	T1+S1	D1	B0	CT, BT	PDR, NPD	PDR, NPD
Aeroexpress	Railway service	T1+S1	D1	B0	CT	PDR, NPD	PDR, NPD
Moscow Central Diameters	Railway service	T1+S1	D1	B0	CT	PDR, NPD	PDR, NPD
Bus	Fuel-based bus service, running on fixed routes by the operator	T1+S1	D1	B0	CT	PDR, NPD	PDR, NPD
Trolleybus	Electric bus service, Have allocated lanes as they are connected to overhead lines	T1+S1	D1	B0	CT	PDR, NPD	PDR, NPD
Tram	Rail vehicles traveling on tracks on public urban streets	T1+S1	D1	B0	CT	PDR, NPD	PDR, NPD
Marshrutka (Shared Minivans)	Minibuses	T1+S1	D1	B0	CT	PDR, NPD	PDR, NPD
Velobike	Bikesharing, retrieved and returned to nearest available dock	T2+S2	-	B2	CT	-	PDR
Delimobil	Carsharing	T2+S2	-	B2	CT	PDR	-
Anytime	Carsharing	T2+S2	-	B2	CT	PDR	-
Car5	Carsharing	T2+S2	-	B2	CT	PDR	-
Udrive	Carsharing	T2+S2	-	B2	CT	PDR	-
BelkaCar	Carsharing	T2+S2	-	B2	CT	PDR	-
Yandex Taxi	Taxi Service	T2+S2	D1	B2	CT	PDR	-
Uber	Ride-hailing	T2+S2	D2	B2	CT	PDR	-
Whoosh	E-scooter Sharing, dockless	T2+S2	-	B2	CT	PDR	-
Yurent	E-scooter Sharing, dockless	T2+S2	-	B2	CT	PDR	-
Yandex Go	E-scooter Sharing, dockless	T2+S2	-	B2	CT	PDR	-

network congestion, among others. The purpose of this taxonomy is to highlight areas where there are challenges faced by fleet managers. While these taxonomies are related to the field, their scopes are distinct from the Mobility Profiles taxonomy.

Through this comparative study with other taxonomies found in the literature, a number of classifications were uncovered which shed light on various aspects of shared mobility. Each taxonomy presented a unique perspective enriching the understanding of various dimensions within the field. However, it is noteworthy that none of the taxonomies directly align with the distinct approach of the Mobility Profiles taxonomy. It stands apart from other taxonomies through its scope which focuses on the data of an operator required to move a passenger from A to B. This focus underscores the novelty of the taxonomy filling a gap within the data exchange practices of Mobility as a Service.

5. Implications, Conclusions, and Future Recommendations

This paper presented a taxonomy that serves to standardise the entry of mobility operators into a Mobility Data Space. The taxonomy was developed by conducting a comprehensive analysis of existing data standards and specifications utilized in the realm of Mobility as a Service for data exchange and service integration. The analysis led to the derivation of five core layers within the taxonomy: Planning, Drivers, Booking, Ticketing, and Payment. Each layer encompasses distinct operational cases, providing a structured framework for the high level identification of how an operator runs their service in order to enable its integration and interoperability with other mobility services.

The taxonomy was validated by examining a list of mobility services offered in Moscow, being one of the top 10 cities for urban transportation according to McKinsey & Company [13]. The city offers a variety of services under Moscow Transport and Yandex [14]. These services were compared against the taxonomy and found to fall under the different cases defined. This, however, is a limited validation that only verifies the coverage extent of the taxonomy. Further validation is required through methods such as an experts review or data experiments to ensure the applicability of this taxonomy.

The Mobility Profiles derived from the taxonomy are to be used as a method to standardise entry to Mobility Data Spaces. This would be valuable in avoiding the independent development of standards within data spaces leading to further silos and interoperability issues. Defining data models, exchange formats, and API specifications for each profile would enable a) A workaround to imposing a specific standard for all mobility providers, b) Defining all the standards that fall under the same profile which will show gaps in vertical interoperability, e.g., Both NeTEx and GTFS can be used for T1 + S1 but there is no verified alignment between these two standards, c) Identifying gaps in horizontal interoperability where certain Mobility Profiles are commonly combined together but their data models do not have an alignment, and d) Identifying and prioritising areas and types of operations that do not have existing standards or specifications. In addition, prominent Mobility Profiles can be used as a basis for standardising contracts which includes data sharing rules, liability and insurance, and other clauses defined according to the layers of the taxonomy. To make this taxonomy more practical, it is proposed to develop a machine-readable version (e.g., an ontology) which would enable the use of the taxonomy within data architectures to automate data validation and access.

Other limitations of the taxonomy include that it does not account for user data which includes personal information, preferences, accessibility, etc. It is recommended that an extension to the taxonomy is defined for standardising Mobility Profiles of users. As discussed, the scope of the taxonomy does not include factors affecting the journey, such as transfers between stations, parking availability, etc. An investigation into the elimination of these factors is required to ensure the practicality of the taxonomy.

In conclusion, the paper presented a novel contribution to building mobility specifications which can be used to raise interoperability between specifications and prevent the development of silos among data spaces. The Mobility Profiles is predicted to be beneficial for advancing the integration of mobility data and regulations for Multimodal Digital Mobility Services (MDMS), especially within the context of MaaS. If proven to be efficient, this approach can be replicated for standardising entry to data spaces of other domains.

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