nuMIDAS

Deliverable 2.1
State-of-the-art assessment

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Key acronyms

ADAS	Advanced Drivers Assistance Systems
AFCS	Automatic Fare Collection System
AI	Artificial Intelligence
API	Application Programming Interface
BI	Business Intelligence
CAVs	Connected and Automated Vehicles
CCAM	Cooperative, Connected and Automated Mobility
CDR	Call Detail Record
C-ITS	Cooperative ITS (Intelligent Transport Systems)
CO2 / CO_2	Carbon dioxide
CPI	Category of Policy Instruments
EC	European Commission
EU	European Union
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
FCD	Floating-Car Data
FHWA	Federal Highway Administration
GA	Grant Agreement
GTFS	General Transit Feed Specification
GIS	Geographic Information Systems
GHG	Greenhouse Gas
HCM	Highway Capacity Manual
HEV	Hybrid Electric Vehicle
ICCT	International Council on Clean Transportation
ICT	Information and Communication Technologies
IoT	Internet of Things
ITS	Intelligent Transport Systems
IVR	Interactive Voice Response

KPI	Key Performance Indicator
LBS	Location-Based Services
MaaS	Mobility-as-a-Service
MDS	Mobility Data Specification
ML	Machine Learning
NAP	National Access Point
nuMIDAS	New Mobility Data and Solutions Toolkit
NUMO	New Urban Mobility Alliance
OD	Origin-Destination
Ox	Objective x
PMV	Personal Mobility Vehicles
PT	Public Transport
PTM	Public Transport Management
P2P	Peer-to-peer (also known as person-to-person)
R&D	Research and Development
SoA	State of the Art
TDM	Travel Demand Management
TfL	Transport for London
TMaaS	Traffic Management as a Service
TNCs	Transportation Network Companies
UAV	Unmanned Aerial Vehicle (i.e., drone)
UITP	Union Internationale des Transports Publics (Internat. Association of Public Transport)
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2G	Vehicle-to-Grid
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VKT / VMT	Vehicle Kilometres Travelled / Vehicle Miles Travelled
VRP	Vehicle Routing Problem
WP	Work Package

1 Executive summary

The mobility ecosystem is rapidly evolving, whereby we see the rise of new stakeholders and services. Examples of these are the presence of connected and automated vehicles, a large group of organisations that rally to establish various forms of shared mobility, with the pinnacle being all of these incorporated into a large MaaS ecosystem. On top of that, new services operate in an environment in which traditional services are well established. Existing tools and policy instruments must not only follow the innovations in mobility but also consider legacy services that still contribute to the mobility of cities. As advances in mobility start to appear within cities and regions, new ways in which data are being generated, collected, and stored arise. Successfully integrating all these various technologies and solutions within the designs of policy makers remains a challenge.

This deliverable summarises the findings from Task T2.1 of the nuMIDAS project. It provides the state-of-the-art analysis based on scientific papers, existing implementations, as well as running research projects. It also focuses on the shift in stakeholder roles and new business models in which is the focus of Task T2.2. The objective is to map the field and to identify possible gaps among the existing tools and the real-world problems and challenges.

It provides the reader with content and insight on at least the following topics:

- Identification and defining key terms within the mobility field.
- Providing a nuMIDAS model linking the terms to show the flexible multidimensional relations among them (as a 2D matrix form wouldn't be sufficient).
- Service-oriented approach was chosen as the optimal level of analysis. For each Service in scope, the following issues were analysed:
    - description and definitions,
    - trends and opportunities,
    - gaps,
    - involved policy instruments,
    - categories of usable tools,
    - high-level use cases involved,
    - solved challenges, and
    - inputs, outputs and KPIs.

Within this deliverable, the state-of-the-art (SoA) analysis via a study of scientific papers, existing implementations, and running research projects is conducted. For each service in scope, we provide an overview of the current state and trends concerning transport/mobility researchers, planners, and policymakers. In this deliverable, the focus is on the currently used tools. This deliverable does not only provide an overview of the tools, but it will also quantify their field and scope.

Besides discussing the traditional approaches, we will also discuss and categorise the challenges (gaps and problems) the transportation field is facing nowadays. Here, we will identify the potential to use the existing techniques and tools for the new challenges. Our main discussion will concern the identification of white spots where the existing tools and methods are not sufficient.

The deliverable also describes a stakeholder and business model analysis. It summarises and describes the traditional stakeholders in transportation and their roles. The focus is on the shift in stakeholder roles as well as the emergence of new business models. This is a particularly topical (i.e., relevant and of importance) task as we observe many new trends, for example, the growth of shared economies, evolution of connected and automated driving, or the expansion of apps that provide location-based services (LBS).

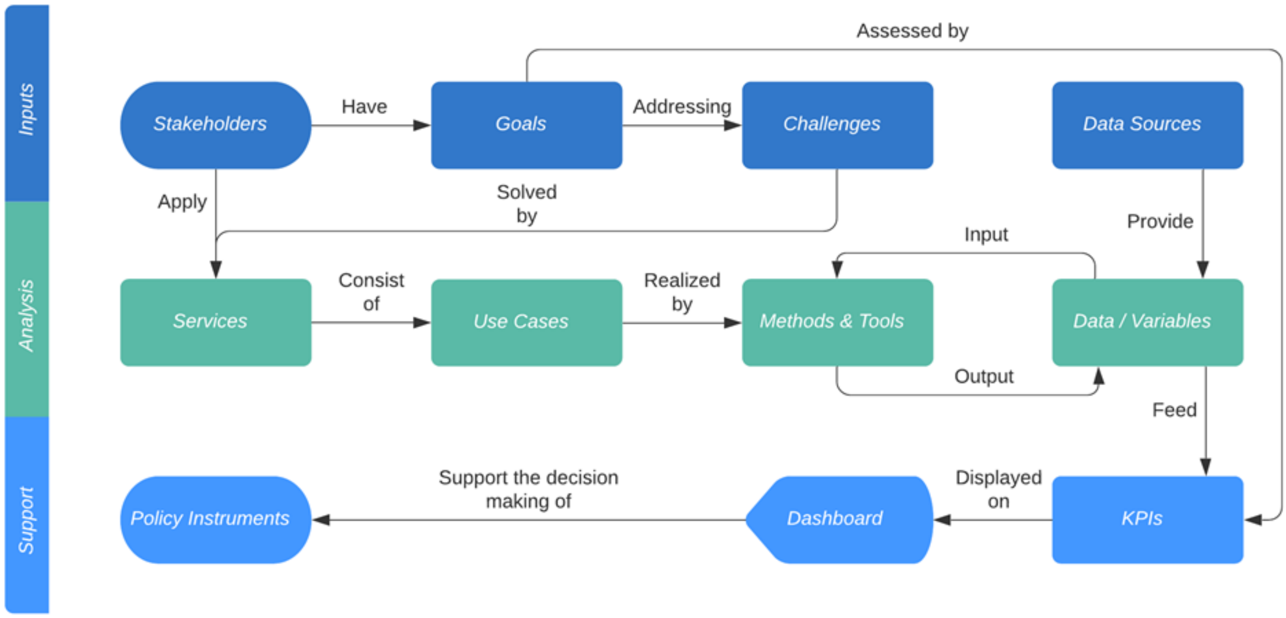
Based on the issues raised above, the nuMIDAS project decided to adopt a broader look at the mobility environment. We have adopted a new approach elaborated in section 3.2 that is broadly covering the following steps:

1. Define and agree on the terminology

   As discussed above, the terminology is being used differently in different fields (even within the mobility field). For this reason, the team must identify and define the most relevant terms within this SoA. The definitions were verified by a workshop as well.

2. Identify links among the terms (nuMIDAS model)

   The terms must be put into perspective and links among them identified.

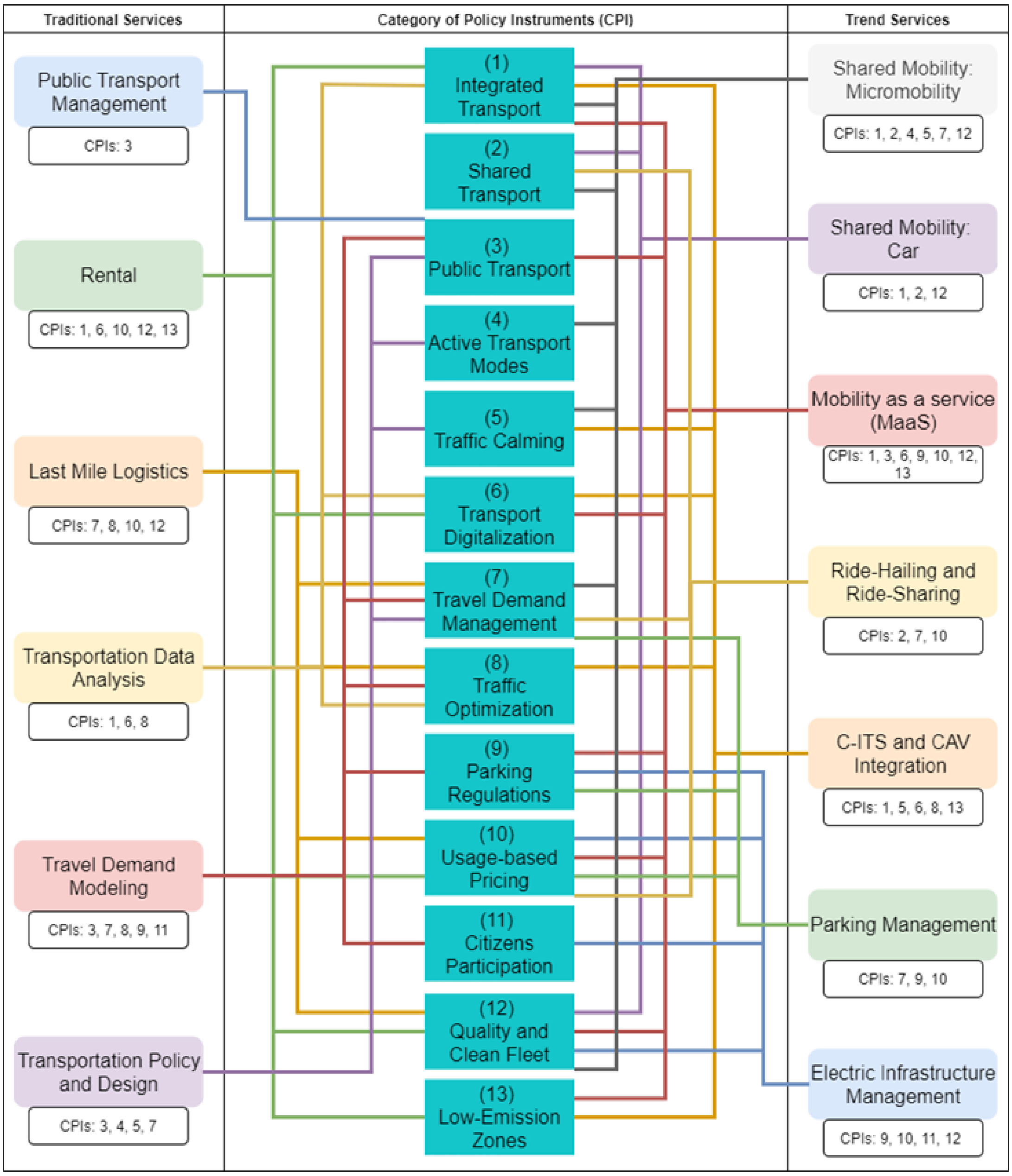


The nuMIDAS model – Service-oriented architecture

3. The use of a service-centred approach

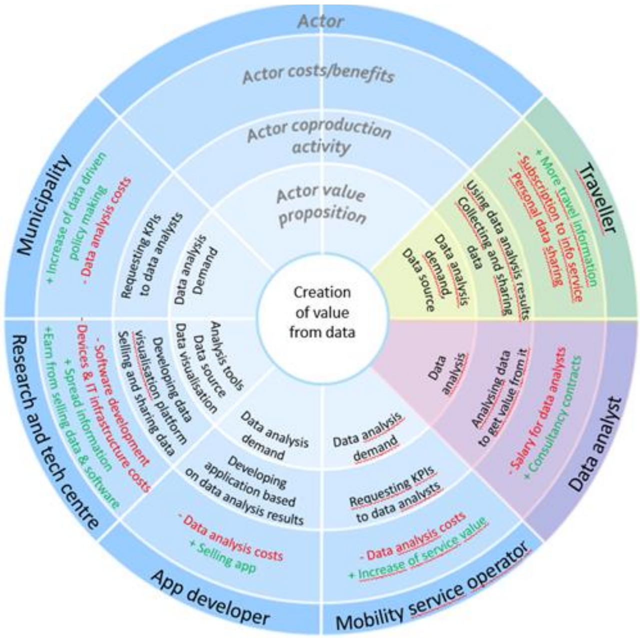
   Within this step, the services in scope are identified. For each of them, a detailed SoA is provided by one of the consortium members and reviewed by another one. A template was provided to ensure unity. After the individual analysis, a big picture was prepared to show links among the services and policy instruments. This big picture allows us to ensure unity in the produced output.

a. Identify relevant Services and define services in Scope of nuMIDAS
b. Describe the service and provide state-of-the-art analysis including a consortium internal review (for each Service in Scope)
c. Describe links to other terms (Challenges, KPIs, and others) (for each Service in Scope)
d. Provide a "big picture overview", use the overview to identify gaps in the SoA and complete the particular SoA (for each Service in Scope). The following figure, also to be found in section 4.4.1 provides a graphical overview of these categories of policy instruments (CPI) connected to the traditional and trend services within the nuMIDAS scope.



Relation between services and categories of involved policy instruments

e. Describe Business model changes (for each Service in Scope) using the service dominant business model Radar, SDMB/R. It is based on the achievement of shared goals and value co-creation by a group of actors who interact to achieve that shared goal.



Example of Transportation Data Analysis business model radar

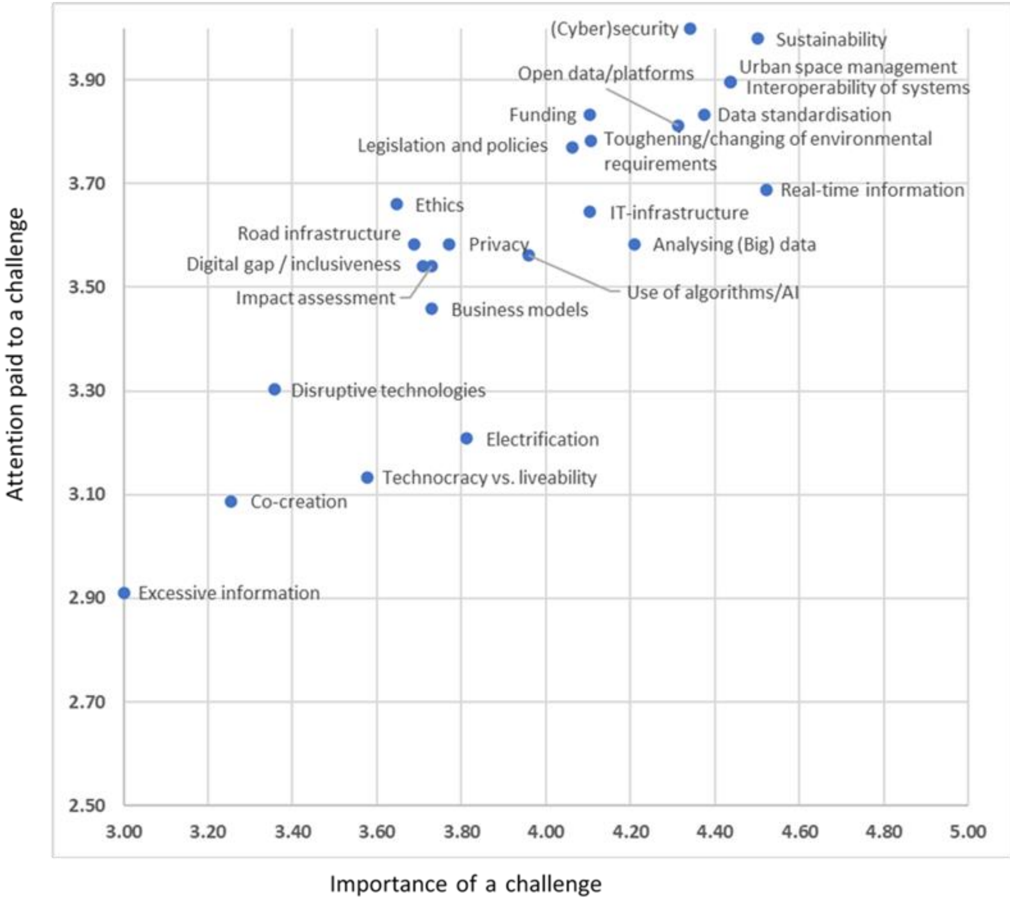
	Transportation Data Analysis	Transportation Policy and Design	Travel Demand Modeling	Public Transport Management	Last Mile Logistics
Municipality	Customer	Focal org.	Core partner	Core partner	Core partner
Traveller	Customer	Customer	Customer	Customer	
(Mobility) service provider	Customer	Core partner	Core partner	Focal org.	
Intermediary	Future partner		Future partner		
MaaS provider			Future partner	Future partner	
Research organisation	Core partner	Enriching partner	Enriching partner		
Infrastructure provider					
Tech company	Customer	Enriching partner			Core partner
OEMs					Enriching partner
Standardisation organisation					
Navigation provider					
Traffic manager			Core partner	Core partner	

An overview of the stakeholder involvement level for each service (excerpt) resulting from the business model radar analysis

4. Provide a summary and conclusions

   In order to make reading of the document easier, an overview and summary is provided. This puts the different services and their SoA into perspective.

To get a more comprehensive picture of the trends, challenges (concerning aspects), stakeholder roles, future prospects, desirable tools, and data as they are perceived in the mobility sector, an online survey was conducted. It was aimed at specialists in the field of transportation from various transport companies (transport managers, mobility operators, logistics operators, consultants etc.), public administration, universities, and research institutions. The survey contained questions from five distinct categories, namely trends, challenges, stakeholders, tools, and data. Two main question groups were formed by rating scale questions asking respondents to rate the importance of 24 different challenges and the attention paid to them. The results are not surprising in the way that the respondents believe that the topic of high importance shall be getting even more attention than they are getting nowadays (see Figure below and details in section 5.2).



Relation between the importance of a challenge and the attention paid to it

The respondents also provided qualitative input that was incorporated into the analysis. Interesting were for example identified new types and roles of stakeholders within the mobility sector**.** The most frequent ones were micromobility service providers, data providers, MaaS providers, technology companies, and further intermediaries between private and public, telecommunication operators and data *brokers, but also citizens' movements and residents' groups to promote sustainable urban mobility.*

The trend of providing anything "as a Service" is growing into the mobility field, led by digitalisation, which plays a major role in each described service. Digital platforms can improve the mobility of anyone within the city by facilitating the flow of information and improving the usage of resources. This may lead to a disruption in traditional services and change of people's behaviour. Cities will have to adjust their policies, affecting business models across all services, in order to build an integrated and efficient urban transport system. In addition to adjustments, digitalisation also supports new types of policies, such as smart pricing of services.

Mobility services cannot be considered separately anymore, but a customisation to their exact goal within the transport system of each given city is necessary, including the user experience, which requires a complex decision making. This also covers a better connection between involved stakeholders (including the citizens and travellers).

The enormous amount of gathered data by municipalities, service providers and other related or unrelated parties is the key to the ability to make these complex choices. Integration and smart use of data for the design of the transport system and policy design are important but challenging.

The role of cities as traffic manager is affected by these developments as well. The increased number of means for information distribution to users of the infrastructure gives traffic managers more options for actual managing of traffic, leading to smarter use of infrastructure. However, with the increasing variety of mobility services and with that, increase in the number of modes, infrastructure within cities is not always sufficient anymore. For example, the presence of small vehicles puts more pressure on bike infrastructure (if there is any). Traffic management and smart infrastructure planning will go hand in hand with further adaptation to the shift in modal split.

We believe that this deliverable has the potential to become a useful tool for various stakeholders (for example decision-makers or transport engineers) within the mobility field. It updates and enhances existing white papers and reports covering the field. It can be the ultimate resource within the changing mobility field.

The Deliverable D2.1 is the basis for further work on the nuMIDAS project. It provides the State-of-the-Art analysis and definition of the terms used within the field. While it focused on the mobility field as a whole, Task T2.3 (Use cases definition) will focus on more details of Use Cases covered by the nuMIDAS Toolkit and selected Case Studies in the partner cities. A detailed use case analysis of the relevant use cases will be provided.

Moreover, Task T2.4 (Extraction of new concepts, variables, and KPIs) builds on D2.1. It will further enhance the SoA analysis by looking at new trends and new KPIs, rather than focusing on the actual status.

Work packages WP3 (Definition of advanced methods and tools), WP4 (Case Studies) and WP5 (Consolidated toolkit for stakeholders), will then further elaborate on the prepared analysis of the prepared case studies in pilot cities.

2 Introduction

2.1 About nuMIDAS

The mobility ecosystem is rapidly evolving, whereby we see the rise of new stakeholders and services. Examples of these are the presence of connected and automated vehicles, a large group of organisations that rally to establish various forms of shared mobility, with the pinnacle being all of these incorporated into a large MaaS ecosystem. As these new forms of mobility offerings start to appear within cities and regions[1], so do new ways in which data are being generated, collected, and stored arise. Analysing this (Big) data with suitable (artificial intelligence) techniques becomes more paramount, as it leads to insights into the performance of certain mobility solutions, and it can highlight (mobility) needs of citizens in a broader context, and in addition to a rise in new risks and various socio-economic impacts.

Successfully integrating all these disruptive technologies and solutions within the designs of policy makers remains a challenge at current. let alone being able to analyse, monitor, and assess mobility solutions and their potential socio-economic impacts.

nuMIDAS (new mobility data & solutions toolkit), bridges this (knowledge) gap, by providing insights into what methodological tools, datasets, and models are required, and how existing ones need to be adapted or augmented with new data. To this end, it starts from insights obtained through (market) research and stakeholders, as well as from quantitative modelling. A wider applicability of the project's results across the whole EU is guaranteed as all the research is validated within a selection of case studies in pilot cities which have varying characteristics. This gives thereby credibility to these results. Finally, through an iterative approach, nuMIDAS creates a tangible and readily available toolkit that can be deployed elsewhere, including a set of transferability guidelines, thus thereby contributing to the further adoption and exploitation of the project's results.

nuMIDAS, the New Mobility Data and Solutions Toolkit, started at the beginning of 2021 under the Horizon 2020 programme and it is being developed by a European Consortium, composed of 9 partners from 6 countries: Belgium, Czech Republic, Greece, Italy, The Netherlands, and Spain.

The project builds on a distributed selection of case studies in pilot cities to provide geographic coverage of the EU. The three pilot cities are: Barcelona (Spain), Milan (Italy), and Leuven (Belgium).

[1] When talking about a 'smart concept', the term 'smart cities' is typically used. We need to keep in mind that it covers not only cities, but also regions as they are binding the cities, smaller and larger, together to realise the necessary installed base, coordinate together the approach and especially keep the borders fuzzy.

2.2 Purpose of this document

This deliverable summarises the findings from Task T2.1. It focuses mainly on the state-of-the-art analysis based on scientific papers, existing implementations, as well as running research projects. It also focuses on the shift in stakeholder roles and new business models which are in the focus of the Task T2.2.

We provide an overview of the traditional research methods and tools supporting transport/mobility researchers, planners, and policy makers. Here, the focus is on the accepted tools. This deliverable does not only provide an overview of the tools, but it will also quantify their field and scope as well as the requirements on data and other resources. Besides discussing the traditional approaches, we will also discuss and categorise the challenges the transportation field is facing nowadays. Here, we will identify the potential to use the existing techniques and tools for the new challenges. Our main discussion will concern the identification of white spots where the existing tools and methods are not sufficient.

The deliverable also describes a stakeholder and business model analysis. It summarises and describes the traditional stakeholders in transportation and their roles. Important will be the shift in stakeholder roles as well as the emergence of new business models. This is a particularly topical task as we observe many new trends. For example, the growth of shared economies, the start of Level 4 or 5 automated vehicles, or the expansion of apps that provide location-based services (LBS) will change the playground significantly. What is going to be the role of traditional traffic managers? We focus additionally on the data needed and conduct a gap analysis to identify missing data.

Within this deliverable, we analyse the state of the art via scientific papers, existing implementations, and running research projects.

2.3 Structure of this document

Chapter 3 of this document provides a motivation for the analysis. The main objectives and assumptions are discussed as they define the approach. It is clear that the analysis focuses on a rather broad subject – research methods and tools supporting transport/mobility researchers, planners, and policy makers. For this reason, Chapter 3 further focuses on the nuMIDAS approach adopted to cover all substantial aspects and dimensions of the analysis, including terminology and links among the various terms.

In Chapter 4, we provide a list of services and classify them according to several attributes. Next to the list of services in scope of the analysis, the main findings, and contributions of the state-of-the-art (SoA) analysis are provided. It includes several aspects of each service: description, involved policy instruments, gaps, opportunities, and the shift in the stakeholder roles are discussed as well as a business radar demonstrating the shift in relevant business models. As a guide for the reader, further content extending Chapter 4 is presented in the Appendix C; each service is analysed by categories of tools and typical use cases, solved challenges, inputs and requisites, and outputs and KPIs (Key Performance Indicators).

Chapter 5 provides insights of the current situation and trends according to stakeholders of the nuMIDAS scope. Chapter 6 summarises the most important conclusions and findings.

The appendixes provide a definition of key terms within nuMIDAS project (Appendix A); List of Services (Appendix B); the complete and detailed SoA analysis with all relevant sources and citations (Appendix C), description of stakeholder roles (Appendix D) and the analysis of a survey aimed at specialists from various transport-related companies and institutions (Appendix E).

3 nuMIDAS approach to state-of-the-art analysis

3.1 Motivation

The nuMIDAS project has several objectives (which are SMART, i.e., specific, measurable, achievable, realistic, and time-bound):

- **O1**: nuMIDAS will recognise the various new and emerging mobility trends, and will provide the relevant conceptual, methodological, and technical needs to analyse, monitor, and assess these.
- **O2**: Gaining an understanding on how conventional concepts and variables (e.g., efficiency, reliability, safety, comfort, and security) change in light of new mobility concepts, as well as with new societal and industrial structures for which the future transport network will provide services.
- **O3**: The identification of major new concepts and variables, given their increasingly important role in transport and mobility analyses, as well as deriving methods that can estimate and quantify them.
- **O4**: Devise advanced methods and tools for the monitoring, assessment, and analysis of mobility solutions.
- **O5**: Review and assess a range of options for collecting and using new data, by means of new data collection and management approaches, including new methods and tools to exploit this data (encompassing also Artificial Intelligence / Machine Learning techniques for dealing with Big Data), taking into account different type of variables such as gender, age, ethnicity, … where relevant.

It is clear that the objectives cover quite a broad spectrum of tools, KPIs, challenges etc. In order to understand them, a state-of-the-art (SoA) analysis needs to be performed (objective of this document). Clearly, this cannot start from scratch. A very important resource for traffic managers and transportation planners is the Traffic Analysis Tools Program formulated by Federal Highway Administration – FHWA (Alexiadis et al., 2004). In their work they cover various important topics dealing with a categorisation of traffic analysis tools, their primary focus, their strength, and limitations as well as criteria for choosing among them for particular projects and applications. All these materials are publicly available and serve in our opinion as a basis for research and development of new improvements in the field of traffic analysis tools.

An overview of the tools as well as their relevance with respect to Planning / Design or Operations as developed by the Traffic Analysis Tools Program is provided in Table 1. We can see seven major categories of the tools.

Table 1: Overview of traffic analysis tool categories and their relevance with respect to analytical context (source: Alexiadis et al., 2004)

Analytical Context	Analytical Tools/Methodologies						
	Sketch Planning	Travel Demand Models	Analytical/ Deterministic Tools (HCM-Based)	Traffic Optimi-zation	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation
Planning	●	●	∅	○	∅	∅	○
Design	N/A	∅	●	●	●	●	●
Operations/ Construction	∅	○	●	●	●	●	●

Notes: ● Specific context is generally addressed by the corresponding analytical tool/methodology.
∅ Some of the analytical tools/methodologies address the specific context and some do not.
○ The particular analytical tool/methodology does not generally address the specific context.
N/A The particular methodology is not appropriate for use in addressing the specific context.

This approach is strongly focusing on the tools, their categorisation, and possible ways how to improve them. That is the central point of the FHWA analysis. However, during our work on nuMIDAS project, we have identified the need to look at the mobility tools differently. At the same time, new tools and methods are needed and shall be analysed within the nuMIDAS project. Here we list the most relevant issues that shall be addressed:

- **The boundaries among the categories are not so crisp any more** – microscopic traffic simulations are incorporating meso- or macroscopic features to minimise their limitations and vice versa. Often it is not possible to distinguish among the categories any more. Often a limitation of certain group is addressed by "lending" some features/techniques from others. That certainly makes sense and it is a valuable approach, but it further removes the boundaries among the categories.
- **Service-oriented approach helping stakeholders to solve real world challenges shall be in focus** – rather than tools. The tools shall provide a service to solve real challenges to stakeholders in cities. The policy maker's or traffic manager's perspective is missing from the classification above. In reality, they must be the central point of an analysis, they see real world challenges, they determine KPIs and they (with help of professional and research community) must adopt some tools or their combination to solve those challenges. This also often resonates in the smart city field, as "services" and not tolls or means become central point (Pribyl and Svitek, 2015). Here, we could call this trend "traffic analysis as a service". Through the services, the users of the transport systems (citizens) gain and their quality of life can be addressed.
- **The field of transportation planning, design and operations must be connected to other city dimensions** – the growing highly populated urban areas and the starting lack of nature's resources have led to establishing a new science field and topic – so called smart cities. One of the important premises is that the mobility related issues and problems cannot be studied and approached separately from other areas (an overview of the various city and more detailed explanation is provided in Pribyl et al., 2019). For example, the way a city is planned and built (urbanism) strongly

influences mobility and vice versa; transportation has huge influence on environment; eGovernment can influence the need to travel; all of these areas must share the same resources.

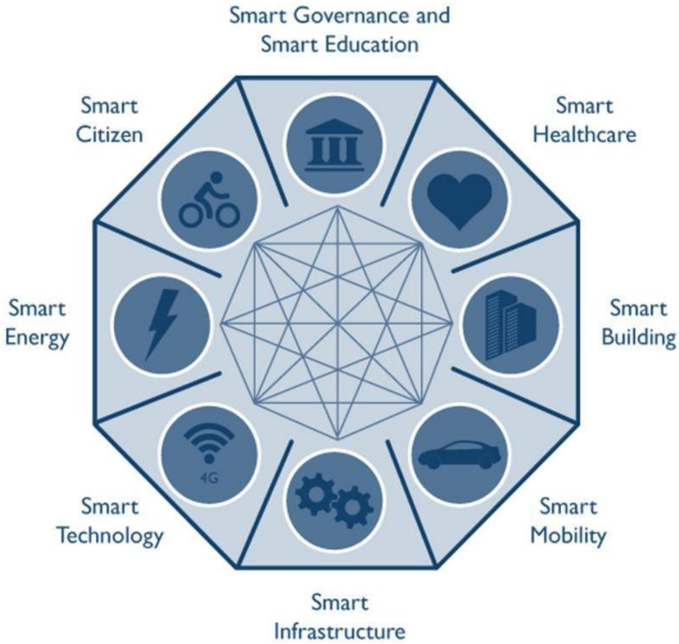


Figure 1: Major areas within a (smart) city (source and more explanation: Pribyl et al., 2019)

- **The reality has many dimensions** – as already mentioned, the classification above would need to have added many different dimensions to help us better understand their focus and strengths. For each tool, we would need to provide challenges and KPIs, we would need to define stakeholders using such tools, we would need to classify them according to the application field and many others. At the same time, the simple tabular overview of the tools and their characteristics would not be able to clarify topics such as whether KPIs are related to Tools, Data, Services, Use Cases, or others.
- **New challenges** – the traditional tools focused strongly on the management or planning of infrastructure investments. The later tools (for example traffic microscopic simulation) allow modelling of impact assessment of certain control measures. Most of the tools are however limited in their abilities to model certain policies (for example detailed pricing, activity participation and others) and their impact on travel behaviour and the efficient use of resources. There are approaches to overcome such limitations (such as nanoscopic simulation models (Dia & Panwai, 2008) or activity-based multi-agent simulations (Horni et al., 2016) but they do not really fit into the classification of tools provided above.
- **New algorithms** – we are facing a rapid growth of digitalisation and automation. This is true not only in the mobility field but in all aspects of our lives. Industry 4.0, digitalisation, or artificial intelligence (for example distributed intelligence using multi-agent technologies) offer new opportunities that are typically not directly supported by the existing mobility tools.
- **New data sources** – similarly to the previous point, the traffic analysis tools must be able to utilise new data sources. For example, cell phone data, Internet of things (where almost each object/sensor can have a unique ID and communicate directly with the outer world over the Internet and many others) are leading to the topic of big data and their processing.

- **New technologies** – the mobility sector is facing many new technologies as well as totally new travel modes. We can see, for example, cooperative systems, automated vehicles, electro-vehicles, micromobility, Hyperloop, delivery drones or automated delivery vehicles, and many others). All such technologies must be incorporated into the traffic analysis tools. Of course, we can see that several providers are improving their tools (for example microscopic simulation models) in order to accommodate new travel modes, but this is often done more from the research perspective.

- **New stakeholders and new business models** – the mobility toolkit shall also react to the changes within the stakeholders. Governments (or traffic planning and operation agencies) are not the only orchestrators of traffic systems anymore. As depicted in Figure 2, new digital platforms provide easy access for new stakeholders and the role of traditional stakeholders is changing. We observe big involvement of citizens (for example direct sharing of vehicles), new start-ups that must be integrated into the traffic management, shift from “Traffic management” to “City management” and others.

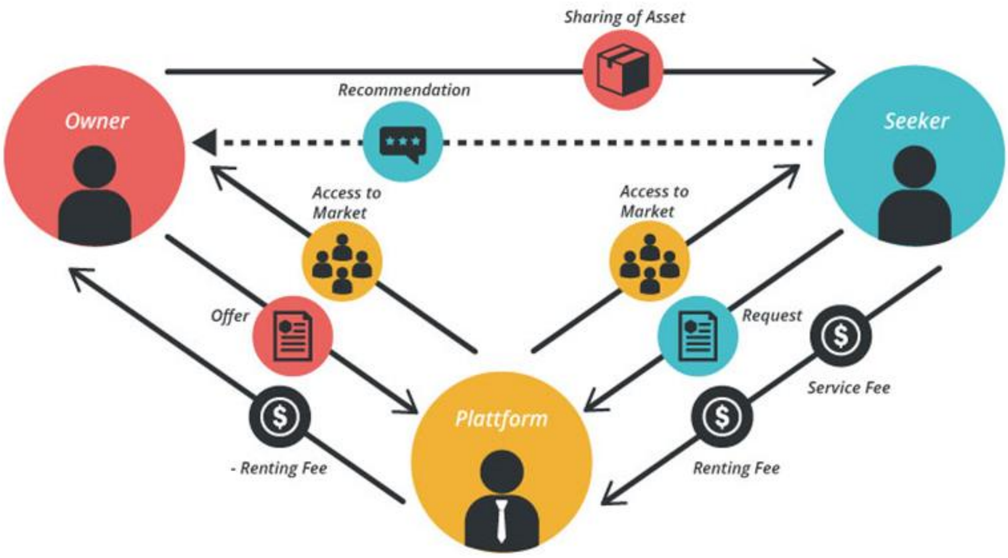


Figure 2: Digital platforms as enabler for new stakeholder involvement (source: https://bmtoolbox.net/patterns/sharing-economy)

- **Proper use of KPIs** – often, certain transportation measures aim at decreasing travel time or decreasing emissions per km travelled. This must however not always lead to an improvement in our quality of life. If we decrease traffic congestions, we can often observe induced travel (i.e., people who would otherwise use an alternative travel mode shift to cars) and we observe the deterioration of the level of service again. If we achieve decreasing fuel consumption (per km), people might tend to travel more kilometres. Having an electric vehicle parked for 8 hours a day in front of my office will also not have any significant impact on the environment. Such measures do not necessarily improve the environment or our quality of life even though our KPIs might claim something else. We need to work with the tools in a way to decrease the vehicle miles travelled, to increase the occupancy of vehicles or, for example, allow sharing of automated electric vehicles.

- **New perspectives (shift from mobility to accessibility)** – it is really necessary to change our perception. All of the above-mentioned issues and points must be taken into consideration at the same time. Our tools must show the impact of policies, it must be easy to add new players and stakeholders, we must provide services rather than infrastructure, and we need to shift our attention from "mobility" to "accessibility". The transportation planners must work together with urbanists as well as other city managers. The ideal result of such cooperation is described by the concept of so-called 20-minute neighbourhood (or 20-minute city) as depicted in Figure 3. The 20-minute neighbourhood is all about 'living locally' – giving people the ability to meet most of their daily needs within a 20-minute return walk from home, with access to safe cycling and local transport options.

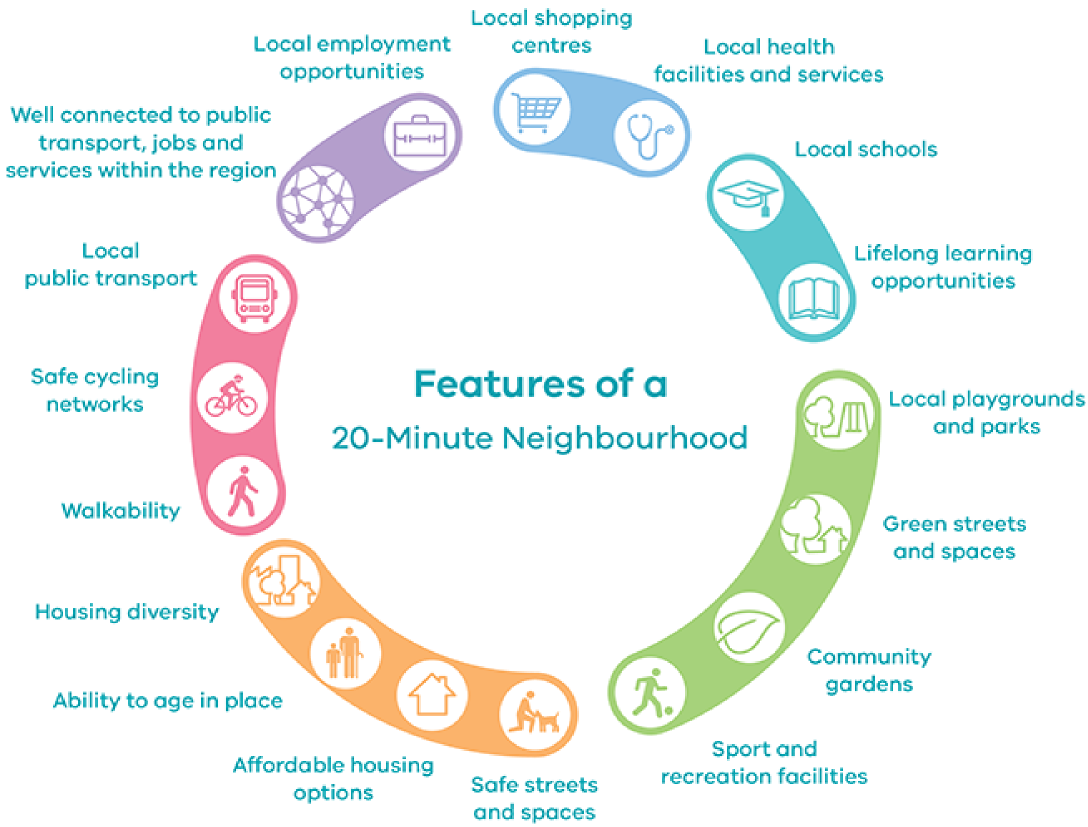


Figure 3: Example of new challenges – 20minute neighbourhood (source: https://www.planning.vic.gov.au/policy-and-strategy/planning-for-melbourne/plan-melbourne/20-minute-neighbourhoods)

All of the above-mentioned issues lead us to the activities to define a new approach within the nuMIDAS project to address the changes in the transportation field. The approach leads to state-of-the-art (SoA) analysis, that is the first step to be used as a starting point for the next tasks and WPs of the nuMIDAS project.

3.2 nuMIDAS approach

Based on the issues raised above, the nuMIDAS project decided to adopt a broader look at the mobility tools and methods environment. We have adopted a new approach that is listed below and then described in particular sub-sections (please note that this is not a structure of a document, but the adopted process):

1. Define and agree on the terminology
   As discussed above, the terminology is being used differently in different fields (even within the mobility field). For this reason, the team must identify and define the most relevant terms within this SoA. The definitions were verified by a workshop as well.

2. Identify links among the terms (nuMIDAS model)
   The terms must be put into perspective and links among them identified.
3. Service-centred approach
   Within this step, the services in scope are identified. For each of them, a detailed SoA is provided by one of the consortium members and reviewed by another one. A template was provided to ensure unity. After the individual analysis, a big picture was prepared to show links among the services and policy instruments. This big picture allows us to ensure unity in the produced output.
   a. Identify relevant Services and define services in Scope of nuMIDAS
   b. Describe the service and provide state-of-the-art analysis including a consortium internal review (for each Service in Scope)
   c. Describe links to other terms (Challenges, KPIs, and others) (for each Service in Scope)
   d. Provide a "big picture overview", use the overview to identify gaps in the SoA and complete the particular SoA (for each Service in Scope)
   e. Describe Business model changes (for each Service in Scope)
4. Provide a summary and conclusions
   In order to make reading of the document easier, an overview and summary is provided. This puts the different services and their SoA into perspective.

3.2.1 Definition of adopted terminology

The first important task within the nuMIDAS project was to define the major Terms used within the field in scope. It was important to find or provide a definition that can be accepted by partners from various fields. Terms in the transportation field are often used differently by other stakeholders and in a different context; there are differences in definitions within the transportation field as to compare for example to the system engineering best practices (see for example the term "Use case"). An overview of the most relevant terms in scope of nuMIDAS project is provided below:

- **Stakeholder:** A person with an interest or concern in mobility issues and transport externalities (for example researchers, developers, municipalities, sharing mobility operators).
- **Actor:** A role played by a person that interacts with the nuMIDAS Toolkit. The system affects and is affected by the behaviour of actors (for example Researcher, planner, policy maker, decision maker).
- **User**: A person that uses a mobility service.
- **Goal:** Desired result that a Stakeholder envisions, plans, and commits to achieve. It is a broad statement and does not describe the methods used to get the intended outcome.
- **Objectives:** Specific, measurable, and actionable targets that need to be achieved within a reasonably short-term time frame. Objectives describe the actions or activities involved in achieving a long-term goal.
- **Challenge:** A real world problem that an Actor desires to solve in order to accomplish the objectives. It differs from methodological problems, which are related to the inabilities of current methods and tools to take into account existing technologies and/or analyse real-world problems).
- **KPIs:** The means to quantify the extent to which each objective is fulfilled.
- **Variables:** Predefined values, inputs, outputs or collected information from other users, sensors, models, and other sources.

- **Dashboard:** An interface facilitating the visualisation of selected data and KPIs, including territorial indicators. The tools will play the role of a “back-end”.
- **User Need:** A physical or functional need for a particular design, product, or process in the nuMIDAS Toolkit provided by Stakeholders. High level requirements in the form of free text.
- **Requirement:** Something that the nuMIDAS Toolkit must do or a property that it must have. The requirements will be linked to User Needs.
- **Use Case:** A high level functionality of the nuMIDAS Toolkit that must fulfil objectives quantified by specific KPIs. They consist of partial activities, analysis methods & tools (existing, updated, combined, or to be developed) solving real-world and methodological problems. An Actor interacts with the nuMIDAS Toolkit through Use Cases.
- **Service:** Any activity related to the mobility sector in which each application corresponds to a specific ecosystem including various actors/stakeholders and technological means/capabilities. It clusters several use cases based on a common specific public need for the Service.
- **Policy Instrument:** Technique used by an Actor to promote certain behaviour of a User or regulate the operation of a service in order to achieve objectives.
- **Case Study:** The application of Services in a specific geographical area considering specific conditions, specific Use Cases, specific data, and existing limitations (if any).
- **Methods:** Models and/or algorithms to support the functions used in the Use Cases.
- **Tools:** Software, service or files that run procedures and methods to support the functions used in the Use Cases.
- **Categories of Methods & Tools:** Aggregation of tools based on their similarity in the application field (similarly to Alexiadis et al., 2004).
- **nuMIDAS Toolkit**: It is a data framework and methodology toolkit aiming to improve the planning, understanding and provision of Mobility Services according to the Goals of Stakeholders. It corresponds to the integration of different Methods and Tools to fulfil the Needs of Actors, in order to support them to achieve their Objectives and to decide on Policy Instruments based on KPIs. If seamless integration, a native dashboard is used to present data and enable data analysis, otherwise guidance to specialised software is provided.

3.2.2 nuMIDAS model – Relations among adopted terms

For the reasons described and explained above, within the nuMIDAS project, we focus on Services available to particular Stakeholders. In order to visualise and describe the various dimensions (mainly characterised by the Terms described above), we have developed a nuMIDAS model – showing relations among the most relevant Terms. The model is depicted in Figure 4.

This nuMIDAS model is general and shall describe the field even outside of the scope of the nuMIDAS project or nuMIDAS Toolbox.

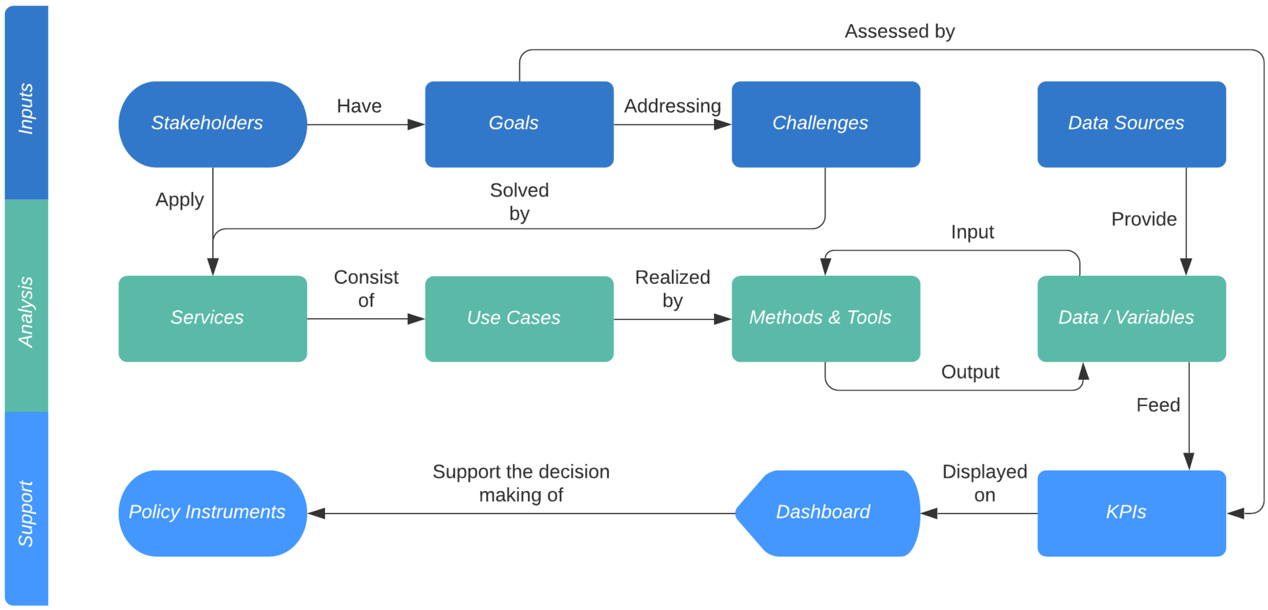


Figure 4: nuMIDAS model – Service-oriented architecture (source: own elaboration)

The model can be understood as follows. *Stakeholders* (for example *Public transport operators*) have certain *Goals* (for example *Environmental sustainability*) that are addressing *Challenges* (for example too much *Pollution*) within a city or their domain. In order to address those *Challenges*, they apply certain *Services* (for example *Public transport management*). The *Service* can be rather large and consist of several *Use cases* (for example *Real-time information*, or *Priority management*).

There are certain *Methods and Tools* that can be used for such *Use Cases*. For example, a *Microscopic simulation* can be used to determine the impact of *Priority management* on traffic congestions and level of service. The simulation feeds data measured in the network (*Data sources*) and generates as output Data about *travel times* (sec), *queue length* (m), *CO_2 emissions* (kg), *average speeds* (km/h), *average delay* (sec) and many others either for the entire simulated network or on particular street segments. Some of these *Variables* correspond to the original *Goals* (in this example *Environmental sustainability*), for example, *CO_2 emissions* (kg), which is then incorporated into a *Dashboard* and shows trend, changes in time or for example can make an alarm in case certain predefined threshold is reached. In this way, based on data dealing with different *Services*, the *Public transport operator* together with other stakeholders can decide on the most suitable *Policy instrument* that addresses multiple *Goals*.

The model shows the complexity of the field and the terminology used. It is not possible to use a simple matrix to show the connections. However, this model and the fact that we adopt a Service-centric approach helped us to prepare a template for the SoA and (what is of utmost importance) will be further used by the next tasks within the nuMIDAS project (for example Use Case analysis).

4 Services-oriented State-of-the-art (SoA) analysis

4.1 Introduction and methodology

For the reasons described above, the nuMIDAS project adopted a Service-oriented analysis approach. It has the right level of detail and provides the most added value to the various Stakeholders.

Based on the experiences of the experts in the nuMIDAS team, literature review and internal brainstorming, a list of Services[2] was defined and is provided in Appendix B. Each Service in this list has various attributes. Next to its name and a short description (longer explanation is part of the SoA analysis), we determined whether it primarily focuses on passenger or freight transport. While it is rather a vague term, we tried to identify whether the service is traditional with respect to the FHWA definitions and classification or whether it rather introduces some new trend. Lastly, with the nuMIDAS project proposal and project objectives in mind, we have determined (based on the applicability for further work within the nuMIDAS project, especially during the case studies or when creating the nuMIDAS Toolkit) whether the service is in scope of nuMIDAS project and the SoA analysis will be provided.

Table 2 provides an overview of the Services in scope of the SoA analysis in nuMIDAS project.

Table 2: Services in scope of nuMIDAS SoA analysis

S_ID	Service name	Service Description
1	Transportation Data Analysis	Analysis of data gathered from multiple sources (including transport infrastructure, smart cards, location-based applications, and social networks) in order to get insights into traffic, environment and travel demands.
2	Transportation Policy and Design	Appraisal and identification of the most appropriate policies, investments, and urban design to be adopted to optimise transport systems performance understood through the fulfilment of several goals and needs.
3	Travel Demand Modelling	The prediction of future travel patterns from a sample of travel behaviour data.
4	Public Transport Management	Organisation of public transport operations to better understand and respond effectively to travel demand by improving the flow of passengers at an acceptable level of service.
5	Last Mile Logistics	Represent the last leg of a journey comprising the movement of goods from a transportation hub to a final destination.
6	Rental	Service that allows people to rent a vehicle for a shorter or longer period of time.

[2] This list is certainly not complete, but it covers more than the scope of nuMIDAS project. The proposed approach is general and can be used even for newly added Services.

7a	Shared Mobility: Micromobility	Demand-driven sharing arrangement of small and lightweight vehicles for the movement of road users operating at speeds, typically below 25 km/h.
7b	Shared Mobility: Car	Demand-driven vehicle-sharing arrangement, in which travellers share a vehicle either simultaneously as a group or over time.
8	Mobility as a Service (MaaS)	Mobility as a Service brings every kind of transport together into a single intuitive mobile app. It seamlessly combines transport options from different providers, handling everything from travel planning to payments.
9	C-ITS and CAV Integration	Exploitation of enhanced connectivity between vehicles (V2V) and between vehicles and the road infrastructure (V2I and I2V) as well as vehicle automation technologies to provide coordinated traffic management services.
10	Electric Infrastructure Management (Electromobility and Charging/Refuelling)	The concept of using electric powertrain technologies and the necessary infrastructure either to charge batteries or refuel hydrogen tanks.
11	Parking Management	The optimisation of parking space, giving real-time car parking information such as vehicle & slot counts, available slots display, reserved parking, pay-and-park options, easy payments, reports, and other features.
12	Ride-Hailing and Ride-Sharing	Ride-hailing reflects the concept of a rider hiring a personal driver to take him/her exactly where he/she needs to go, but the vehicle is not shared with any other riders. Ride-sharing reflects the concept of a rider sharing a vehicle with other riders.

To ensure that the level of details and quality of the analysis will be as consistent as possible over the various Services, a detailed Template suggesting the main topics and questions the analysis must answer is provided. Different project partners were responsible for the SoA for each Service. Each SoA was then reviewed by another nuMIDAS partner. This review was not only formal, but it also consisted of the literature and project review and enhanced the original analysis so that the results correspond to the view of at least two different partners. After that, during integration into this deliverable, another review and editing was performed. In this way, we believe, high level of quality and unification is achieved.

4.2 Stakeholder and business models analysis

Over the last twenty years, in a fast-evolving market, using business models as a method for mapping and describing the business proposition of a product has increasingly grown in popularity. Where a business strategy is the long-term focus of a company, the business model is agile and shows the landscape of the proposition. One of the most common approaches is the business model canvas developed by Osterwalder and Pigneur (2010), as presented in Figure 5. Their model makes it possible to capture or develop a business model by thinking about a standardised set of topics, the value for the customer, stakeholders and resources play a key role.

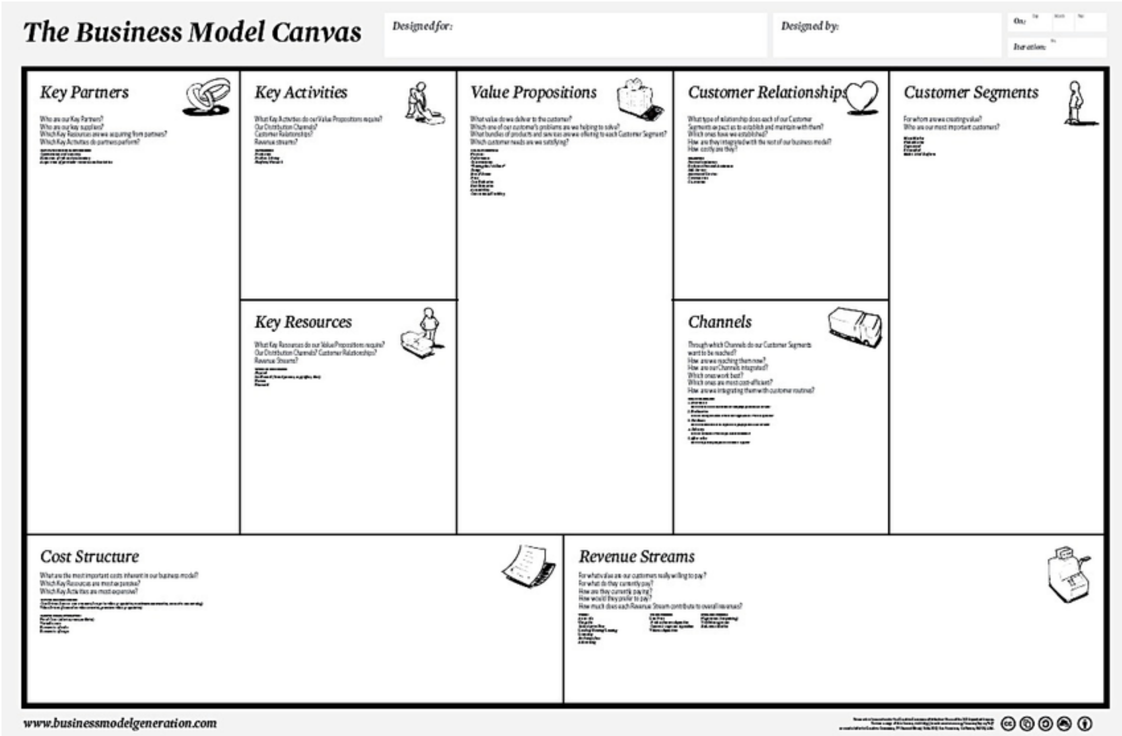


Figure 5: Bussiness model canvas by Osterwalder and Pigneur (2010)

The focus of a company is on unique selling points, cost minimisation, profits of a product and their position in the market in comparison to the competition. In the field of New Mobility and end to end services for road users/travellers, companies make use of service-orientated business models. However, (local) governments focus on adding societal value, where topics such as safety, environmental impact and mobility are key factors. For users, mobility is a choice based on travel costs in terms of money, time, preferences, and accessibility.

From a governmental perspective, a shift in the role in the mobility landscape is upcoming. In the last decades, governments developed policies regarding private and public transport, organised where which modes (pedestrians, vehicles, busses, goods delivery) are allowed and how things are regulated, from speed limits, restricted areas, mode specific infrastructure up to traffic light regulated junctions. While the role in public transport was already more service-oriented, many other mobility trends are now pointing in this service-oriented direction, resulting in an even more complex environment facilitated by connected personal devices, connected vehicles and roadside systems.

In this complex environment, customer expectations are high. Services are expected to be coherent and integrated whenever possible, while operations have to be simple on the users end. A successful service-oriented business model often requires a combination of multiple disciplines. The capability to combine these disciplines is often not present within a single company, resulting in complex collaborations. Municipalities, (road) authorities, service providers, equipment or IT providers and other stakeholders have to come together to engineer a seamless system with a positive societal value and business case (which may be facilitated by governmental funding), while the rapid development of new technologies and services is ready to disrupt current or future systems and markets. Therefore, maintaining a strong market position requires businesses to be agile, user friendly and innovative.

In order to get an overview of the playing field, a stakeholder and business model analysis is performed, as follows:

- For each service within the nuMIDAS scope, a stakeholder and business model analysis is performed by providing a Service Dominant Business Model Radar (SDBM/R);
- The SDBM/R are provided with a high-level approach and are generally applicable service-wide and may not be on a use-case basis;
- The service is described by providing a user story;
- For each stakeholder within the business models, a description is given of their role, including identified changes, and expected changes in their role in the future;
- To summarize the results, a general overview of the common stakeholders and their roles within each service is provided;
- A business engineering approach was conducted, it incorporated a service-oriented playing field with many stakeholders whose goals and shifting roles were possibly contradictory.

A business engineering approach with a service-dominant perspective is the BASE/X framework, which supports an agile approach for evolving (mobility) services. The SDBM/R is based on this framework. A description of the BASE/X framework and the SDBM/R is provided below.

4.2.1 BASE/X Framework

BASE/X is a business engineering framework for setting up a well-structured business model where the added value of the service (to the end-user/customer, needed functions, stakeholder roles, etc.) needs an agile approach. A distinguishment is made between goals (what?) and operations (how?), and business strategy and agile market offerings (Turetken & Grefen, 2017). These distinguishments are represented in a four-layered model, which can be found in Figure 6. The four-layered model represents the coexistence of the organisational aspects, business strategy, service compositions and the dynamics regarding the business models and coherent business services.

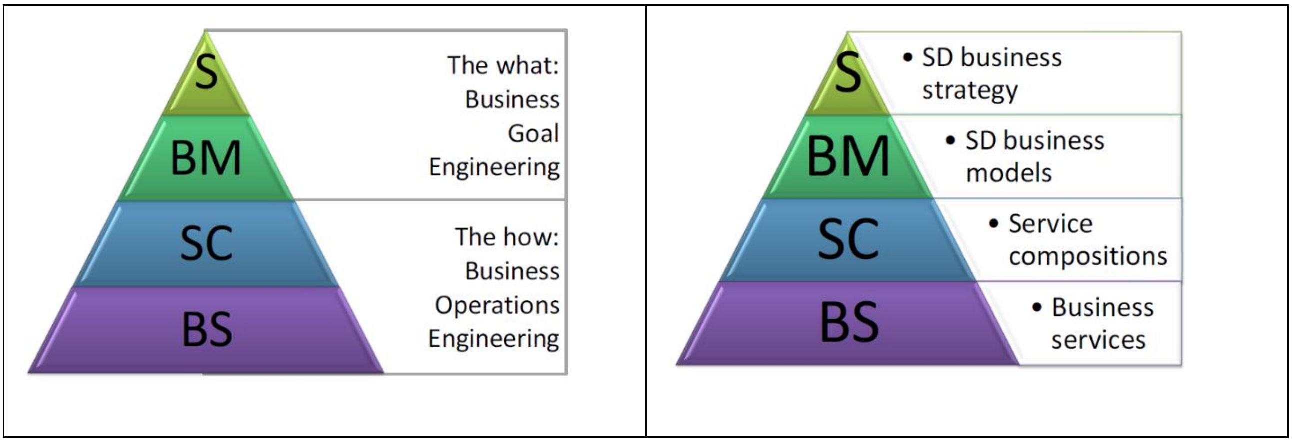


Figure 6: BASE/X Business Pyramids (Traganos et al., 2015).

In the top half of the pyramid is the 'What', describing the long term business strategy and the agile business model for a service, in short:

- A business strategy, the long term, relatively stable, strategy that is slowly evolving over time;
- A business model, the integrated solution-oriented complex services following from the fluid market dynamics. These are agile and thus can be activated, changed, or deactivated on demand.

On the bottom half of the pyramid, the 'How' is described in the daily business operations containing the resources of the organisation, personnel and technical infrastructures which are relatively stable over time. This is decomposed as:

- Service compositions, containing a combination of business services (and also services of partner organisations in a business network) to realize the functionality required by a business model. By nature, these services are agile and follow the behaviour of their business model;
- Business services, representing the building blocks from the organisation itself and the partners used to fulfil the business model goals. They are more stable over time (as they constitute the use of personnel and technical infrastructure to achieve the goals).

As the focus in the nuMIDAS project is on developing a toolkit and dashboard for Mobility services, we concentrate our main attention on the business model layer. In the evolving market of mobility services, new business models often require multiple parties with different types of expertise. To create a strong overview of these business models and their related important stakeholders, the Service Dominant Business Model Radar (SDBM/R) is used.

4.2.2 Service dominant Business Model Radar (SDBM/R)

The service dominant business model Radar, SDMB/R, was created based on the achievement of shared goals and value co-creation by a group of actors (businesses, firms, government, and customers) who interact to achieve that shared goal (Turetken et al., 2017). The Business Model Canvas was the starting point for this development. The current version of the SDBM/R can be found in Figure 7.

Figure 7: Service dominant Business Model Radar (Turetken & Grefen, 2017)

In the radar, the value-in-use is the focal point of the service (the inner-most circle in Figure 7), and around it, there are three circles, named and described as:

- *Actor value proposition*, which represents the contribution of the actor to the value-in-use;
- *Actor coproduction activity*, which represents the activities that the actor performs in regard to achieving the co-creation of the value-in-use. The effects are observable for the customer;
- *Actor costs and benefits,* which represents the financial and non-financial costs and gains for the co-creating actor.

Each slice of the radar represents one of the co-creating actors and their role in the co-created value-in-use. All actors, including the customer, collaborate in a way that makes it clear what interest they have in the service at hand. Often, the focal organisation is the actor that initiates the service, but this may be dynamically chosen, based on perspective. In the other slices, the customer and the other partners that contribute actively to the service are presented.

Since in the current phase of nuMIDAS, only general services have been identified and use cases still have to be selected, a general approach is taken for each business model radar. Furthermore, the municipality is considered in each business model, as nuMIDAS focusses on urban mobility and policy design. In order to fill in the business model radars, first, a general user story for the service is described. The user story offers a high-level approach for the (future) service of the business model. As the goal is to not only describe business models but also identify changes in current and future stakeholder roles, the scope of the business models is widened in time. Furthermore, the municipality is taken into account in every business model, as urban mobility is the focus of nuMIDAS.

The following steps were taken in order to fill in the radars:

1. Identify the co-created value-in-use and the targeted customer from the user story;
2. Determine the components of the value-in-use and the associated stakeholder roles. The focal organisation often will take the role of the organiser or orchestrator. Since a general view is created, only directly involved stakeholders are included;
3. Determine the costs and benefits of the actors. This can be financial and non-financial. Costs typically relate to a benefit, often related to another actor in the radar;
4. Determine for all the actors the high-level activities that, when combined, realize the actor value proposition. These activities should fit on the user story and should fit the tasks in the business process by the actors.

The design of the business model radars is an iterative process, so previous steps may have been revisited during development.

In addition to the SDBM/R, a more detailed description of each actor will give insight into the specific stakeholder role for the service, as well as describe how this stakeholder role may have changed or is expected to change. This is also summarised for each service in a paragraph describing the previous or future changes in the business models. Furthermore, for each stakeholder, a level of involvement in the service is given as well, which is used to find important stakeholders. These levels are:

- Focal organisation, this party is the initiator and is responsible for the main activities of the business model;

- Core partner, a party that actively contributes to the essential parts of the service;
- Customer, who is most often the traveller or the stakeholder that makes use of the value-in-use;
- Enriching partner, who enhances the value-in-use of a service;
- Future partner, who is a partner that is expected to find its place in the business model in the (near) future.

General findings from all the business radars will be presented in a summary. For the summary, stakeholders from all SDMB/Rs will be categorised to be able to draw general conclusions on stakeholder involvement and expected shifts in both stakeholders and business models.

4.3 State-of-the-art analysis

The main objectives of this deliverable are to provide the state-of-the-art analysis based on scientific papers, existing implementations, as well as running research projects. It provides an overview of the traditional research methods and tools supporting transport/mobility researchers, planners, and policy makers, as well as the previously described stakeholder and business model analysis.

Not to be limited by space of the deliverables' main body and at the same time not to miss any important aspect of the particular Services, the detailed results of the analysis are provided in Appendix C. The text is therefore organised as follows. For each service, the main text contains a general overview consisting of the description of the service and the discussion of its importance, trends, gaps, and opportunities, involved policy instruments and a brief summary of the stakeholder and business model analysis (sections 4.3.1 – 4.3.13). Appendix C then contains the description of available tools. For each tool category, it provides typical use cases, solved challenges, necessary inputs and requisites, and outputs and KPIs (sections C.1 – C.13). For the outlined business models, more detailed descriptions of each stakeholder per service can be found in Appendix D (sections D.1 – D.13).

4.3.1 Transportation Data Analysis

4.3.1.1 Introduction

The increased availability and quality of a wide range of transport domain-specific or useful tools for the transport domain data constitute a main prerequisite and driver for the development of new and further enhancement of existing data-intensive applications in the field of Intelligent Transport and Intelligent Transport Systems (ITS). The vision of ITS is to exploit ICT advancements for fully informing travellers, improving traffic safety, increasing transport efficiency reducing adverse environmental impacts, taking concurrently into consideration requirements relating to seamless service provision, affordability, security, and privacy (Giannopoulos et al., 2012). These data sets are also useful for supporting transport planning applications. These, for instance, include the detection of trips by utilising Call Detail Record (CDR) data (Zhao et al., 2016), the management of travel demand in public transport systems with the purpose to reduce overcrowding building upon automatically collected fare data (Halvorsen et al., 2016), the understanding of heterogeneous travel patterns and of the mobility of each individual on the basis of smartcard data (Goulet-Langlois et al., 2016), the estimation of excess journey time (e.g., the difference between actual passenger journey times and timetable-based journey time) also utilising smartcard data (Zhao et al., 2013). Dabiri and Heaslip (2018) based on the adopted typology of data provide a typology of enabled applications. For instance, they address data from traffic flow sensors useful for enabling signal control and traffic control strategies. Similarly, they address data from probe vehicles as useful for applications relating to incident detection, traffic state estimation, capturing human mobility, identifying significant locations with a transport network, estimating OD tables, and mining the trajectories of vehicles or humans.

Data analytics aim to integrate heterogeneous sources of data, draw inferences, and perform predictions about the future. Domains that are closely associated with data analytics are data mining, online analytical processing (OLAP), visual analytics, big data analytics, and cognitive analytics. The advent of Internet of Things (IoT) revealed the need for integrating both semi structured and unstructured data into the processes of data analytics. This translates to a need for including in the processes heterogeneous sources of data, such as weather sensors, traffic signal controllers, social media, mobile devices, traffic prediction and forecasting models, vehicle navigation systems, as well as information exchanged between connected vehicles (V2V networks) and connected vehicles and smart infrastructure (V2I networks). Data analytics may be discerned into the following interrelated facets that are of ascending sophistication and require data of ascending amount and diversity: descriptive, diagnostic, predictive, and prescriptive analytics (Gudivarda, 2017).

Descriptive analytics focuses on describing and providing a short summary regarding the basic features/properties of the data to be analysed. Such descriptions and summaries are of particular interest during the stage of data pre-processing (e.g., during noise reduction and detection of outliers). Descriptive analytics is realized via two approaches, namely *descriptive statistics*, and *exploratory data analysis*. *Descriptive statistics* relies on the computation of central tendency (mean, median, mode, quantile) and dispersion measures (standard deviation, variance, range, IQR). The choice of the appropriate measures depends, among others, on assessing the degree to which data are (or not) normally distributed. This calls for the use of visualisation techniques that is the focal point of exploratory data analysis. *Exploratory data analysis* is based on three distinct processes: a) presentation (providing a quick and cursory familiarity with data), b) visual exploration (facilitating the identification of patterns and their quantification), and c) discovery (enabling an ad hoc analysis for answering specific research questions). Popular graphical tools utilised in the context of exploratory data analysis include boxplots, bar graphs, histograms, error bars, pie charts, QQ plots, and, more recently, radar charts. Descriptive analytics do not provide insight into the root causes of a situation or an event. This falls within the scope of *diagnostic analytics* that relies on several techniques stemming from the field of data mining, such as correlation analysis, univariate and multivariate regression, Principal Component Analysis (PCA) and factor analysis. *Predictive analytics* enable the forecasting of future states using probabilistic models, such as neural networks, decision trees, logistic and Cox regression, and cluster analysis. A key process within predictive analytics is feature selection through which the variables that have considerable predictive value are recognized. For feature selection, several techniques have so far been proposed, such as univariate selection, feature importance, correlation matrix with heatmap. Finally, the scope of *prescriptive analytics* is to evaluate and identify potential solutions to the problems that have been identified by diagnostic analytics, building upon the predictions of future outcomes enabled by predictive analytics. Utilised tools typically involve modelling and "what-if" scenario analyses as a means of evaluating potential courses of action and supporting the identification of those that maximize positive outcomes and prevent the occurrence of negative outcomes. Stochastic optimisation is also used to determine and gain a richer understanding of how to achieve better outcomes (Gudivarda, 2017).

Data analytics have evolved within the field of Database Management Systems (DBMS). One of the first focus areas of data analytics was on SQL analytics, which constitutes a set of OLAP functions that are accessible through the SQL database query language. Some years later the focus has shifted on business analytics, a main component of which is data warehouses. Data warehouses are large databases optimised for column-oriented processing in which data are gathered from multiple sources, cleaned, transformed, and made available for use. A subfield of business analytics is data mining, which involves the extraction of actionable insights from data warehouses by discovering correlations and hidden patterns in the data. The next focus of data analytics was on visual analytics that includes several subfields, such as data representation and transformation that involve the transformation of conflicting and dynamic data to support visualisation and analysis. A very recent focus of data analytics is big data analytics. The goals of big data analytics are similar with the other data analytics techniques. However, they have to overcome the challenges of data heterogeneity and complexity as well as the speed of data generation and their unprecedented volume, rendering tasks, such as feature selection, extremely difficult. These challenges call for specialised computing hardware and software. The most recent focus of data analytics is on cognitive analytics, which merge visual analytics and big data analytics by removing the human from the loop. Humans are replaced with cognitive agents whose goal is to mimic human cognitive functions. Systems that are classified as cognitive analytics-related extract features from structured, semi-structured, and unstructured data and employ taxonomies and ontologies to enable reasoning and inference (Gudivarda, 2017).

Data types

The collection of data for improving the performance of transport infrastructure and services was always a topic of high concern for several actors involved in the design and operation of transport systems, including infrastructure operators, traffic managers, transport service providers, transport planners, and governmental authorities. However, the collection of data at an acceptable amount and quality, enabling the extraction of useful information was traditionally perceived as a costly and time-consuming process. In the last decade(s) with the substantial advancement of Information and Communication Technologies (ICT) the amount, type, quality, and availability of transport domain-specific or useful for the transport domain data have changed drastically. These data may be discerned into a) roadway data, including loop detectors and data from vision-based technologies (e.g., CCTV cameras), b) vehicle-based data, including Floating Car Data (FCD) and data from connected vehicles, c) traveller-based data, including data from social networks and navigation applications, and d) wide-area data, including aerial vision data (Khan et al., 2017).

Specific tools used for transportation data analysis, including the examples of use cases and solved challenges, are discussed in appendix C, section C.1.

4.3.1.2 Importance

Dabiri and Heaslip (2018) pinpoint the importance of multi-source data for supporting the operation of smart transportation. Smart transportation offers an effective alternative to the construction of new transport infrastructure for enhancing the capacity of a transport system by applying intelligent mobility policies building upon the extraction of hidden knowledge from multi-source data. In this respect, transport data analysis may be viewed as a key driver for enhancing the performance of transport systems, following a resource-optimal approach. Transport Systems Catapult (2015) that address data as a "new form of oil" for the transport industry identify five key mobility themes in which the exploitation of transport-related data may lead to the creation of future value. The first mobility theme relates to the development of autonomous systems that are expected to optimise the performance and efficiency of passenger transport and logistics services making better use of existing network capacity and reducing fuel costs and transport emissions. The second area relates to end-to-end journeys that are expected to increase transport comfort, delimit transport inequalities, especially for people with reduced mobility, and reduce the generalized cost of transport, encompassing passenger and freight transport. The third theme relates to infomobility that is expected to lead to easier to use transport networks and services and constitute an important driver for transport personalization (i.e., the provision of tailored assistance to travellers considering their particular needs). The fourth theme relates to transport resilience enabled by a more direct response to unexpected situations, the formulation of evidence-based adaptation plans, and the reduction of excessive costs attributed to service delays or cancellations. The last theme relates to smart infrastructure enabling a resource-optimal operation of transport systems as discussed above.

4.3.1.3 Trends

Within Europe, the increasing rate of data sharing is heavily supported by the contemporary policies of the European Commission. Such policies encompass the development of National Access Points for each Member State providing access to ITS-related data as classified according to the Delegated Regulations no.885/2013, 886/2013, 962/2015, and 1926/2017 that supplement the ITS Directive (2010/40/EC). Important facets of the concept of NAPs with respect to transport data analysis constitute (Aifadopoulou et al., 2019): a) the improved comprehension of data (i.e., humans will be able to readily understand the structure, meaning, and nature of data), b) the improved processibility of data (i.e., machines will be able to automatically process and manipulate the data with a dataset), c) the improved discoverability of data both by humans and machines, and d) the increased rate of data re-use by different data "consumers". An interfacing concept with that of NAPs constitutes data standardization. In particular, the abovementioned Delegated Regulations suggest the publication of standardized data to the National Access Points. For each data type one or more standards are suggested (e.g., DATEX II for the provision of real-time traffic information and TN-ITS for static roadway data).

In addition, much related concept to that of NAPs constitutes what has been suggested by the European Commission as the European Mobility Data Space. The cornerstone of this strategy is the creation of an ecosystem in which several stakeholders of the mobility and transport ecosystem will interact and exchange data through appropriate API-interfaces creating digital and non-digital touchpoints that facilitate the identification of innovative solutions in common faced issues and challenges (Bitkom, 2020). Use cases that are expected to be enabled by the European Mobility Data Space concerning the mobility sector include: a) the optimal utilisation of transport infrastructure in a dynamic context (e.g., inner-city dynamic pricing with the objective of minimizing traffic jam), b) the provision of seamless multimodal mobility services based on the exchange of real-time timetable information, booking processes and ticket validation, c) the optimal scheduling of long-distance public transport services based on static and real-time data, and d) digital parking management based on dynamic parking supply and demand data, reducing vehicle hours travelled, fuel consumption, and emissions.

4.3.1.4 Gaps

The constant evolvement of new data sources translates to a wide range of possibilities in terms of better organizing transport systems and services. However, such a constant evolvement also translates to significant challenges and gaps that need to be resolved/filled in. Such challenges and gaps may be discerned into research- and practice/deployment-related.

Research-related

- Existing research endeavours in Big Data are mainly focused on investigating conventional transport planning topics not covering to a satisfactory extent novel applications.
- Limited research on the analysis of multi-source data
- Limited research on the assessment of data quality and the validation of data-driven/data-enabled applications.
- Limited exploitation of advanced mathematical models and Machine Learning-based techniques for extracting more information from available data sources.
- Limited research on the combination of data analytics with simulation-based techniques to enhance the validity of the models used by the latter (existing models are mainly behavioural-driven instead of data-driven)
- Limited research on tackling incomplete information from social network-based data building upon collaborative filtering.

Practice/deployment-related

- Unresolved privacy concerns regarding the use of Big Data, especially in cases that data proving insight on the mobility of individuals shall be linked with location-based data.
- Limited attempts to utilise participatory sensing and data fusion techniques to increase the spatial coverage of traffic-related information.
- Limited attempts to fully link available big data providing insight into the mobility of individuals with spatial, environmental, and socio-demographic characteristics.
- Underutilisation of open data.
- Low availability of high-definition data that may lead to scientific discoveries.
- Complexity of business models that shall be adopted to enable the availability of multi-source data.

4.3.1.5 Opportunities

The evolvement of new data sources, including Big Data, offers a unique opportunity to the research community taking into account that the focus has been shifted from sample to size. In this respect, the accuracy of conducted studies is expected to increase by responding successfully to the needs of governmental authorities, companies, and people. Furthermore, scientific studies will rely to a lesser extent on behavioural-driven models, considering that measurements themselves will be better able to capture reality.

Another significant opportunity in the field of transport data analysis relates to open data. This is also stressed by the European Commission willingness to include transport in the top-five impactful thematic areas. To this end, transport is one of the data domains of the European Data Portal (EDP). A major consequence of data opening is that a wider range of software developers will have access to data required for providing traveller information services to the end-users of transport systems. This translates to the creation of additional socio-economic benefits, such as the possibility to spend more time working or to spend more time on non-work activities.

The increase of cellular subscriptions that have been noticed from 1993 to 2019[3] constitutes an opportunity for transport data analysis taking into account that cellular phones constitute an efficient platform enabling, among others, the identification of space-time mobility trajectories. However, the extent to which cellular data will be exploited heavily relies on the extent to which associated privacy concerns will be resolved.

Finally, the rise of Artificial Intelligence (AI) constitutes a major opportunity for transport data analysis. According to Abduljabbar et al. (2019), two prominent use cases of AI applications in transport constitute incident detection and the development of predictive models. The former implies the use of AI algorithms (e.g., ANNs) that may use both simulated and roadway sensory data to detect incidents by comparing traffic flow related variables over time. In the context of the latter, past research has focused on the prediction of traffic flow, mobility demand, traffic accidents building upon real-time and historical data.

4.3.1.6 Involved policy instruments

- **Enhancement of data standards**: Standardised data exchange constitutes one of the main objectives of the ITS Directive. It involves the publication of data to relevant exchange infrastructure that comply with certain rules with the aim of increasing their level of reuse and understandability by both humans and machines.
- **Development of data partnerships**: Data are often generated and used by several actors involved in the mobility ecosystem without being accessible to the research communities and third parties. The development of data partnerships in the context of which several actors will interact following collaborative models and creating value from data constitutes a policy instrument for increased data availability.
- **Development of data exchange infrastructures**: The development of data exchange infrastructures is another focal point of the ITS Directive. The main purpose of creating data exchange infrastructures is to disrupt the phenomenon of data concentrated in silos by utilising publication in data exchange nodes providing direct access to that data or the information required to make these data reachable.

[3] Statista. Number of mobile (cellular) subscriptions worldwide from 1993 to 2019.

- **Inform individuals and businesses about the benefits of transport data analysis**: The extent to which individuals and businesses are willing to share data, enabling transport data analysis, relies on the perceived benefits. By informing these actors of the benefits of data exchange, including added value, the rate of data sharing is expected to increase.
- **Development of legislation to handle privacy concerns**: Existing privacy concerns, e.g., at the level of linking traffic informative data with spatial data, may unlock several opportunities derived from the application of data analytics in the transport sector.
- **Non-discriminatory access to data**: Non-dissimilatory access to data constitutes an important prerequisite for creating an equal ecosystem of data exchange and analysis, wherein several actors may innovate by finding solutions to common issues or providing increased services to end users building upon data-driven techniques.
- **Data opening**: The development by the EC of the open transport data is an important step towards increasing the availability of open data. However, a constant challenge constitutes the acquisition of more open data from multiple data providers. This heavily relies on the extent to which data holders will be convinced whether returned value outweighs the cost of data opening.

4.3.1.7 Stakeholder and business model analysis

The value-in-use of transport data analysis is the creation of value from data: enhancing mobility efficiency by providing analysis of transport data for several end users such as policy makers, travellers, mobility service operators, app developers. The value created can vary depending on customer needs and consequently the data analysis type. As described above, the four levels of data analysis of ascending sophistication are: descriptive analysis, diagnostic analysis, predictive analysis, and prescriptive analysis.

A standard chain of events for transport data analysis is the following.

- A customer (e.g., policy maker, company) requires support from a data analyst.
- The data analyst studies the request and searches for suitable data within the customers availability and public/private data providers.
- The public/private data providers have previously collected data, or start collecting the required data, including via Internet of Things devices.
- The data analyst makes use of commercial or open-source software or programming language to perform the data analysis according to the customer request.
- The result of data analysis can be a static report or a model/tool that enables customers to retrieve updated information.
- To enable customers to perform analysis (e.g., data visualisation) a dashboard/app can be implemented by data analysts and software developers.

In Figure 8: Business model radar for Transportation Data Analysis for Transportation Data Analysis, important stakeholders, their activities and added value to the business model can be found. More detailed descriptions of each stakeholder can be found in Appendix D, section D.1.

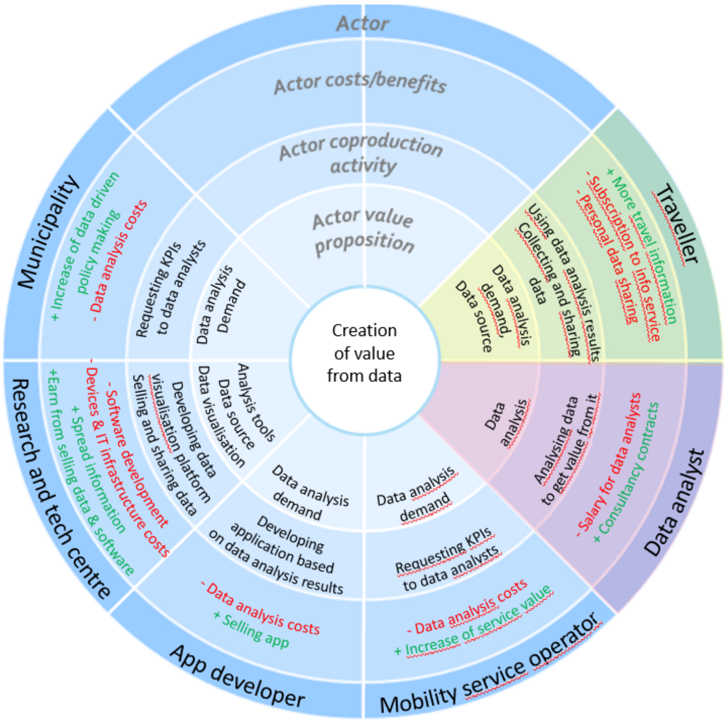


Figure 8: Business model radar for Transportation Data Analysis (source: own elaboration)

Data analysis can provide valuable information to several potential customers in the transport and mobility fields. Users of transport services can enhance their travel performance and make more informed decisions, policy makers can use data analysis to plan and regulate the development of transport services within cities, mobility service operators can develop their business with the support of business intelligence tools. All these use cases are not new but are strongly improving in the recent years because of the increasing acknowledgement of the importance of data-driven decision-making, the increased availability of data and data analysis professionals and companies.

4.3.2 Transportation Policy and Design

4.3.2.1 Introduction

Transport policy can be defined as a set of constructs and propositions supporting effective decision-making processes and optimal allocation of resources within a transport system, including the management and regulation of existing transport activities. Within the mobility field, Pojani and Stead (2018) identify four types of policy instruments: (i) Regulation (including control of development), (ii) Fiscal instruments, (iii) Information, awareness, and education and (iv) Public infrastructure provision. These policies are most commonly designed by the public sector, as governments either own or manage many components of the transport system and have levels of jurisdiction on all existing transport modes (Rodrigue, 2020).

Transport policies are intrinsically linked with transport planning, as they determine the allocation of resources and can shape the normative framework in which transport planning is implemented. By definition, transport planning is an applied discipline that involves the definition of policies, the design and placement of physical infrastructure as well as the drafting of future scenarios, all resulting in transport plans with geographically specific recommendations and long-term strategies (Lovelace, 2021). These plans usually aim to make the mobility of people and goods move towards a more sustainable, efficient, and user-centric model.

Specific tools used related to transportation policy and design, including the examples of use cases and solved challenges, are discussed in Appendix C, section C.2.

4.3.2.2 Importance

Nowadays, digital tools give transport planners the ability to assess and evaluate the results of potential policies, as well as communicate these results effectively to multiple stakeholders, such as elected officials, the private sector and civil society, resulting in better-informed and evidence-based decision-making processes (U.S. Department of Transportation, 2017). In addition, the rising availability of digital traces in cities provides a fertile ground for data-driven solutions to solve current problems (Graells-Garrido et al., 2020), in line with the principles of smart cities (Dameri, 2013), and address 21st-century objectives commissioned to transport practitioners. These include: reducing congestion, diminishing carbon emissions to mitigate climate change, as well as increasing citizen engagement in decision-making processes, road safety and the use of active modes of transport, such as walking and cycling (Lovelace, 2021).

Moreover, there are many stakeholders interested in integrating digital tools into transport planning and policy making. For example, urban planners have the mandate to leverage travel information to improve operations and planning and support decision-making processes, as well as enable researchers to model the effects of various transport solutions and understand mobility and traffic patterns in a region (city or suburban area), thus promoting the concept of smart cities. In addition, public funding agencies are interested in getting access to mobility data and extract actionable information with the aim of better understanding the performance of their investment strategies and implementing more effective policies, in line with principles relating to equitable and inclusive mobility.

4.3.2.3 Trends

Within transport policy-making there is an increasing trend to address social and political issues as opposed to technical and engineering issues (Rodrigue, 2020). Transport policy processes are becoming more responsive towards environmental concerns, such as poor air quality greenhouse gas emissions, and social concerns, such as growing inequalities.

In addition, current transport planning paradigms promote high density (adequate people and activity per square kilometre ratios), walkable neighbourhoods to improve public health, economic dynamism and environmental quality, as studies have shown that the risk for chronic diseases may be reduced significantly if the neighbourhoods are walkable and the urban environment promotes physical activity (Dogan et al., 2018).

4.3.2.4 Gaps

Researchers agree that the integration of data science methods in transport planning and policy design may provide powerful and cost-effective solutions. However, such integration is debatable, as there are still open issues and barriers, such as the lack of interpretability and interoperability of data-driven tools and solutions (Graells-Garrido et al., 2020; Lovelace, 2021). For example, Dogan et al. argue that existing transport modelling tools have not been successfully integrated into urban design processes, as they, inter alia, require technical expertise in traffic modelling and heavy computational power, which make it difficult to be accessed by urban planners and designers.

Along these lines, one of the biggest challenges regarding the use of new data-driven tools in policy-making is actionability, in other words, ensuring that data-driven tools lead to useful decisions (Del Ser et al., 2019).

In addition, technological barriers are still present. Although there are increasingly more data being collected, analysed and integrated into policy-making there are certain limitations concerning the precision of data, as researchers and practitioners recognise that big data from mobile phones, social media, and on-board vehicle systems include biases in representation and accuracy (Griffin et al., 2020).

4.3.2.5 Opportunities

Modelling, processing, analysing and visualising massive datasets, also referred to as Big Data analytics, is considered an opportunity for the transport operators to provide a safer, cleaner and more efficient transport system, involving the provision of personalized services to end users that maximize their transport experience (Torre-Bastida et al., 2018).

The use of open data in transportation signifies a massive opportunity for local governments and their urban economies. A recent report assessing the benefit of the provision of free, accurate and real-time open data by Transport for London (TfL) concluded that, besides helping London's economy by up to £130m annually, it has (Deloitte, 2017):

- Saved time for passengers- estimated at between £70m and £90m per year.
- Provided customers better information to plan journeys, travel more and use more services.
- Translated into economic benefit for small, medium, and large businesses by creating commercial opportunities for third-party developers who use TfL´s open data.
- Incentivised innovation by having thousands of developers working on designing and building applications, services, and tools with TfL's APIs.

In addition, as the current development of data-driven tools allows the construction of simulators and models, such as digital twins, featuring unprecedented levels of realism (Del Ser et al., 2019), these models can support urban planners, urban designers, and transport operators in more effective participatory and collaborative decision- and policy-making processes, hence advancing towards the concept of "smart citizens" (Dembski et al., 2020).

4.3.2.6 Involved policy instruments

- **Vehicle restrictions:** Driving restriction policies for restricting car driving and license plate restriction policies for limiting vehicle purchases (Zhang et al., 2019).
- **Transit oriented development:** Structuring urban development taking into account walking distance from mass public transport stations (Lamour et al., 2019).
- **Pedestrianisation schemes:** Development of walkable areas in strategic areas of city centres through the encouragement of mixed land-use, population density, commercial density, and intersection density (Kim et al., 2020) as a measure to bring benefit to social, economic, and environmental benefits (Tanan & Darmoyono, 2017).
- **Active commuting**: Commuting by foot or bicycle as a low- maintenance and cost-effective transport mode to diminish emissions, traffic congestion, and more efficient use of urban land due to a reduction in parking lots (Kim et al., 2020).
- **Parking regulations:** Implementation of different policies (tariffs, limited parking durations, residents preferential treatment) trying to mitigate car related externalities, reclaim public space and reduce car ownership and car use (Albalate & Gragera, 2020).
- **Low emission zones:** Measure to reduce the emissions caused by motorised vehicles by establishing a protected area, frequently larger than a municipality, where vehicles without an environmental label cannot circulate during an established period of time (e.g., week days).

4.3.2.7 Stakeholder and business model analysis

In this business model, the value in use is the provision of a framework that ensures a safer, smarter, sustainable, and more efficient mobility for citizens, which itself can enable social, environmental, and economic development and contribute to improving the quality of life of society as a whole. Hence, the end user is the traveller who navigates around a given geographical area (town, city, metropolitan area, region) utilising a single or multiple modes of transportation, being them of the public or private domain.

It is important to highlight that transport policy design is a complex process that occurs on different levels of government and over different time frames. Due to their strategic importance and permanence (e.g., building a new train station) certain decisions can take a great period of time, while others, which are more operational (e.g., adding a bike lane, changing traffic direction) can be conducted relatively fast to ensure a real-time temporary benefit. However, due to the increasing availability of urban data, the boundary between these two dynamics is becoming blurred, mainly because they can both be benefited from the same data sources (PoliVisu, 2020).

This business model scenario will focus specifically on policy making processes which **have a direct use of data** and place the **municipality** as the focal organisation in charge of policy making, though it is relevant to mention that policy making processes can be conducted from different government levels and can include multiple methodologies. In this business model scenario:

- Citizens perform their daily activities in a geographical area, interacting with different devices, platforms, and modes of transportation.
- Technological companies and applied researchers develop solutions that enable the understanding of complex urban systems, in the form of sensors, platforms or devices. Sensors installed throughout a given geographical area and intelligent devices -which are connected to other devices through IoT- record massive amounts of raw data (big data) generated by the activity of citizens, goods, and vehicles. This data can include information on the user, their activity, the position of fixed and mobile objects, as well as classify vehicles by typology, measure speed, track vehicles through Origin-Destination matrices, monitor flows, etc.
- Data is organised in datasets that belong to different agents, given that they have different competencies and are in charge of different networks relevant for the functioning of a mobility and urban system. These agents can include different levels of the public sector (local, regional, and national), private sector (tech giants and entrepreneurs), as well as scientists and international organisations. If open data principles are ensured, the municipality can have access to an array of datasets that complement each other.
- Data specialists in the municipality and in some cases also policymakers develop the following process: store, manage and analyse raw data through data analysis and visualisation tools, which have been developed by software developers.
- Policy teams within the municipality utilise analysis and visualisation tools to understand the state of the mobility system and generate a diagnosis, as well as conduct experiments (e. g. scenario simulations) to observe the impacts of different interventions before agreeing on the best way forward.
- The decisions taken are shared and/or validated with other bodies of the municipality to understand the viability, economic feasibility, and alignment with broader policies in place or policies in the process of being developed by the municipality. Depending on the type of decisions, the validation process can be very agile and undergo many consultations inside the municipality and/or with civil society groups. Once approved, these decisions materialize into a concrete policy that can be desegregated into projects and actions with a specific allocation of financial and human resources, as well as a timeline to get implemented. As previously stated, policies can be implemented in the short term (operational) or as part of a broader long-term strategy which gets published periodically, usually in a Sustainable Urban Mobility Plan (Eltis, 2021).
- Finally, policies - in the form of regulation, fiscal instruments, information, awareness, and education activities or public infrastructure provision- are implemented in coordination with transit operators and other levels of government. These policies will have direct and indirect effects in multiple stakeholders including citizens/ travellers, private companies, and other levels of government. Subsequently, certain KPIs associated with the policies could be developed to monitor in real-life the effects and success of the policy in place.

In Figure 9, important stakeholders, their activities and added value to the business model can be found. More detailed descriptions of each stakeholder can be found in Appendix D, section D.2.

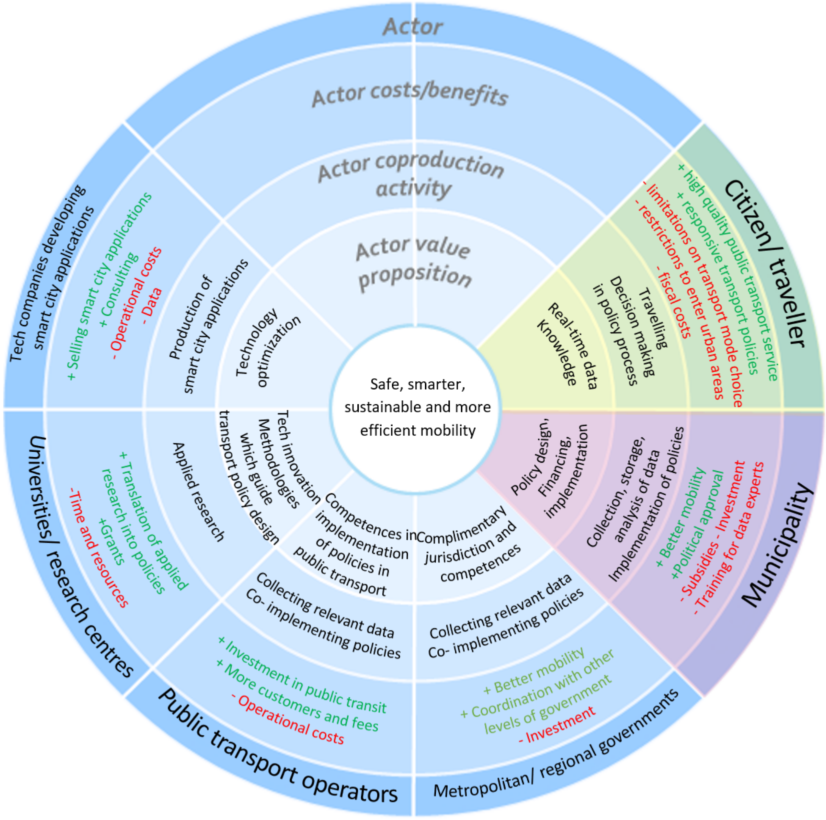


Figure 9: Business model radar for Transportation Policy and Design (source: own elaboration)

New players in the data market

The way the public sector obtains and uses data for policy making has changed in the past decades, transitioning from an almost complete government monopoly on policy-relevant data that prevailed in the early 21st century to the proliferation of new data owners and service providers, mainly from the private sector, who collect and store data, including floating car data (Waze, Google, TomTom), exercise data (Strava), origin/destination data (Vodafone, Deutsche Telecom, Telefónica) (PoliVisu, 2020).

Experimentation in policy making

Analysis and visualisation tools provide an ideal virtual environment for trial and error and an opportunity to learn in an agile manner. Within the policy design, process policymakers are increasingly adopting an experimental approach in which they can re-design and tweak new policy solutions and monitor and adapt already implemented measures to mitigate any undesired effects. (PoliVisu, 2020). This approach can open the participation of more stakeholders in transport policy design, ranging from other levels of government, different departments in the municipality, civil society, etc. As a consequence, travellers can benefit from a more agile data-based policy-making process that incorporates a wider range of perspectives and knowledge.

4.3.3 Travel Demand Modelling

4.3.3.1 Introduction

Travel demand models can be defined as computer-based representations of the movement (trips) of people and goods around a transport network within a defined area that has certain socio-economic and land-use characteristics. It is intended to provide an indication of how trips will respond, over time, to changes in the transport network and land use (JASPERS, 2014).

Classical travel demand models are based on the principle of transport demand and supply. The transportation demand can be thought of as a set of trips that are aggregated by purpose, time of day, day of the week, origin, destination etc. Often, it is derived from various socio-economic activities distributed over space (Ortúzar & Willumsen, 2014). Transportation supply is formed by facilities (roads, parking spaces, railway lines, etc.), services (transit lines and timetables), regulations (road circulation and parking regulations), and prices (transit fares, parking prices, road tolls, etc.) that produce travel opportunities (Cascetta, 2009). Long-standing experimentation and development have resulted in a general structure which has been called *the classical four-stage transport model* and which is depicted in Figure 10.

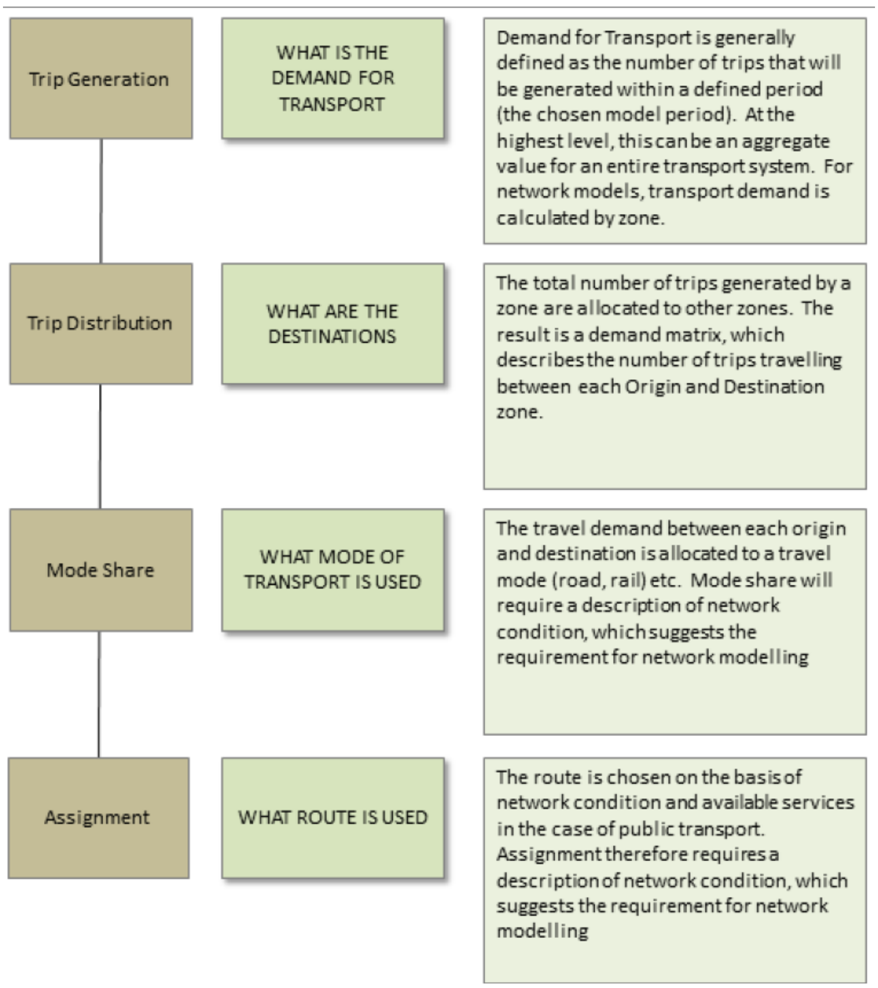


Figure 10: Structure of the four-stage model (JASPERS, 2014, p. 15)

Currently, the combination of *activity-based* and *agent-based approaches* is gaining attention. In the former, travel demand is derived from the demand for the participation in various activities, planned and executed within a household context and spread in space and throughout a 24-hour (or longer) period in a continuous manner, and travel and location choices are limited in time and space and by personal constraints (Chu et al., 2012). In *agent-based models*, individual travellers and also individual vehicles are treated as autonomous units, so-called *agents*, that learn and update their travel patterns iteratively on the basis of defined rules, as they interact among themselves and with the environment. An agent-based approach allows for more realistic modelling of complex systems with their dynamics (Scherr, 2020).

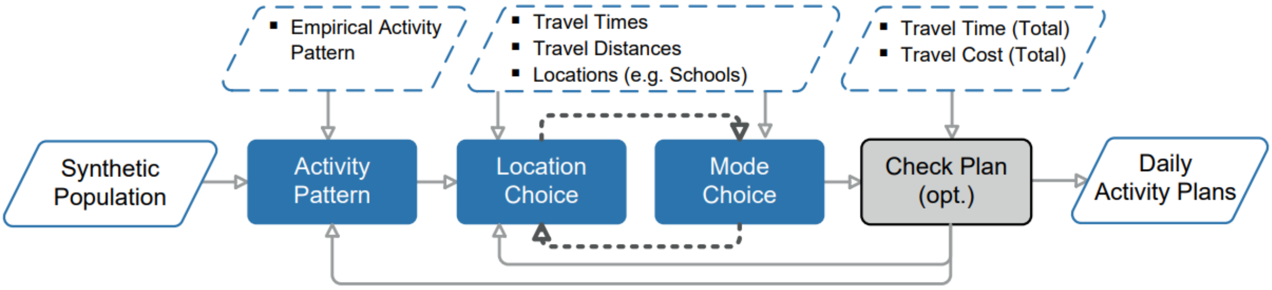


Figure 11: Modules of agent-based demand models (Krajzewicz et al., 2019, p. 15)

Specific tools used for travel demand modelling, including the examples of use cases and solved challenges, are discussed in section C.3.

4.3.3.2 Importance

A valid representation of the current situation provided by travel demand models helps to identify and explain infrastructure bottlenecks, shortcomings, and environmental impacts, and to present the found issues to a broader audience (Krajzewicz et al., 2019). Moreover, outcomes of traffic demand models are indispensable for --- but not restricted to --- local governments, transportation planners and providers to support transportation plans and policies. They allow to anticipate and evaluate impacts of various changes, either operational (e.g., changes in public transport routes or schedules, the introduction of a multimodal transportation system, design of new traffic light signals or their schedules, installation of dynamic message signs to provide travellers with real-time information), infrastructural (e.g., building a new road or a rail line, new bus terminal, changes of lanes), regulative (e.g., the introduction of zones with a restricted access of certain vehicles, toll zones, changes in parking policies, speed limits, guidance for heavy-duty vehicles, emission regulations), urban (e.g., new residential, business or shopping buildings, changes in urban spatial structure), technological (e.g., the use of alternative-fuel vehicles, automation, V2X-communication, new adaptive traffic light controls) or socio-economic. Models help the planners to forecast resulting changes in travel behaviour, and thus changes in network performance and environmental impacts.

4.3.3.3 Trends

Recent years brought the shift from this *macroscopic* approach based on aggregated data to *microscopic* approaches where each traveller is simulated as an autonomous decision-making unit. *Mesoscopic models* share the properties of macroscopic and microscopic traffic models. They explore individual vehicles in detail and then approximate the cumulative temporal and spatial traffic behaviour. Thanks to the increased computer performance, microscopic models can now be used for large scale regions. Although the classical four-stage model is still relevant today, the introduction of new transport modes and technologies (e.g., autonomous vehicles, route guidance or Mobility-as-a-Service) are accompanied by a shift towards agent-based models, usually combined with activity-based and other models.

4.3.3.4 Gaps

There is a need for a properly defined body of knowledge for agent-based models with a unified language and definition of terms, clear standard procedures, analysis, and model expectations (Kagho et al., 2020).

4.3.3.5 Opportunities

Scherr et al. (2020) identified the following opportunities to improve agent-based simulations:

- The use of mathematical optimisation to replace the plan-building heuristic.
- Methodological improvement of agent-based simulation to reproduce and understand travel demand peaks.
- Extending the idea of agents' learning based on an individual memory to all steps of individual travel demand, especially to the early steps (activity and tour generation, destination and mode choice, time choice and plan-building), where the activity-based approach involves individual preferences but no yet agent-based learning.
- Development of consistent mode choice models (trip- and tour-based) across travel demand and network simulation.

Kagho et al. (2020) highlight the problem of achieving system/social optimum as one of the important upcoming opportunities to improve the agent-based models since current simulations are aimed at achieving user equilibrium.

4.3.3.6 Involved policy instruments

Transport models are substantial for the assessment of transport policies and schemes, forecasting their outcomes and evaluation of their effectiveness. Complex transport simulation models work with various modes of transport including public transport, and infrastructure in full detail including parking places, charging stations etc. (Ziemke et al., 2019). They allow to model various scenarios and check impacts of various policies as for example:

- **Road user charging:** Charges required from road users with the aim to compensate for the costs caused by their transports (i.e., road wear, accidents, pollution) or to change their behaviour to reduce congestion and/or emissions. These charges can be based on the distance travelled in a specified area, the number of times a vehicle crosses a specific link or enters a specific area, or on the specific time period.
- **Road user rewarding:** Awarding travellers by money or other kinds of incentives instead of a punishment. The aims of these policies are the same as in the previous case.
- **Parking regulations:** Policies related to on-street or off-street parking of vehicles (e.g., charges, limited parking durations, residential parking permits) aimed at the mitigation of car related externalities.
- **Public transport fares:** Setting the cost that travellers have to pay for public transport services.
- **Fuel pricing:** Setting the fuel tax with the aim to control citizens‘ travel behaviour.
- **Private car restrictions:** Regulations imposed with the aim to decrease attractiveness and possibility of private car usage. They include time, zone and distance restrictions, speed limits and rules for car ownership.

- **Road capacity allocation:** Policies setting public the public transport priority with the aim to reduce travel time and thus increase the attractiveness of public transport.
- **Pre-trip planning support:** An instrument allowing a traveller to obtain relevant information before the travel, supporting the decision on its mode, route, and departure time. This information includes transport schedules and travel time estimations, and it can be provided via smartphones, radio channels, television, and online services.
- **Real-time traffic information:** Providing information about the current traffic situation, which can be used to adapt the travel behaviour, e.g., route choice or departure time. This information can be provided via variable message signs or information systems.

4.3.3.7 Stakeholder and business model analysis

The value-in-use in the business model for a travel demand modelling is a sustainable, smart, safe, and efficient mobility. Tools for modelling and optimisation are provided by public or private research or technology centre. Their proper use, including checking assumptions and an appropriate analysis and interpretation of results, helps to improve the traffic network performance, cooperation between transport modes, and thus mobility experience of individual travellers as well as the environment and living conditions for citizens. Travel demand models allow to simulate various future scenarios and evaluate their impacts. They are essential for transport planning and demand management, allowing improved decision making of municipalities on policy instruments and transportation strategies. For traffic management centres, they help to improve traffic management and operations. For various mobility providers, they help to optimise their fleet management, operation and offered services. However, ill-defined models or misinterpretation or results may lead to the support of inappropriate or inefficient actions, policies, or investments, or at least to misjudgements on future traffic demand, allocation, and effects of various traffic management actions (Niittymäki & Nevala, 2003).

There is a variety of different types of tools (see section C.3), both commercial and open-source. Developing a model intended as a support of transportation planning requires the identification of key issues and problems, and the definition of goals, objectives, and criteria. It is also desirable to reach a consensus among elected representatives at different levels of government,[4] officials, citizens, and experts about the future of the transportation system, and to identify the trade-offs among the quality of transportation service, environmental impacts, and costs (Heyns & van Jaarsveld, 2017).

The basis of any transportation model is adequate data on the present state of the system and its use, including traffic data, transit ridership statistics, census information and travel surveys. Further, data are gathered on land use, development trends, environmental factors, and financial resources. In recent years, developing technologies and the possibility to process big data initiated the use of additional data sources, such as GPS data (especially those traced from smartphone apps, possibly accompanied with other real-time data gathered by accelerometers, gyroscopes, and other sensors). Other important sources are mobile phone data providing spatiotemporal information on recent system usage, transit smart cards data providing on- and off-boarding information and data from social media such as Twitter, Instagram or LinkedIn that contain

[4] To remain within the scope of nuMIDAS project, the focus is laid on the local level in the business model, and municipality is considered as the focal organisation in charge of policy making.

hash-tags and check-in data related to an activity, location, or event, and are therefore helpful for the analysis of destination/origin of the activity (Tajaddini, 2020).

In Figure 12, important stakeholders, their activities and added value to the business model can be found. More detailed descriptions of each stakeholder can be found in Appendix D, section D.3.

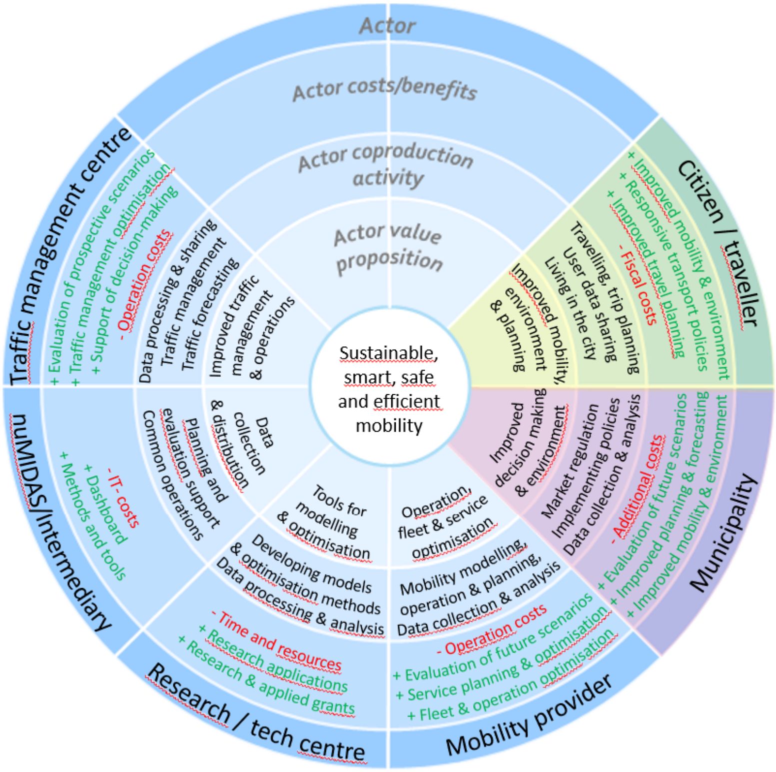


Figure 12: Business model radar for Travel Demand Modelling (source: own elaboration)

Changes in business models are especially related to data sources and processing. In recent years, due to the development of technologies and big data processing, traditional data collection methods started to be complemented by new data sources such as mobile network data, GPS traces from smartphone apps, transit smart cards data and information from social networks. This holds both for trip-based and activity-based models, and brings new stakeholders, namely data owners, to key positions of business models (Tajaddini, 2020; Willumsen, 2021). Data owners operate at a strategical and operational level, aiming at the collection of relevant data and having data provision as the value proposition. They profit from selling data to third parties and face operational costs related to data collection and sharing.

4.3.4 Public Transport Management

4.3.4.1 Introduction

A robust public transit network is a backbone of an urban transportation system. A focus of public authorities on environmental challenges and optimisation has created a need for *Public Transport Management* to emerge as a professional field. A "public transport manager" would deal with closer integration of design, planning, and management of the public transport infrastructure (Gudmundsson, 2010).

The key function of Public Transport Management (PTM) is to merge behavioural science and systems engineering to determine how to improve the flow of passengers on mass public transport, better understand demand, and offer policy solutions to public transport operators to help them respond to emerging challenges in this space. Specific tools used for this aim are discussed further on.

4.3.4.2 Importance

PTM represents a set of various solutions and tools that aim at making public transport services more efficient and sustainable for operators and drivers while putting the end-users at the centre of the approach. Its key elements comprise fleet and terminal management as well as real-time passenger and driver information.

Nowadays PTM encompasses various electronic systems such as automatic fare collection system (AFCS), security and surveillance systems (passenger, driver, transport, payment, etc.) and collection of solutions to increase cost-efficiency and minimise the environmental impact.

Public transport as well as its management systems become more and more cooperative, integrated, and automated which can provide various intelligent transport solutions. One of the examples of an intelligent transport solution can be public transport priority at the crossroads, where bus or coach, for instance, receives priority at traffic lights, which brings several benefits such as an increase in transport efficiency, reduction of emissions, and increase public transport attractiveness for users.

4.3.4.3 Trends

There are several trends that have a strong impact on PTM: one of them is *Sustainable Smart Cities*. This concept is based on the introduction of modern technologies into the city to improve quality of life, increase the efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social as well as cultural aspects and with a minimal impact on the environment. A variety of measures are needed in different fields, ranging from governance to ecology and economy (Höjer & Wangel, 2015).

Another important concept that shapes the PTM landscape is *smart mobility*.[5] The key idea behind it is that mobility within a city includes transportation by various environmentally friendly modes of transport, by using modes of transportation alongside or even instead of owning a gas-powered vehicle. It can have many different forms, including ride-sharing, car sharing, public transportation, walking, biking, and more. *Mobility as a Service* (MaaS) is one of the smart mobility services which plays one of the key roles in PTM. It aims at integrating various forms of transport services into a single mobility service accessible on demand. Through a single application, it provides access to mobility, with a sole payment channel instead of multiple ticketing

[5] https://www.geotab.com/blog/what-is-smart-mobility/

and payment operations. MaaS aims at providing an alternative to dependency on car ownership that may be seen as convenient, flexible, reliable, and cheaper. The main building blocks of Mobility as a Service are access to multimodal mobility services, single journey planning and ticketing options for the user, as well the provision of reliable and advanced travel information from the planning phase until the end of a journey. MaaS has the potential to reduce the environmental impact of transport and congestions, further optimise the city transport system, solve the mobility challenges of larger cities with soft measures and consequently reduce the need for public funding and subsidies in the transport sector, which has a direct impact on PTM (Leonard & Coconea, 2019).

Micromobility is another recent innovative urban transport trend that refers to a range of small, lightweight devices that are operating at velocities that do not exceed 45 km/h. It provides a short-distance travel option. The biggest potential of micromobility lies in solving the first and last mile issue, by improving access to public transport, and thus increasing access to services and opportunities, and similarly contributing to changes in mobility patterns and behaviours, aimed at less car-centred urban mobility systems (Oeschger et al., 2020). Micromobility devices include bicycles, e-bikes, electric scooters, shared bicycles and other PMV (personal mobility vehicles) (Yanocha & AllanInstitute, 2019). A constantly expanding scale and influence of micromobility has a significant impact on public transport as well as on its management.

4.3.4.4 Gaps

The efficiency of a transport system depends on several elements, such as available technology, governmental policies, the planning process, and control strategies. Indeed, the interaction between these elements is quite complex, leading to intractable decision-making problems. The planning process and real-time control strategies have been widely studied in recent years, and there are several practical implementations with promising results (Ibarra-Rojas et al., 2015).

The main gaps related to PTM can be gathered in several groups, namely integrational/interoperability, technological, infrastructural, governmental and challenges connected with congestion and standardisation.

Integrational: Public transport integration is based on connecting different transportation modes operating in a certain transportation system, providing solutions to facilitate passengers'/goods transfer between the modes and assuring the safe, smooth, and efficient flow of passengers/goods from their origins to their destinations (GUIDE, 1999, Ibrahim, 2003). However, this integration into one PTM system is not an easy task because various sub-systems are not always compatible with each other. This is caused by different communication methodologies or tools that are used, or additional means to make the interaction and exchange of information between the sub-systems are required.

Integration of an urban public transportation is defined as an organisational process by which elements of the passenger public transportation system (network and infrastructure, fares and ticketing systems, information, and marketing components) and a variety of carriers who serve different transportation modes, interact more closely and efficiently. This is to generate an overall improvement in service quality level and enhanced performance of the combined public and individual transportation. The implementation of different transport integration solutions may result in the following benefits (Prospects 2003): reduction of travel times, transportation costs, traffic congestion and environmental pollution. Transport integrating solutions may improve the urban public transportation system accessibility and overall competitiveness as well as assure better utilisation of different transportation means and infrastructure (Soleckaa & Żak, 2014).

Technological: From the technical perspective, public transport systems are largely incompatible among themselves and limited to local or regional geographic areas. It causes certain difficulties to bring several systems together and work as one integrated PTM system to have better control over transport flow and be able to provide real-time solutions to the emerging problem.

Infrastructural: One of the biggest challenges for the PTM is the existing infrastructure that was designed and constructed some time ago before the introduction of the transport management systems. The current infrastructure not always meets new transportation requirements and needs, but even hinders the implementation of efficient, sustainable, and safe solutions, such as the lack of cyclist's pads or priority lines for buses and coaches, etc. The infrastructural challenge requires significant financial investment from both public and private sectors. Once they are in place, they can significantly contribute to efficient management of the public transport system and reduction of the transport environmental impact.

Governmental: Each public transport requires a supportive set of rules, a legislative framework that can help public transport to tackle various transportation and mobility issues, such as traffic jams, pollution, sustainability, improvement of infrastructure, accessibility, etc. The government and local authorities are playing an important role in providing favourable financial schemes as well as financial encouragement for the private companies to invest in public transport services that can be done via low-interest rates or grants. The success formula is when both private and governmental sector works together in solving various transport challenges. When the legislation around public transport is favourable then it can largely contribute to the fast development and implementation of various transport solutions.

Congestion: An increase of public transport use and extension of its networks often leads to increased levels of crowding and congestion (e.g., rush hours), which can worsen public transport system performance and reduce customer satisfaction (Li & Hensher, 2011). A quick response to rising public transport demand is needed to increase its capacity, such improvements require long time frames and significant resources to develop more structured conceptual and methodological approaches for public transport travel demand management (Halvorsen & Koutsopoulos, 2019).

Standardisation: The current situation with standardization related to representation and exchange of data about public transportation systems remains still under development. It leads to severe interoperability issues that depend on the data from diverse sources. Many interoperability problems arise from the use of old information systems to manage operational data such as schedules and tariffs. Thus, exchanging data with external systems becomes very difficult. Standardization implies that there is a consistent, comprehensive, and agreed-upon set of parameters for how data is to be reported. GTFS (discussed further) is a web-based application aiming to simplify the creation and editing of public transportation data that could be easily exchanged in a normalized format (Braga et al., 2014).

4.3.4.5 Opportunities

With the growth of urban areas and their population worldwide, PTM plays a key role in urban planning and development. City planning largely impacts how much a city supports business growth, and of which transportation management has a key role to play. This process is accompanied by continues growth in urban travel demand. Therefore, the main opportunities of PTM are largely related to the planning, design, operation, multimodal access for all transportation users and integrating new innovative transport solutions.

It is important that a unified approach to integrate multi-modes of traffic and efficient feeder network is adopted and PTM will play a key role.

PTM is based on congregating and analysing all received data that streams from various sub-systems that are working together and in a harmonious way. This powerful source of multiple data collected from user's shared schemes and public transport patterns can help to understand people's behaviour as well as the impacts and limitations of these solutions on existing models. It allows to identify street segments with high levels of expected demand, models that permit to predict trip origins and destinations as well as transport use. Prediction and forecast of public transport demand within the urban area will help to efficiently organise and manage transport supply, foresee congestions and bottlenecks, and properly tackle environmental challenges.

PTM is also open to new developments and innovative solutions. Available big data will support a smooth introduction of new transport mode solutions, such as caterpillar trains, hyperloops, cable cars, clip air, elevated bus system, modular systems, etc. as well as infrastructural innovative solutions such as floating tunnels, creation of the internet of roads (IoR). Big data that is shared by PTM system enables an easy integration, design and planning of various public transport solutions that intend to make the user's trip efficient, quick, safe, cheap, and comfortable.

4.3.4.6 Involved policy instruments

There is a number of available transport policy instruments that are used to address various transportation challenges. They are the building blocks of general transport strategies and target different issues to make public transport system work homogeneously and in an integrated way. Their main purpose is to meet user's travel demand so that his trip is comfortable and safe as well as reduce environmental impact and embrace new transport demands, such as digitalisation, new services, etc.

- **Travel Demand Management (TDM)**: the PTM system puts the user of the public transport and the demand for transportation at the core of its activities. Managing user's demand can be a cost-effective alternative to increasing capacity. It also has the potential to deliver better environmental outcomes, improved public health, stronger communities, and more prosperous cities. TDM techniques link with and support community movements for sustainable transport. Therefore, the government encourages public transport operators to make travelling as easy as possible for users, by providing up-to-date travel information, comfortable vehicles, and a wide range of facilities at stations. By optimising connections with other modes of transport, it increases the efficiency of the transport and reduces waiting time for the user. In this case, the TDM provide PTM system with the application of policies and strategies to address the user's travel demand and provide the best possible solution to it.
- **Low Emission Zones**: the policies also target the environmental impact of public transport, namely, sustainable public transport aims at reduction of greenhouse gas emissions. To achieve this, the government works with other public authorities and transport operators to encourage more people to use public transport. At the same time, the policy tools encourage public transport to opt for a green fleet, to reduce the environmental impact. The Low emission zone strategy aims to create a defined area where access by some polluting vehicles is restricted. The policy stands in favour of public transport fleet vehicles that consist of alternative fuel vehicles, hybrid electric vehicles, plug-in, and zero-emission vehicles such as all-electric vehicles. Therefore, the low emission zone

significantly impacts the PTM systems and also provide data and transport solutions that can be offered to the end user.

- **Transport Digitalisation**: the key element to ensure efficient, comfortable, and safe public transport lies in the digitalisation approach of all public transport services as well as real-time information of the whole public transport system. The development of new services is based on the principle of shared mobility and it is also directly linked to the concept of Mobility as a Service (MaaS). Digitalisation policy creates a level playing field for various companies to offer their services and creates favourable conditions for new companies to enter the market with new services. Therefore, PTM system integrates the data coming from offered services in order to make public transport more efficient and sustainable.
- **Integrated Transport**: this policy provides the incentives as well as strategies to combine various modes of transport into one system to maximise ease and efficiency for the user in terms of time, cost, comfort, safety, accessibility, and convenience. Different modes of transport have different technical and operational capabilities which create certain challenges to bring all modes into one efficient system. Therefore, integrated transport policy outlines some provisions for various modes to be included in one public transport system. PTM systems play a key role in managing various modes to meet user's travel demands and offer the best solution for them.
- **Financing Public Transport:** The main sources of financing are ticket revenue, government subsidies and advertising. Public transport is composed of those mobility services that receive resources from a Public Transport Administration (PTA) so as to lower the price that users have to pay for them. These services, often offered through mass transit or collective modes of transport, are provided most often by public operators, but in some cases, they are provided by private companies, usually under some kind of concession scheme. Whether public or private, many mass transportation services are subsidized because they cannot cover all their costs from fares charged to their riders. Such subsidies assure the availability of mass transit, which contributes to making cities efficient and desirable places in which to live (Schofer, 2017).

4.3.4.7 Stakeholder and business model analysis

The focal point of PTM system is the end-user of the public transport. The system is constructed in a way that it endeavours to provide the user with the most optimal itinerary, considering real-time, journey information, public transport fleet availability, etc. Based on aggregated users' location and destination data as well as traffic information (traffic flow, congestions, bottlenecks, accident, infrastructure, etc.), the PTM system can detect the problematic areas, or the areas with the growth in public transport demand, or underserved areas to provide an optimised solution(s) to manage traffic in a specific area. The utter aim of the system is to make all users' journeys enjoyable, comfortable, and efficient travel, and the use of the public transport fleet in the most efficient way without delays.

In this business model, the information on growing public transport users' demand is detected by the system, which is based on the travelling patterns of users, infrastructure, availability of public transport, low emission zone, park & ride, etc. The solution is offered by the system for more reliable arrival times based on trip time advice and floating traffic data.

The traffic manager provides the floating traffic data concerning the density and flow of traffic within the city. This data is combined with growing users' demand by the service provider and information from the public transport operator as well as data from the MaaS provider. An optimisation for traffic flow or routing advice accommodated by estimated trip time can be suggested to a traveller. This allows avoiding traffic congestions, efficient use of the public transport and reliable information on the final destination arrival of the traveller. A municipality that is not directly involved in the exchange of real-time data creates favourable investment conditions for unfolding new services, promotive public transport, and development of the best possible PTM solution for the end-user's demand.

As a general solution of the service generated by the PTM system offers more reliable travel solutions for the end-users of the public transport. It means less waiting for the arrival of the transport, short travel time, comfort, safety, as well as efficiency of public transport use, which implies lower costs, fewer accidents, congestions, and efficient use of MaaS services. A value-in-use of this business model is the optimal public transport system for a traveller.

In Figure 13, important stakeholders, their activities and added value to the business model can be found. More detailed descriptions of each stakeholder can be found in Appendix D, section D.4.

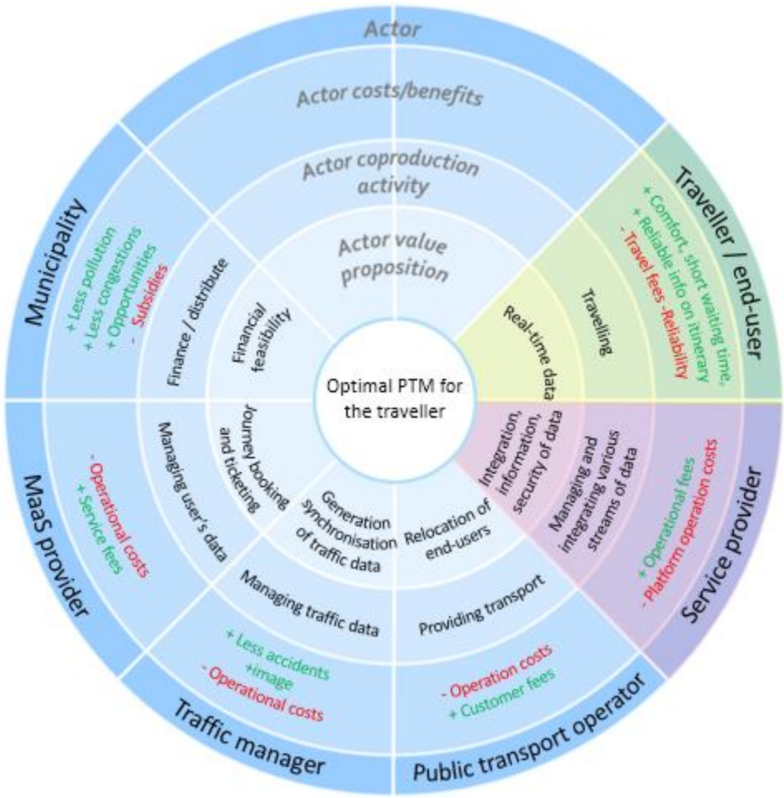


Figure 13: Business model radar for Public Transport Management (source: own elaboration)

Third-party service provider

One of the possible transitions in the business model for PTM system can be made when the management of the entire public transport system is transferred from the service provider to the third party, or a private company. This transfer should be beneficial for various stakeholders, for a level playing field will be created for all stakeholders with equal chances and rights for success. It will also serve as an incentive for other private companies and other services providers to join the system, by introducing new services and bringing new data that can boost the potential and value of the entire PTM system. It will also increase the level of provided services for the traveller and enhance the efficiency of the system, potentially can bring new sponsors, and decrease the cost for the provided services by the end-users. The only downside of the third-party service provider can be that other stakeholders of the business model can be reluctant or not willing to share their data with the private company who in its turn has to ensure security and privacy of provided data.

Private companies as sponsors

The business model for financing and subsidizing the public transport system can be potentially transferred from municipalities to private companies. In such a transition of sponsoring, the shift can stimulate environmentally friendly behaviour of all stakeholders. It will have a beneficial impact on creating a positive image of the company and increase corporate social responsibility. By maintaining an uninterrupted flow of traffic, less pressure is made on public transport fleet management, who will not have to deploy extra units to solve the traffic problems. It also has a positive environmental impact. As traffic improves, less dangerous situations are created during the congestions. This can lead to a decrease in the number of accidents. It can serve as another signal and incentive for other private companies, such as insurance companies, to participate as a sponsor, who can reduce the cost for offered services as the offered services can be compensated through a decrease in insurance pay-outs.

4.3.5 Last Mile Logistics

4.3.5.1 Introduction

Last mile logistics can be described as the process of planning, implementing, and controlling efficient and effective transportation and storage of goods, from the order penetration point to the final customer. Thus, it concerns the last stretch of the supply chain from the last distribution centre to the recipient's preferred destination point (Olsson et al., 2019).

Specific tools used for last mile logistics, including the examples of use cases and solved challenges, are discussed in section C.5.

4.3.5.2 Importance

Last mile logistics plays an essential role in goods supply chain because it is the real contact point between providers and customers (Bosona, 2020). Furthermore, the tendency in rapid urbanization and the increasing e-commerce exert significant pressure on the last mile logistic system, which is one of the biggest challenges for city management in terms of traffic congestion and sustainability (Guo et al., 2019).

4.3.5.3 Trends

The increase of e-commerce has led to huge parcel volumes being delivered especially in large urban areas. Therefore, the delivery phase is subjected to a higher resulting number of vehicles in circulation and a higher distance travelled. The adoption of green vehicles (lightweight electric vehicles, cargo bikes, unmanned aerial vehicles (UAVs – drones), etc.) is being evaluated because of their potential to reduce the environmental burdens connected to last mile delivery, particularly in urban environments (Patella et al., 2020).

Some innovations have the potential in reducing the impacts and externalities of last mile logistics. They can be classified into five main categories:

- new vehicles (electric vehicles,
- autonomous vehicles, and UAVs),
- proximity stations or points (concerning optimizing the capacity of depot stations with high saturation rates),
- collaborative urban logistic,
- optimisation of transport management and routing (real-time data, prediction methods and decision support systems),
- innovation in public policies and infrastructures

Their combinations would create a smart logistics system (Ranieri et al., 2018).

4.3.5.4 Gaps

Many policy makers are focused on controlling loading and stopping zones to reduce congestion, better control illegal stopping and parking, and promote pedestrian zones to lower air pollution. But a reduction in parking locations has consequences on congestion and the environment since it could lead to illegal parking in order to complete the deliveries or drive extra miles to find a stopping location.

Knowledge, experience, and relationships of the drivers have a large impact on the delivery effectiveness. They require time to be developed by novice drivers so there are several suggestions to help them: vehicle scheduling decisions (ensuring overlap between rounds is reduced and encouraging more optimal routing through the city), loading sequence of the parcels (to minimize searching time when parked), on-route vehicle navigation decisions (taking into account traffic problems), picking the best stopping point (knowing in advance where to park), last-mile ability and recall skills (enabling the driver to quickly and accurately locate the parcels required on-board the vehicle at each stopping location). Another point is to be effective at the point delivery without prior knowledge. In this case, other solutions could be evaluated: on foot decision making (how many delivery addresses to deliver to on-foot each time the vehicle is parked), optimizing walking routes, locating the point of entry, the journey inside the building, a decision about what to do when no-one is available to receive the delivery, and accepting collections.

The growth of last-mile logistics is restrained by the capacity of infrastructures, sizes of warehouses, and the limited number of locations to place new depots in cities. This condition, compounded by affordability and availability of land for local depots, will lead to locate depots even further from urban centres and to drive extra miles to/from the first/last delivery point (Bates et al., 2018).

4.3.5.5 Opportunities

Electric, hybrid, and fuel cell electric vehicles (FCEVs) are technological innovations able to reduce externalities: they have positive impacts on environmental and noise pollution, and they are mature for the market. Electric vehicles such as mopeds and motorbikes, as well as a quad, tricycle, and other small vehicles with three or four wheels, comprise another innovative proposal with the introduction of light means for mobility and delivery, suitable for urban areas. They are agile, with low impacts on the city, the need of only a few spaces for parking and are useful for delivering small parcels (Ranieri et al., 2018).

The concept of sharing economy can be also applied in the context of last mile logistic services. Crowdsourced delivery is a new logistic concept that uses the crowd (i.e., ordinary people) as the workforce to deliver goods. This concept is capable of combining goods deliveries with journeys of ad hoc people to reduce delivery costs, shorten lead time, increase delivery flexibility, mitigate traffic-related problems, and promote social networking activities (Guo et al., 2019).

The optimisation problem should consider not only the delivery addresses but also walking, where to stop and how to optimise loading which are critical points since they are not supported by digital technology yet. The possible change to bring in is to consider both walking and driving optimisation. Furthermore, in order to damp the time the driver spends to find the entrance and to run in and out of buildings, mobile parcel depots can be used where several parcels are dropped off and a curb side worker delivers them within the last 100 metres (Bates et al., 2018).

The combination of using public transport as means of bringing goods to a distribution point that is integrated into an (existing) public transport hub and provides distribution lockers or last mile distribution from this point can combine multimodal functions and access points for a neighbourhood/residential area. In the H2020 project MAVEN a case study was performed on unmanned logistics. The combination of using public transport shuttles to bring goods to the PB-hub and last mile delivery by pods was investigated regarding the impact on the traffic network with the use of sidewalks, bicycle lanes by the pods. In the case study platoon management, queue estimation and signal optimisation, signal priority and negotiation were part of the use case (Zhang et al., 2019).

4.3.5.6 Involved policy instruments

- **Incentives to green vehicles adoptions:** several administration authorities incentivize the adoption of green vehicles to control local pollution (Patella et al., 2020).
- **Carbon pricing policy:** increasing the purchase price and the oil price in order to boost the electric vehicles penetration (Arroyo et al., 2019).
- **Pricing area:** the vehicle pays for daily access to the restricted area, which is usually the central urban area (Ranieri et al., 2018).
- **Cordon pricing:** the vehicle pays in every crossing of the restricted area (Ranieri et al., 2018).
- **Distance based pricing:** the cost is related to the distance travelled by the vehicle in the restricted area (Ranieri et al., 2018).
- **Traffic management prioritising instruments:** platoon management, use of bus lanes, optimising traffic flow (shuttles, Pods, e-bikes etc.)
- **Grant access to restricted areas, such as pedestrian zones and cycling lanes:** using curb side, bicycle lanes, bus lanes for last mile delivery.
- **Creation of distribution centres:** hubs, distribution locations.
- **Parking regulations:** restriction on duration of stop and time-of-the-day restrictions, users' restrictions, geometric design, location relative to the block, parking pricing strategies, booking system, parking-meter technology, and signage system (Butrina et al., 2017).

4.3.5.7 Stakeholder and business model analysis

In this business model, the value-in-use is the last mile logistic itself i.e., receiving packages directly at home or nearby (lockers or available urban shops in the neighbourhood).

Generally, the chain of events for last mile logistics starts from the online customers and ends at the delivery to the same customer.

- The customer buys something online paying an extra fee to receive the package at home.
- The online shop uses a certain delivery company to send the package.
- The delivery company picks up the parcel and stores it in a warehouse/micro hub, whose delivery company is the owner, or it could be rented.
- The delivery company loads on a vehicle all the packages to deliver along the optimised path.
- The driver stops at the address and delivers the package to the customer. Alternatively, the delivery could be done around the address, for example to a shop nearby.

Sometimes, the customer can define the nearest locker as a delivery address. In this case, the very last mile is made personally by the customer who must go to the locker station to pick up the package.

In the last few years, the purpose is to make last mile logistics more sustainable by using greener vehicles and new technologies. So, there are several projects that use e-bike, autonomous cars, or Unmanned Aerial Vehicles (UAVs). The main problem to solve is the reduced vehicle capacity and autonomy.

Furthermore, model/software developers are trying to make the delivery paths more efficient for the delivery companies.

In Figure 14 and Table 3, important stakeholders, their activities and added value to the business model can be found. More detailed descriptions of each stakeholder can be found in Appendix D, section D.5.

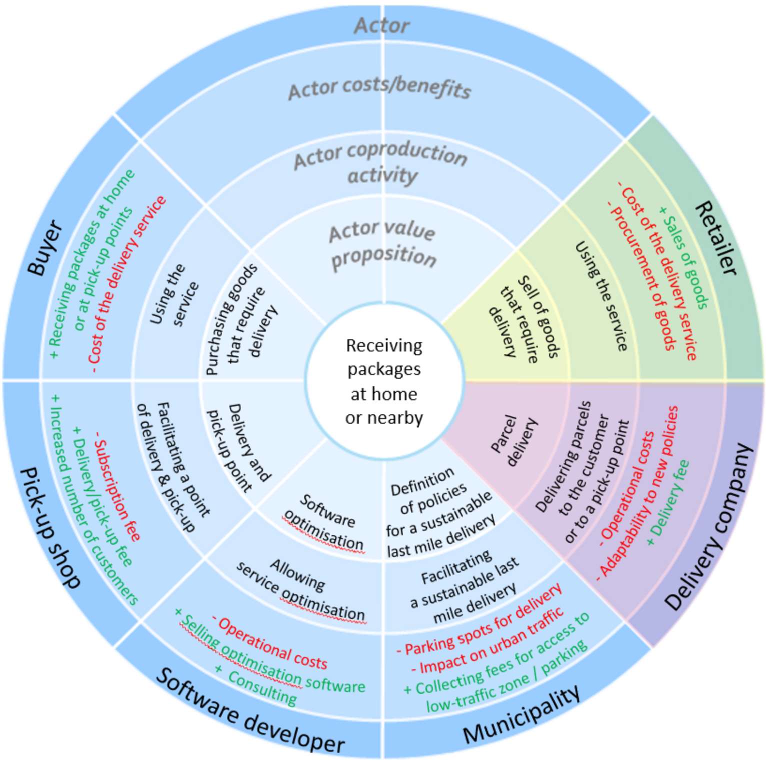


Figure 14: Business model radar for Last Mile Logistics (source: own elaboration)

Table 3: Additional stakeholders for Last Mile Logistics

Actor	Actor Cost/Benefits	Actor Coproduction activity	Actor Value proposition
Micro hub / Warehouse	+ Storage fee - Real estate costs - Operational costs	Storing parcels from different customers, Warehouse handling	Temporary storage of parcels
Vehicle manufacturers / OEMs	+ Selling new delivery vehicles - R&D of new delivery vehicles	Development and production of delivery vehicles that better suit city policies and delivery needs	Production of vehicles to enable faster/greener delivery

Policy instruments are essential tools in the business model because they can lead to deep changes in delivery companies, especially concerning the sustainability of the last mile logistic process. In the last few years, the tendency of the municipalities is to ease the access to more environmentally friendly vehicles in the urban area and to limit the access of heavy vehicles (lorries, vans).

There are some challenges related to the implementation of the new technologies that can affect last mile delivery business models. Generally, the autonomy and/or the capacity of these vehicles is reduced compared to conventional vans. Furthermore, costs are still higher than conventional vehicles.

Last mile deliveries can benefit from data collection and the development of models/tools for logistics optimisation at both strategic and operational level. As an example, deliveries can benefit from real-time data as traffic and parking spots occupancy.

As mentioned, the most disruptive change in last mile delivery business models will occur when autonomous vehicles will be available and will be allowed to run within cities.

4.3.6 Rental

4.3.6.1 Introduction

A vehicle rental service allows customers to hire a vehicle for a certain pre-defined period of time, ranging usually from several hours to 12 months. Hiring of vehicles for more than a year is usually referred to as a lease (Gierczak-Korzeniowska, 2020). Shorter time periods are usually connected with car-sharing services that are discussed in chapter 4.3.8 of this SoA.

Rented vehicles are usually owned by a rental agency and there exist fixed (but possibly numerous) locations where hired vehicles can be picked up and returned. Vehicles are rented to corporate or leisure travellers, owners of damaged vehicles who are awaiting repair or insurance compensation (Mordor Intelligence, 2020), or to city dwellers who can rent a car just when they need it instead of owning it (Leontyeva & Mayburov, 2017). Rental stations used by customers to pick up and leave a car are usually aggregated in pools, i.e., groups of stations that share the same fleet (Queirós, 2020).

In Europe, various associations representing bank-owned, captive insurances and independent lessors as well as long and short-term vehicle rental companies are joined in the Leaseurope (2021) alliance.

Specific tools used for rental services, including the examples of use cases and solved challenges, are discussed in section C.6.

4.3.6.2 Importance

Vehicle leasing, rental and sharing represent an important component of the Mobility-as-a-service (MaaS, see section 4.3.9; at least the second level of integration is considered) that brings new business models and ways to organise and operate various transport options. For companies, the related advantages include access to improved user and demand information and new opportunities to serve unmet demand for transport operators. For users, MaaS offers an alternative to the use of a private car that can be as convenient, more sustainable, and even cheaper (MaaS Alliance, 2017).

Vehicle leasing and rental have a great potential to assist the transition towards sustainable transport means and replacing old polluting vehicles with cleaner and energy efficient ones. Already today, rental fleets in Europe are cleaner than the average European car stock. Convenient policies discussed in section 4.3.6.6 can further motivate rental companies to increase the share of alternative-fuel vehicles, above all electric vehicles and fuel cell electric vehicles powered by hydrogen. Moreover, through the integration with MaaS, the rental sector can offer opportunities to embrace new technologies and support digitalization (Leaseurope, 2021).

4.3.6.3 Trends

The report of Mordor Intelligence (2020) refers to an increasing demand for online car rental services. Online tools are often used for booking, verification of documents, e-signing contracts, cashless transactions, providing information regarding the car, pick-up, and drop-off at a certain place etc. These innovations together with the use of various telematics solutions and the extension of services offered are also motivated by the recent development of ride-sharing/ride-hailing and car-sharing services. Integration of various kinds of mobility services and the development of MaaS systems offers customers an alternative to vehicle ownership (Rentalmatics, 2021; Kamargianni et al., 2018).

For example, the Whim MaaS system in Helsinki Metropolitan Area, based on agreements with Finland's rail and city public transport companies and other private transport providers,[6] offers a package providing unlimited access to public transport, free taxi rides (below 5 km, max. 80 rides per month), unlimited amount of 30-minute bike rides, unlimited access to basic rental vehicles (for up to 30 days at a time) and other services (Whim, 2021).

4.3.6.4 Gaps

A great part of data collected by rental companies, especially those on drivers' behaviour, mileage and fuel consumption, trip destinations etc., have a great importance for public authorities. Since most car rental companies are private, there is a need for an institutional set-up allowing continuous private-public cooperation and data sharing, ensuring in a technology-neutral and actor-agnostic approach, which is important for informed policymaking, regulation, and effective infrastructure developments (ERTICO – ITS Europe, 2019).

4.3.6.5 Opportunities

In general, interesting opportunities are related to the development of alternative-fuel and autonomous vehicles. These new technologies can boost the profits of rental companies and motivate them to increase their share in fleets. Rental companies may profit from charging possibilities, access areas with restrictions for vehicles with internal combustion engines, benefit from simpler relocation of vehicles if they can move autonomously (Conejero et al., 2016), etc. However, the question of whether electric vehicle rental has a positive effect on the attitude of customers towards this technology remains open (Langbroek, 2019).

Given these new possibilities enabled by policy instruments and new technologies, it is desirable to develop optimisation tools that include these opportunities and incorporate them into rental software. For example, Oliveira et al. (2018) show that integrating decisions on pricing and fleet size and allocation allow for significant improvements due to the flexibility gained by using not only price but also fleet size as a tool to manage demand. Several other tools related to fleet and revenue management are discussed in section C.6.2 in Appendix C. However, they are not so tangible and easy to use as the rental software.

4.3.6.6 Involved policy instruments

- **New/increased tax on fossil fuels** that would increase prices for gasoline and diesel, and thus motivate people to drive less and use alternative-fuel vehicles and other modes of transportation (Wicki et al., 2019).
- **Restricting access of fossil-fuelled cars to downtown areas:** the authorities can restrict the access of fossil-fuel vehicles to downtown areas on certain days, e.g., 1 or 3 or 5 days per week (Wicki et al., 2019). Consequently, rental companies that own non-fossil-fuelled cars would provide the services to travellers that still own fossil-fuelled cars.
- **Requirements for newly registered cars:** stricter fuel consumption and emission standards (e.g., new Euro 7 norm) would make registration of cars using a lot of gasoline or diesel more difficult and expensive. This would motivate people to use cars consuming less fossil fuel, alternative-fuel cars, and other modes of transportation (Wicki et al., 2019).

[6] E.g., taxi companies TaksiHelsinki and Lahitaksi, car rental companies Sixt, Toyota car rentals, Hertz and Go Veho, vehicle sharing companies ALD Sharing and City Bike and others.

- **Restrictions on quality of the fleet for the shared mobility/rental** to reduce pollution (CIVITAS, 2020)
- **Integrated transport:** integrating rental services into multi-modal transport allows reducing the number of privately owned cars (Kamargianni et al., 2018).
- **Mandatory reporting on environmental impacts** (CIVITAS, 2020).
- **Differentiated prices of roads** according to street characteristics allow for redistribution of traffic through time and space (CIVITAS, 2020).
- **Better data collection and digitalisation, sharing platform and relevant standard KPIs** (CIVITAS, 2020).
- **Parking regulations:** discouraging parking fees, parking time restrictions and other parking regulations (Santos et al., 2010) can contribute to making car rental in combination with other transport services more convenient than owning a private car.

4.3.6.7 Stakeholder and business model analysis

In accord with the future vision of reducing car ownership, the value-in-use in the business model for vehicle rental service is mobility independence without the need to own a car. In a combination with other transport means, it provides a sustainable, comfortable, and affordable mobility.

Rented vehicles are usually owned by a rental company, and there usually are fixed locations where hired vehicles can be picked up and dropped off. In many cases, these places are located at airports, railway stations and city centres with other locations scattered throughout the city. It is often possible to return a vehicle at a place that differs from that of picking it up. New technologies allow for booking and paying for a rented vehicle online, and for locking/unlocking and starting/stopping cars electronically through mobile apps, so that it is no longer necessary to hand physical keys over to customers.

Before the use of this service, a customer plans to rent a car for a journey or series of journeys. First of all, he/she requests detailed information about cars and prices. This can be done by calling or visiting the rental company (in classical models) or online. If the customer is satisfied, he/she books the selected car, using a credit or debit card and providing necessary information. The rental company makes a quick background check of his driving history and the type of his insurance. If the insurance is found insufficient compared to identified risk, the customer may be asked to purchase rental insurance or make a down payment. Before picking a car up, it is usually necessary to provide proof of address, driver’s licence, insurance, a valid telephone number and/or email address. Recently, this can also be done online. Credit or debit cards are usually used as means to bill customers for any liabilities in the case a vehicle is damaged.

Rental prices and taxes are based on location, company, and vehicle type. Besides insurance, additional payments may be related to returning a vehicle without a full tank of gas (battery) or too late or early, having another driver on file, additional miles (in the case of mileage restrictions), damage to the interior or exterior (dents or discolorations), etc.

In recent years, rental services to a certain extent are often included in price packages for Mobility as a Service.

In Figure 15, important stakeholders, their activities and added value to the business model can be found. More detailed descriptions of each stakeholder can be found in Appendix D, section D.6.

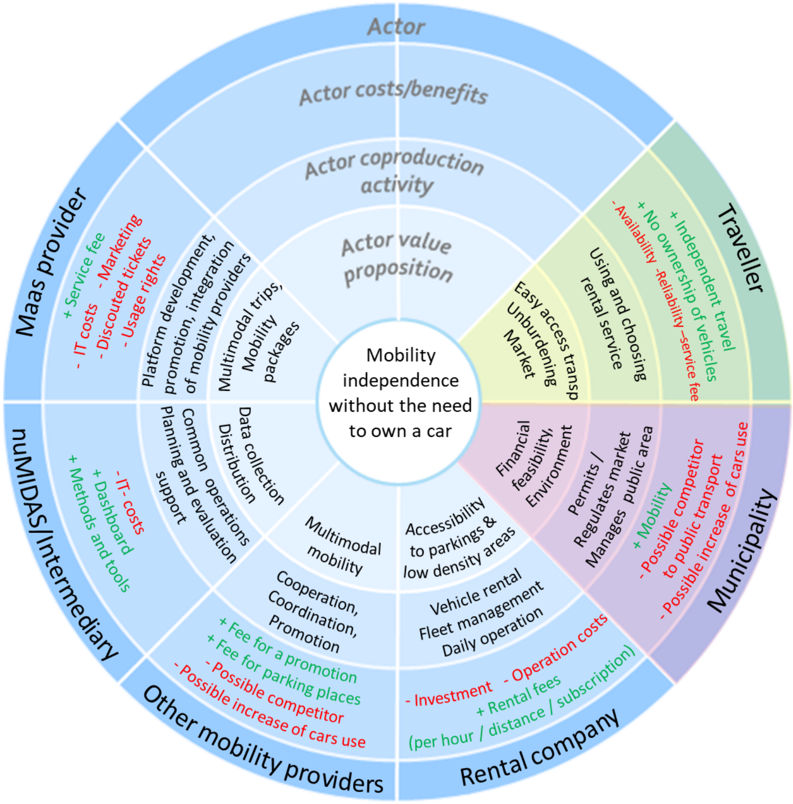


Figure 15: Business model radar for Rental Services (source: own elaboration)

In a classical model, it was necessary to provide all documents, sign a rental contract and take keys physically in a rental office. New technologies allow the transition towards models where all these steps can be done online, without a physical contact. It makes the service more flexible and accessible, and it also corresponds to the increasing demand for online rental services.

Some rental companies also provide car-sharing services (see section Car Sharing4.3.8) with on-demand or subscription-based bookings. Similarly, some car-sharing companies provide rental services. With the development of MaaS systems, rental services are often included in transport packages. The integration with other mobility services has the potential to reduce car ownership, and thus contribute to a more sustainable transport.

4.3.7 Micromobility

4.3.7.1 Introduction

Micromobility is a transport solution that has the goal of providing short-distance travel options, including first and last kilometre trips (Abduljabbar et al., 2021). Micromobility solutions uses light-weight devices and vehicles which are either exclusively human-powered vehicles (e. g. bicycles, skates, skateboards, and kick-scooters), or propelled without human energy input (e. g. e-bikes, e-scooter, hover-boards) whose power supply is gradually reduced and cut off at speed no higher than 45 km/h (Santacreu et al., 2020).

Shared micromobility schemes enable users to have a short-term access to a micromobility vehicle on an as-needed basis. These schemes may be station-based (vehicles can be picked up from and returned to any station or kiosk), dockless (vehicles can be picked up from and returned to any location, eventually under some restrictions) and hybrid (a combination of the previous two systems). In bike-share and scooter-share systems the fleet of vehicles is either owned and maintained privately or publicly, or publicly owned and privately maintained (Shaheen et al., 2020).

Specific tools used for micromobility, together with the examples of use cases and solved challenges, are discussed further on.

4.3.7.2 Importance

According to Abduljabbar et al. (2021), the interest in micromobility comes from its flexibility, sustainability, cost-effective solutions, and on-demand transport alternatives to private vehicles for short-distance travel.

4.3.7.3 Trends

Bike-sharing services have been evolved since their introduction, and at periods of time these services follow patterns of what they offer and how they operate (se called generations). Currently, the 4th (and last) generation of bike-sharing services offer information about the different types of available bicycles (including e-bikes), fees, location of docking stations and kiosks for ticketing, and parking information. Also, user interface technology, bicycle redistribution system (according to consumer demands), and integration with public transport cards. Electronic smartcards and membership-based programs are used for seamless experience and theft avoidance (Abduljabbar et al., 2021).

4.3.7.4 Gaps

Open data sharing is still not always available, though useful to understand micromobility impacts, identify possible gaps in the transportation network, and monitor equitable service standards (Abduljabbar et al., 2021). Such information is important to offer multimodal, real-time transportation information through smartphone apps, websites, and other platforms (Shaheen & Cohen, 2019). Although it is already possible to use existing work for advanced analysis by transportation planners, there is still room for improvement. Demand predictivity might be improved by the inclusion of additional predictors and machine-learning techniques. A model presented by Merlin et al. (2021) can identify 56–60% of street segments in the top 5% of usage in trip destinations with high levels of expected scooter demand.

Micromobility is often simulated using microscopic flow models that describe the movements of individual road users, based on several factors at each time step given. However, simulation with macroscopic models, which model the evolution of movements using aggregated quantities of density, average speed, and flow, is still uncommon. The reason for this is that usually the speeds for bicycle and car classes cannot depend on the vehicle-bicycle composition leading to that density. Some works, such as (Wierbos et al., 2021), present a macroscopic model using class-specific speed functions that depend on the density of all classes as independent variables, considering the space headway of both cars and cyclists.

4.3.7.5 Opportunities

Abduljabbar et al. (2021) point out that public agencies should have access to standardised and open data. Shaheen and Cohen (2019) describe guiding principles on the adoption of open data standards for micromobility policies, they are: defining the type, format, and standards for publishing data sets; inclusion of metadata with methodological information (how the data were collected and geocoded); ensuring open format and open license data that is machine-readable; guaranteeing high-quality data that don't require extensive effort to use the datasets.

Shared mobility schemes collect data that may typically include time-based and location-based, which help to understand spatial patterns given the behaviour of users (Abduljabbar et al., 2021). There exist models that allow identifying street segments with high levels of expected scooter/bike demand, models that allow predicting trip origins and destinations (Merlin et al., 2021). For instance, Nikiforiadis et al. (2021) present the methodology for making optimal decisions on the locations of charging stations for shared micromobility vehicles, it is desirable to incorporate additional data sources and models for demand estimation.

Other opportunities are related to the planning, design, operation, and maintenance of the curb access to enable safe, convenient, and multimodal access for all transportation users. Its key elements include policy processes, device caps limiting the number of micromobility devices, service area limitations, designated parking areas, fees, equipment, and operational requirements, determining sidewalk zones, etc. (Shaheen & Cohen, 2019).

4.3.7.6 Involved policy instruments

- **Encourage users to rethink private vehicle ownership:** reduce the number of cars (Abduljabbar et al., 2021)
- **Promotion of active modes of travel:** helping to reduce greenhouse gas and other pollutant emissions (de Bortoli, 2021), bringing important health and economic benefits, easing peak-time congestion, and reducing travel time (according to Gössling (2020), average vehicle speed was below 20 km/h in many cities).
- **Adaptation of urban infrastructure for all users' needs:** not only for individual and family short distance travel but also for parcel delivery in urban areas (DeMaio, 2009)
- **Alternative access to places:** especially those with restrictions for private vehicles such as narrow roads and streets in inner-city areas (Shaheen et al., 2013)
- **Fleet management policies:** to rebalance devices to achieve a proper density and/or service equity), stagnant device rebalancing, removal of unsafe or inoperable devices (Nikitas, 2019; Shaheen & Cohen, 2019).
- **Sidewalk and curb space management policies:** important to reduce cluttering and accommodate micromobility, delivery services, and pick-up and drop-off locations (Shaheen & Cohen, 2019)
- **Integrated transport:** access to public transport can be improved by solving the first- and last-mile problem, which contributes to a less car-centred urban mobility system (Møller et al., 2019).

4.3.7.7 Stakeholder and business model analysis

In this business model, the value-in-use is easy access to lightweight vehicles for the first or last mile of a trip. Easy access to these modes results in an increase in mobility and flexibility, as point-to-point travelling at higher speeds than walking becomes more accessible without the need for increased PT coverage.

The customer journey starts with a desire to travel to a location, from a location where the traveller does not have access to a personal vehicle or requires a different vehicle than personally available. The traveller has access to either a central spot where these vehicles are available or uses an app on his smartphone that tells him where the nearest available vehicle is. This is provided by the micromobility operators. Some micromobility operators give travellers the possibility to reserve a vehicle. The traveller can take the vehicle and use it for as long as desired (often within some boundaries, e.g., time limit or geofence). Vehicles (e.g., bike-share and scooter-share) can be picked up from and returned to any station (called station-based system), or vehicles can also be picked up from and returned to any unrestricted location (dockless system). Nevertheless, a combination of the previous two systems is also possible (hybrid system).

The fleet of vehicles is either owned and maintained privately or publicly, or publicly owned and privately maintained. The micromobility operator facilitates the use of the vehicles by managing the fleet. Daily operation includes maintenance of vehicles, but also fleet distribution (especially in case of dockless vehicles) and charging in case of electric vehicles. Since operations of this service use street space, the spatial planning of municipalities is directly affected by parked vehicles. Dockless vehicles can be parked anywhere, which sometimes results in vehicles parked in undesirable parts of a sidewalk. Furthermore, since the fleet size is a competitive advantage when multiple micromobility operators are present within the same city, operators battle with fleet size to increase their service level, resulting in an increase in usage of space. Regulation of usage of space by these vehicles, but also the number of micromobility operators, is therefore required.

In the future, platforms, where many mobility services are combined into a single service may be available. MaaS providers will combine as many services as possible to achieve universal and easily accessible mobility. In order to facilitate competition between providers, standardisation may be required for these MaaS services. Furthermore, data from all services has to be available, which may be through a central data-point open to both MaaS providers and governments or intermediaries for monitoring and evaluation of policies.

In the business model radar below, important stakeholders, their activities and added value to the business model can be found. More detailed descriptions of each stakeholder can be found in Appendix D, section D.7.

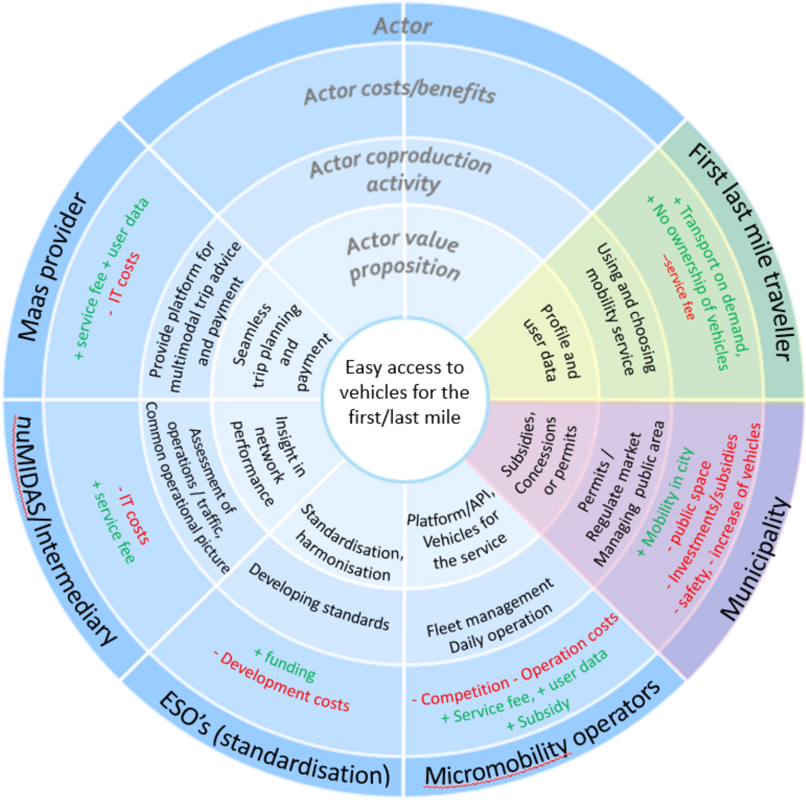


Figure 16: Business model radar for Micromobility (source: own elaboration)

How business models will change is still uncertain. Due to MaaS, micromobility business models may take on other forms, depending on implemented policies. One possibility could be that cities will handle this in a similar way as PT is organised with concessions. Micromobility operators would maintain current business models but specific to certain areas. Another possibility is that when MaaS is implemented, business models will change to take on the competition, as this means that there is a central platform for mobility services and payment. In such a scenario, micromobility operators may act as fleet owners that maintain their vehicles and share information about their fleet, instead of traditionally providing a private application for vehicle localization and payment. Meanwhile, first, and last mile travellers (which previously relied on different apps to decide how to travel) can then rely only on one app to get information.

Another aspect depends on the participation of future partners, i.e., ESO (standardisation) and nuMIDAS (intermediary). The intermediary and standardisation actors may take the responsibility from micromobility operators and software companies regarding data distribution and data analysis. Relevant tools and data standards may be provided to the focus organisation, enabling a common framework for planning, evaluating and operations.

Cities will gain more experience with micromobility and learn about the effects. The complementarity to the transport system in a city of the service is important and dependent on the goals of the city. Research has shown that travellers substitute all types of modes with electric shared mobility, which may result in an increase in the number of vehicles on the road (Liao & Correia, 2020). Furthermore, it is debated that micromobility users may show more unsafe behaviour, leading to traffic safety issues. Therefore, data / research is required on how to move travellers away from the car, to micromobility and PT, but not from active modes and PT to micromobility.

4.3.8 Car Sharing

4.3.8.1 Introduction

Car Sharing is a model of car rental in which users rent cars for relatively short periods of time, usually from a car-sharing operator who owns a fleet of vehicles and is responsible for their maintenance (Mounce et al., 2019). There are different models in existence: Station based (one-way or roundtrip), Free floating, and Peer to peer (P2P) car sharing (Shaheen et al., 2020).

In Station-based car sharing, a service operator provides a fleet of vehicles to its members to be rented on a short-time basis. Users must pick a shared vehicle in a station and return it to the same location (roundtrip) or to another station (one-way).

In Free-floating car sharing, a service operator allows members to pick up a vehicle at one location and park it at another one within the service area, no stations are required.

In P2P car sharing, a service operator provides only a platform that matches the offer of private vehicles to demand. The fleet is not owned by the service operator, but members of the service can share their own private vehicles and make them temporarily available for shared use.

Vehicles used in car sharing are typically fuel efficient and lead to positive effects in the reduction of urban emissions and city congestion (Ferrero et al., 2018).

Specific tools related to car-sharing services are discussed in Appendix C, section C.8.

4.3.8.2 Importance

Car sharing increases mobility for community members to reach destinations otherwise inaccessible by public transport, walking or biking. Persons without access to private cars (e.g., students and young people who do not have enough money to purchase a private car) can also increase their mobility options. Car sharing increases citizens' awareness about the social and environmental impact of the use of private cars and encourages and supports multi-modal communities by providing an additional transportation option (Ferrero et al., 2018).

Several academic and industry studies collectively show the following commonly associated outcomes of car sharing (Shaheen et al., 2019):

- Purchasing of private vehicles is reduced or delayed;
- Increased use of alternative transportation modes (e.g., walking, biking);
- Reduction of vehicle kilometres travelled (VKT) for members who replace private cars with shared cars;
- Increased mobility options for formerly carless households;
- Reduced fuel consumption and greenhouse gas (GHG) emissions;
- Greater environmental awareness.

4.3.8.3 Trends

The growing attention in environmental issues caused an increased usage of electric and hybrid vehicles. Furthermore, the development of information and communication technology allowed new car-sharing models, such as free-floating car-sharing services (Ferrero et al., 2018).

General trends and research perspectives are mainly related to users' behaviour analysis, analysis of the demand, optimisation tools for the design and the management of the service, and business models linked to car-sharing services (Ferrero et al., 2018).

The P2P car-sharing industry has evolved since it was initially launched in 2010. In some countries, including France and the Netherlands, P2P carsharing is even more prevalent. In contrast, there is a relatively lower number of P2P carsharing vehicles in countries such as the United Kingdom or Italy, most likely due to insurance regulations that restrict private vehicle rental (Shaheen et al., 2019).

4.3.8.4 Gaps

One of the biggest challenges is related to the supply-demand imbalance of cars in given locations, especially during peak hours (Ren et al., 2020). Vehicles distribution becomes unbalanced over time and carries out redistribution issues for operators (Mounce et al., 2019).

Likewise, one of the most critical aspects of car-sharing service planning concerns the overlapping territory covered by different providers/models of the service. A city can foster both free-floating and station-based models. A well-defined territory in which cities define clearly separated areas in which these models can operate helps the economic sustainability of the service.

Moreover, it is crucial to determine the ideal number of the fleet required on public tenders for operators interested in providing a car-sharing service. In this way, the available fleet will be in compliance with the user needs and, at the same time, it will not exceed a number that may be economically unsustainable for the operator.

An additional challenge for the car-sharing service is the need for public infrastructure which needs to be guaranteed by the city. Specifically, there is the need to facilitate the installation of parking lots as well as electric charging facilities if needed. At the same time, the density of traffic flow in the city and the demand should be studied before launching the service, as it is crucial to be able to have a certain number of users so it could be profitable and attractive for operators to run the service.

4.3.8.5 Opportunities

Car-sharing systems have the potential to integrate with public transport through intermodal connectivity and become important components in city transport systems of the future. It could be a substitute for public transport for those who would rather generally use a car, whereas, for those who usually use public transport, it is in conjunction with it (Mounce et al., 2019).

Data collection and analysis poses a great opportunity for sharing mobility systems to increase their efficiency. On one hand, data analysis can improve the service for the users in the sense of matching the demand with the available vehicles and, on the other hand, it could influence positively the economic profit of operators.

4.3.8.6 Involved policy instruments

- **Tax credits for car-sharing users**: especially for employers (Jung & Koo, 2018).
- **Discounts and subsidies for shared vehicle providers**: discounts for parking lot spaces, subsidies for purchasing electric vehicles (EV), free installation for normal-speed EV chargers (Jung & Koo, 2018).
- **Integrated transport**: discount on the public transport system to reach a car-sharing station (Jung & Koo, 2018).
- **Discounts for operators that use electric fleet**: operators of car-sharing services that use an electric fleet have discounts on the annual fees that must be paid to the public administration (Municipality of Milan, Carsharing call for tenders, 2017, 2019, 2021).
- **Encourage the use of electric fleet**: through the design of the requirements of the tenders, the public administration can assure that the operators of car sharing use only an electric fleet and therefore contribute positively to the amount of CO2 emissions on the environment, especially if electricity from renewable resources is purchased (Municipality of Milan, Carsharing call for tenders, 2017, 2019, 2021).
- **Dynamic pricing policies**: can be designed to adjust and balance temporally and spatially cars availability (Giorgione et al., 2019).
- **Parking management**: a guaranteed number of parking instalments managed by the Municipality and paid by the operators by an annual fee (Municipality of Milan, Carsharing call for tenders, 2017, 2019, 2021). Some municipal parking policies include: 1) provisions for on-street parking, 2) parking time limit exemptions, 3) creation of carsharing parking zones, 4) free or reduced cost parking spaces and/or parking permits, 5) universal parking permits (i.e., carsharing vehicles can be returned to any on-street location) and 6) formalized processes for assigning on-street parking spaces (Shaheen & Martin, 2010).

4.3.8.7 Stakeholder and business model analysis

The value-in-use is the mobility independence without the need to own a car. It would be achieved due to the availability of shared cars for users that can renounce buying a private car or for users that couldn't afford to buy a car. The shared cars must be well distributed in the city in order to fill the demand. Car sharing offers a unique service that complements public transport and can be part of a wide strategy (MaaS) aiming at reducing the number of private cars in cities.

There are two main business models (Tart et al., 2018):

- In a standard business model of car sharing, the service is run by a company that provides the fleet of vehicles, the app/platform to register to service and rent the vehicles.
- In a Peer to Peer (P2P) business model of car sharing, a company provides an app/platform where users can share their own cars or rent other user's cars.

A standard chain of events for car sharing is the following:

- A service operator provides a certain number of vehicles within the operational area or in the car-sharing stations, and an app or a platform for the users.

- Users subscribe to the service via an app or a website, providing ID, driving license and credit card information.
- When the operator confirms the subscription, the users can start using the service.
- Users check on a web map the availability of cars close to the desired location and book it.
- When the user reaches the vehicle, he/she can open it by means of dedicated card or with a smartphone.
- They drive the car to the desired location and end the trip using a card or a smartphone.
- The platform calculates the cost of the trip and charges the user.
- The car is now available for further uses.

In Figure 17 and Table 4, important stakeholders, their activities and added value to the business model can be found. More detailed descriptions of each stakeholder can be found in Appendix D, section D.8.

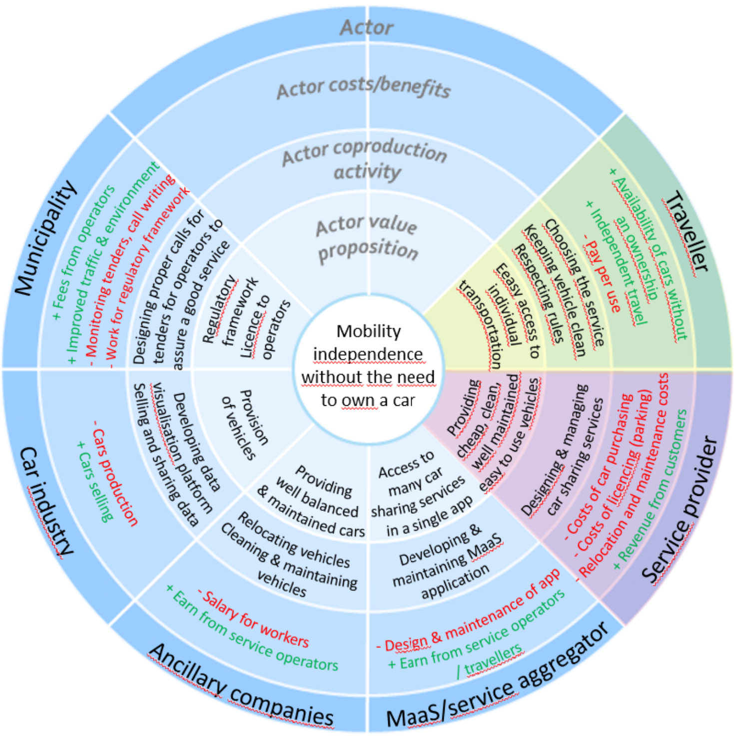


Figure 17: Business model radar for Car Sharing (source: own elaboration)

Table 4: Additional stakeholders for Car Sharing

Actor	Actor value proposition	Actor coproduction activity	Actor benefits	Actor costs
Research & Development	Test new possible service models, for specific users, with specific vehicles	Studying theoretical models and test them with pilots	Get consulting and other funds to do research and development	Salary for researchers

User operators (P2P)	Provide their own cars	Subscribing to the service, maintaining their cars	Earn from renting their own cars	Renounce to car availability
Matching platform operator (P2P)	Match offer and demand, guarantee insurance	Providing an app to match offer and demand of shared cars. Providing users with insurance cover	Earn fees for uses	Cost of development and maintenance of the app. Costs of insurance
nuMIDAS/ Intermediary	Data collection & distribution	Common operations, Planning and evaluation support	Dashboard Methods & tools	IT costs

Car sharing can benefit from Maas development. With a Maas approach, users can have a better guide in a multi-modal/multi-operators' mobility offer. Maas approach is also fundamental in a planning phase for policy makers: mobility services could be optimised and better coordinated if planned with a holistic view. The sharing of data from each sharing service operator is a prerequisite for the development of Maas.

The P2P business model is actually operating only in a few countries for legal and insurance reasons. Legislators might be working to open this market in the following years. This could be a significant change in the current market.

Automated Vehicles seem to perfectly fit for shared use. When this technology will be available, the car sharing market is expected to change significantly.

Municipalities will have to foresee and drive changes in business models in order to offer a smooth and regulated transition and evolution of the market, to offer a better service to citizens and avoid failure in new service operators.

4.3.9 Mobility as a Service

4.3.9.1 Introduction

Mobility as a Service (MaaS) integrates various transport modes and services from different operators to provide a user-orientated transport solution via a single digital interface which includes planning, reservation, and payment for all included services (Jittrapirom, 2018; Smith & Hensher, 2020). In MaaS systems with an advanced level of integration, platforms provide an intermodal journey planner enabling a combination of public transport, car sharing, bike and scooter sharing, taxi, car rental etc., a booking system, an easy payment procedure and real-time information. MaaS users can either buy a pre-defined mobility package that would correspond to their needs or they can use a pay-as-you-go option (Kamargianni et al., 2016).

In the domain of multimodal mobility, Sochor et al. (2018) distinguish several levels of integration:

- **Level 0: No integration** (single, separate services)
- **Level 1: Integration of information** (includes multimodal travel planner, price information etc.)
- **Level 2: Integration of booking and payment** (allowing to find, book and pay for a single trip)
- **Level 3: Integration of the service offer** (focusses on customer's holistic mobility needs, the service is bundled, possibly subscription-based, there is a full two-way responsibility from the end user to supplier and vice versa)
- **Level 4: Integration of societal goals** (public authorities can influence the societal and ecological impacts of mobility services by setting conditions for the operators and individual transport service providers to create incentives for desired behaviour; this approach can be integrated at any level)

In the following text, level 2 will be considered as a minimum. Interactions between users and core service providers is depicted in Figure 18.

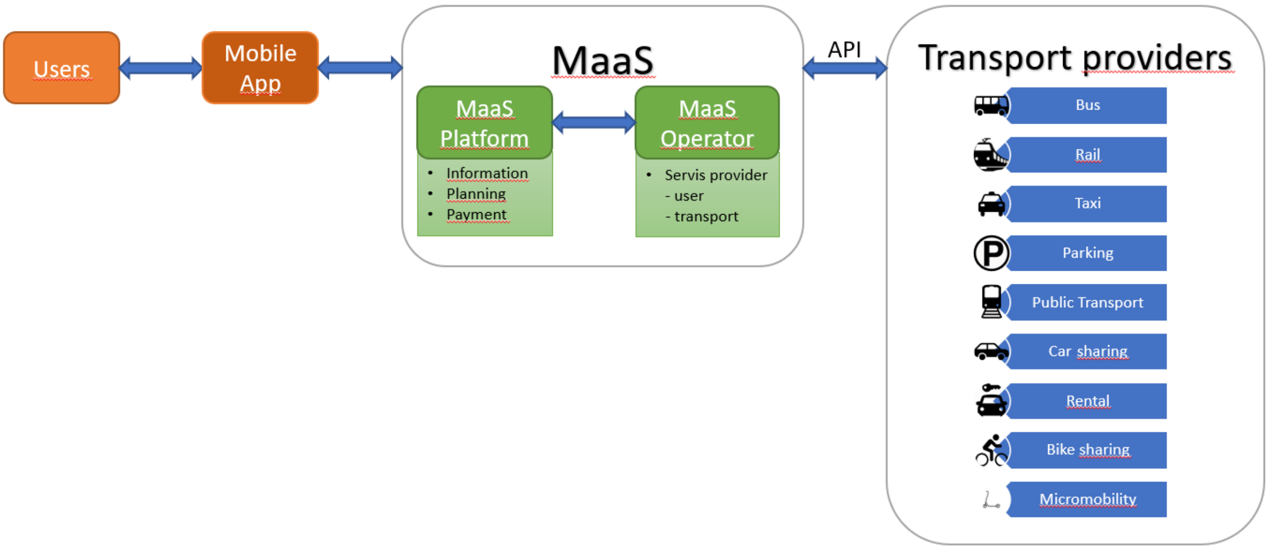


Figure 18: MaaS ecosystem (source: adopted from ERTICO – ITS Europe, 2019)

Besides customers, actors involved in the MaaS Ecosystem include transport operators, data providers, technology and platform providers, infrastructure providers (roads, EV charging infrastructure, parking facilities, ICT infrastructure, etc.), insurance companies, regulatory organisations, universities and other research institutions, media, marketing, and advertising firms. An important role is played by transport authorities as they promote collaboration with various stakeholders (Arias-Molinares, 2020). A more detailed description of the roles of key stakeholders is provided in Appendix D, section D.9.

Specific tools related to MaaS, including the examples of use cases and solved challenges, are discussed in Appendix C, section C.9.

4.3.9.2 Importance

MaaS has the potential to reduce private vehicle ownership and the share of trips made with individual vehicles by offering citizens an equal sense of convenience, reliability and flexibility, control over travel time and costs (Magoutas et al., 2018). A properly designed MaaS service can therefore reduce congestion, parking problems and emissions of greenhouse gases and other pollutants, and improve the performance, efficiency, safety, and security of the transport system (de Stasio, 2018).

For example, Kamargianni et al. (2018) refer to a survey of Londoner's attitudes according to which 36 % of non-car-owning participants stated that they would delay purchasing a car and 40 % stated that they would not purchase a car at all if MaaS were available. Among car-owning participants, 33 % stated that MaaS would help them become less dependent on cars and 25 % claimed that they would not buy a car at all if MaaS were available. Arias-Molinares and Garcia-Palomares (2020) cite the results of Ubigo's trial version and a subsequent survey, where 36 % of non-car-owning users stated that they would delay purchasing a car, and among regular car users, 35 % claimed that they would shift to public transport, 17 % to bicycle and 17 % to walking.

Moreover, MaaS systems provide valuable data from which information on passengers and traffic flows can be extracted, e.g., information on passengers' travelling patterns, preferences and choices that help decision makers to plan for better systems and a real-time adaptation to a changing demand (Cruz and Sarmento, 2020).

MaaS systems provide benefits also to transport operators as they offer new sales and information channels, as well as new fare products which help to attract new customers etc. They, therefore, help to increase the use of collective and shared mobility services and their economic efficiency (Dubois et al., 2019).

Last but not least, a higher utilisation rate of vehicles enables easier technology shifts to more environmentally friendly technologies (Holmberg P., 2016).

4.3.9.3 Trends

The report by Prescient & Strategic Intelligence (2019) refers to the growth of the MaaS market, especially the related vehicle sharing and rental services. This growth is driven by the shift to the online booking system and the cost-effectiveness and convenience allowing the user to pay according to the journey length or duration, without a significant investment covering the vehicle cost, insurance, maintenance etc.

Another noticeable trend in MaaS is the increasing electrification of fleets of car-sharing and rental providers, motivated by policies implemented at various levels of government (Research and Markets, 2019). A clear example is WeShare, a car-sharing provider with a fully electric fleet that belongs to the Volkswagen Group and operates in Berlin and Hamburg (since 2019 and 2021, respectively) with plans to expand to other European cities (Friedel, 2020).

Further growth is expected to be driven by the usage of autonomous vehicles for rental and sharing services which can reach nearly half of the expenditure incurred by owning a vehicle (Prescient & Strategic Intelligence, 2019).

4.3.9.4 Gaps

The integration of public and private-led services, typical for MaaS, implies a growing need for a unified institutional setup allowing continuous cooperation, data sharing and dialogue of all market stakeholders, including MaaS services, established actors and new mobility service providers. This cooperation should be ensured in a technology-neutral and actor-agnostic approach. Based on the dialogue, the city and/or the region should build a common vision with the right incentives and risks and profit-sharing so that everyone can benefit and admit it as fair. Reciprocal data sharing (aggregated, anonymized usage data including demand data such as origin-destination requests) among cities, public transport authorities, public transport operators and other mobility providers is crucial for all sides, helping to improve the service level and usage of mobility services and to support decisions made by transport planners (ERTICO – ITS Europe, 2019). However, there is still progress to be made to achieve the necessary data standardization.

4.3.9.5 Opportunities

Through MaaS platforms, users are offered the opportunity to choose a transport product or the combination of transport products that best match their requirements for each individual journey in an easy manner. MaaS can respond to user’s general preferences concerning travel aspects like speed, convenience, comfort, and cost, but also journey specific needs. In addition, users can use various types of modes and their combinations more efficiently. MaaS has therefore a potential to make better use of existing transport services and resources and also provide better intermodal connectivity within a region. Opportunities for users therefore include:

- Better connectivity between transport modes for users
- Users (residents and tourists) can travel faster and easier
- Better use of urban environment and infrastructure
- Ecological fuel (EV) for rental/carsharing cars
- Lower service costs than for individual cars
- More efficient route planning (shorter delay)
- Availability (effective spatial, time and quality coverage of services)

Nevertheless, it is also necessary to apply convenient policies to motivate citizens to replace car ownership with the use of MaaS, and what is even more crucial, to avoid the situation when MaaS users substitute not only personal car trips but also public transport journeys with car-sharing and ride-sharing services (Alyavina E. et al., 2020).

4.3.9.6 Involved policy instruments

- **Promoting the use of public transport:** the realisation of MaaS which is in principle user-oriented is consistent with the policy directions promoting the use of public transport instead of private cars as a countermeasure to global warming in the transport sector (Sakai, 2019).
- **Prioritization and financial support of public transport**: priority systems can provide substantial benefits related to travel time and reliability (CIVITAS, 2010). Increased governmental spending for

public transportation, such as trains, buses, or tramways would lead to an improved infrastructure and lower prices for tickets that would motivate people to drive less and use other modes of transportation (e.g., reducing prices by 15 % or 30 %).

- **Integrated transport:** integrating public transport, vehicle rental and sharing services into multi-modal transport allows reducing the number of privately owned cars (Kamargianni et al., 2018).
- **Promoting modal shift:** shifting demand from personal-use and single-occupancy vehicles to more sustainable modes (de Stasio et al., 2018).
- **Information campaigns:** campaigns informing people about the negative impacts of cars on human health, wildlife, climate, and environment can motivate people to drive less and use other modes of transportation (Wicki et al., 2019).
- **New/increased tax on fossil-fuels** that would increase prices for gasoline and diesel, and thus motivate people to drive less and use alternative-fuel vehicles and other modes of transportation (Wicki et al., 2019).
- **Requirements for newly registered cars:** stricter fuel consumption and emission standards (e.g., new Euro 7 norm) would make registration of cars using a lot of gasoline or diesel more difficult and expensive. This would motivate people to use cars consuming less fossil fuel, alternative-fuel cars, and other modes of transportation (Wicki et al., 2019).
- **Reducing subsidies for (fossil fuel) car industry:** This would result in higher prices for cars that run on fossil fuel and would motivate people to drive less and use other modes of transportation (Wicki et al., 2019).
- **Restrictions on quality of the fleet for the public transport and the shared mobility/rental** to reduce pollution (CIVITAS, 2020).
- **Low emission zones:** the authorities can determine areas in a city where access is restricted for vehicles that do not satisfy a certain emission standard (Hoen et al., 2021). Banning the most polluting vehicles would lead to the reduction of air-polluting emissions and an increased interest in the services provided by the MaaS system.
- **Restricting access of fossil-fuelled cars to downtown areas:** the authorities can restrict the access of fossil-fuel vehicles to downtown areas on certain days, e.g., 1 or 3 or 5 days per week (Wicki et al., 2019). Consequently, public transport, rental/sharing companies etc. that own non-fossil-fuelled cars would provide the services to travellers that still own fossil-fuelled cars.
- **Mandatory reporting on environmental impacts** (CIVITAS, 2020).
- **Congestion charge:** if the price of entry is set at an optimal level, charging vehicles entering a certain zone can significantly reduce congestion. Improved public transport performance and discouraging costs motivate travellers to use MaaS system (Hoen et al., 2021).
- **Differentiated prices of roads** according to street characteristics allow for redistribution of traffic through time and space (CIVITAS, 2020).
- **Better data collection and digitalisation, sharing platform and relevant standard KPIs** (CIVITAS, 2020).
- **Deployment of Intelligent Transport Systems (ITS):** the use of information and communication technologies in transport (e.g., the use of phones, satellites, computers, sensors etc. for dynamic traffic management, real-time traffic information, satellite navigation, tracking & tracing, multi-

modal journey planners, electronic toll collection, in-vehicle safety systems) has a potential to lead to the reduction of congestions, fatalities, injuries, and pollutant emissions (Ocakoglu, 2009).

- **Discouraging parking fee in city centres:** a combination of free or low-cost parking near public transport stops (at all origins and destinations), preferably in garaged car-parks, and high rates for parking on streets in city centres (Knoflacher, 2006; Santos et al., 2010).
- **Travel demand management:** Chang et al. (2019) point out that the sustainable implementation of MaaS needs to include travel demand management and an appropriate pricing scheme for private motorized vehicles.

4.3.9.7 Stakeholder and business model analysis

The value-in-use in the MaaS business model is an accessible (both physically and economically), flexible, seamless, convenient, and sustainable transport system. The availability of a transport system with the mentioned properties has the potential to satisfy most mobility needs while reducing the amount of privately owned cars and the share of trips made by individual motor vehicles, in favour of more environmentally friendly transport modes and technologies. This shift can lead to the mitigation of congestion, parking problems, emissions of greenhouse gases and other pollutants, as well as the improvement of the time reliability, efficiency, safety, and security of the transport system.

The following model is related to a MaaS system with an integration level 2 or higher (see section 4.3.9.1). At the beginning, a customer desires to travel from a certain location to some destination. He or she uses a MaaS provider's platform to find a convenient multimodal trip and obtains information on its price, duration, transport modes, number of transfers etc. The customer can also obtain information on travel time, distance, and parking possibilities in case of using a private car. These features help the customer consider certain aspects as well as preferences and eventually decide whether to use the MaaS service. If the customer decides to use the MaaS service, he or she can make a reservation (if necessary) for a preferred time, pay for the trip and the journey can start. The trip is then realized by providers of mobility modes included in the trip.

The operation of various mobility providers who cooperate within the MaaS system is discussed in other chapters of this deliverable. Involved services include public transport, car sharing and rental, shared micromobility, taxi, ride-hailing and ride-sharing, parking management etc.

Achieving the above-mentioned sustainability goals requires the implementation of convenient policies and regulations both at the governmental and local levels. For example, it is desirable to motivate transport providers to use cleaner and smart technologies, and for customers to shift from the use of private cars towards MaaS. At the same time, it is necessary to prevent travellers from replacing the use of public transport services with car rental/sharing. Policy instruments related to MaaS are discussed in section 4.3.9.6. To remain within the scope of nuMIDAS project, the focus is laid on the local level in the business model, and the municipality is considered as the focal organisation in charge of policy making.

In Figure 19, important stakeholders, their activities and added value to the business model can be found. More detailed descriptions of each stakeholder can be found in Appendix D, section D.9.

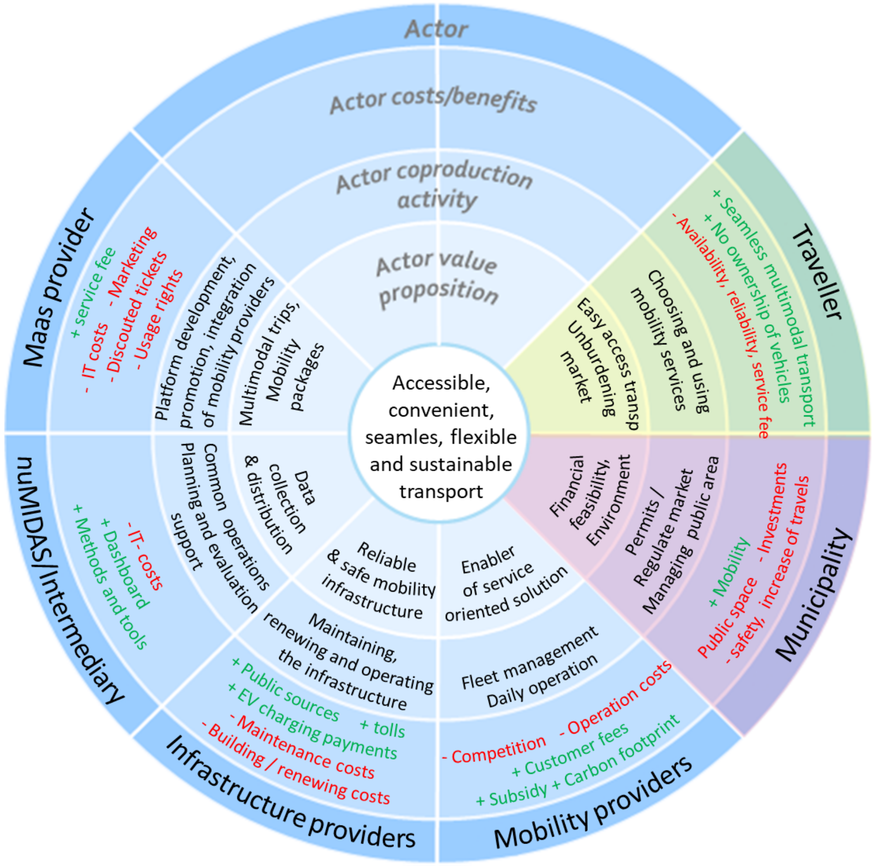


Figure 19: Business model radar for Mobility as a Service (source: own elaboration)

Polydoropoulou et al. (2020) identified the following risks for the successful implementation of MaaS: an imperfect regulatory framework of the cities, the lack of standardisation and openness of the application programming interfaces and the need for transport-related investments. Moreover, some mobility providers may lack the capacity and resources to be able to make the shift to technologies embedded in the MaaS system, and thus may be unwilling to participate there without support.

Even when already established, MaaS systems are still under development, as new technologies and transport modes evolve. An especially significant trend that can be observed is the growth of shared mobility and the increasing importance of OEMs as actors in the MaaS business model. It is expected that by 2030, revenues from manufacturing and selling cars will remain at the same level, while revenues from MaaS will substantially increase (Blanco & Esmaeilzadeh, 2020). The development of car-sharing and car-rental services can also contribute to wider economic impacts. Dimitriou et al. (2019) point out that with an increasing access to vehicles, more people can travel to locations previously inaccessible to them and take part in new activities. Due to substantially higher utilisation, sharing and renting cars can become more profitable than buying and maintenance of a privately owned vehicle, which would increase the disposable income of drivers (Inland Transport Committee, 2020).

Moreover, automated vehicles have a great potential to influence traveller's behaviour, improve road safety, contribute to congestion mitigation, and decrease the cost of incorporating car solutions into MaaS systems (Cruz & Sarmento, 2020). They can also erase the distinction between car-sharing and ride-sharing services (Dimitriou et al., 2019).

4.3.10 C-ITS and CAV Integration

4.3.10.1 Introduction

Cooperative Intelligent Transport Systems (C-ITS) constitute technologies and applications that exploit short- and long-range communications to digitally connect and enable information exchange between vehicles (V2V), vehicles and roadside infrastructures (V2I), as well as vehicles and vulnerable road users, such as pedestrians, cyclists, and motorcyclists (Edwards & Zunder, 2018). The deployment of C-ITS services has been the main objective of several EU-funded R&D projects, in which both “Day 1” and “Day 1.5” C-ITS services have been deployed (Mitsakis et al., 2018). C-ITS services[7] are expected to have significant benefits at the sides of driver/traveller experience, operational efficiency, road safety, and environmental conditions (Edwards & Zunder, 2018). C-ITS services are based on the exchange of standardized messages[8], which along with the adoption of common architectures at a cross-border level enable interoperability across C-ITS applications (Kotsi et al., 2020a). In Europe, the development of C-ITS standards and specifications is primarily under the responsibility of the European Telecommunications Standards Institute (ETSI) and the European Committee for Standardization (CEN) (Festag, 2015). With the aim of accelerating interoperability and ensuring the coordinated development of C-ITS applications at the EU level, the C-ROADS platform (2021) was established in 2016. This platform aims to develop harmonized C-ITS specifications through pilot installations and cross-testing of C-ITS services in 18 countries coordinated by the C-ROADS Steering Committee.

Until today, C-ITS technologies have been mostly used as Advanced Drivers Assistance Systems (ADAS), exploiting V2V and V2I communications to assist and coordinate automated vehicle functions. Taking into consideration that the number of C-ITS deployments in complex urban (and highway) environments increases, together with the penetration rate of Connected and Automated Vehicles (CAVs), the need to integrate C-ITS and CAV technologies also increases. This process promises to unlock significant opportunities related to the provision of more advanced and fully coordinated traffic management services, leveraging on the characteristics and functionalities of automated vehicles (Kotsi et al., 2020b; Maerivoet, 2019).

Specific tools used for C-ITS and CAV integration, including the examples of use cases and solved challenges, are discussed in section C.10.

[7] Examples of C-ITS services according to the Impact Assessment study carried out by DG-MOVE (2018) include: Cooperative collision risk warning (CCRW) service, Emergency electronic brake light (EBL) service, Emergency vehicle approaching (EVA) service, Green Light Optimal Speed Advisory (GLOSA) & Time to Green (TTG) service, Hazardous Location Notification (HLN), Information on fuelling & charging stations for alternatively fuelled vehicles (iFuel) service, Park & Ride information (P&Ride) service, Off street parking information and management (PInfo) service, On street parking management and information (PMang) service, Probe vehicle data (PVD) service, Roadworks warning (RWD), Signal violation / Intersection safety warning (SigV) service, Traffic information and smart routing (SmartR) service, Slow or stationary vehicle(s) warning (SSV) service, Shockwave damping (SWD) service, Traffic jam ahead warning (TJW) service, Traffic signal priority request by designated vehicles (TSP) service, In-vehicle signage (IVS/VSGN) service, In-vehicle speed limits (VSPD) service. According to C-ROADS platform (2021), there are five groups of Day 1, Day 1.5, and Day 2 C-ITS services, including Signalized Intersections, In-Vehicle Signage, Probe Vehicle Data, Hazardous Location Notification, and Road Works Warning, that are associated with several use cases.

[8] Examples of standardized messages according to Rondinone and Correa (2018) include: Cooperative Awareness Message (CAM), Decentralised Environmental Notification Message (DENM), In-Vehicle Information Message (IVI), Signal Phase and Timing (SPAT), Intersection Geometry Message (MAP), Collective Perception Message (CPM), Manoeuvre Coordination Message (MCM) and Multimedia Content Dissemination Message (MCDM).

4.3.10.2 Importance

A wide range of important KPIs is expected to be improved through the advanced traffic management services which constitute one of the main products of C-ITS and CAV integration. These KPIs are mainly related to five thematic areas (Transport Systems Catapult, 2017; Swarco, 2021). The first thematic area is *road safety*. It involves the combination of achievements in the field of C-ITS targeting road safety (e.g., Hazardous Location Notification) with achievements in the field of automated vehicle technologies (e.g., Adaptive Cruise Control) to provide enhanced safety-related services. By that means, the number and severity of road collisions are expected to reduce drastically. The second thematic area is *road congestion*. It involves the use of integrated C-ITS and CAV technologies to couple CAVs with roadside infrastructure with the aim of controlling traffic in a highly coordinated manner (i.e., enhanced connectivity between traffic managers and automated vehicles and vehicle fleets). Through this approach, KPIs such as travel times and average vehicle speeds either on a network or vehicle fleet-level are expected to be improved. Moreover, the capacity of existing infrastructure can be utilised better, decreasing the need for investments in *physical infrastructure* (third thematic area). The fourth thematic area is *vehicle emissions*. It is expected that V2V and V2I information exchange will augment the superior nature of automated vehicles in accomplishing driving tasks in a more energy-efficient manner than human beings (Dong et al., 2018). The last thematic area may be viewed as *cross-cutting*. It relates to the exploitation of integrated C-ITS and CAV technologies to make urban areas more attractive. This is attributed to the increased quality of life within urban areas due to reduced accidents, reduced bottlenecks and congestion, fewer vehicle emissions, and better management of urban spaces.

4.3.10.3 Trends

C-ITS and CAV integration are associated with several trends of mobility innovation. A first example constitutes Cooperative, Connected and Automated Mobility (CCAM). According to the European Commission (2021a), communication between, vehicles, infrastructure and other road users is a critical aspect for safeguarding the future of automated vehicles and their smooth and full integration in the overall transport system. Most importantly, cooperation, connectivity, and automation are not viewed as competitive with each other but as three interacting properties that will merge harmoniously over time. Building upon this rationale, several Member States have signed Letter of Intents to showcase their willingness to develop 5G cross-border corridors in an effort to provide full capable communication infrastructures supporting CCAM solutions (Europe 5G Observatory, n.d.). CCAM solutions enable a wide range of use cases, such as those presented by Wijbenga (2019) in the context of the TransAID project, encompassing coordinated driving and sensor sharing. The former is associated with a situation in which a group of highly automated vehicles exchange information and negotiate with each other in order to deny or help the coordination of a manoeuvre, while the latter is associated with information exchange within a mixed traffic environment, including connected and not connected vehicles.

Another trend enabled by C-ITS and CAV integration is the provision of services oriented to individual road users or vehicles (Maerivoet, 2019). According to this shift, new traffic management frameworks shall disrupt the practice of addressing transport modes in isolation and users as a whole but rather provide cross-modal dynamic traffic management solutions targeting the needs of individuals, following a “connected system of systems” approach. A significant prerequisite in order to fulfil this objective is the reachability of individual persons and vehicles, irrespective of time- and location-related factors. Moreover, such an objective implies the need for cooperation among different ecosystemic actors through new customer-oriented business models. A characteristic approach is TM 2.0 (Tzanidaki, 2016). According to this framework, Traffic Management Plans provided by road operators should be coherent with dynamic traffic information provided by traffic service providers, who are better placed to guide traffic and inform drivers or vehicles in an individualised manner. Such cooperation between road operators and service providers and other actors of the relevant ecosystem may be viewed as the first step towards the combination of direct and indirect measures for managing traffic.

Both C-ITS and CAV technologies rely on the availability of sufficient and accurate data streams. This has been recognized by the European Commission which, through relevant legislation, suggests the creation of National Access Points (NAPs) providing access to ITS-related data. According to this approach, it is expected that datasets isolated in silos will come into play adhering to well-defined data exchange protocols and quality criteria supporting, among others, the realization of CCAM solutions (Aifadopoulou et al., 2019).

Another trend to be mentioned is the development of fully automated Traffic Management Systems. Such systems are enabled by a wide range of frameworks and tools, supporting:

- Multi-source data fusion;
- Definition of dynamic traffic management strategies;
- Provision of coordinated C-ITS services (e.g., individualised advice to targeted road users or vehicles);
- Real-time assessment and selection of the proper dynamic traffic strategies based on both microscopic traffic simulation and the use of traffic-related KPIs; and
- Advanced visualisation.

A relevant system that bundles C-ITS services for achieving traffic management objectives has been developed in the context of C-MobILE project (Kotsi et al., 2020a).

Finally, recent efforts are placed on creating harmonized approaches concerning the categorisation of road infrastructures, concerning their capability to support infrastructure assisted automated driving. In this direction, the Infrastructure Support Levels for Automated Driving (Erhart et al., 2020) have been defined, similarly to the SAE automation levels of AVs. The categorisation ranges from no support to CAVs up to fully automated complex operations and traffic management/guidance through interconnected physical and digital road infrastructures' elements and AVs.

4.3.10.4 Gaps

Despite the importance and expected benefits of C-ITS and CAV integration as well as the recorded progress in this field, there are several gaps that need to be filled. These gaps may be discerned into research-related and practice/deployment-related.

Research-related gaps

- There is a scarcity of driver-vehicle models that are able to replicate the full range of already known, as well as most probable future CAVs and Self Driving Vehicles (SDVs) functions and capabilities (Do et al., 2019).
- Lack of commonly accepted frameworks to assess the potential impacts of traffic management scenarios in large-scale mixed vehicle fleet environments (Innamaa et al., 2018; Auld et al., 2017).
- Lack of ground-truth data to calibrate and validate underlying models, resulting in low accuracy.

- Low exploitation and rate of development of mature and reliable AI-based technologies despite their potential to solve problems such as event forecasting and action planning both at a network and service level (USDOT, 2020).

Practice/deployment-related

- Low utilisation of data derived from National Access Points to support the assessment and monitoring of CCAM-based solutions and services (Aifadopoulou et al., 2019).
- Limited existence and lack of awareness concerning traffic management technologies that exploit vehicle connectivity (European Commission, 2018).
- Use of C-ITS technologies mostly as ADAS without links to operational traffic management (Kotsi, 2020b).

4.3.10.5 Opportunities

Building upon the gaps discussed above, there are several opportunities that can navigate future efforts in the field of C-ITS and CAV integration. These opportunities include the exploitation of:

- the increased rate of deployment of short- and long-range communication standards and networks (ETSI ITS-G5 and 5G) for the exchange, collection and provision of data and information for connected vehicles and infrastructures (V2X, C-ITS);
- the increasing rates of CAVs;
- AI capabilities to support model-free traffic flow simulation and the quantification of synthetic KPIs;
- multi-source data (open-source data, social network data, data from National Access Points etc.);
- advanced visualisation solutions to support the ex-post assessment of CCAM-based traffic management services adopting a KPI-based approach.

4.3.10.6 Involved policy instruments

As it was mentioned in section 4.3.10.1, C-ITS and CAV technologies contribute to the fulfilment of several objectives classified into various thematic areas. Therefore, a wide range of policies and policy instruments may be used as a tool of increasing their rate of deployment, providing incentives to all actors of the relevant ecosystem. Such instruments include:

- **Green transport policies related to Green Deal**: EU's vision for a green, smart, and affordable mobility oriented to achieve the objectives of CO_2 emissions reduction and climate neutrality is heavily associated with making CCAM a reality and the increased use of smart mobility data and Artificial Intelligence (European Commission, 2020).
- **Road safety policies**: Despite existing evidence suggesting that the safety impacts of vehicle automation are difficult to estimate in precise (European Road Safety Observatory, 2018), road safety remains one of the main drivers of vehicle automation. The same holds true for vehicle connectivity, enabling the provision of safety-related warnings.
- **Transport digitalisation**: Digitalisation and the increased exploitation of Big Data are expected to enhance the current maturity and deployment rate of CCAM solutions. Key consideration constitutes the creation of an interconnected ecosystem, fostering data sharing and thus promoting innovation and creating business opportunities for a wide range of actors of the relevant ecosystem (European Commission, 2021b).

- **Transport personalisation**: The provision of integrated and personalised door-to-door mobility services constitutes the main driver of several innovative mobility concepts, with the main representative being Mobility as Service (MaaS). Despite the existing evidence suggesting that the low speeds of automated vehicles hinder their full exploitation potential for providing attractive personalised mobility services (Metropolia University of Applied Sciences, 2020), this is expected to change in the future with the gradual advancement of automated vehicle technologies. In addition, existing communication standards stemming from the field of vehicle connectivity are expected to create new opportunities for MaaS.
- **Promotion of Traffic Management as a Service (TMaaS)**: It involves the creation of cloud-based digital traffic management centres (TMCs) integrating existing physical TMCs by building upon the capabilities offered by vehicle connectivity and Big Data (Morlion, 2016).

4.3.10.7 Stakeholder and business model analysis

This business model's value-in-use is better and safer traffic management. The traveller wants to travel from one location to the other. From the vehicle side, V2V communication and automated driving technologies will increase travel safety, as these technologies will help with accident avoidance. The V2I communications in combination with automated driving technology will also be able to contribute to optimised traffic management. Automated driving will have a positive effect as it, for example, provides consistent driver behaviour. It can keep a consistent speed, and it will not make sudden actions on the road that confuse other drivers. This will be applicable for the private car owner, but also one of the main business models to be exploited with the integration of C-ITS and CAV is the provision of shared autonomous vehicles. These applications will have further impacts on what traffic management will entail for the stakeholders involved.

Shared autonomous vehicles will likely be operated in a fleet by a private fleet operator. This will enable quick response time to anywhere in a city as it can be monitored where all the vehicles are. This will also allow for a good distribution for the vehicles that can be based on for example expected travel needs during the day throughout the city. The private fleet operator can be a service provider, or an OEM car manufacturer that, next to selling cars, aims to provide a transport service to its users. The municipality of a city will have the task to make sure the city is built to support the development of such vehicles and transport services. Public space can be repurposed, as shared services may reduce the need for parking spaces for private vehicles. On the other hand, the municipality needs to make sure that these vehicles can operate safely in an environment with a lot of vulnerable road users. Think of the cyclists, motorcyclists, pedestrians. Additionally, the municipality may need to be involved in (part) of the exploitation of these services, as the private organisations may prefer to keep their fleet in a densely populated area, excluding other demographics from sufficient access to this service.

The road authority will need to cooperate with mainly the OEMs that produce the communications technologies that will be used by the car manufacturer OEMs to make sure that information exchange between vehicles, and between vehicles and infrastructure, will be adequate for ensuring road safety. Together with C-ITS standardisation procedures for this information exchange in order to make sure that all different OEMs will be able to have their vehicles integrated into the network.

With the insurance companies, it will have to be decided what actor in the system will be faced with liability if an accident occurs. Especially during the transition period of C-ITS and CAV integrated vehicles with regular vehicles on the road it can be expected that there still will be accidents.

In Figure 20, important stakeholders, their activities and added value to the business model can be found. More detailed descriptions of each stakeholder can be found in Appendix D, section D.10.

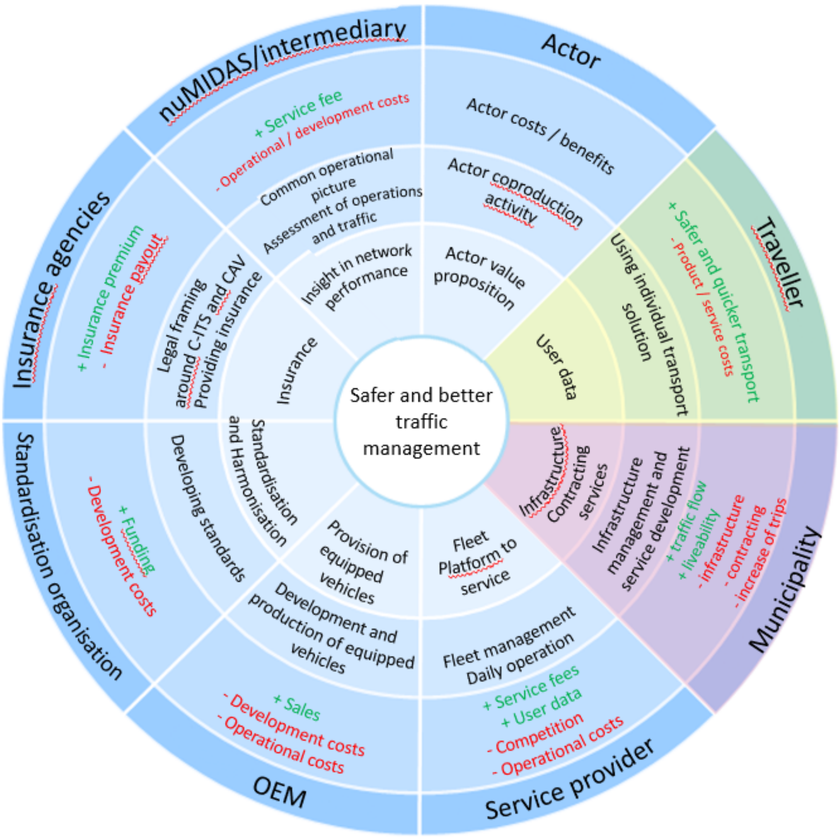


Figure 20: Business model radar for C-ITS and CAV integration (source: own elaboration)

The business models for the private organisations in the system are likely to shift more towards service-oriented instead of product-oriented business models. For example for fleet operators of autonomous and connected vehicles, and car manufacturers will start diversifying towards providing mobility services instead of focusing on the sales of cars towards private car owners. A change that can be expected is the integration of the mobility services into a MaaS platform. In such a system, travellers can use this platform to order a vehicle from any service provider. Next to advantages for ease of use or quick response times, this will have as an advantage that the traveller can always get the vehicle that is closest to them. This reduces the unnecessary distance travelled by the vehicle, which in turn reduces stress on the available infrastructure.

For the traveller, the commute will be valued differently. The travel time will go from the time that is perceived as a loss towards the time that can be used efficiently. The service providers for shared autonomous vehicles will aim to create a shift towards less car ownership.

For the success of C-ITS and CAV integration, it will be really important that the standardisation actors develop and/or implement the standards for the communication technologies. Data exchange with an intermediary organisation can help the public organisations with assessing the performance of the services delivered, and the functioning of the infrastructure that enables the autonomous vehicles.

4.3.11 Electric Infrastructure Management

4.3.11.1 Introduction

To reach their emissions reduction and air quality goals, many cities are working to increase the uptake of electric vehicles (EVs) by their citizens and businesses. While most charging for light-duty electric vehicles is done at home and work in the early stages of the market, the development of a robust public charging network is required as the market matures, particularly in dense urban environments where many drivers lack access to private charging. Local governments play an important role in developing EV charging infrastructure due to their authority over parking, building codes, and permitting and inspection processes.

Despite the recent advances in battery construction, battery EV charging is still relatively slow and batteries costly. The current transportation sector concentrates on using battery EVs also for heavy-duty and public transport, even if there are other alternatives available and worth considering (in-motion charging, fuel cells EVs). Fuel cell EVs may be preferred in some cases due to their quick refuelling time and longer range, despite their lower well-to-wheel efficiency, as the prices of fuel cells decrease (Bethoux, 2020) and hydrogen generating stations may be located at petrol stations or at locations with large renewable sources installed, where hydrogen generation serves as a means of excess energy storage and power grid stabilisation. Also, the current petrol station infrastructure may be modernised and used to provide hydrogen for private EVs.

Battery EVs are likely to play a significant role in integrating renewable energy sources into the electric power distribution grid, e.g., by storing energy in times of excess generation and providing energy back to the network during times of peak load. Conversely, inadequate, or poor management of EV charging could result in negative impacts on power quality and grid reliability. The collective impact of EVs on the electricity distribution grid will depend on a variety of factors, including power ratings, charging time (off-peak or on-peak), charging rate and pattern, the geographic distribution of EVs and their state of charge, etc. The negative impacts could include voltage instability, harmonic distortions, load imbalance and overload of the electricity distribution grid (Chan, 1993).

Cities should further develop their energy management in a coordinated way and through an optimal approach, by profiting from the synergies among different energy solutions. A comprehensive model that includes all energy-related activities while keeping the model manageable is highly desirable in order to meet the increasing energy needs of present cities. For example, Calvillo et al. (2015) propose five main energy-related intervention areas for a city – generation, storage, infrastructure, facilities, and transport (mobility), see Figure 21. These areas are related to each other but contribute to the energy system in different ways: generation provides energy, while storage helps in securing its availability; infrastructure involves the distribution of energy and user interfaces; facilities and transport are the main final consumers of energy, as they need it to operate. Energy systems' implementations are supported by three main layers: intelligence (control/management), communication, and hardware (physical elements and devices). Hence, multidisciplinary solutions are expected.

Specific tools used for electric infrastructure management are discussed in Appendix C, section C.11.

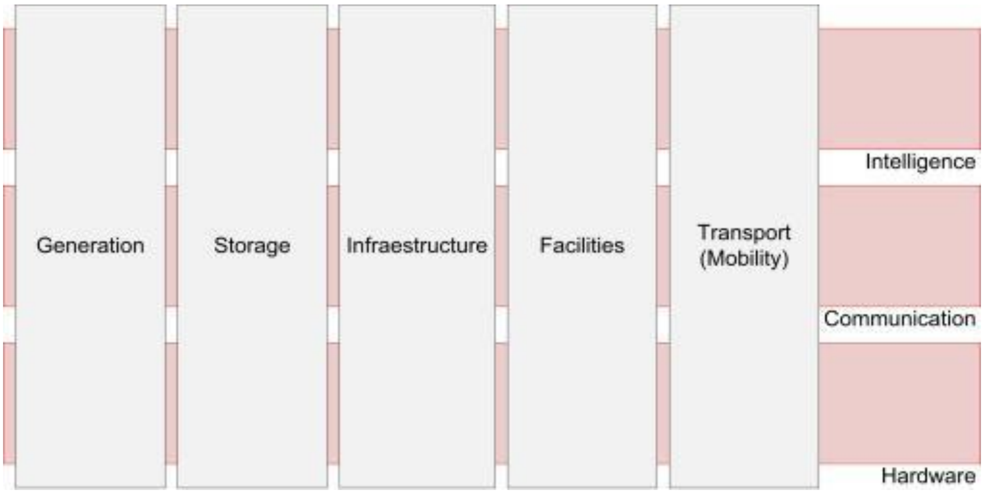


Figure 21: Five main energy-related intervention areas for a city (Calvillo et al., 2015)

4.3.11.2 Importance

In the coming years and decades, the number of electric vehicles (battery-electric and plug-in hybrid vehicles) will substantially increase. According to the EU EUCO301 scenario that projects reaching the 2030 EU energy and climate targets and CO2 standards, the number of electric cars and vans will get progressively more stringent, driving the shift towards low emission mobility (Eurelectric, 2015). In this scenario, by 2050 up to 34% of all final energy demand in passenger car transport could be electric. The related additional electricity demand (about 356 TWh) would increase overall EU electricity demand by 10%; it will also present a new challenge for distribution grids: the load curve of the local power grids is going to change, posing new challenges for electricity generation, transmission, and distribution infrastructure (PlanGridEV, 2017). If EV batteries are charged without any strategy, this may result in an increase of expected energy not served by the power system or the need for additional peak load capacities. At the same time, an optimised charging strategy may represent additional flexibility for the power system and thus facilitate the integration of variable renewable energy sources and bring down power generation costs (European Commission, 2018).

4.3.11.3 Trends

Growing consumer awareness: For many consumers, EVs have been a niche market, but this is currently changing, mostly due to factors as a growing number of charging stations, decreasing battery cost, predicted decrease in the production of vehicles with internal combustion engine (ICE) and stronger regulations for those vehicles. Also, many concerns, e.g., range anxiety, start to disappear as more households start to use EVs (AAA, 2020).

Improvements to charging infrastructure: Current typical EV owners use either hybrid EVs or charge them at home using their private AC chargers. The limited number of residential charging stations is expected to grow rapidly as the number of registered EVs grows. Fast chargers are becoming widely available, and the efficiency and power rating of wireless EV chargers rises (ORNL, 2018).

Growth of the personal EV and HEV market: Current personal EVs and HEVs production grows, the market share of newly sold HEVs in the EU reached almost 20% in Q1 2021.[9]

[9] https://www.acea.be/press-releases/article/fuel-types-of-new-cars-battery-electric-5.7-hybrid-18.4-petrol-42.2-market

Slow uptake of heavy-duty EVs, e-buses and e-vans: While many cities currently consider transforming their ICE bus fleets to e-buses, the progress is slow, probably mainly due to very high infrastructure and vehicle costs and other operational reasons (IEA, 2021). Some municipalities and regions therefore consider either using in-motion charged vehicles (i.e., battery-trolleybuses) or switch to fuel cells (Sustainable Bus, 2021).

4.3.11.4 Gaps

The intermittency of renewable sources, the increasing demand, and the necessity of energy-efficient transport systems, among other things, represent important energy challenges that are better addressed as a whole (Morvaj et al., 2011) rather than separately, as is usually the case. Digital simulation models have been developed to assist stakeholders in understanding urban dynamics and in evaluating the impact of energy-policy alternatives. However, very often these efforts lack the “full picture” and, therefore, produce suboptimal solutions.

One of the limiting factors of charging station construction are the incurred costs. The ICCT review (International Council on Clean Transportation, 2021) reports that the administrative (soft) costs related to single charger construction are significantly higher than the hardware cost. Another problem in EV infrastructure planning is the fact that the electric power grid is often in hands of private investors: this implicates the need for tight collaboration between municipality and power grid owners during the whole course of planning, as the planning of charger locations cannot be done independently from the grid owner – in many cases the charging station locations that are optimal from the municipality and transportation point of view are exactly the places where the construction of chargers would be costly due to necessary update of the power grid infrastructure.

It is apparent that municipalities and other stakeholders *do not have appropriate tools at hand that would help them to streamline the complicated process of identifying appropriate charging locations*, ensuring their adequate connectivity to the grid, issuing permits etc. The closest thing to a tool is currently used in Stockholm, where location planning for charging stations is facilitated by a heatmap specifying locations where new chargers may be built (SWECO, 2020). A different approach is used in London, where TfL has a special task force (The Mayor’s Electric Vehicle Infrastructure Taskforce, 2019) and manual (Transport for London, 2019) that help to coordinate the process.

According to (International Council on Clean Transportation, 2021), current policies seem to be *reactive* rather than *proactive*, i.e., the interviewed municipalities react to the demand instead of actively model its future development.

4.3.11.5 Opportunities

The following opportunities have been identified:

- Vehicle-to-grid (V2G) technology offers a possible opportunity to sell excess energy via two-way chargers (Shariff et al., 2019); this has been experimentally tested already in 2013 (Shinzaki et al., 2015).
- EV fleets (e-buses, trolleybuses, taxis, light-duty vehicles) can be used as dynamic energy storage, and due to their movement energy may be transported to places where it is needed.
- Both battery EVs and hydrogen generation units may be used to stabilise power grid.

- Using in-motion-charged public transport vehicles instead of opportunity-charged or depot-charged ones may stabilise the power grid and lower the running costs (trolley:motion, 2020).

4.3.11.6 Involved policy instruments

The instruments include also general, state-wide policies that municipalities may benefit from.

- **Promotion of EVs:** Different policies may be activated to promote the use of EVs over ICE vehicles, e.g., alleviating congestion charges for EVs, lifting parking time constraints, imposing additional taxes on fossil fuels, or more favourable road pricing for EVs.
- **Endorsing private charging stations:** Mainly for owners of island systems, who may use their EVs as a stabilisation element and additional energy storage.
- **Aggregators:** Place should be given to new actors, such as aggregators that can bundle the shiftable load of all flexible consumers and/or establish real-time pricing for final costumers themselves. This echoes the relevance of paving the way for aggregators, as required by the Member States through Article 17 of the proposed recast of the Electricity Market Directive (European Commission, 2017b).

4.3.11.7 Stakeholder and business model analysis

As the central value-in-use, a widespread, convenient, efficient, and stable infrastructure for e-mobility is considered. In many regions, this infrastructure is not yet available to the desired extent. The preliminary step is therefore a proper infrastructure planning which requires cooperation of a central government, municipalities, energy suppliers, location owners, charging system providers, mobility providers and also researchers in the field of transportation who can help to coordinate activities of individual actors and plan a convenient infrastructure, taking into account the present state of the electrical grid, traffic intensities in various parts of the traffic network, travel demand, etc.

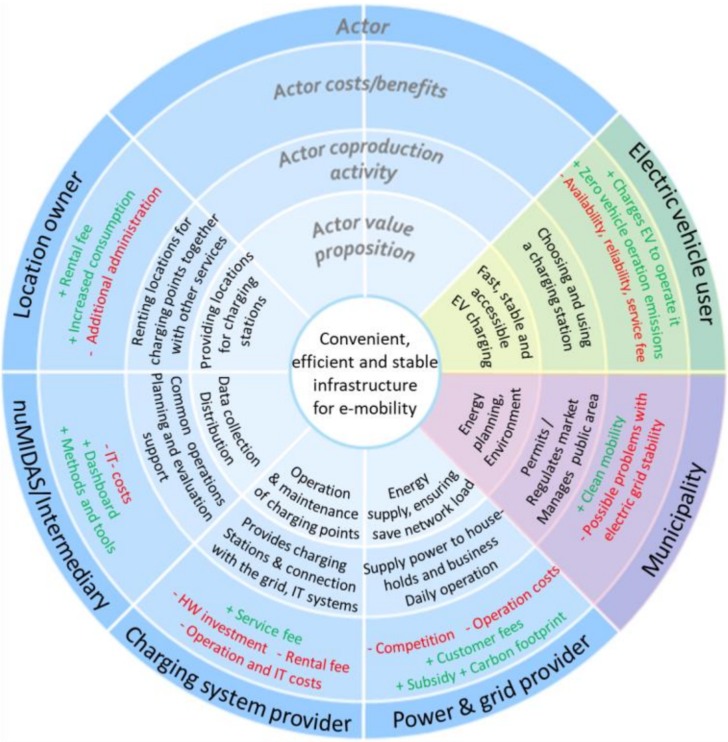


Figure 22: Electric Infrastructure Management business model radar (source: own elaboration)

Once a charging infrastructure is available, the scenario starts with the production of electric energy. It is then transported by a power grid to the location where charging point hardware in combination with internal or external software is used to supply energy from the grid to the vehicle. The use of the equipment requires maintenance and service provided by a charging system provider. In most cases, this actor also manages the direct contact with electric vehicle owners in the form of service, payment, and marketing. Individual actors and their activities are discussed in the Appendix D, section D.11.

In Figure 22, important stakeholders, their activities and added value to the business model can be found. More detailed descriptions of each stakeholder can be found in Appendix D Stakeholder role descriptions. At present, short-distance trips and charging at home or work prevail among users of personal electric vehicles. Technical development and the overall increase of e-mobility is expected to lead to the increase of long-distance trips and the number of users without home charging opportunity, and thus to increased demand for public charging points. And vice versa, a sufficiently dense network of publicly available charging points has the potential to drive the growth of e-mobility.

Another aspect that can change the present business model is the development and testing of Electrical Road Systems (ERS) that allow charging during driving. Besides overhead power lines limited to commercial vehicles[10], these systems also include attempts for the ground-level power supply through inductive coils embedded in the road[11] that can be used by any vehicle, which allows for public charging through power metering and billing systems. Since the main locations in this solution are public roads, private-public partnership solutions can be expected to be involved in the corresponding business models.

Further, since personal vehicles are parked for ca. 95 % of the time, their batteries could be used to let electricity flow from them to the electric distribution network and back. For customers, the use of this vehicle-to-grid (V2G) technology would increase the utilisation of their electric vehicles and therefore reduce the costs per kilometre. For energy providers, it helps to balance variations in energy production (especially in the case of renewable sources) and consumption. In the private segment, a number of power and grid providers are already offering this solution to customers. Promising are also projects aimed at the integration of electric mobility and the Local Energy Community with the purpose of increase the use of renewable energy (Verde et al., 2020). The extension to public charging points requires reaching a critical number of vehicles in order for a V2G solution to be commercially viable, e.g., at parking spaces close to large shopping malls or travel centres.

The present model would also be influenced by the development of fuel cell vehicles. The public hydrogen fuelling infrastructure is very limited now, but it may substantially change in the forthcoming years.

[10] After the successful completion of system tests on roads in California and Sweden, the overhead contact line system developed by Siemens Mobility GmbH achieved a TRL (technology readiness level) 7 in 2018. Since 2019 it has been tested in several locations in Germany (Hartwig et al., 2020).

[11] Inductive systems were tested in South Korea since 2013, later in Germany, but TRL 6 could not be exceeded, and the tests were discontinued (Hartwig et al., 2020). At present, an inductive system for lorries and busses is tested in Gotland.

4.3.12 Parking Management

4.3.12.1 Introduction

Parking Management is a set of policies and strategies which result in more efficient use of parking facilities (Litman, 2019). The approach to parking management varies according to the scope, type of parking facility and its users. It can be solved at local level, district level, city level, etc. The parking facilities can be divided according to different aspects. For instance, on-street and off-street parking determine whether a parking lot is accessed directly from a street. Off-street parking is usually accessed by a barrier which makes feasible a barrier-based payment system. Off-street parking includes both ground parking (eventually ramp parking) and the parking facilities within or under a building. Another aspect used to classify parking lots is the ownership. More precisely, private parking is reserved for specific groups of users, whereas public parking is open to the general public. A distinction can also be made according to the purpose of parking facilities. For example, policies and strategies are different for domestic parking, Kiss & Ride, public transport hub parking spaces etc. Residents, employees, and customers/visitors then represent the main types of users considering that parking facilities are designed having in mind a combination of these types of users (Litman, 2019; Barter, 2016). A key tool for parking management is the provision of information to drivers, such as current parking availability, regulations, or price. This information can be provided both online and offline by means of signs, maps, brochures, websites, electronic guidance systems, etc. It should also advise alternative travel options including walking, public transport, car sharing, etc. (Litman, 2019).

Specific tools used for parking management, including the examples of use cases and solved challenges, are discussed in Appendix C, section C.12.

4.3.12.2 Importance

The undoubtable increase of vehicles all over the world and the increasing demand for mobility result in the increased demand for parking facilities and the need for effective parking management solutions. An appropriately applied parking management allows for the efficient utilisation of parking infrastructure. It can significantly reduce the number of required parking spaces, and thus also facility costs to governments, business, developers, and citizens. Informing drivers on available spaces and prices also substantially decreases the share of traffic that is cruising for parking (Hampshire & Shoup, 2018), and thus reduces the vehicles' fuel consumption, saves drivers' time and frustration (Litman, 2019). Parking management is therefore a key challenge to more sustainable mobility in urban areas (Kirschner & Lanzendorf, 2019), considering that poor parking management leads to overcrowding of vehicles, resulting in traffic congestion. It also contributes to air and noise pollution (Grand View Research, 2019).

4.3.12.3 Trends

There are many commercial solutions for local parking management focusing on individual private off-street parking. Capterra (2021) or G2 (2021) provide a survey of the most popular software solution addressing different types of off-street parking. Such systems tend to achieve predictive, flexible, and dynamic parking management (BePark, 2021). The most advanced systems support dynamic assignment and reassignment of parking places in real time. Such systems continuously monitor an area to relay information on parking space availability. It combines various equipment and software (cameras, parking meters, sensors, and automatic gates) in order to improve security and reduce adverse impacts on traffic caused by vehicles in search of a parking space (Gautam, 2019). There is another trend which has appeared in off-street private parking recently. It is the philosophy of Airbnb being applied to parking (Kerb, 2021; Parkamo, 2021).

On-street parking management usually emerges gradually. Once the on-street parking becomes saturated, a rationing of parking access is required. The main tools for this are: time limits, permits (preferential/reserved access), and pricing (Barter, 2016). Private sector's actors are often contracted out by an authority to handle the on-street parking management. The contract typically involves signage, pricing, and enforcement equipment, monitoring systems, etc.

In recent years, there is a tendency to develop a smart parking ecosystem including two types of flows (Lin et al., 2017): traffic flow and information flow (see Figure 23). Traffic flow is represented by vehicles that involve the drivers' parking behaviour, whereas information flow is based on parking data. A set of sensors and technologies is used as a transition element between these two flows. On one side, they are used to acquire parking data mapping the parking behaviour and, on the other side, they are used to provide useful parking information to drivers.

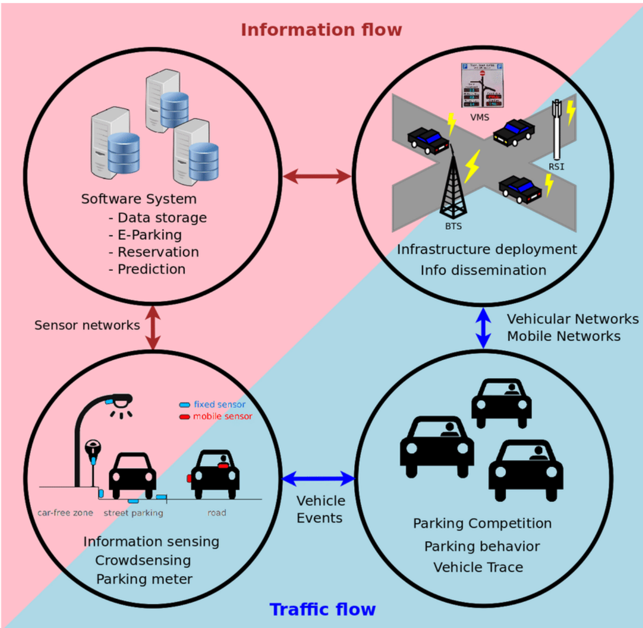


Figure 23: Overview of Smart Parking ecosystem (Lin et al., 2017)

An important aspect of information flow is the sharing of parking data across platforms around the world. This is the reason why the Alliance for Parking Data Standards has emerged. The Alliance aims to create a common language for data elements and definitions in the parking, transport and mobility sectors that will facilitate seamless integration, compatibility and communication between parking entities, the automotive industry, IT developers, as well as map and application providers (British Parking Association, 2021).

4.3.12.4 Gaps

Each city and even each district within a city can have its particular parking problems. Moreover, one strategy to parking management can be effective for a specific city or place around the world and non-effective for another one. Thus, there is no one-size-fits-all solution.

Authorities are used to implement *ad hoc* parking management where decisions are based on impressions rather than on solid information. The collection and analysis of parking data are often missing, as well as the evaluation and update of already set strategies (Barter, 2016).

In many cases, off-street parking is under-utilised due to the lack of information on parking availability or insufficient collaboration between private and public sectors (Barter, 2016). The problem is that a great deal of data related to off-street parking is possessed by private companies that may have concerns about security, privacy and disclosure of their business model, and the usable data sharing therefore requires governments, businesses, and consumer advocates cooperate to establish mutually agreeable data-sharing practices (Sperling & Safford, 2019). Moreover, VMS (Variable Message Signs) which are often used to inform drivers about parking availability are usually positioned in areas adjacent to the off-street parking facilities (McDonald et al., 2010). In this respect, their utility decreases significantly.

4.3.12.5 Opportunities

The information provided by VMS is usually available only at the area close to the parking area. The use of GPS, smartphones and cloud software is increasing, which boosts the development of easy way-finding mobile applications that provide real-time data to help drivers navigate to the nearest vacant parking space. The growing demand for real-time data to determine the availability of car park spaces is expected to drive the demand for parking management solutions. The growing adoption of parking management systems at corporate campuses, airports, and shopping complexes is also projected to drive market growth over the forecasted period (Grand View Research, 2019).

4.3.12.6 Involved policy instruments

According to Kirschner & Lanzendorf (2019), the following five parking policy concepts promoting sustainable transport in urban areas can be determined. Other policies is added from sources cited below.

- **Maximum parking requirements:** Determining the maximum amount of parking lots spaces per unit in new residential buildings with the aim to support the use of public transport.
- **Physical detachment of residence and parking:** Physical separation of residence and parking space, such that the distance from homes to residential parking is not shorter than the distance to nearest public transport station.
- **Residential parking permits and the limitation of available parking space:** Permits for residents can be used for the regulation of available public space for parking and the restriction of the access to parking for non-residents.
- **Performance-based pricing:** Pricing policy that varies by time of day and by location. It can discourage the use of private cars in areas that are well served by public transportation. Moreover, revenues may be used to support more sustainable means of transport.
- **Parking as a demand management strategy:** Reduction of the number of off-street parking spaces to decrease the likelihood of owning one or more cars.
- **Information and communication:** Dynamic route guidance to available parking places, either at the road side (information) or via a satellite navigation system (communication) (Mingardo & White, 2018).
- **Shared parking:** Private parking owners (hotels, companies, universities, hospitals, etc. and individuals) can rent out their parking space at times they don't use it. It can reduce the parking requirements (Palmer & Ferris, 2010).

4.3.12.7 Stakeholder and business model analysis

The value-in-use in the business model of smart parking management is the improved parking experience and efficiency of parking space resources. From the drivers' point of view, it helps to save time otherwise spent by searching a free parking space and to optimise costs of parking. For cities, it helps to use the available parking infrastructure more efficiently, mitigate problems with congestion and environmental burden related to cars that are cruising and searching for parking, and promote parking further away from city centres where low-cost parking spaces exist. Parking becomes increasingly data-driven and guided based on real-time sensing information, which contributes to the efforts to achieve sustainable mobility (Rinnekangas, 2020). It is also expected that smart parking systems will help to reduce traffic accidents resulting from driver attention deficits as they concentrate on searching for parking spaces or rush to occupy existing ones. For parking spaces providers, a smart parking system helps to maximize the utilisation of available spaces and resources, and thus to increase the revenue. Moreover, as these systems work with processed data from cameras and various sensors, they are expected to improve traffic law enforcement through the identification of real-time cases of density violation and illegal or improper parking (Biyik et al., 2021).

In a smart parking system scenario, a driver uses an IT platform administrated by a parking system provider before his trip or before he reaches the destination to find a parking space at a convenient location and for a convenient price. The driver can make a reservation, pay for it, and is also offered an optimal route for his trip and navigated to the selected place.

Parking spaces are owned by different owners (cities, private companies, individual parking spots owners, etc.) and managed by various parking space providers cooperating with the parking system. Parking system provider facilitates a connection between parking space providers and drivers who search for suitable parking meeting their needs of optimal price, time and/or location. Thanks to the system, drivers have detailed information allowing better decision making on parking. Parking space providers can offer their vacant spaces for a reservation using real-time sensing of parking spaces. They become part of a coherent marketplace, improve their market visibility towards drivers with minimal effort and increase their revenue from increased space rental transactions. Parking system providers contribute with real-time information on the availability of parking spaces, and in turn, they receive revenue per parking space transaction. Payment and reservation are provided by parking payment providers in the form of their end-user applications which integrate parking systems via open APIs. They receive a share of each reservation transaction.

Forming the outlined ecosystem is feasible as a form of gradual development to maintain growth by adapting on evolving needs by users and organisations.

In the business model radar below, important stakeholders, their activities and added value to the business model can be found. More detailed descriptions of each stakeholder can be found in Appendix D, section D.12.

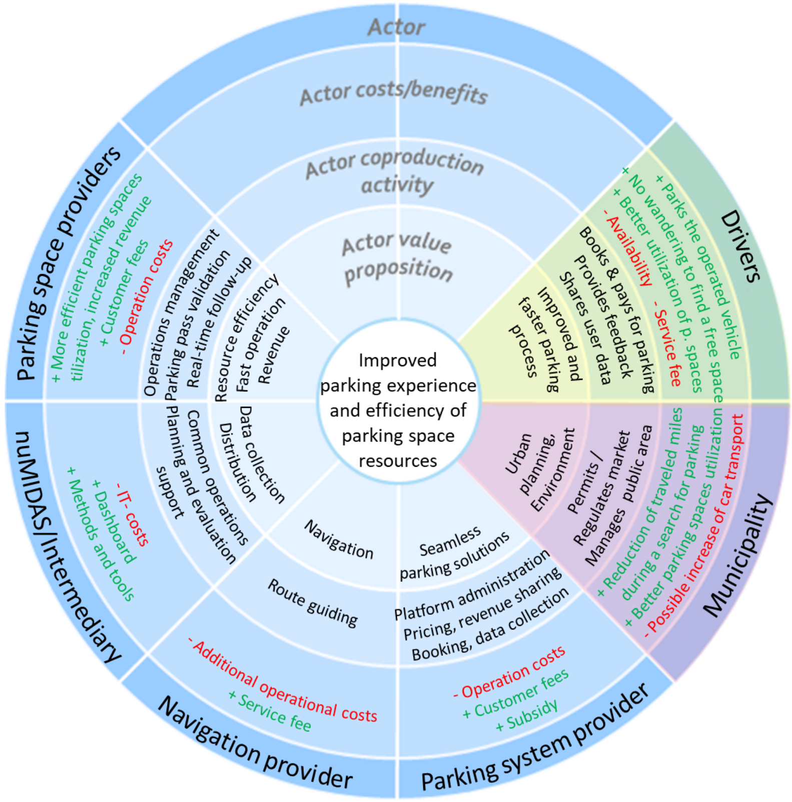


Figure 24: Parking Management business model radar (source: own elaboration)

The traditional parking model was based on free or fixed-rate on-street parking with physical parking meters. Undervalued parking and the lack of information resulted in excess demand for a bounded resource accompanied by lost revenue, increased congestion due to an increased drive-alone rate for commute trips and cars looking for a free parking lot, decreased access to business, environmental harm, and inconveniences to travellers (FHWA, 2012). Fixed prices, isolated physical parking meters and missing or incomplete information on available parking spaces leading to under-utilisation of existing parking spaces persists in many cities. However, there is a trend towards smart business models outlined in the previous paragraphs, allowing the mitigation of the mentioned problems.

Even the existing smart parking solutions are subject to further development driven by new technologies. With the development of electric mobility, it is expected that parking facilities will broaden their business by offering charging possibilities. Various forms of car sharing lead to fewer car kilometres driven per person, which may lead to fewer trips and hence to fewer parking transactions. Sharing concepts also increase the share of time that cars are in use, and therefore reduce the time they are parked (Mingardo & Witte, 2018). Further changes are also expected to occur with wider use of autonomous vehicles that will substantially change the use of vehicles and how they leave parking spaces through self-leaving abilities and mechanical valets (Biyik et al., 2021).

4.3.13 Ride-Hailing and Ride-Sharing

4.3.13.1 Introduction

Ride-hailing and *Ride-sharing*, thanks to the support of new technologies such as the use of smartphone applications, are new useful means of transport in order to satisfy the growing demand for transport within cities.

In particular, ride-hailing is not entirely new. In fact, it is the evolution of the deal-a-ride service (Gilibert et al., 2020). The only difference is that while now the booking is done instantly with your smartphone, in the case of the deal-a-ride, however, the booking had to be made before (Gilibert et al., 2020).

Ride-hailing services let people use smartphone apps to book and pay for a private car service or in some cases, a taxi. They may also be called ride-booking services (Henao & Marshall, 2018).

Ride-sharing services aim to bring together travellers with similar itineraries and time schedules. Ride-share providers across the globe offer online notice boards for potential car-poolers, whether for daily commutes or one-time trips (Agatz et al., 2012). Different types of ride-sharing can be identified in the literature: ride-sharing with static requests, where all requests are known before the trip starts; ride-sharing with dynamic request, where new requests can be added during the execution of the transport service; and ride-sharing with either deterministic or stochastic requests (Martins et al., 2021).

Specific tools used for Ride-hailing and Ride-sharing services are discussed in section C.13.

4.3.13.2 Importance

Ride-hailing has brought new mobility choices to urban residents, who can take advantage of an easier and less expensive option to travel in comparison with conventional taxi services. Passengers travel in a private vehicle where they do not have to bear the cost of their own vehicle, besides not having any responsibility for driving and parking (de Oliveira Souza et al., 2021).

Monetary, environmental, and social costs associated with single occupancy vehicles could be reduced by more efficient utilisations of empty seats in passenger transport cars. This is the goal of ride-sharing strategies, which, apart from generating substantial economic impact to users, aims to reduce the number of vehicles on the road and, as consequence, contribute to diminishing traffic and pollution (Martins et al., 2021).

4.3.13.3 Trends

If rides with on-demand ride services mainly consist of trips over relatively short distances, then there is a complementarity between ride-hailing and electric mobility. Another issue that is likely to grow in importance in the future is the mobility of people who are physically impaired, due to age or other reasons. This service is usually provided by taxis, but several US cities are working on regulations that would involve the issue in on-demand market segments (Franckx, 2016).

The tendency for shared mobility services as ride-sharing is to adopt not only electric but also autonomous vehicles especially for environmental concerns (Tafreshian et al., 2020). Other innovations are ride match aggregators, websites or other interfaces that search all ridesharing databases, and multimodal integration to connect ridesharing with other transportation modes (Franckx, 2016).

4.3.13.4 Gaps

Although ride-hailing undeniably requires less space for parking, the time the driver spends circulating while waiting for passengers can increase congestion rather than easing it, consequently increasing the emission of pollutants. Furthermore, these services sometimes replace not only conventional taxi, but also transportation modes that are more sustainable such as public transport and personal non-motorized modes (de Oliveira Souza et al., 2021). However, research on this topic is scarce due to the lack of open data (Henao & Marshall, 2018).

The further development of ride-sharing faces several behavioural barriers, the most important of which are: (a) the flexibility and convenience of the private vehicle (b) the desire for personal space and time and the aversion to social situations (c) the reluctance to share rides with strangers or use one's own vehicle to pick up more than one stranger (Franckx, 2016).

Another gap that can be highlighted is the optimisation problem of the best route that the driver has to take in a ride-hailing service (Cao et al., 2021), which would increase the load factor of a vehicle, reducing, consequently the number of cars circulating and therefore congestion.

4.3.13.5 Opportunities

The presence of ride-hailing services is shaping travel behaviours and emergent urban mobility patterns. These services can either being an addition for public transport, covering the first and the last mile problem in passenger transport (Acheampong et al., 2020).

Ride-sharing can also be integrated with the public transport system, and thus enhance urban mobility. It can serve as a feeder system that connects less densely populated areas to public transport (Stiglic et al., 2017). Furthermore, with Mobility-as-a-Service (MaaS) becoming a more popular mode of transportation, the integration of ride-sharing into MaaS operations and its implications on the MaaS level of service can be investigated (Tafreshian et al., 2020).

4.3.13.6 Involved policy instruments

- **Free or reduced-price access to high-occupancy toll lanes:** the higher is the occupancy rate, the lower is the toll (Franckx, 2016)**.**
- **Parking cash-out:** employees can opt out of a parking space and receive compensation from their employer who leases/owns the space (Franckx, 2016).
- **Pre-tax commuter incentives:** commuter is not taxed on ride-sharing expenses (Franckx, 2016).
- **Periodic credit:** transportation network companies (TNCs), who provide on-demand services as ride-hailing, have a maximum amount of vehicle-kilometres to drive; if this limit is exceeded, they must pay a surcharge (Franckx, 2016).
- **Integrated transport:** public transport operators offer discount codes for the use of ride-sharing services also in order to increase the number of people using public transport, especially those who live in suburban areas (OECD-ITF, 2017).

4.3.13.7 Stakeholder and business model analysis

In these business models, the value-in-use is mobility independence without the need to own a car. Indeed, ride-sharing and ride-hailing are complementary and additional services of both public and private transport, corresponding to a future vision in which many citizens will not own private cars.

Ride-Sharing is not a new mobility service, so some business models, such as carpooling, are not so innovative. However, with the advent of the internet, a new business model has emerged: the P2P (peer to peer) ridesharing (Cohen and Kietzmann,2014). This business model allows a meeting between user A, who offers a mobility service, and user B, who instead looks for a transport service in order to make his/her travel. Its scenario can be described in the following way.

- A user (user A), who owns a car, has to travel from location A to location B.
- To split the trip costs, the user decides to insert all the details of the trip (time and point of departure, time arrival, how many free seats there are in the car, the price, etc.).
- Another user (user B), who is looking for a ride on the ride-sharing app to go to his/her destination, sees that user A, with whom he/she shares the whole journey or at least a part of it, still has seats available on his/her car.
- User B books and pays for a seat in user A's car through the app.
- User A accepts both the booking and the payment from User B.
- On the day of departure, user A and user B meet at a designated place.

In the case of ride-sharing, the driver doesn’t make a profit but receives a small “subsidy” regarding the costs of the trips (fuel, toll, etc.) (Cohen & Kietzmann, 2014).

Ride-sharing applications or platforms can be implemented within a single MaaS platform. In this way, the MaaS platform will become a single application in which it is possible to book all the mobility services existing in a city.

In Figure 25 and Table 5, important stakeholders, their activities and added value to the business model can be found. More detailed descriptions of each stakeholder can be found in Appendix D, section D.13.

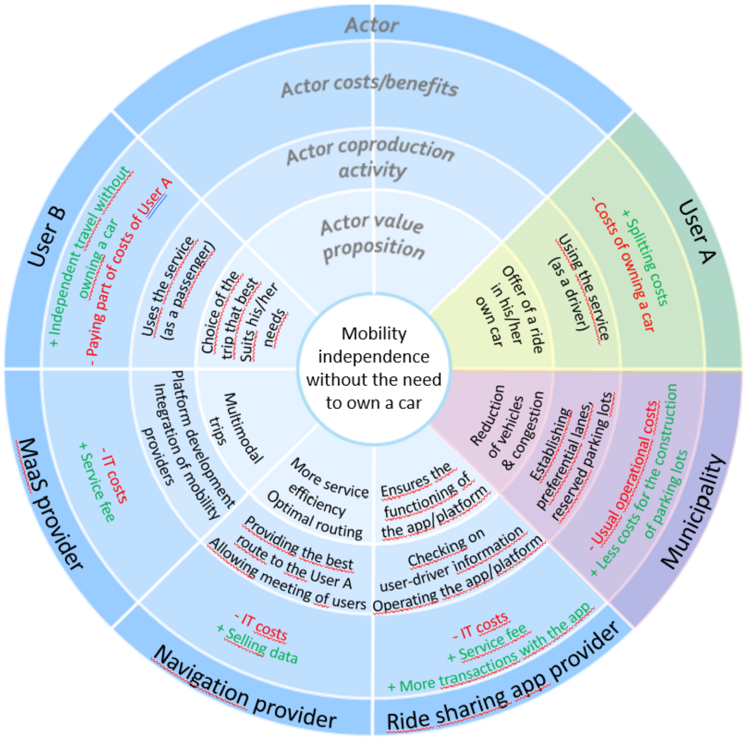


Figure 25: Business model radar for Ride-Sharing (source: own elaboration)

Table 5: Additional stakeholders for Ride-Sharing

Actor	Actor value proposition	Actor coproduction activity	Actor benefits	Actor costs
nuMIDAS/ Intermediary	Data collection & distribution	Common operations, Planning and evaluation support	Dashboard Methods & tools	IT costs

For Ride-Hailing, Wei et al. (2020) have identified three different business models:

- Premier model: In this case, each user uses one car with one driver. Specifically, the driver can be a driver who collaborates with the platform or who is hired by the platform (at the moment there are few cases of hiring by ride-hailing platform).
- Pooling model: In this business model, which is linked to ridesharing, the driver is a person with his own private car who offers the remaining seats in order to share the travel costs.
- Hybrid model: it is a combination of the two previous business models.

Since the hybrid business model is not so widespread, the pooling model can be considered a ridesharing service. Its scenario can be described as follows.

- The customer needs to move from point A to point B.
- Through an application, the customer books and pays (or pays at the end of the journey) a transport service by car with a personalized driver who picks him up at the desired point and takes him to another point always desired by the customer.

With regard to ride-hailing, the creation of MaaS platforms can therefore lead to providing a variety of multimodal choices in the urban transport sector.

The Ride-Hailing specific business model radar can be found in Figure 26. An additional stakeholder to the business model can be found in Table 6.

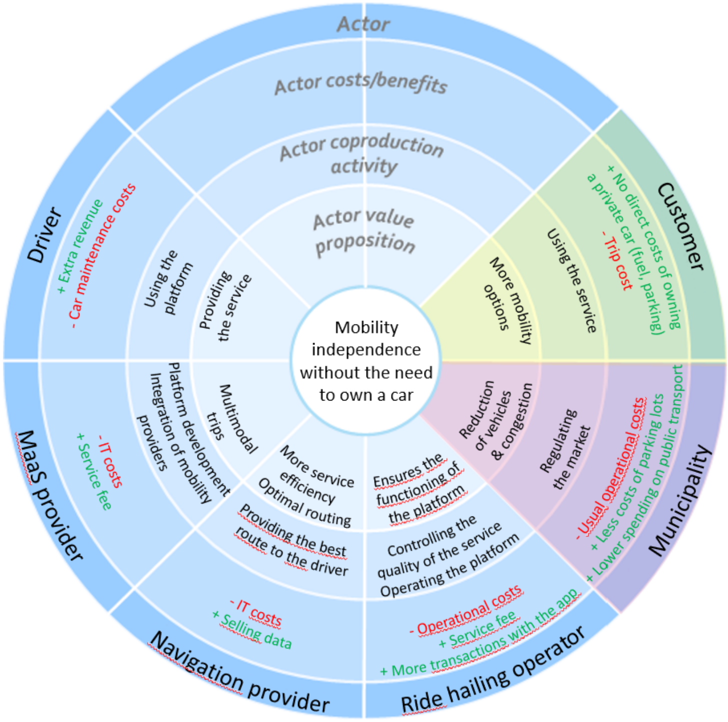


Figure 26: Business model radar for Ride-Hailing (source: own elaboration)

Table 6: Additional stakeholders for Ride-Hailing

Actor	Actor value proposition	Actor coproduction activity	Actor benefits	Actor costs
nuMIDAS/ Intermediary	Data collection & distribution	Common operations, Planning and evaluation support	Dashboard Methods & tools	IT costs

Ride-sharing and Ride-hailing can benefit from MaaS development and implementation. In fact, these two services, in the future, could merge into only one platform where the customer can choose which service is suitable for his/her need.

Moreover, the ride-hailing service could change, in the near future, its business model due to the implementation of the taxi sharing service. Taxi sharing allows different people, that share the same path or part of it, to share a taxi and split the costs of the trip.

In the end, autonomous vehicles are a very important innovation that could transform the business models of ride-hailing and ride-sharing. Specifically, with this technology, a fleet of cars provides both private and collective service, combining both ride-hailing and ride-sharing in a single transport service. In this way, actors as “user A” in ride-sharing and “driver” in ride-hailing will no longer exist.

4.4 State-of-the-art analysis – Summary

4.4.1 Policy instruments perspective

In the previous sections of Chapter 4, we provided a description of each service in the scope of nuMIDAS. In order to understand the relations between the discussed services, each policy instrument was categorised into some of 13 categories based on the pool of all policy instruments described within this chapter.

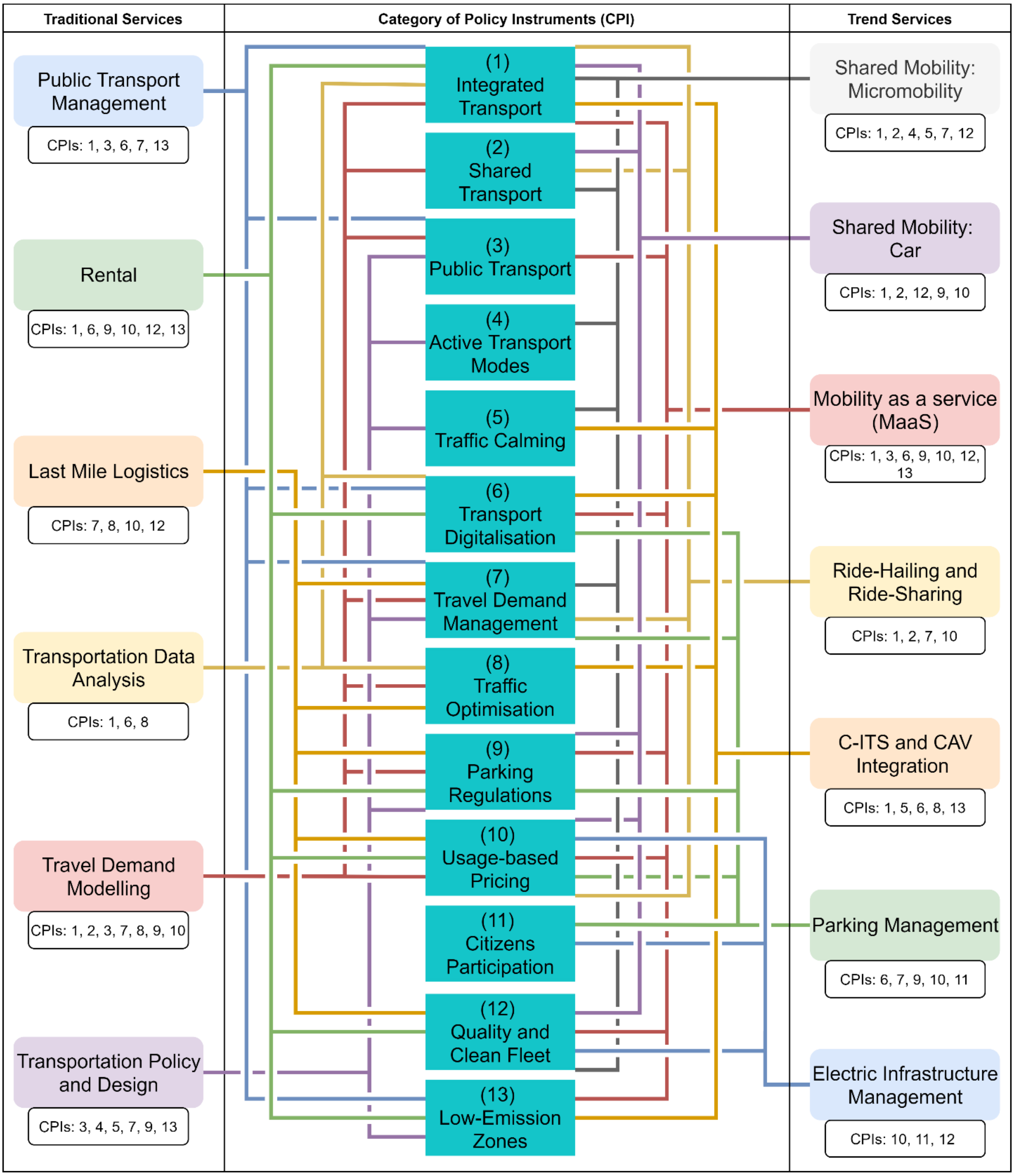


Figure 27: Relation between services and categories of involved policy instruments (source: own elaboration)

Figure 27 provides a graphical overview of these categories of policy instruments (CPI) connected to the traditional and trend services within the nuMIDAS scope.

4.4.2 Tools perspective

The relation between services can also be drawn from the perspective of common categories of tools used to solve problems and challenges of each service in the nuMIDAS scope. As the description of the tools is very long – and consequently located in the appendix – a summary of the tools (i.e., software and methodologies) used for the services is provided in the following sections, where each tool was categorised into one of 7 categories according to its functionalities.

4.4.2.1 Macroscopic traffic simulation (strategic planning) tools

Macroscopic models are a classic type of strategic planning tools and the most widely used type of travel demand models. Commonly, the studied area is divided into zones that are represented by their shape and by a single point corresponding to the zone centroid. Centroids represent the origin and destination of all trips from and to the zone, thus matrices with average costs (e.g., time or distance) between zones are calculated based on stages trip distribution and mode.

Macroscopic traffic simulation tools are used for capturing the effects of bottlenecks and wave propagation. Recently, they are also used for the implications of C-ITS and Cooperative Automated Vehicle (CAV) technologies, and evaluate investments in these technologies and transport infrastructure taking into account emerging mobility patterns. Example of such tools are: TRIMODE (Fiorello et al., 2018), CUBE (Bentley Systems, 2021), Omnitrans (Dat.mobility, 2021), Emme (INRO, 2021b), TransCAD (Caliper, 2021a), SATURN (Atkins, 2021). In addition to the usages aforementioned, PTV Visum (PTV Group, 2021) also includes strategic multi-modal transport modelling and environmental impact assessment.

Other proposed methodologies include estimation of the impacts of automated vehicles on the performance of a transport network and travel demand (Friedrich at al., 2018), and a method to estimate the impact of automated vehicles on traffic parameters, such as road capacity and saturation (Obaid & Torok, 2021). Sonnleitner and Friedrich (2020) discuss the possibility of using PTV Visum (PTV Group, 2021) to demonstrate and evaluate the impacts of automated vehicles on capacity and network performance, perception of automated travel time, ride-matching and vehicle scheduling for high-level automated vehicles that allow unmanned ridesharing or carsharing services.

4.4.2.2 Micro-simulation tools

Microscopic simulation models traffic flow by modelling the behaviour of individual vehicles, in which the representation of travel demand is based on route choice models, while driving behaviour is related to acceleration, lane-changing and gap-acceptance models (Toledo, 2005).

Micro-simulation tools are used for: estimating the emission vehicle profile by routes/areas/vehicle and public parking; Exploring effects of new mobility modes and policies on public transport and the overall transport network performance; The impacts of specific C-ITS enabled traffic management scenarios; Improvement of charging infrastructure planning; Traffic operations assessment; Intermodal transport simulation; Environmental impact assessment; Pedestrian simulation. There are several micro-simulation tools that model either drivers or automated vehicles behaviour, the most used ones are, according to Vrbanić et al. (2021): AIMSUN (Aimsun, 2021), VISSIM (PTV Group, 2021), and SUMO (SUMO, 2021).

Among specific features of micro-simulation tools, Aimsun´s simulation platform Aimsun Ride, which is oriented to new demand-responsive transportation services, can model and analyse Mobility as a Service (MaaS) frameworks, including: competition between different providers or services, attractiveness levels of different types of service, algorithms for generating different offers, pricing models, and target service levels, rides offered in isolation or combined with public transport as part of a holistic transportation model. Automated vehicles modelling and logistics simulation is present for example in SUMO (2021) or VISSIM (PTV Group, 2021), while Codecá (2018) proposes a parking management framework. Ferreira and d'Orey (2014) uses the large-scale simulation platform DIVERT for testing new taxi operations, such as sharing trips and new hybrid formats.

4.4.2.3 Agent-based simulation tools

Agent-based models consider individual users and also individual vehicles as agents that make autonomous decisions as they interact with other agents and their environment, which is governed by certain rules. Simulations aim at a user equilibrium of all agents across the whole transport system, given that at each iteration these agents update their travel patterns due to competition for space-time slots (Scherr, 2020).

Agent-based simulation tools aid at: the assessment and monitoring of demand responsive transport systems; Visualising options with a mix of public/sharing/public modes of transport related to emissions; Providing route options with a mix transport modes taking emissions into account; Estimating the emission vehicle profile by routes/areas/vehicle and public parking; Exploring effects of new mobility modes and policies (e.g., micromobility, park and ride, low emission zones, private vehicle restriction measures, dynamic access restrictions etc.) and external information (weather, public events, …) on public transport and the overall transport network performance; Impacts of specific C-ITS enabled traffic management scenarios; Identification of more busy public transport stops, more frequent trips, analysis of service quality; Improvement of charging infrastructure planning; Modelling impacts of unforeseen crisis (e.g., extreme weather, floods, pandemics). Example of these tools are MATSim (MATSim, 2021a), MobiTopp (MobiTopp, 2021), CityMoS (CityMoS, 2021), Immense platform (Immense, 2021), POLARIS (Auld et al., 2016), ALBATROSS (Arentze & Timmermans, 2004) and SIMBA MOBi (Scherr W. et al., 2020).

Other usages of agent-based model are revenue management in public transport (Bouman & Lovric, 2016), examining impacts of mobility-oriented policies (Adnan et al., 2021), leisure trips modelling (McArdle et al., 2016), fleet management and infrastructure operations (Immense platform, 2021), predicting impacts of urban development (Immense, 2020a), electromobility and charging infrastructure simulation (Márquez-Férnandez et al., 2019), and evaluation of district evacuation scenarios (Klupfel & Lämmel, 2016).

4.4.2.4 Optimisation tools

Optimisation tools for transport systems have the goal of identifying proper strategies and solutions when problems have multiple, often conflicting, objectives that should be fulfilled over time. The field domain is very broad and may be divided into several sub-fields, such as linear, non-linear, dynamic, stochastic, constrained, and unconstrained optimisation (Floudas & Pardalos, 2020; Dasgupta et al., 2006).

Traffic signal optimisation is a good example of optimisation problem, and the tools LISA+ by Schlothauer and Wauer[12] and TRANSYT by TRL[13] are well established for that purpose. Another very common problem is the Vehicle Routing Problem (VRP). The tool VRP Spreadsheet Solver is used for representing, solving, and visualising the results of more than 64 variants of the VRP, unifying Excel, public Geographic Information System (GIS), and metaheuristics (Erdoğan, 2017). Alternatives are also tested using a Large-scale Neighbourhood Search (LNS) algorithm in (Zubin et al., 2020). The VRP optimisation is also explored by Zubin et al. (2020), where drones are used for last-mile logistics of medical delivery. Additionally, localization of facilities is also a popular type of problem, which is studied by Iwan et al. (2015) for parcel lockers localization within a city.

Among trend services' problems, resource allocation between transit services and the operation of shared mobility services relying on highly automated (autonomous) vehicles is provided in (Pinto et al., 2020). Sonneberg et al. (2015) introduce a decision support system that provides strategic optimisation of location, number, and size of stations for electric vehicles with specific charging infrastructure, station-based car sharing in a two-way mode. Relocation models that maximize profit for providers and customers (or minimize costs) are modelled by means of mixed integer programming models in (Illgen & Höch, 2018; Gambella et al., 2017). A pricing scenario for CAVs is explored in (Delle Site, 2021). Esztergár-Kiss and Kerényi T. (2020) propose a methodology for the creation of mobility packages for the MaaS system users that allow to determine the convenient price and specify the modes of transport included in a package (and to which extent).

4.4.2.5 Data visualisation and analysis tools

Data analytics have the purpose to integrate heterogeneous sources of data, establish conclusions, and perform predictions. Several domains are related to data analytics, including data mining, online analytical processing, visual analytics, big data analytics, and cognitive analytics (Gudivarda, 2017); including Machine Learning (ML), which popular methods include regression methods, decision trees, artificial neural networks (ANNs), and support vector machines (Bhavsar et al., 2017).

Apart from some well-known tools for general data analysis, such as MS Excel, Python, R, MatLab, Statistical Package for Social Sciences (SPSS), Structured Query Language (SQL), Microsoft PowerBI, Tableau, ArcGIS (ESRI, 2021), and KIBANA – GRAFANA dashboards, data analysis tools are often specific for the application.

Examples of applications for shared mobility include the total number of vehicles per operator, distribution requirements, restricted area rides, infrastructure planning, parking area performance, monitoring of vehicle condition and lifespan, enforcement, and measure accessibility. Bluesystems[14] and Vianova[15] offer real-time data collection, offline data collection, and real-time reaction to anomalies on public transport or irregular parking. The New Urban Mobility Alliance (NUMO) micromobility data analysis tool focus on trip patterns, modal shift, how to provide safe spaces, equitable access, and the real environmental impacts of micromobility (New Urban Mobility Alliance, 2021a). SharedStreets Mobility Metrics is intended for analysis of the Mobility Data Specification (MDS) data standard, aggregating useful & privacy-protecting metrics (SharedStreets, 2021). Remix visualises corridors and where people are travelling, and addition to identifying

[12] https://www.schlothauer.de/en/software-systems/lisa
[13] https://trlsoftware.com/products/junction-signal-design/transyt
[14] https://www.bluesystems.ai
[15] https://www.vianova.io

risk areas and digitizing public policies. City Dive provides a dashboard to monitor fleets, trips, usage patterns such as: number of vehicles available, the density of vehicles available per area, number of trips, analysis of trips patterns per hour and per day, origins/destinations. Urban Sharing allows to understand day-to-day user behaviour, propose redistribution of vehicles to meet user-demand, and predict fleet's maintenance needs. Populus manages not only shared mobility vehicles but also commercial delivery operators, and helping the management of streets and curbs. Other tools focus only on locating stations, vehicles and possibly displaying some information about them: Bike Share Map,[16] City Bikes,[17] Data Flow (Fluctuo),[18] and Bestmap API Bikes.[19]

Public Transport Management includes a number of smaller sub-systems, from fleet management tools, traffic management and planning, parking and road safety, real-time vehicle tracking to journey planning applications for end-users (Ambrož et al., 2016). The Moovit tool provides a very comprehensive and accurate understanding of travel patterns to and from a region for improving first/last mile access to stations, aligning timetables to improve network connectivity, building access roads or pathways to a station, and assessing the impact of future transit changes on riders and local residents. Vianova allows to control parking of devices, supervise fleet deployments and availability, contributing to the analytical and planning perspective, such as the evolution of fleets sizes, patterns of supply and demand, planning and prioritising access to curb space to prioritize people and goods.

Transport policy and design is aided by Urbano, which is a CAD integrated design toolkit designed to help analyses active transport modes and evaluates the accessibility to amenities and public transport. In addition Urbano gives insight in the understanding of the implications of urban design choices in very early stages of an urban design process (Dogan et al., 2018). OSMnx is useful for acquiring, constructing, analysing, and visualising complex street networks. Propensity to Cycle Tool (PCT) is an online open-sourced interactive map-based web for assessing cycling potential (Department for Transport, 2015).

Advanced tools for Dynamic Traffic Management (DTM) presented in (Kotsi et al., 2020b) contributes to the incorporation of C-ITS into operational traffic management. Such a system enables the realization of sustainable urban mobility goals and the promotion of cooperation between different actors of the mobility ecosystem based on new business models. The C-ITS enabled DTM system is developed in the context of the C-MobILE project that accounts for the following aspects: motorway parking availability for trucks, urban parking availability, traffic light priority and green splits, flexible road capacity, in-vehicle signage, mode and time advice, shockwave damping, and metering.

Besides commercial applications for off-street parking, Barone et al. (2014) suggest the IPA (Intelligent Parking Assistant) for an architecture of public and off-street parking management based on an IoT platform. An already existing example of such a system is the Nice smart parking project (Grimaldi & Fernandez, 2019). Moreover, an international toolkit focused on on-street parking management is found in (Barter, 2016).

[16] https://bikesharemap.com
[17] https://citybik.es
[18] https://fluctuo.com/data-flow
[19] https://bestmap.net/api_bikes

4.4.2.6 Mobility planning tools

Mobility planning tools involve the planning of trips by mobility service (e. g. shared mobility, public transport, etc.) users. They can be from private apps that provide a journey with a fleet of vehicles owned by one operator or a MaaS platform, which features journey planning, optimisation, ticketing, payment, and communication (Signor et al., 2019).

Planning of single modal trips can be exemplified by the car rental systems: HQ Rental Software, RentSyst and MyRent. Such tools are designed to automate and control car rental business operations, including fleet management, customer service, bookings, reservations management, driver management, vendor management, accounting, payments, inventory management, rates management, on a common platform. Another example is the CleverShuttle service, which is a sharing ride-hailing service used as a complementary service to local public transport (Inclusion Project, 2019).

MaaS tools support multi-modal trips and include functionalities of managing user profile & subscription, planning of trips, analyse of supply and demand, manage booking, ticketing, and payment, and receiving of data reports. Examples of such tools are the apps: Whim in Helsinki, Zipster in Singapore, and WienMobil in Vienna. Other apps only provide multimodal route planning, such as Bestmap, CityMapper, and Moovit.

4.4.2.7 Electric infrastructure management tools

Electric Infrastructure management tools design, analyse, and control energy management systems. They aim to provide availability and reliability for electric vehicle journeys the electric power distribution networks. Considering the two-way characteristics of EVs, such vehicles not only consume energy but also provide power to grid (Mahmud & Town, 2016).

Several tools for energy market analysis, electric vehicle (EV) design, traffic modelling, power network analysis, renewable and/or EV integration in distributed energy systems, are for instance: Vehicle-to-Grid Simulator (V2G-Sim), power system analysis toolkit (PSAT), multi-domain systems modelling (ANSYS Simplorer), modelling vehicle integration (MORPHEE tools), power systems simulation tool (Simpow), distributed system design (CANoe) (Mahmud & Town, 2016). Current EU projects also concentrate on fast charging (ELECTRIC) and on building fast-charging stations networks (EUROP-E, ULTRA-E, NEXT-E).

However, there is a lack of tools for locating charging stations (CS) that would be necessary for municipalities. In Europe, the eCharge4Drivers (2021) project aims to provide a tool to guarantee the optimum mix of charging options, while the METIS mathematical model provides analysis of the European energy system for electricity, gas, and heat, though not at municipality level (European Commission, 2019). In the US, the Electric Vehicle Infrastructure Projection Tool (EVI-Pro, 2018) provide guidance on plug-in electric vehicle (PEV) charging infrastructure to regional/national stakeholders.

4.4.3 Data standards perspective

There are several projects launched for standard data in transportation. The Mobility Data Specification (MDS) is a standardized way for municipalities or other regulatory agencies to ingest, compare and analyse data from mobility service providers (MDS, 2021a). Although MDS data is not public, it is related to public data through the General Bikeshare Feed Specification (GBFS) standard, a project of the MobilityData / NABSA (North American Bikeshare Association), which is being used by over 500 shared mobility systems worldwide. GBFS provides real-time or semi-real-time docked and dockless (but GBFS do not fully support the latter) bike-share and scooter-share data in a uniform format with an emphasis on findability, such as stations and station information, available bikes, and system operating information (GBFS, 2021a).

GTFS stands for "General Transit Feed Specification" which defines a common format for public transportation schedules and associated geographic information. Additionally, GTFS-Flex is an extension of the GTFS designed to enable trip planning for various types of demand-responsive or paratransit service. GTFS-Realtime is an extension to GTFS designed to focus on easing implementation, good GTFS interoperability and an emphasis on passenger information. An alternative to GTFS-Realtime is a REST API/XML, where REST stands for Representational State Transfer (REST). It is important to note that there are many alternative data-exchange formats that are compatible with RESTful APIs, including JSON and HTML, but the most used in transportation spaces is eXtensible Markup Language (XML). NeTEx stands for Network Timetable Exchange, which is a Public Transport data standard that aims at systemising and harmonizing European passenger information data. It provides a means to exchange data for passenger information such as stops, routes timetables and fares, among different computer systems, together with related operational data. SIRI stands for Service Interface for Real-Time Information, and it is a protocol that allows the exchange of dynamic information about public transport services and vehicles.

DATEX-II is the electronic language used in Europe for the exchange of traffic information and traffic data, and its latest update of DATEX-II has broadened its focus to the domains of urban mobility, electromobility charging infrastructure, logistics, electronic traffic regulations and cooperative, connected, and automated mobility. The INSPIRE (INfrastructure for SPatial InfoRmation in Europe) corresponds to the standardization and interoperability of common data models, code lists, map layers and additional metadata to be used when exchanging spatial datasets, particularly for describing Transport Networks. Additionally, INSPIRE compatibility should be sought with the standard format DATEX II. TPEG is a short for Transport Protocol Experts Group. It is a global data protocol suite for traffic and travel-related information, including information on road conditions, weather, fuel prices, parking, or delays of public transport. TAP-TSI stands for Technical Specification for Interoperability (TSI) for Telematics Applications for Passenger services (TAP). It allows for the harmonization/standardisation of procedures, data, and messages to be exchanged between the computer systems of railway companies, of the infrastructure managers and of the tickets vendors in order to provide reliable information to passengers and to issue tickets for a journey on the EU railway network.

The TOMP (Transport Operators and MaaS Providers) is being developed with the aim to facilitate the implementation of MaaS and the corresponding exchange of data in Europe. The TOMP-API describes a full MaaS journey, including operator information, planning, booking, support, payments, and trip execution. Its main purpose is to provide a generic and open interface between Transport Operators and MaaS Providers, enabling an open ecosystem. Because MaaS includes intercity trips, air travel is in the scope of MaaS, so as air travel standards such as the AIDX (Aviation Info Data Exchange). The global XML messaging standard is used for exchanging flight data between airlines, airports, and any third party consuming operational data.

4.5 Stakeholder roles and business model analysis – Summary

In chapter 4.3, for each service the Service Dominant Business Model Radar was presented, based on the provided user story. Furthermore, the recent changes and expected changes in both the business model and stakeholder roles were described on the level of each stakeholder. In this chapter, general findings from these radars are given by taking a bird's-eye view over the stakeholders identified in all the nuMIDAS services. Since there are many stakeholders spread over the different services, of which some fulfil similar or overlapping functions, a categorisation of the stakeholders is made. This categorisation can be found in Appendix D. These stakeholder categories are then used to find which type of stakeholders can be found in each service. Furthermore, general findings for each category are presented for each stakeholder category. Concludingly, as nuMIDAS has a focus on urban solutions, special focus is put on the impact of the business models on cities and their policies.

4.5.1 Stakeholder service involvement

In order to get insight into involvement of types of stakeholders over all services, an overview of stakeholder involvement over all services was made. This overview can be found in Table 7. In addition, the level of involvement in each service is also presented. These levels of involvement consist of:

- Focal organisation, this party is the initiator and is responsible for the main activities of the business model;
- Core partner, a party that actively contributes to the essential parts of the service;
- Customer, who is most often the traveller or the stakeholder that make use of the value-in-use;
- Enriching partner, who enhances the value-in-use of a service;
- Future partner, who is a partner that is expected to find its place in the business model in the (near) future.

From the table, a quick and general overview can be found, and patterns in stakeholder involvement can be identified. To get more insight into these patterns, Table 8 presents counts of stakeholder involvement roles for each stakeholder category. Findings for the most common stakeholder categories are highlighted in the following paragraphs per stakeholder category.

Table 7: Stakeholder involvement overview

	Transportation Data Analysis	Transportation Policy and Design	Travel Demand Modeling	Public Transport Management	Last Mile Logistics	Rental	Micromobility	Car Sharing	MaaS	C-ITS and CAV Integration	Electromobility and Charging/Refuelling	Parking Management	Ride-Hailing and Ride-Sharing	TOTAL
Municipality	Customer	Focal org.	Core partner	Core partner	Core partner	Enriching partner	Core partner	Core partner	Core partner	Core partner	Core partner	Core partner	Enriching partner	13
Traveller	Customer	Customer	Customer	Customer		Customer	Customer	Customer	Customer	Customer	Customer	Customer	Customer	12
(Mobility) service provider	Customer	Core partner	Core partner	Focal org.		Focal org.	Focal org.	Focal org.		Focal org.		Focal org.	Focal org.	10
Intermediary	Future partner		Future partner			Future partner	Future partner	Future partner	Future partner	Future partner	Future partner	Future partner	Future partner	10
MaaS provider			Future partner	Future partner		Future partner	Future partner	Future partner	Focal org.				Future partner	7
Research organisation	Core partner	Enriching partner	Enriching partner					Enriching partner						4
Infrastructure provider									Core partner		Focal org.	Core partner		3
Tech company	Customer	Enriching partner			Core partner									3
OEMs					Enriching partner			Enriching partner		Core partner				3
Standardisation organisation							Enriching partner			Enriching partner				2
Navigation provider												Enriching partner	Enriching partner	2
Traffic manager			Core partner	Core partner										2

Table 8: Counts of stakeholder involvement level per stakeholder category

	TOTAL - ROLE				
	Core partner	Focal org.	Customer	Future partner	Enriching partner
Municipality	9	0	1	0	2
Traveller	0	0	12	0	0
(Mobility) service operator	2	0	1	0	0
Intermediary	0	0	0	10	0
MaaS provider	0	0	0	6	0
Research organisation	1	0	0	0	3
Infrastructure provider	3	0	0	0	0
Tech company	1	0	1	0	1
OEMs	1	0	0	0	2
Standardisation organisation	0	0	0	0	2
Navigation provider	0	0	0	0	2
Traffic manager	2	0	0	0	0
	19	**0**	**15**	**16**	**12**

Municipality

The municipality can be found in each service as a strategical and tactical stakeholder. A growing mobility market within a city requires a city to increasingly manage, integrate and improve its mobility system. Even though the municipality can be found in each service, it is mentioned as a focal organisation in only the transportation policy and design service. For other services, the municipality is often a core partner, providing permits or subsidies. Municipalities also determine space usage in the city, which is the basis of the mobility system. Municipalities implement policy instruments as mentioned for each respective service in the state-of-the-art analysis. These policies affect the services and influence their opportunities, but they may also challenge them to find new solutions.

Traveller

The traveller is, in almost all of the described services, the customer in the business model. The services are designed to contribute to a more efficient, more integrated, and more sustainable way of travel for the customer. Often, the traveller contributes to the business model by allowing organisations to gather and use data in order to provide the service. In addition, there will also be positive externalities to the society from travellers using these improved and optimised travel modes. Also, all residents of a city will benefit from improved parking spot availability, increases in the liveability of a city, or from the use of electric vehicles, in the form of less noise and environmental pollution.

(Mobility) service provider

Often the business models require some sort of mobility service provider. Mostly, the service provider is seen as the focal organisation of a service as the organisation that offers the operational means of travel to the traveller in form of a vehicle, as well as the way to access the service, often through digital platforms. The service providers use these platforms to gather data from their users, which can be sold to interested parties or used to improve their service on both operational and tactical levels. In services where this data from mobility services is used, the service providers are a core partner in the business model. For example, in the Travel Demand Modelling service data from service providers could be used as input for estimation of OD-matrices or travel times.

Intermediary

The intermediary organisation can be a future partner in most of the described services. The exact interpretation of activities of the intermediary organisation are still unknown, but it offers opportunities in a mobility ecosystem that is getting increasingly interconnected. Services can often be brought to a higher standard with data sharing between organisations. An independent intermediary organisation will likely contribute to willingness to share data between organisations and can evaluate the functioning of a service objectively. The evaluation may lead to strategical, tactical, and operational advice, depending on the interpretation of the role of this stakeholder.

MaaS Provider

These stakeholders are expected to affect the mobility system as a whole. MaaS providers can be found in the business models of many services, mostly as a future partner. While it is sure that it will affect the system, it is unsure how and what is to be expected in terms of effects on the mobility system, roles of other stakeholders and policy instruments. The MaaS providers are expected to cover strategical, tactical, and operational layers.

4.5.2 Trends and impact on the city

As the centre of technical development and with the municipality as the strategical and tactical core of the city, municipalities are required to determine their long-term vision, while adapting to rapid commercial developments.

The trend of providing anything “as a Service” is growing into the mobility field, led by digitalisation, which plays a major role in each described service. Digital platforms give anyone within the city the possibility to access information and vehicles. This inclusiveness will come at a cost, as the number of trips will increase. Another worrying effect on the modal split within cities is the shift from public transport to easy-access electric vehicles. Even though the increase in trips currently consists of many small vehicles, free-floating car-sharing services are growing in numbers as well.

Cities will have to adjust their policies, affecting business models across all services, in order to build an integrated and efficient urban transport system. In addition to adjustments, digitalisation also supports new types of policies, such as smart pricing of services. As can be seen from the business model radars, municipalities can influence and benefit from each individual system. However, mobility services cannot be considered individually anymore, but require customisation to their exact goal within the transport system of each given city, including the user experience, which requires complex decision making.

The enormous amount of gathered data by municipalities, service providers and other related or unrelated parties is the key to the ability to make these complex choices. Integration and smart use of data for the design of the transport system and policy design are important but challenging. The role of trusted third parties will be important for the integration of all these sources of data, as well as for translating the data to valuable historic, real-time, or predictive insights. Municipalities should start exploring the possibilities of these types of collaborations.

The role of cities as traffic manager is affected by these developments as well. The increased number of means for information collection and distribution from/to users of the infrastructure gives traffic managers more options for management of real-time traffic, leading to smarter use of infrastructure. However, with the increasing variety of mobility services and with that, increase in the number of modes and increasing connectivity requirements, infrastructure within cities is not always sufficient anymore. For example, the presence of small vehicles puts more pressure on bike infrastructure (if there is any). Traffic management and smart infrastructure planning will go hand-in-hand in further adaptation to the shift in the modal split. This includes the changes in requirements for the electrical infrastructure within cities. As demand for electricity will increase due to electric vehicle usage, policies, and technical innovation to tackle related issues are required.

5 Survey results

5.1 Introduction

To get a more comprehensive picture of the trends, challenges (concerning aspects), stakeholder roles, future prospects, desirable tools, and data as they are perceived in the mobility sector, an online survey was conducted. It was addressed to the specialists in the field of transportation from various transport companies (transport managers, mobility operators, logistics operators, consultants etc.), public administration, universities, and research institutions. The survey contained questions from five distinct categories, namely trends, challenges, stakeholders, tools, and data. Two main groups were formed by rating scale questions asking respondents to rate the importance of 24 different challenges and the attention paid to them. The remaining questions were open-ended. 12 of them were aimed at inquiring trends and the related issues and challenges identified by respondents in the urban mobility sector at present and those expected to come up in the next 10 years, namely in the domain of services, policies, traffic management and others (specified by the participant). Other 3 questions asked about new types of stakeholders observed within the urban mobility sector, the change of the role of traditional stakeholders (i.e., policy makers, service operators, traffic managers, users, legislation, OEM, insurance companies, etc.) during the past few years, and the expected additional shift in their roles in the next 10 years. Further, the survey contained 7 questions directed at mobility-related tools. They asked about tools available for policy makers nowadays, observed shifts and improvements in the existing tools or emergence of new ones, main gaps regarding the needs or expectations of policy makers, and the most critical challenges and risks that can impact existing methodological tools supporting transport/mobility researchers, planners, and other stakeholders. Finally, new KPIs and new types of mobility-related data supporting data-oriented policy-making were inquired, together with their benefits on policy-making (3 questions). The last group of optional questions asked the respondents to add anything he/she considers important for the project and to fill personal information.

The survey was carried out in four languages, namely English, Greek, Italian and Spanish. In total, 119 responses from 15 countries were delivered. Only 34 % of them were fully filled in, the others were incomplete or partially filled in. More details on the numbers of returned surveys and the overview of their state by language and country can be found in Appendix E, section E.1.

5.2 Summary of quantitative results

As it was mentioned, the first group of questions with numerical answers was related to the importance of 24 different challenges in the terms of goals that we want to achieve in the area of mobility in the near future. For each of them, respondents were asked to rate its importance by a number between 1 (not important) to 5 (very important). In the second group of rating scale questions, respondents were asked to express their opinion about the attention paid to the same challenges. The task was to rate the challenge from 1 (we should pay no attention) to 5 (we should pay more attention), with 3 meaning that we are paying the right amount of attention. The results are summarised in Figure 28 depicting the mean values of both mentioned rates for all challenges from the survey. The horizontal axis represents the mean value of the importance rate and the vertical axis represents the mean value of the attention rate. It can be observed that the least important of given challenges with the least deserved attention was considered excessive information, while sustainability, (cyber)security, urban space management, interoperability of systems and organisations, data standardisation and open data platforms are found the most important and deserving more attention compared to the present state. Great importance is assigned also to real-time information, although participants from the academical domain find the present attention adequate. A more detailed analysis including sorting by countries and domains in which participants are working is provided in the Appendix E, section E.2.

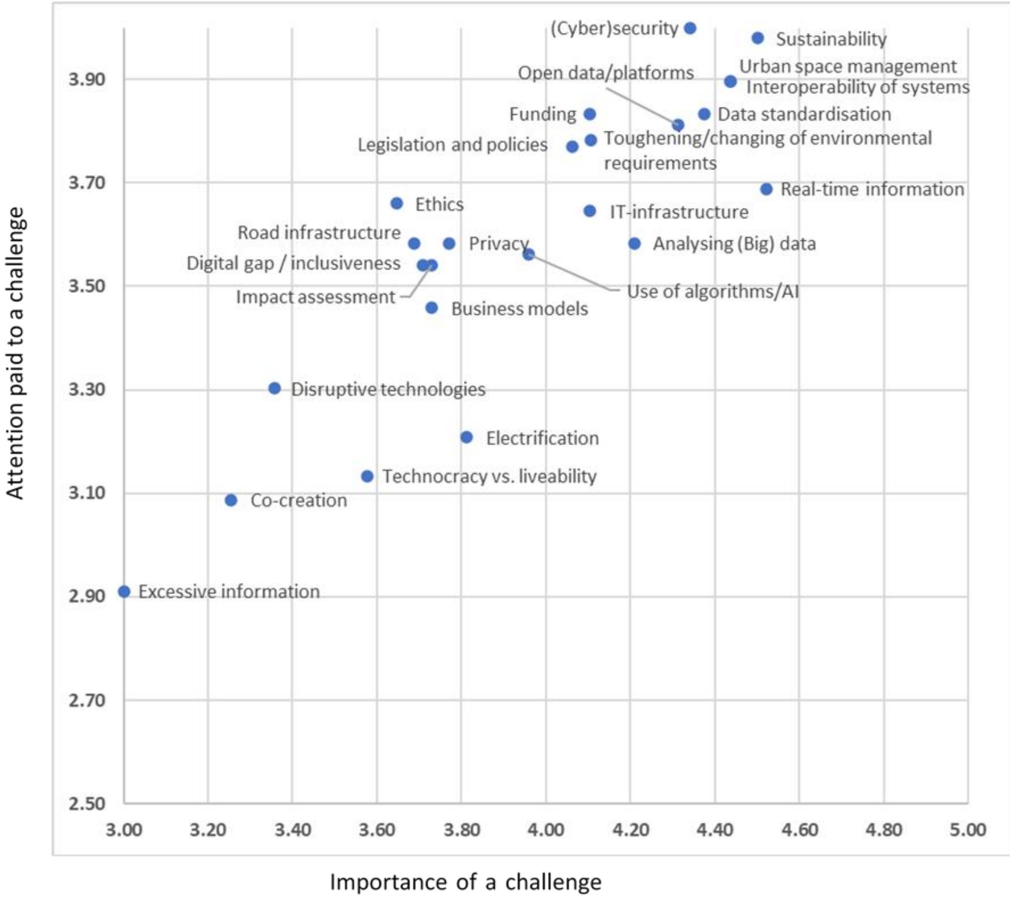


Figure 28: Relation between the importance of a challenge and the attention paid to it (source: own elaboration)

5.3 Summary of qualitative results

A more detailed analysis of answers to open-ended questions are contained in Appendix E, section E.3. Here the most interesting findings are pointed out.

Trends in the urban mobility sector

The most frequently mentioned services include micromobility, Mobility-as-a-Service, Autonomous Vehicles, Sharing Mobility, and the implementation of Connected, Cooperative and Automated Mobility. Highlighted policies were related above all to traffic calming and less accessibility for cars in inner cities, which would increase road safety, health, and quality of life. Similarly in the connection with traffic management, the prioritization of public transport, cycling and pedestrian accessibility over cars, together with the regulation of active mobility, centralisation of traffic lights, smart roads and road safety were cited. Future mobility is expected to be electric, shared and connected to a smart and cooperative system. Respondents also anticipate greater coordination between the public and private sectors, also thanks to the dissemination and sharing of data, and the use of drones in the last mile logistics.

Stakeholders in the urban mobility sector: new types and roles

The mentioned new stakeholders are closely correlated with the new mobility trends. The most frequently mentioned ones were micromobility service providers, data providers, MaaS providers, technology companies, and further intermediaries between private and public, telecommunication operators and data brokers. Stakeholders new also with respect to business models included in the literature review were *citizens' movements and residents' groups to promote sustainable urban mobility*, *right of use of public space sellers* and *mobility assets managers*. The majority of the respondents anticipated an additional shift in stakeholder roles within the following 10 years and increasing importance of new/smart mobility operators.

Mobility-related tools

Respondents mentioned tools such as drones, cameras, sensors for recording and collecting traffic Big Data, satellite, incident detection tools and surveys for retrieving user opinions. In the field of software applications, the tools included, e.g., data analysis tools, simulation models (macroscopic and microscopic simulation of urban transport systems as fundamental for policy makers to evaluate alternative future scenarios), forecast of traffic conditions in a network, tools for dynamic traffic management, dashboards, and visualisation platforms. Answers also mentioned tools for training to mitigate the lack of skilled personnel in public and private offices. The majority of the stakeholders (75%) observed improvements in the existing mobility-related tools and the emergence of new tools.

Several cited gaps were related to data. Responders complained that in many cases it is not available, up-to-date, accurate (e.g., data on origins and destinations of trips or travel motives per trip), integrated, open or recorded to build a history of events. Other listed gaps include for example the integration of micromobility and public autonomous transport modes in simulation tools (yet as it is mentioned Appendix C, section C.3.3.5, available tools for agent-based modelling, such as MATSim or the commercial Immense platform, allow this task), social cost-benefit analysis, tools enabling the involvement of local communities in policy-making, and high costs of specific tools and their implementation for public offices, including the training of personnel.

In particular, it was highlighted that available tools are not always aligned with policy objectives. For example, dashboards on high-level goals like inclusiveness, liveability, accessibility, sustainability are not available, which opens the space for the nuMIDAS toolkit.

Challenges and risks

Results of rating questions aimed at the importance of challenges and the corresponding attention are summarized in Figure 28. In the answers to open-ended questions, most of the mentioned challenges related again to available data and tools for its processing, and modelling of travellers behaviour. Respondents highlighted the need for a correct management of privacy and confidentiality agreements with the risk of delays on the technical procedures and risks related to cyber security (especially when dealing with private and personal data). Another cited challenge was the application of a holistic approach, with the risk of thinking that the solution to a problem is only technological or political without thinking about heuristics, configurations, modelling, management, maintainability, and impacts. For more details, see sections E.2 and E.3.9 of Appendix E. Full answers dealing with risks will be elaborated further in the next steps of the project.

New types of mobility-related data, new KPIs

Sections E.3.10 – E.3.12 provide a detailed overview of answers dealing with new types of mobility-related data that should be collected, new key-performance indicators (KPIs) that policymakers need, and their benefits for policymaking. These results represent valuable input for the next work on the project and for the design of the nuMIDAS toolkit.

6 Conclusions

As explained above, this deliverable summarises the findings from Task T2.1. It focuses mainly on the state-of-the-art analysis based on scientific papers, existing implementations, as well as running research projects. It also focuses on the shift in stakeholder roles and new business models which are in the focus of Task T2.2.

Within this deliverable, we analysed the state of the art via scientific papers, existing implementations, and running research projects. This deliverable describes the current state of knowledge and provides and explains the methodological approach to move towards a better understanding of changes in the mobility field. We analysed the existing terminology and proposed a nuMIDAS model linking these terms to show interdependencies and relations.

It was identified that there needs to be a shift from the tool-based analytical approach towards a service-oriented analysis. That is the main trend and need to be recognised from the market and it is also the basis of our analysis. For each Service in scope, the following issues were analysed:

- description and definitions,
- trends and opportunities,
- gaps,
- involved policy instruments,
- categories of usable tools,
- high-level use cases involved,
- solved challenges, and
- inputs, outputs and KPIs.

This list demonstrates that besides discussing the traditional approaches, we focused also on the challenges the transportation field is facing nowadays. The potential to use existing techniques and tools for such challenges was also described. Our main discussion concerns the identification of white spots where the existing tools and methods are not sufficient.

The deliverable also focuses on stakeholders and business models. It summarises and describes the traditional stakeholders in transportation and their roles. Important will be the shift in stakeholder roles as well as the emergence of new business models. This is a particularly topical task as we observe many new trends. For example, the growth of shared economies, the start of Level 4 or 5 automated vehicles, or the expansion of apps that provide location-based services (LBS) will change the playground significantly.

This deliverable is the result of an extensive literature review and thus is rather large. To make reading of the document easier, the main points and issues of the analysis were included in the main text, but another (also important) information was included in Appendixes. We believe that this deliverable has the potential to become a useful tool for various stakeholders (for example decision-makers or transport engineers) within the mobility field. It updates and enhances existing white papers and reports covering the field. It can be the ultimate resource within the changing mobility field.

The Deliverable D2.1 is the basis for further work on the nuMIDAS project. It provides the State-of-the-art analysis and definition of the terms used within the field. While it focused on the mobility field as a whole, Task T2.3 (Use cases definition) will focus on more details of Use Cases covered by the nuMIDAS Toolkit and selected Case Studies in the partner cities. A detailed analysis of the relevant use cases will be provided. Moreover, Task T2.4 (Extraction of new concepts, variables, and KPIs) builds on D2.1. It will further enhance the SoA analysis by looking at new trends and new KPIs, rather than focusing on the actual status. WP3 to WP5 will then further elaborate on the prepared analysis of the prepared case studies in pilot cities.

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Appendix A Definition of key terms

Term	Definition	Examples
Stakeholder	A person with an interest or concern in mobility issues and transport externalities.	Researchers, developers, sharing mobility operators, municipalities.
Actor	A role played by a person that interacts with the nuMIDAS Toolkit. The system affects and is affected by the behaviour of actors.	Researcher, planner, policy maker, decision maker.
User	A person that uses a mobility service.	Passenger of public transport, car sharing user, driver, cyclist, pedestrian, person planning a trip.
User Need	A physical or functional need for a particular design, product, or process in the nuMIDAS Toolkit provided by Stakeholders. High level requirements in the form of free text.	The user shall be able to search all roads. The service must be available 24/7.
Goal	Desired result that a stakeholder envisions, plans, and commits to achieve. It is a broad statement and does not describe the methods used to get the intended outcome.	Economic efficiency, environmental protection, safety, accessibility, environmental sustainability, economic regeneration, financial feasibility.
Objective	Specific, measurable, and actionable target that needs to be achieved within a reasonably short-term time frame. Objectives describe the actions or activities involved in achieving a long-term goal.	Reduction of number of accidents by 15%, decreasing pollutions by 30%, reduction of the number of vehicles in the city centre by 40%, widen the offer of shared mobility service to users by 50%, breakeven point within 2 years.
Challenge	A real world problem that an Actor desire to solve in order to accomplish the objectives. It differs from methodological problems, which are related to the inabilities of current methods & tools to take into account existing technologies and/or analyse real-world problems).	Congestion, pollution, low utilisation of existing technologies.
Mobility Service	Any activity related to the mobility sector in which each application corresponds to a specific ecosystem including various actors/stakeholders and technological means/capabilities. It clusters several use cases based on a common specific public need for the Service. "We apply Service-centric approach and level of details for the nuMIDAS model"	Traffic Monitoring and Travel Demand Modelling, Parking Management, Traffic management and control/ operations, Micromobility, Shared Mobility and Rental.

Policy Instrument	Technique used by an Actor to promote certain behaviour of a User or regulate the operation of a service in order to achieve objectives.	Restriction of road usage by vehicle type (e.g., low emission zone or pedestrian zone).
Methods	Models and/or algorithms to support the functions used in the Use Cases.	Artificial intelligence, deep learning, genetic algorithm.
Tools	Software, service, or files that run procedures and methods to support the functions used in the Use Cases.	Eclipse SUMO, Vissim.
Categories of Methods & Tools	Aggregation of tools based on their similarity in the application field.	Macroscopic modelling, mesoscopic modelling, microscopic modelling, data and predictive analytics, optimisation and mathematical programming, econometrics, systems thinking and system dynamics, multi-criteria decision analysis.
Variables	Predefined values, inputs, outputs or collected information from other users, sensors, models, and other sources.	Travel demands, congestion prices, traffic volumes from sensors, traffic volumes from models, measured emissions, travel time, shared vehicle use
KPIs	The means to quantify the extent to which each objective is fulfilled.	Number of accidents per flow intensity, emissions per flow intensity, number of alternative modes that can be used to reach a destination at an acceptable level of service, % of area served by sharing mobility services, % of economic failure of new sharing mobility operators after n years.
Use Case	A high-level functionality of a system that must fulfil objectives quantified by specific KPIs. They consist of partial activities, analysis methods & tools (existing, updated, combined, or to be developed) solving real-world and methodological problems. An actor interacts with the system (e.g., the nuMIDAS toolkit) through use cases.	Multimodal routing: plan route for each travel mode, get price for each mode and trip, pay for trip, reserve the mode. Parking Management: real-time information, dynamic pricing, very short-term reservation.
Dashboard	An interface facilitating the visualisation of selected data and KPIs, including territorial indicators. The tools will play the role of a “back-end”.	A graphical user interface showing the shared mobility demand in different areas of Milan.
Requirement	A statement that identifies a system, product, or process characteristic or constraint, which is	The methods and tools to be developed should be able to combine microscopic traffic simulation and AI algorithms in

	unambiguous, testable or measurable, and necessary for product or process acceptability.	order to assess traffic management scenarios.
Use Case	A high-level functionality of a system that must fulfil objectives quantified by specific KPIs. They consist of partial activities, analysis methods & tools (existing, updated, combined, or to be developed) solving real-world and methodological problems. An actor interacts with the system (e.g., the nuMIDAS toolkit) through use cases.	Multimodal routing: plan route for each travel mode, get price for each mode and trip, pay for trip, reserve the mode. Parking Management: real-time information, dynamic pricing, very short-term reservation.
Case Study	The application of services in a specific geographical area considering specific conditions, specific use cases, specific data, and existing limitations (if any).	Parking management application in Barcelona centre. Scooter sharing, bike sharing, car sharing, moto sharing in Comune di Milano.
nuMIDAS Toolkit	A software aiming to improve the planning, understanding and provision of *Mobility Services* according to the *Goals* of *Stakeholders*. It corresponds to the integration of different *Methods* and *Tools* to fulfil the Needs of Actors, in order to support them to achieve their Objectives and to decide on *Policy Instruments based on* KPIs. If seamless integration, a native dashboard is used to present data and enable data analysis, otherwise guidance to specialised software is provided.	

Appendix B List of Services

The following list provides an overview of the main initially considered Services. As it was discussed in section 4.1, the Services were classified into categories denoted as *traditional* (with respect to the FHWA definitions) and *trend* (expressing that the service introduces some new trend). Based on the applicability for further work within the nuMIDAS project, especially during the prepared case studies in pilot cities or when creating the nuMIDAS Toolkit, it was also determined whether a Service whether is in scope of nuMIDAS project and the SoA analysis will be provided.

S_ID	Service	Description	Examples of Use Case	Focus	Type	Relevance	Situation
1	Transportation Data Analysis	Analysis of data gathered from multiple sources (incl. transport infrastructure, smart cards, location-based applications, and social networks) in order to get insights of traffic, environment, and travel demands.	Visualise real-time or time-based air quality, visualise real-time or density maps of traffic accidents/incidents, visualise real-time or time-based QoS, visualise real-time or time-based travel times, visualise real-time or time-based parking spaces, visualise real-time or time-based traffic counts.	Passengers and Freight	Traditional	Case study: all	In scope
2	Transportation Policy and Design	Appraisal and identification of the most appropriate policies, investments, and urban design to be adopted to optimise transport systems performance understood through the fulfilment of several goals and needs.	Modify the traffic network (new road, change number of lanes, new cycling lane), prohibit certain vehicles in certain roads, simulate congestion charge.	Passengers	Traditional	Case study: Barcelona - Factual (Low emission zone)	In scope
3	Travel Demand Modelling	The prediction of future travel patterns from a sample of travel behaviour data.	Define travel demands based on changes in the network and facilities (e.g., due to the decision of the construction of a new quarter, new bus terminal, etc).	Passengers and Freight	Traditional	Case study: Barcelona - Factual / Literature review: useful, mature area	In scope

4	Public Transport Management	Organisation of public transport operations to better understand and respond effectively to travel demand by improving the flow of passengers at an acceptable level of service.	Define public transport locations and capacity, schedule, lines, and routes, as well as pricing scheme.	Passengers	Traditional	Case study: Barcelona - Factual	In scope
5	Last Mile Logistics	Represent the last leg of a journey comprising the movement of goods from a transportation hub to a final destination.	Represent the last leg of a journey comprising the movement of goods from a transportation hub to a final destination.	Freight	Traditional	Case study: Milan (Zero Carbon Logistics) / Literature review: useful, mature area	In scope
6	Rental	Service that allows people to rent a vehicle for a shorter or longer period of time.	Set up group of people that would rent vehicles instead of using public transport or own a car, pricing scheme, set up pick-up and drop-off locations, distribution of Origin-Destination (OD) of rental users.	Passengers	Traditional	Proposal: Milan - Poliedra	In scope
7a	Shared Mobility: Micromobility	Demand-driven sharing arrange-ment of small and lightweight vehicles for the movement of road users operating at speeds, typically below 25 km/h.	Set up group of people that would share bicycles instead of using other transport mode, define location and capacity of sharing stations, pricing scheme.	Passengers	Trend	Case study: Barcelona - Factual / Literature review: useful and innovative, find gaps	In scope

7b	Shared Mobility: Car	Demand-driven vehicle-sharing arrangement, in which travellers share a vehicle either simul-taneously as a group or over time.	Set up group of people that would share vehicles instead of using other transport mode, define location and capacity of sharing stations, pricing scheme.	Passengers	Trend	Case study: Milan - AMAT + Poliedra / Literature review: useful and innovative, find gaps	In scope
8	Mobility as a Service (MaaS)	Mobility as a Service brings every kind of transport together into a single intuitive mobile app. It seamlessly combines transport options from different providers, handling everything from travel planning to payments.	Routing considering selected transport modes and specific requirements (reduced walking distance, preferred flat route, less connections, fastest, ...), get price for each mode and trip, pay for trip, reserve the mode, etc.	Passengers	Trend	Case study: Leuven, Barcelona - Factual / Literature review: useful and innovative, find gaps	In scope
9	C-ITS and CAV Integration	Exploitation of enhanced connectivity between vehicles (V2V) and between vehicles and the road infrastructure (V2I and I2V) as well as vehicle auto-mation technologies to provide coordinated traffic management services.	Set up a group of vehicles and infrastructure elements that are connected, define behaviour of connected vehicles and infrastructure elements once information is available at range.	Passengers and Freight	Trend	Literature review: useful and innovative, find gaps	In scope

10	Electric Infrastructure Management (Electromobility and Charging/Refuelling)	The concept of using electric powertrain technologies and the necessary infrastructure either to charge batteries or refuel hydrogen tanks.	Location and capacity of refuelling and charging stations, pricing scheme, define the distribution of vehicle types (including their distance ranges).	Passengers and Freight	Trend	Case study: Milan - AMAT + Poliedra (El. Shared Mobility) Case study: Barcelona - (data from e-charging stations)	In scope
11	Parking Management	The optimisation of parking space, giving real-time car parking information such as vehicle & slot counts, available slots display, reserved parking, pay-and-park options, easy payments, reports, and other features.	Define parking zones and restrictions, parking capacity, pricing scheme, provide or simulate very short-term parking reservation.	Passengers	Trend	Case study: Barcelona (Park & Ride data) / Literature review: useful and innovative, find gaps	In scope
12	Ride-Hailing and Ride-Sharing	Ride-hailing reflects the concept of a rider hiring a personal driver to take him/her exactly where he/she needs to go, but the vehicle is not shared with any other riders. Ride-sharing reflects the concept of a rider sharing a vehicle with other riders.	Set up group of people that would hire a vehicle (and who would accept share the vehicle) for certain trip instead of using other transport mode, define the number and type of available vehicles, pricing scheme, define the algorithm that connects rides to users.	Passengers	Trend	Case study: Milan - AMAT (Taxi sharing) / Case study: Barcelona - Factual + AMBI (Seniors transport)	In scope

13	Vulnerable Road Users Management	Non-motorised road users, such as pedestrians and cyclists as well as motorcyclists and persons with disabilities or reduced mobility and orientation.		Passengers	Trend	Literature review: useful and innovative, find gaps	Out of scope
14	Priority Management of Emergency Vehicles	Cooperative traffic management schemes and sensing techniques for providing priority to emergency vehicles.		Special case	Trend	Literature review: useful and innovative, find gaps	Out of scope
15	Route Guidance	Routing and rerouting of vehicles through in-vehicle navigation systems by utilising real-time traffic information.		Passengers	Trend	Literature review: useful and innovative, find gaps	Out of scope
16	Priority Management of Road Users	The definition of priority levels for each road user and the coordination of the traffic according to these priorities.		Passengers	Trend	Literature review: useful and innovative, find gaps	Out of scope
17	Fleet Management	The management of vehicles that includes vehicle maintenance, overseeing fuel consumption and fuel costs, driver management, asset utilisation, route planning, and the implementation of programs that increase producti-vity and reduce risks.		Passengers and Freight	Trend	Literature review: related to other services, new area	Out of scope

18	Traffic management and control/operations	The application of methods and tools to preserve traffic capacity and improve the security, safety, efficiency, and reliability of the overall road transport system.		Passengers and Freight	Traditional	Literature review: useful, mature area	Out of scope
19	Crowd management	The process of planning and directing large groups of people.		Passengers and Freight	Traditional	Literature review: related to other services, mature area	Out of scope
20	Transport Infrastructure Management	Maintenance, expansion, re-design, and redevelopment of transport infrastructure (incl. road and rail infrastructure) as well as of fixed-location assets along transport infrastructure (e.g., refuelling stations, public transport stops, terminal, and stations).		Passengers and Freight	Traditional	Literature review: related to other services, mature area	Out of scope
21	Environmental Analysis and Assessment	The process of identifying, estimating, and evaluating the environmental impacts of existing and proposed projects by conducting environmental studies.		Passengers and Freight	Traditional	Literature review: related to other services, mature area	Out of scope

22	Land Use and Urbanism	Land use refers to the purpose the land serves, for example, recreation, wildlife habitat or agriculture. Urbanism involves urban design to promote economic and environmentally friendly habits, e.g., walkable neighbourhoods containing housing, jobs, and other needs.		Passengers and Freight	Traditional	Literature review: related to other services, mature area	Out of scope
23	Logistics and Supply Chain	Logistics refers to the movement, storage, and flow of goods, services. Supply chain is a way to link business processes into a business model to foster competitiveness.		Freight	Traditional	Literature review: related to other services, mature area	Out of scope

Appendix C State-of-the-art assessment

C.1 Transportation Data Analysis

C.1.1 Data visualisation

The extent to which new knowledge can be discovered from diverse data relies on the availability of effective data visualisation tools. Visualisation tools can be addressed as effective if they provide insight into unmatched pattern, building upon the capabilities of the human visual system and cognitive problem-solving process. Data visualisation can help by enabling the uncovering of patterns and relationships. Data visualisation can also prove useful for communicating the results of data-driven solutions. The data visualisation pipeline initiates with the raw data that an analyst wishes to study. These data are transformed into data structures, which store entities that are associated with raw data. Data structures may include the outputs of analytical algorithms, such as clustering or machine-learning algorithms, that may be needed to discover new knowledge from the raw data or reduce the search space. Afterwards, visual mappings transform data structures into visual elements, building upon spatial layouts, marks, and properties (i.e., visual structures). Visual structures are, in turn, transformed into user views using parameters, such as locations, scaling, and clipping (Steed, 2017). An example of visual systems' classification constitutes the scheme proposed by Keim (2002), according to which visualisation systems are classified based on three dimensions: a) the type of data to be visualised, b) visualisation techniques, and c) interaction and distortion methods. Data types include one-dimensional data (e.g., temporal data), two-dimensional data (e.g., geographical maps), multi-dimensional data (e.g., relational tables), text and hypertext (e.g., articles), hierarchies and graphs (e.g., web documents), and algorithms and software. Similarly, visualisation techniques include standard 2D/3D displays (e.g., bar charts and x-y plots), geometrically transformed displays (e.g., landscapes and parallel coordinates), icon-based displays (e.g., needle or star icons), dense pixel displays (e.g., recursive pattern technique), and stacked displays (e.g., tree maps). Finally, interaction and distortion methods include interactive projection, interactive filtering, interactive zooming, interactive distortion, and interactive linking and brushing.

C.1.2 Machine Learning in transport data analysis

Machine Learning (ML) constitutes a collection of methods and tools that renders computer systems capable of automating data-driven model building and programming. With the increased rates of data generated in transport systems, it is now possible to utilise ML for developing ITS applications. Typical example constitutes the identification of patterns, such as traffic flow and the behavioural profile of a driver in relation to the time of a day or the prevailing traffic conditions respectively, with the aim of improving the performance a transport system and identifying future trends. ML is also widely applied in automated vehicles' functions. Automated vehicles collect data through various sensors and based on ML algorithms take decisions to navigate safely and efficiently through traffic. Popular methods depending on the objectives of each application constitute regression methods, decision trees, artificial neural networks (ANNs), and support vector machines (Bhavsar et al., 2017).

C.1.3 Popular tools for data analytics

- **MS Excel** constitutes a data analysis tool that can be utilised mainly for small-sized datasets. It provides a convenient platform, including many functionalities, such as modelling, visualisation, reporting, and dynamic charts (Chou, 2019).
- **Python** is widely utilised interpreted high-level programming language but also a powerful data analysis tool. It supports a wide range of use cases, such as data crawling, data cleaning, data modelling, data visualisation, as well as applications related to data mining, machine learning and text mining. It includes a wide variety of libraries that can be used for data processing and visualisation with SciPy, Numpy, Matplotlib and Plotly being some major representatives (Chou, 2019).
- **R** is a programming language and open-source software environment enabling statistical computing and graphics. It constitutes a mature data analysis data analysis environment that supports a wide range of applications, such as data cleaning, data reduction, web crawling, visualisation, hypothesis testing, statistical modelling, and reporting (Chou, 2019).
- **MatLab** is a programming language heavily utilised in the engineering community for numerical computation purposes. It includes a rich set of toolboxes that are classified into several categories, such as parallel computing, AI-data science-and statistics, mathematics, and optimisation, reporting and database access, code generation, and application deployment. One of the bigger advantages of MatLab is the user-friendly and intuitive visualisation capabilities, encompassing pre- and post- data processing analysis (Chou, 2019).
- **SPSS** (Statistical Package for Social Sciences) also constitutes a statistical tool integrated in graphical user interface environment. Its core functions include a) statistics, providing a wide range of basic statistical functions (e.g., frequencies, cross tabulation, and bivariate analysis), b) modelling, enabling the development and validation of predictive models, c) text analytics for surveys, enabling knowledge discovery from open ended survey questions, and d) visualisation, enabling the creation of a wide variety of visual and diagrams, such as density charts and radial boxplots (Alchemer, 2018).
- **SQL** (Structured Query Language) is programming language oriented to manage data in relational databases, supporting data reading, manipulation, and editing. SQL constitutes a powerful tool for aggregating data over large datasets and on multiple tables at a time (Mode Analytics, 2021).
- **Microsoft PowerBI** constitutes an accessible business intelligence data visualisation tool which enables the feeding of multi-source data to dashboards and BI reports and support connection and communication with various other software packages and programming frameworks. However, PowerBI is subject to data volume limitations (GURU99, 2021).
- **Tableau** constitutes ad data visualisation tool that falls into the category of business intelligence. It supports visualisation of data in dashboards and worksheets and overcomes the data volume limitations of Power BI, thus enabling the visualisation of multi-source big data. However, existing evidence suggests that Tableau is not readily accessible to all user types given their technical background (GURU99, 2021).
- **GIS** (Geographic Information Systems) may be viewed as a framework for gathering, managing, and analysing data, supporting a wide range of data types. The most significant difference with the previously mentioned tools is the spatial processing capabilities supported by GIS frameworks, thus enabling the identification of spatial patterns and relationships (ESRI, 2021). ArcGIS constitutes a widely utilised proprietary solution, while QGIS constitutes a widely utilised open-source solution.

In addition to the aforementioned, various web-based GIS frameworks are also available (e.g., kepler.gl).

- **KIBANA – GRAFANA dashboards** constitute open-source solutions that facilitate the development of dashboards using large datasets. A prominent functionality of KIBANA is data querying and analysis. For instance, users can search data indexed in Elasticsearch to locate specific events and data values, thus enabling diagnostic analytics. Similarly, GRAFANA building upon its Graphite target parser enables easy metric and function editing, as well as the development of charts with smart axis formats. Significant difference between the two mentioned solutions constitutes the inability of GRAFANA to execute full-text data querying, which is supported by KIBANA a main purpose of which is to analyse log messages (Yigal, 2020).
- **STATA** constitutes a general-purpose software package supporting data manipulation, visualisation, statistical analysis, and automated reporting. An interesting feature of this software package is that it may be used either as a point-and-click application by exploiting its graphical user interface environment or as a command-driven application, enabling the execution of more complex analyses. It includes a rich list of features comparable to other relevant packages (e.g., SPSS), including, for instance, the development of linear models, the analysis of time series, Bayesian analysis, the development of Structural Equation Models (SEM), cluster analysis, and network analysis (University of South Australia, 2021; Stata, n.d.; Cox, 2005).
- **SAS** standing for “Statistical Analysis System” constitutes a statistical software supporting data management, advanced analytics, multivariate analysis, business intelligence, and predictive analytics. Similarly to STATA, it may also be used as a point-and-click application or through SAS language, enabling more complex analyses. Moreover, similarly to STATA it includes a rich list of features. An interesting tool included in SAS package is the so-called social media analysis tool, enabling the archive and analysis of conversations in popular platforms (e.g., Facebook and Twitter) but also in other forums and blogs (Salkind, 2010; Retail Info Systems, 2010).

C.1.3.1 Example use cases

The aim of the current subsection is to demonstrate the use of data analytics and in particular Big Data analytics, in example use cases found in the relevant literature. Such use cases revolve around real-time crowd traffic flow estimation, (short-term) traffic state prediction, and traffic congestion detection.

Tang et al. (2015) suggest a framework for extracting accurate and timely crowd traffic flows within an urban environment. This framework makes use of static data (i.e., bus and subway stations and commercial-based regions) and various – heterogeneous – dynamic data (i.e., taxi, bus, and subway data) with the aim of computing in real-time crowd traffic flows in Shenzhen (China) but not making predictions. The city is partitioned in several commercial-based regions resembling mobility attractive areas (e.g., shopping malls, leisure places, living and working areas) by exploiting geographic information and not solely relying on a grid-based approach. After that, a solution framework is applied, including four main layers as depicted in Figure 29.

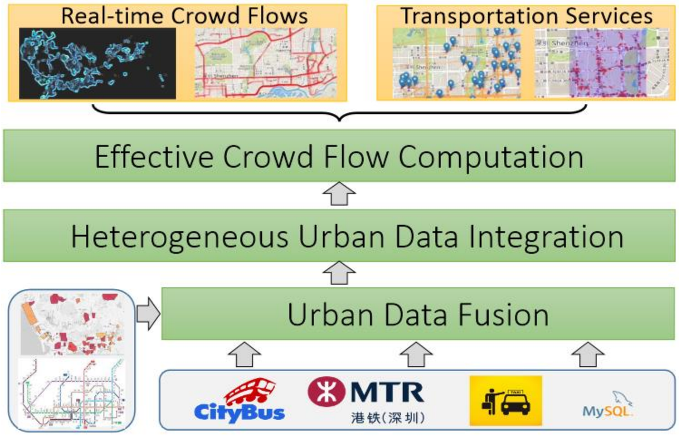

Figure 29: Solution framework for crowd flows computation problem (Tang et al., 2018)

The first (bottom) layer is related to data collection, wherein both mutable and immutable data are collected. Collected data in conjunction with city's partitioning are then fed to the second layer, which involves data fusion. The main challenge in this layer is how to address incomplete data for specific transport modes and identify in a precise manner the origin and destination of trips made through these modes. For instance, utilised bus data include only users' get-in information and not get-out information. Such a problem is tackled by grouping available daily records for all modes of transport by each user identifier. This grouping supports the identification of combined trips and movement patterns, such as home-to-work and work-to-home trips, that enables the inference of the origin and destination of each bus trip (i.e., when a combined trip is identified get-off information becomes available). The results of this layer are fed to the third one the objective of which is to identify the origin and destination of each passenger, irrespective of the transport mode used. This objective is fulfilled by grouping records by each user identifier and then sorting in an ascending order the derived results by the time of swiping card[20]. OD pairs are identified by consecutive records with the first one corresponding to the origin and the second the destination of a trip. With respect to taxi trips, origins and destinations are available in taxi trade data but these data do not include GPS information. To this end, a cross join operation is executed linking taxi trade data with taxi GPS data by each taxi identifier. Finally, the derived integrated data from the third layer are fed to the fourth layer, wherein the real-time crowd flows are estimated and made available to applications. This implies the computation of the inflows and outflows of each commercial-based region of Shenzhen. To this end, for OD pairs derived from swiping card data bus and subway stations are matched with commercial-based regions. OD pairs derived from taxi data, not being in a fixed location, are matched with commercial-based regions through three alternative algorithms. The first involves a computational geometric technique (i.e., point-in-polygon testing), the second involves an R-tree-based computation technique, while the third involves a label-grid computation technique.

Antoniou et al. (2013) suggest a framework for dynamic data-driven traffic state estimation and prediction. The rationale of this framework is depicted in Figure 30. Input data (i.e., traffic observations) may include attributes, such as speed, density, flow, number of lanes, grade, meteorological information, vehicle mix, and driver mix.

[20] Swiping card data for bus services include the inferred data for passengers get-off.

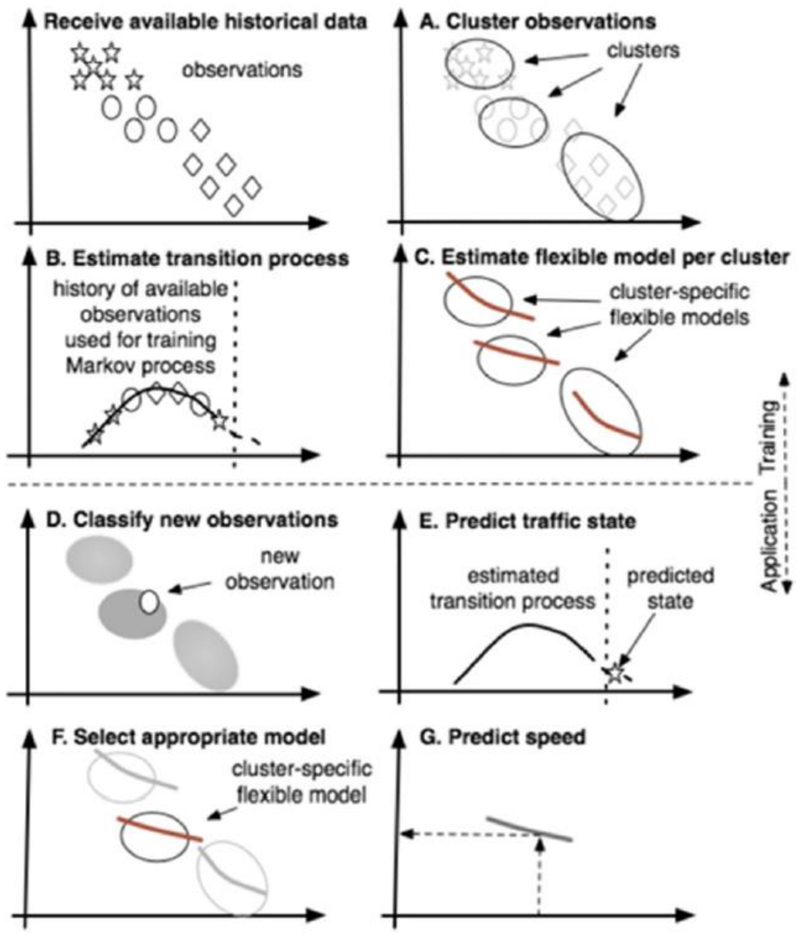

Figure 30: Framework for dynamic data-driven traffic state estimation and prediction (Antoniou et al., 2013)

The proposed framework is comprised of training and application steps. Training step makes use of input data with the aim of a) identifying traffic states through clustering available – historical – observations, b) estimating the transition process between the regimes defined by the aforementioned clusters, c) estimating traffic models for each cluster. It is notable that the term "traffic state" implies a state in which traffic can be assessed by several parameters, including flow, speed, and density. Moreover, the term "regime" means a grouping of traffic states with similar characteristics. This grouping is attained by clustering traffic in the first stage of the application step that can be achieved following either a model-based hierarchical agglomerative approach, a nearest neighbour classification approach, or neural network-based approach. The second stage involves the creation of a model oriented to predict the forthcoming traffic state based on clusters' time series. The authors suggest for this purpose the adoption of a Markov chain approach. The third stage involves the creation of a flexible regression model based on observations corresponding to each cluster. The authors suggest the use of LOESS curves for this purpose. Such a regression model relates speed with the full range of remaining – input – data. On the other hand, application step application step builds upon incoming real-time data. Its scope is: a) to classify incoming observations to appropriate regimes, b) to perform short term predictions of the traffic state through the developed model for estimating the evolution of traffic states, c) to select the appropriate traffic model based on the derived result and d) to perform speed prediction. The authors apply the proposed framework in two case studies in Irvine, CA, and Tel Aviv, Israel, providing encouraging results.

Guo et al. (2017) present a method for road traffic congestion detection using Big Data from mobile phone devices, providing location and time information. As depicted in Figure 31, the proposed method consists of four main steps.

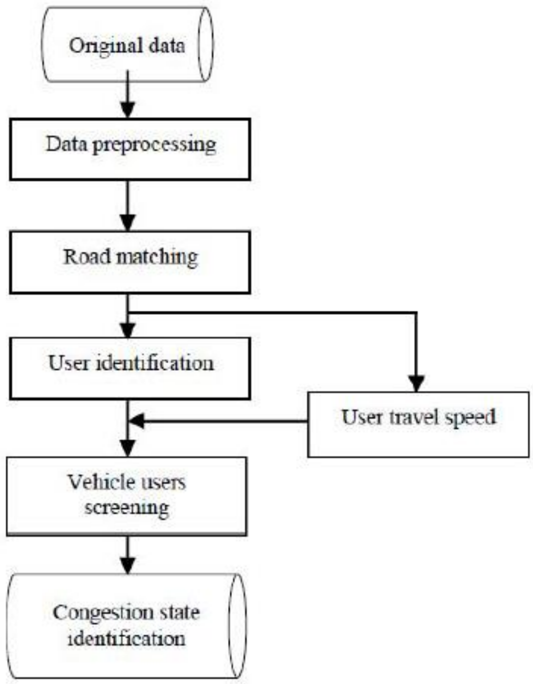

Figure 31: Main steps of the method for road traffic congestion detection using Big Data from mobile phone devices (Guo et al., 2017)

The first step revolves around data preprocessing in the context of which invalid data are deleted, the remaining – valid – data are sorted and merged, and the phenomenon of "Ping-Pong handover" is eliminated. As invalid are treated the data that include no information. Sorting by phone number and connection time is performed as a means of facilitating the remaining analysis. Moreover, merging is performed with the aim of preventing duplicates of records resulting by not moving mobile phones (in such a case a mobile phone is continuously connected to the same base station). "Ping-pong" handover involves a situation in which in a short period of time a mobile phone jumps back and forth between several different base stations. It is accepted that a mobile phone is not moving if it connects back to the same base station within half an hour. In such a case, only the first record remains valid. The second step involves road matching and user identification. For this purpose, a base station is fitted to a road segment if its vertical distance from this segment is less than 300m. In the context of user identification, a user sequence is obtained including all the mobile phone users on the road for each road. This is achieved by assessing the similarity between base station switching sequence of each road with the base station switching sequence of each user. The third step revolves around vehicle users screening, in which the travel mode of each mobile phone user is identified and the vehicles users travelling on the road are screened. Travel mode is identified with aim of treating as a valid only in-vehicle moving users. This is achieved by classifying into two clusters the users based on their travel speed using k-means algorithm. The fourth step revolves around traffic congestion state identification for each road. Such a purpose is served by calculating the statistical average speed of all vehicles on a road and classifying the derived results into four clusters, resembling serious congestion, congestion, slight congestion, and smooth conditions.

C.1.3.2 Solved challenges

The methods and frameworks demonstrated in the previous section pave the ground for the solution of a wide range of challenges associated with transport data analysis. All of them constitute novel applications moving well beyond traditional transport planning processes. This is, for instance, prominent in the method suggested by Antoniou et al. (2013), wherein, by exploiting historical and real-time (dynamic) data and data analytics, predictions are made for traffic speed without the need for employing traffic simulation models, the development of which is often much costly. Moreover, these methods and frameworks utilise multi-source data through data fusion techniques, thus increasing the spatial coverage of available information regarding traffic and mobility of individuals. This is quite prominent, for instance, in the framework suggested by Tang et al. (2015). Moreover, the handling of incomplete data and techniques for grouping data in order to derive to useful information presented by Tang et al. (2015) as well as data pre-processing techniques included in the method suggested by Guo et al. (2017) constitute two best-practice examples for enhancing the quality of available data. Finally, all of the frameworks and methods presented support the application of artificial intelligence and Machine Learning techniques, which constitute two main representatives of advanced technologies that are expected to fundamentally change transport engineering, enabling a wide range of new perspectives and opportunities. Relevant applications shall be increasingly elaborated by researchers, in order to derive to mature tools supporting evidence-based mobility management, traffic operations and decision support.

C.1.3.3 Inputs and requisites

The inputs and requisites of transport-related applications based on data analytics greatly depend on their scope. In this respect, it is impossible to provide a generic relevant categorization that will be applicable in all cases. A useful source of information on the types of data used in such applications are the Delegated Regulations supplementing the ITS Directive (885/2013, 886/2013, 962/2015, 1926/2017). In these regulations data categories are classified as follows: data related to safe and secure car parking, data related to road safety, traffic-related data, and multimodal traffic operations-related data. In effort to categorise the types of data included in the above presented applications, the following categories may be discerned:

- GPS data from moving vehicles
- Smart card data
- Taxi trade data
- Geospatial (open-source) data
- Data from mobile devices (incl. CDR data)
- Sensory data collecting traffic-related and meteorological information
- Static road data

C.1.3.4 Outputs and KPIs

Similar to inputs and requisite, outputs and KPIs greatly depend on the scope of each application. The outputs that can be extracted form the applications presented above are the following:

- Passenger inflow and outflow of between specific regions in a city
- OD matrices including specific locations of a city (e.g., public transport stations, taxi stations, etc.)
- Congestion state judgment
- Short-term speed predictions

C.2 Transport Policy and Design

C.2.1 Simulation tools

Simulation tools use a variety of formulas and algorithms to replicate travel behaviour. They can be used to evaluate a range of improvements and strategies at isolated locations, on corridors, or wide areas (U.S. Department of Transportation, 2017).

An example of simulation tools useful for transport policy and design is MATSim. It stands for Multi-Agent Transport Simulation, is an world-wide used, open-source, traffic flow simulation framework (Horni et al., 2016), where a large number of individual, synthetic persons ("agents") and their trips are simulated (CIVITAS, n.d.).

C.2.1.1 MATSim

MATSim enables the simulation of entire urban transport systems, creating opportunities for detailed model experiments based on transport networks that can be edited using a plugin to the JOSM GIS (Horni et al., 2016, Lovelace, 2021). This tool is based on the co-evolutionary principle, where every agent repeatedly optimises its daily activity schedule while competing for space-time slots with all other agents on the transport infrastructure (CIVITAS, n.d.).

C.2.1.2 Solved challenges

- Can simulate millions of agents or huge detailed networks.
- Can simulate private cars, taxis, and public transportation.
- High speed: can simulate whole days within minutes.
- Similar to other traffic simulation tools but incorporates other choice dimensions like time choice, mode choice or destination choice.
- Modularity: offers the option to compute emissions, noise, and accessibility.
- Useful for multi-modal transport planning, evacuation planning, public transport (including fleets of autonomous vehicles) or freight planning.

C.2.1.3 Inputs and requisites

Minimally, MATSim needs the following files (Horni et al., 2016):

- config.xml, containing the configuration options for MATSim (a list of settings/parameters that influence how the simulation behaves).
- network.xml, containing the description of the (road) network, the infrastructure on which agents (or vehicles) can move around. The network consists of nodes and links (in graph theory, also denoted as vertices and edges).

- population.xml, providing information about a list of persons, each person contains a list of plans, and each plan contains a list of activities and legs[21] (how an agent plans to travel from one location to the next; each leg must have a transport mode assigned).

C.2.1.4 Outputs and KPIs

The main outputs MATSim generates are (Horni et al., 2016):

- Leg Histogram: In every iteration, a leg histogram is plotted. A leg histogram depicts the number of agents arriving, departing, or being en-route per time unit. Histograms can be created for each transport mode and for all transport modes.
- Trip Durations: For each iteration a trip durations text file, listing number of trips and their durations on a time bin level for each activity pair (e.g., from work to home or from home to shopping), is produced.
- Link Stats: In each iteration, a link stats file containing hourly count values and travel times on every link of the network is printed.

Figure 32: Simulation of taxis based on a fixed demand in Poznan, Poland (MATSim, 2021b)

C.2.2 Network Analysis tools

Network analysis tools use spatial data to identify and visualise strengths and weaknesses of geographical coverage and network connectivity in a coherent mapping exercise (Scheurer et al., 2007).

- **OSMnx**: an open-source tool oriented to make the collection of data and the creation and analysis of street networks simple, consistent, automatable, integrating graph-theoretic and transport/urban design perspectives.
- **Urbano**: an easy-to-use CAD integrated design-toolkit designed to help planners and designers in the urban design process. It allows the user to effortlessly build a mobility model and run network

[21] Part of a trip between two stops.

analysis and transport simulations on Rhinoceros3D CAD platform (popular among designers). This model analyses active transport modes and evaluates the accessibility to amenities and public transport, using contextual GIS, OpenStreetMap, and Google Places data (Google Places API) (Dogan et al., 2018).

C.2.2.1 Spatial network analysis

OSMnx has been used for a wide range of research and real-world applications, with a focus on spatial network analysis via functions for calculating a range of transport network measures (Lovelace, 2021).

C.2.2.2 Urban design

The Urbano tool is aimed at supporting design decision making involving street layout and program and density allocation. It provides an active feedback for various travel-related metrics, and thus bridges the gap between the design and simulation process.

C.2.2.3 Solved challenges

Specifically for spatial network analysis:

- Effective tool to overcome data availability and consistency limitations.
- Useful for acquiring, constructing, analysing, and visualising complex street networks.
- Allows anyone to download walkable, drivable, or bikeable urban networks from OpenStreetMap for any city name, address, or polygon in the world and then automatically analyse and visualise them (Boeing, 2018).
- Helps technical and non-technical planners use OpenStreetMap data to model urban layouts, circulation, accessibility, and resilience (Boeing, 2018).

In the case of urban design:

- Uses updated open-source data to produce mobility models.
- Closes the knowledge gap for design technicians with low computational/ technical skills
- Helps planners understanding the implications of urban design choices into very early stages of an urban design process.
- Provides key information to improve pedestrian activity, such as neighbourhood walkability, expected pedestrian use of each street based on amenities in place, lack or over saturation of amenities, etc.

C.2.2.4 Inputs and requisites

Data used for OSMnx include:

- Infrastructure types
- Amenities/points of interest
- Building footprints
- Elevation data
- Street bearings/orientations
- Speed/travel time

Data used to build an Urbano model include (see Figure 33):

- Street network (geometry, metadata)
- Building outlines with meta data (amenities, population size)

Both sets of data can be imported from GIS or Open Street Map through the Urbano tool.

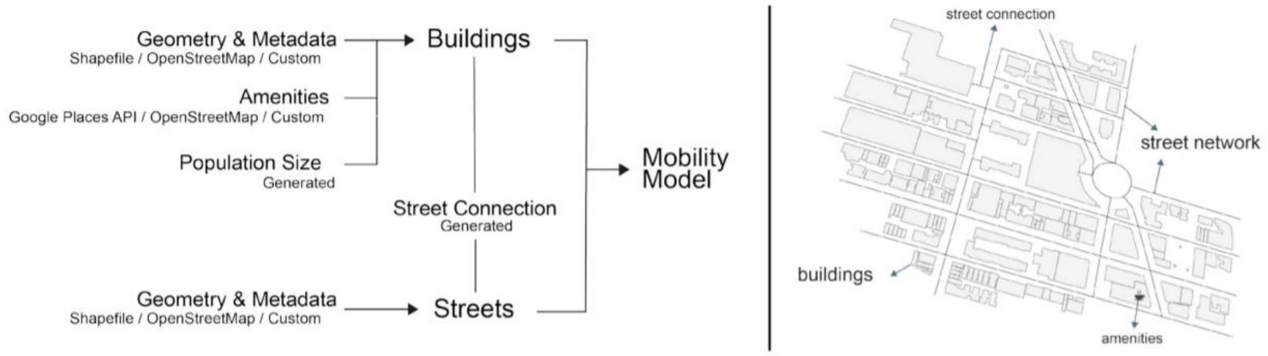

Figure 33: Data that is used to build an Urbano model (Dogan et al., 2018)

C.2.2.5 Outputs and KPIs

OSMnx provides:

- Topological and spatial analyses to automatically calculate dozens of indicators.
- Shortest-path routes that minimize distance, travel time, elevation, etc.
- Travel distance and travel time with isoline and isochrone maps.

Urbano offers:

- City building geometry (3D)
- Topological graphs in which streets segments are represented as edges and intersections (and endpoints) are represented as vertices.

- Walkscore:[22] walkability metric which determines a score ranging from 0 to 100 based on the proximity to amenities such as grocery stores, restaurants, shops, banks, coffee shops, etc., rewarding higher street intersections and lower average block length (Dogan et al., 2018).
- Amenity score: density of people derived from the concentration of amenities on a street/area.
- Spatial distribution of amenities (classified by the typology of building facilities).
- Pedestrian use of each street: useful when deciding the allocation of crosswalks, pedestrian streets, sidewalk width, etc.

C.2.3 Location-based data visualisation tools

Web user interfaces are in-browser graphical user interfaces rather than a web API which provide multiple advantages in terms of participatory planning (Lovelace, 2021). For example, the Propensity to Cycle Tool (PCT) is an online open-sourced interactive map-based web tool funded by the UK's Department for Transport to map cycling potential (Department for Transport, 2015). It differs from other tools for assessing cycling potential and has wider implications for how models can and should be used in relevant decision-making processes.

C.2.3.1 Decision making on cycling infrastructure investments

PCT has been designed to support cost effective investment in cycling infrastructure (Lovelace et al., 2017) putting an emphasis on where to maximise cycling uptake. By exploring scenarios of change including Go Dutch—in which cycling levels are simulated to grow to Dutch levels nationwide— stakeholders can build business cases for investment along desire lines with high cycling potential and better understand health and environmental benefits of interventions in different places (Lovelace, 2021).

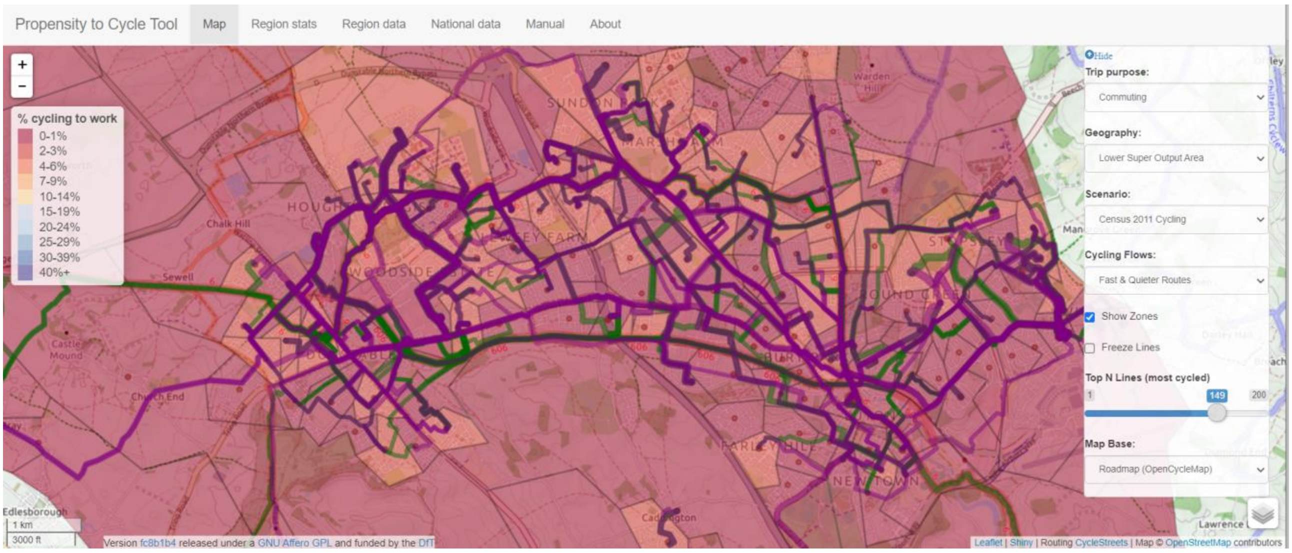

Figure 34: Propensity to cycle tool (Aldred et al., 2017)

[22] https://www.walkscore.com/methodology.shtml

C.2.3.2 Solved challenges

- Allows the construction of scenarios 'cycling futures' based on a series of options (government targets, gender equality in bike use, use of electric bikes).
- Identifies the highest cycling potential in different types of roads (quiet, fast).
- Takes into account factors such as hilliness and trip distance and differentiates between mechanical bicycles and electric bicycles.
- Differentiates between commuting data and travelling to school data, based on UK census.

C.2.3.3 Inputs and requisites

Among the inputs and requisites of the Propensity to Cycle Tool:

- Trip purpose (commuting or school travel)
- Geography
- Scenario (see 5.1.5.2)
- Cycling flows (straight lines, fast routes, quiet routes, etc)
- Map base (satellite, road map, topographic, etc)

C.2.3.4 Outputs and KPIs

Among the outputs and KPIs of the Propensity to Cycle Tool:

- Top *n* roads with highest cycling potential, ordered by:
  - Number of cyclists
  - Increase in number of cyclists
  - Physical activity benefits (Health economic gain)
  - Carbon saving (reduction in CO2/ Car distance)

C.3 Travel Demand Modelling

C.3.1 Classical macroscopic models

Macroscopic models are classic and the most widely used type of travel demand models in current practice. The most common approach to treat space in macroscopic models is to divide study area into zones that are represented by their shape and by a single point called the zone centroid. This notional spot is best thought of as floating in space and not physically on any location on a map. Centroids represent origin and destination of all trips from and to the zone. Centroids are attached to the network through centroid connectors representing the average costs (time, distance) of joining the transport system for trips with origin or destination in that zone. Matrices are usually the result of the stages trip distribution and mode choice in the classic four stage model.

- **PTV Visum** is probably the most widely used tool in the world. The tool is developed by the company PTV Group from Karlsruhe in Germany (PTV Group, 2021). Its name (Visum – abbreviation from „Verkehr in Städten – Umlegungsmodell“, i.e., "Transport in Cities – Assignment model") refers to its original purpose to solve problems within the fourth stage of the classic model at the macroscopic level. After more than 40 years of development, PTV Visum has become a complete software package for transport and traffic analyses, forecasts, and GIS-based data management on urban, regional, or national levels. It models all transport modes (including demand-responsive transport) and their interactions in a unified network data model. It enables import/export network data sets from/to various data formats, calculate various demand models (four stage algorithm, tour-based, activity-based) and use different assignment methods (various highway assignment procedures, dynamic traffic assignment, mesoscopic assignment, headway-based and timetable-based public transport assignment, stochastic assignment for slow modes, etc.). PTV Visum can also solve problems related to intersection design and signal controlling, or public transport operations down to the level of line blocking and fleet allocation. All methods can be embedded in a scenario management environment, allowing to develop and compare different variants of transport infrastructures and policies. PTV Visum includes tools for graphical and numerical data analysis (thematic maps, 3D plots, filtering and aggregation in tables, matrix analysis, etc.) allow to evaluate and present the modelled data in various forms. PTV Visum is still macroscopic simulation tool, but it can be used in cooperation with the microscopic tool PTV Vissim.

- **TRIMODE** (TRansport Integrated MODel of Europe) is an example of the use of the software PTV Visum (Fiorello et al., 2018). The TRIMODE model includes a full four stage transport model of passenger and freight movements across the European Union and its neighboring countries, an energy model with dynamic vehicle fleets for all transport modes and an economy model representing the complete macroeconomic system of European countries. The passenger demand model is embedded within the PTV Visum software plus several appended modules developed as Python scripts to manage in a consistent and transparent form some tasks that are not part of standard software functions.

- **CUBE** is a software package for various transport modelling tasks from macroscopic to microscopic level (Bentley Systems, 2021). It is developed by Citilabs which was acquired by Bentley Systems in 2019. The package contains 6 basic modules:

  - CUBE Voyager for macroscopic movement of people and vehicles, supporting trip, tour, or activity-based methodologies, in addition to exchange via GIS and GTFS formats
  - CUBE Avenue for mesoscopic traffic modelling
  - CUBE Cargo for freight modelling
  - CUBE Land for land-use modelling
  - CUBE Dynasim for microscopic traffic simulation
  - CUBE Access for metrics on people's accessibility to valued destinations, such as employment, health services, transportation hubs, and entertainment

- **Omnitrans** is macroscopic travel demand modelling software developed by Dat.mobility from Netherlands (Dat.mobility, 2021). It includes various modifications of the classic four stage model (simultaneous mode choice, destination choice, departure time choice) and several methods for trip assignment (static and dynamic/semi-dynamic assignment of car traffic including junction modelling and ramp metering, frequency-based and schedule-based assignment of public transport and several specific assignment methods for cycling and slow traffic).

- **Emme** is originally a macroscopic simulation tool (INRO, 2021b). It was developed by INRO in Canada. In Emme it is possible to implement virtually any zonal-aggregate travel demand model with any feedback structure, trip generation and distribution choice models. Emme also includes tour-based models, activity-based and land-use models. Emme can be combined with microscopic simulation tool Dynameq (INRO, 2021a).

- **TransCAD** (Caliper, 2021a) combines GIS and transportation modelling capabilities in a single integrated platform. It is developed by Caliper in the USA. It is a macroscopic simulation tool, however it can be combined with microscopic simulation tool **TransModeler** (Caliper, 2021b). TransCAD includes various demand models (four stage algorithm, activity-based) and different assignment methods (multi-modal and multi class assignment, origin user equilibrium assignment, dynamic equilibrium traffic assignment, public transport assignment).

- **SATURN** is macroscopic road assignment software developed by Atkins in Great Britain (Atkins, 2021). It covers the fourth stage of the four-stage model, but only in road transport. This software can be bundled with DIADEM software (Department for Transport, 2020). The core part of this software is an incremental hierarchical logit model of the following demand responses: trip frequency, time period choice, mode choice and destination choice/distribution. Travel times and other costs are provided by a third-party traffic assignment model, with interfaces provided for SATURN.

C.3.1.1 Traffic planning

PTV Group (2021) claims that its software PTV Visum offers functionalities necessary for traffic planning, including a four-step travel demand model supplemented with a tour-based demand model. It allows for evaluating plans related to various domains from highway operations to public transport. It can also be combined with PTV Vissim for a microscopic simulation (see the following group of tools).

C.3.1.2 Strategic multi-modal transport modelling

PTV Group (2021) refers to a complex multi-strategic transport model PRISM, developed by transport authorities in West Midlands, UK, using the software PTV Visum and covering all transport modes. PRISM is primarily aimed at the improvement of public transport to increase its share in the overall mobility mix. It is used for the assessment and prioritization of planned infrastructure investments, scheme feasibility and initial sifting, long-term accessibility studies, long-term mobility plans, corridor planning, evaluation of timetable changes, bus priority, new rail lines and new park & ride stations. Its key indicator was the accessibility of jobs within 45 minutes by public transport.

C.3.1.3 Environmental impact assessment

The software PTV Visum includes emission calculation according to HBEFA 3.3,[23] based upon emission factors of the Handbook Emission Factors for Road Transport 3.1 and containing historic and projected fleet compositions (shares of different vehicle types) for different years and countries (Germany, Austria, Switzerland, Sweden, Norway, and France). It allows to define a custom fleet composition and to estimate cold start emissions based on origin traffic of zones. It covers only pollutant emissions and fuel consumption, but not noise. The calculation is based on volume values for cars, coaches, LDV, HDV and motorcycles. Emissions can be displayed by link, by territory or network-wide (PTV Group, 2021).

C.3.1.4 Automated vehicles modelling

Sonnleitner and Friedrich (2020) discuss PTV Visum macroscopic models related to automated vehicles. These models are used to demonstrate and evaluate the impacts of automated vehicles on capacity and network performance, perception of automated travel time, ride-matching and vehicle scheduling for high-level automated vehicles that allow unmanned ridesharing or carsharing services. For more details, see section 4.3.10.

C.3.1.5 Solved challenges

- A correct capture of bottleneck effect and wave propagation.
- An appropriate intersection flow behaviour simulation.
- Modelling of various traffic scenarios with accurate qualitative and quantitative results.

C.3.1.6 Inputs and requisites

Their input consists mainly of the socio-demographics, the road network and public transport offers as well as activity locations in an area.

Table 9: Inputs and requisites for macroscopic simulation models

Elements	Comments
Transport network	A real-world transport network can be extracted from OSM or other GIS application, using a filter for obtaining components and information relevant for the model (e.g., certain types of roads, public transport routes etc., information on speed limits etc.) and if

[23] http://www.hbefa.net/e/index.html

	necessary, changed according to an investigated scenario, supplemented with further infrastructure elements.
Public transport supply	Even today, it is often done manually. Most of discussed software have modules for the import of GTFS (the General Transit Feed Specification) data. However, GTFS provides a timetable for each operation day, but they does not describe a "plan" or a "typical working day" – the data have to be manually adjusted.
Demand data	Socio-demographic data (e.g., number of inhabitants) from GIS Traffic intensities (e.g., from detectors), Zone-to-zone matrices in usual data formats.

C.3.1.7 Outputs and KPIs

After computing the demand and subsequently the traffic on the roads, these models deliver information about the use of the road network and public transport, including capacities, average velocities, etc. Inbetween steps of demand generation deliver the modal split or the number of performed trips.[24]

Table 10: KPIs for macroscopic models

Level	KPI	Impacts		
		Environmental	Economic	Social
Societal level	**Total vehicle-kilometres travelled**	x	x	
	Total motorway lane-kilometres	x	x	
	Number of kilometres with ITS	x	x	
	Average/total travel times	x	x	
	Average speeds	x		
	Traffic density (number of vehicles per unit length per lane)	x	x	x
	Traffic flow (number of vehicles crossing certain point per unit time)	x	x	
	Public transport supply in route-kilometres (or seat-kilometres or passenger-kilometres)	x	x	x
	Connection times at transport facilities	x	x	x
	Modal split	x	x	x

[24] For more details see https://www.eltis.org/sites/default/files/tool/conduits_key_performance_indicators_its.pdf.

	Average distance and duration of transfers between modes	x	x	x
	Average parking search time at public transport facilities	x	x	
	Average commuting time / distance by public and private transport	x	x	
	Percentage of non-motorised trips for commuting	x	x	
	Number of kilometres of non-motorised facilities	x	x	
	Traffic flow (number of vehicles crossing certain point per unit time)	x	x	

C.3.2 Traffic flow simulations – microscopic models

Microscopic models are especially useful for traffic flow simulations that can be used to replicate the behaviour of all common modes of transport, including pedestrians, bicyclists, road- and rail-based public transport as well as motorized individual transport, including passenger and heavy duty vehicles. A typical application of traffic flow simulations is the design of single intersections or corridors, mostly regarding the schedule and synchronization of traffic lights. They use an exact representation of simulated traffic participants (e.g., various vehicle types of specific sizes, maximum velocities, accelerations, etc.), what enables an exact representation of traffic – yet at the price of a high effort spent on defining a simulation (Krajzewicz et al., 2019). The following list contains several examples of tools that belong to this category.

- **SUMO** (Simulation of Urban Mobility) is an open-source, highly portable, microscopic, and continuous traffic simulation package developed by the Institute of Transportation Systems at the German Aerospace Center to handle large networks and allowing for intermodal simulation. It is freely available and published under the Eclipse Public License V2 (SUMO, 2021), own algorithms can be implemented and evaluated. The simulation is capable to replicate the movement of different modes of transport, including individual car transport, public transport (both road- as well as rail-based), bicyclists, and pedestrians. SUMO supports different intersection types, including right-before-left or priority intersections, those controlled by traffic lights and roundabouts. It allows for importing or generating road networks and importing or generating a demand (Lopez et al., 2018; Krajzewicz et al., 2019).

- **Aimsun Next** is a commercial software that covers all levels from microscopic to macroscopic (Aimsun, 2021). The software is developed by Aimsun which was acquired by Siemens in Germany. Aimsun Next has grown from a microsimulator to a fully integrated application that now fuses microsimulation (including a pedestrian simulator), mesoscopic simulation, macroscopic functionalities, travel demand modelling and even two hybrid simulators (macro-meso and micro-meso) – all within a single software application. In travel demand modelling part, it includes the classic four-stage model.

- **PTV Vissim** is a world-wide used robust software for microscopic, mesoscopic and hybrid (combination of both) simulations. Similarly as PTV Visum, it was developed by the German company PTV Group from Karlsruhe (PTV Group, 2021). PTV Vissim is capable to simulate all modes of transport from classical to new ones. It supports individual motorized transport including passenger and heavy-duty freight vehicles with freely definable dynamics and other attributes, and also various kinds of public transport, bicyclists, pedestrians, rickshaws etc. Its important feature is a high spatial resolution used, which enables an exact dimensioning of lanes, intersections, halts, etc. Simulated infrastructure also allows for a high variability, including different kinds of traffic lights, variable speed signs, etc. PTV Vissim offers APIs for programming own behaviour models and also APIs for interaction with real-world traffic controllers, including Sitraffic Office, VS-Plus or LISA+. Moreover, it allows for a close cooperation with the above-mentioned macroscopic tool PTV Visum.

C.3.2.1 Traffic operations assessment

All mentioned microscopic simulation tools allow for the study of consequences of various traffic operation solutions, as for example introducing and enforcing variable speed limits, installing local-express lanes, and coordinated traffic lights, imposing differentiated road pricing, or optimizing traffic signal timing (Gounni, 2019; Aimsun, 2021).

C.3.2.2 Intermodal transport simulation

In microscopic models, individual users are simulated. They therefore allow for modelling of intermodal transport where a specific traveller needs to undertake a series of trips, using different modes of transport, e.g., personal car, public bus, or walking (Gounni, 2019; Aimsun, 2021).

C.3.2.3 Environmental impact assessment

Microscopic simulation tools allow to measure the number of emitted pollutants and consumed fuel, and thus support the development of solutions aimed at the reduction of air and noise pollution and the consumption of non-renewable fuels. For example, SUMO includes two emission assessment models: a model based on HBEFA v2.1 (a continuous reformulation of the HBEFA v2.1 emissions database), and PHEMLIGHT, a derivation of the original PHEM – Passenger Car and Heavy Duty Emission Model, developed by TU Graz and based on detailed measurements of an extensive European set of vehicles including passenger cars, light duty vehicles and heavy duty vehicles from city buses up to 40 ton semi-trailers. For these categories, various classes with respect to size, emission standard (Euro 0 – 6) and fuel (gasoline, diesel, CNG, BEV) are distinguished and modelled on the basis of their physical parameters and the measured full engine characteristics. However, only a restricted number of classes are included in the public version, others has to be approved by TU Graz (Gounni, 2019). Both emission models enable the calculation of fuel/energy consumption and emission of key pollutants (from the point of view of a greenhouse effect or a health respect: CO_2, CO, HC, NO_x, and PM) for any specific region and scenario, both for the present mix of vehicles (with respect to vehicle and fuel types) and for prospective future technologies. The program user is free to adjust vehicle parameters and import any real (possibly modified) or artificial network and specify traffic intensities in various places.

C.3.2.4 Parking management

Codecá (2018) present an open general-purpose Python Parking Monitoring Library (PyPML)[25] integrated with the software SUMO (2021) and using the Traffic Control Interface (TraCI) to gather and aggregate the parking monitoring information for the improvement of parking management. As individual use cases, the authors investigate various optimisations (three that are built-in in SUMO and achieved using static configuration files, further an optimisation leading to parking areas load balancing and a driver-oriented optimisation).

C.3.2.5 Pedestrian simulation

Aimsun Next offers a pedestrian simulator developed to model the movement of pedestrians on sidewalks, the interaction between pedestrians and traffic at crosswalks, and the boarding and alighting process at public transport stops. The focus is on ease of use, speed, multi-platform support and deep integration with the Aimsun Next platform to extend the mobility modelling workflow, e.g., the possibility of using Dynamic Public Transport Assignment to get skims for the four-step model (Aimsun, 2021).

C.3.2.6 Automated vehicles modelling

Sonnleitner and Friedrich (2020) refer to the application of the software PTV Vissim for the creation of microscopic models related to automated vehicles of various levels of automation, various automation functions, various sensor equipment, and various driving logics. These models were developed in the framework of the European project CoEXist aimed at preparing the transition phase during which automated and conventional vehicles would coexist on cities' roads. Microscopic models of automated vehicles are discussed in more details in section C.10.2.1.

C.3.2.7 Logistics Simulation

Logistics is an interdisciplinary research field, covering aspects of operations research, mathematics, statistics, computer science and engineering. Applications, techniques, and models proposed by these disciplines often require verification and validation. In SUMO, this domain is implemented in by containers and container stops (Gounni, 2019).

C.3.2.8 Solved challenges

- Estimating the emission vehicle profile by routes/areas/vehicle and public parking.
- Exploring effects of new mobility modes and policies on public transport and the overall transport network performance.
- Impacts of specific C-ITS enabled traffic management scenarios.
- Improvement of charging infrastructure planning.

C.3.2.9 Inputs and requisites

Basic inputs are again the network data together with additional traffic infrastructure and traffic demand. Now individual vehicles are to be specified.

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[25] PyPML library is freely available on GitHub https://github.com/lcodeca/pypml under GPLv3 license.

Table 11: Inputs and requisites for microscopic simulation models (e.g., SUMO, 2021)

Elements	Comments
Transport network	Network data together with additional traffic infrastructure (see Table 9).
Traffic demand	For vehicles that are to be simulated, their types and routes have to be specified.
Additional data	Further infrastructure related data (e.g., traffic lights and their programs, induction loops, bus stops, railways, charging stations and their types and parameters), additional visualisation elements, dynamic simulation control structures (variable speed signs and rerouters), calibrators, parking areas etc.

C.3.2.10 Outputs and KPIs

To evaluate investigated simulation scenarios quantitatively, simulations provide a wide range of outputs, as for example (Lopez et al., 2018):

Table 12: Selected outputs for microscopic simulation models (e.g., SUMO, 2021)

Output	Comments
Full output	Various information of all edges, lanes, and vehicles
Raw vehicle positions dump	Positions and speeds for all vehicles for all simulated time steps.
Emission output	Emission values and energy consumption of all vehicles for every simulation step.
Floating car data (FCD)	Name, position, angle, and type for every vehicle.
Trajectories output	Trajectory Data following includes name, position, speed, and acceleration for every vehicle following the Amitran standard
Lane change output	Lane changing events with the associated motivation for changing for every vehicle.
Simulated detectors	Traffic data collected from modelled detectors (e.g., inductive loop detectors, lane area detectors, multi-entry-exit detectors etc.).
Protocols of traffic light switching	Information about the state of a traffic light, information about the switches of a traffic light signal responsible for a certain link, etc.
Queue output	Lane-based calculation of the actual tailback in front of a junction.

Traffic data can be listed separately for individual elements or aggregated over edges, lanes, trips etc.

Some of basic KPIs are listed in the following table.

Table 13: KPIs for microsimulation models

Level	KPI	Impacts		
		Environmental	Economic	Social
Societal level	**Total distances of vehicles** driven in an area during a given time period by different types of vehicles	x	x	
	Fuel/energy consumption (by vehicles or aggregated)	x	x	
	Fuel mix (the percentage of the share of various fuel types in a given period)	x	x	
	Emissions (CO_2, CO, NO_x, PM; per vehicle-km by vehicle and fuel types or by system user; total emissions for a given time period; values for edges)	x		x
	Noise	x	x	x
	Edge lane traffic	x	x	
	Collisions among vehicles and between vehicles and pedestrians	x	x	x
	Traffic light states	x	x	
	Surrogate safety measures (e.g., headway, brake rates)	x	x	x

C.3.3 Agent-based models

Agent-based models are essentially microscopic: they consider individual users and also individual vehicles as autonomous units – agents, that make autonomous decisions as they interact with other agents and their environment, governed by certain rules. Using the memory, which is kept for each of them, agents iteratively learn and update their travel patterns during the competition with other agents for space-time slots. Simulations aim at a user equilibrium of all agents across the whole transport system, i.e., they are based on the co-evolutionary principle (Scherr, 2020).

- **MATSim** (Multi-Agent Transport Simulation) is an activity-based, open-source, extendable multi-agent simulation platform developed by ETH Zurich and TU Berlin. It is implemented in Java and designed for large-scale scenarios. It consists of several modules which can be combined or used stand-alone and which can be replaced by custom implementations to test single aspects of the analysis (MATSim, 2021a). It brings together microscopic description of demand by tracing the daily schedule and the synthetic travellers' decision.

- **MobiTopp** is another activity- and agent-based, open-source, modularized simulation software implemented in Java. It was developed by Karlsruhe Institute of Technology (MobiTopp, 2021) and similarly as other tools from this group, it models every person, household, and car of the planning area.

- **CityMoS** – the City Mobility Simulator platform is a microscopic agent-based discrete event simulation platform developed by the research teams at TUMCREATE. It has evolved from a microscopic traffic simulator for cars into a feature-rich mobility simulation platform encompassing both private and public transport, including electric buses and their charging infrastructure. (CityMoS, 2021).

- **Immense platform** is a commercial software aimed at agent-based transport simulations, intended for fleet managers, infrastructure operators and transportation planners (Immense, 2021).

From other agent-based tools, let us name **POLARIS** (Auld et al., 2016) and **ALBATROSS** (Arentze & Timmermans, 2004).

C.3.3.1 Travel demand simulation and forecasting

Scherr W. et al. (2020) present the agent-based multimodal travel demand model called SIMBA MOBi, where agents react to transport supply across all mobility choices. Long-term choices include vehicles ownership and work locations. The simulation of daily travel patterns if individual agents is based on the sequential combination of activity frequency, activity durations and destinations, together with a rule-based time-of-day scheduling, balancing individual preferences of travellers with system constraints (capacity constraints of the transport infrastructure and natural time and space constraints). The authors used SIMBA MOBi to model transport in Switzerland and validated it’s results against empirical observations. SIMBA MOBi has three major behavioural modules:

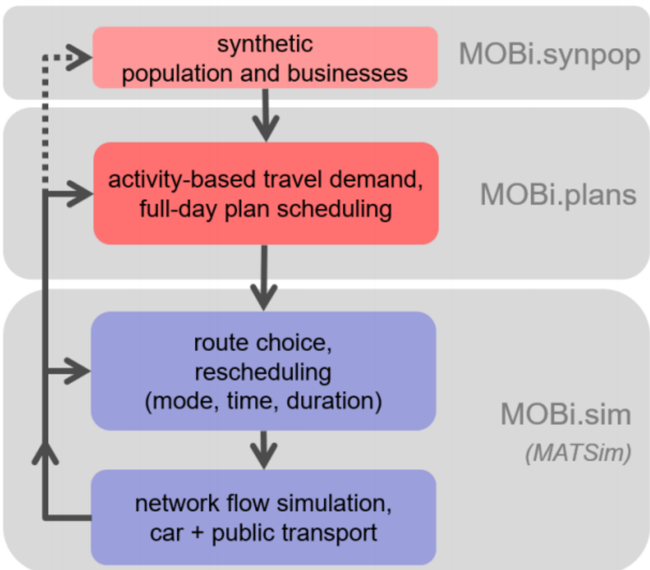

Figure 35: The main behavioural modules of SIMBA MOBi (Scherr et al., 2020, p. 156)

MOBi.synpop that generates a resident population for the existing state and allows modelling future synthetic populations (including persons, households, businesses, and other institutions). The module

MOBi.plans constructs 24-hour activity and travel plans for each agent in the synthetic population, and the module MOBi.sim simulates 24-hour dynamic network flows of cars and public transport using the above-mentioned open agent-based software MATSim. In MOBi.sim, the agents choose their final modes, route, and departure times for each trip on the basis of traffic condition and a full-day public transport schedule, considering travel time, parking search time (in the case of individual car use), service frequency, number of transfers, parking cost and distance.

C.3.3.2 Revenue management in public transport

Bouman and Lovric (2016) discuss the application of agent-based simulation for the study of public transportation revenue management considering time-based pricing strategies (peak markups and off-peak discounts). Here transportation demand was generated from smart-card data collected in a Dutch urban area, and the software MATSim was used for the core of the simulation. The structure of this system is depicted in Figure 36.

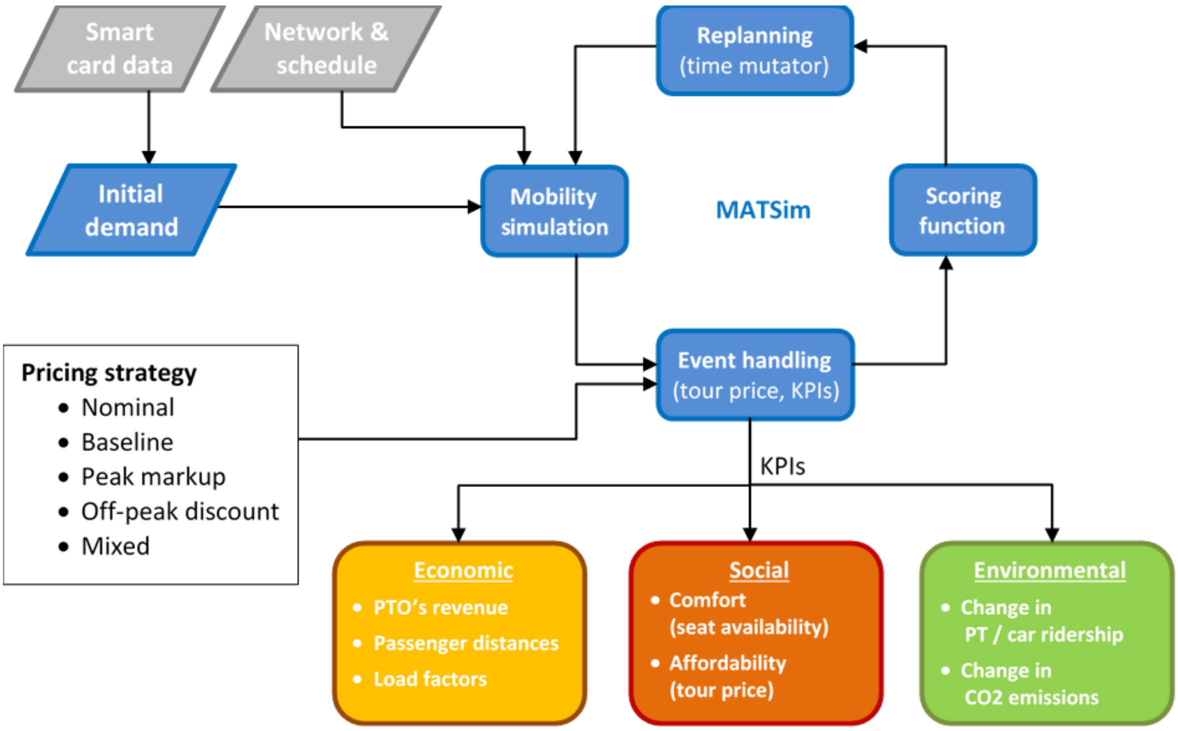

Figure 36: Decision support system for revenue management in public transport (Bouman & Lovric, 2016, p. 478)

C.3.3.3 Examining impacts of mobility-oriented policies

Various transport-related policies (e.g., congestion charging, public transport fare reduction, increased parking prices, road pricing, low emission zones) have a direct impact on travel behaviour of individual users, who may change their choices of a mode/route/departure times or even the sequence of out-of-home activities (Adnan et al., 2021). These changes subsequently lead to second-order impacts of the considered policies, such as the improvement of air quality, congestion reduction etc. To refine the interventions or introduce more innovative ones, a multi-agent-based simulation platform, where individual travellers and their behaviour are in the spotlight, represents a convenient and flexible tool allowing to model and explore impacts of various policies.

Adnan et al. (2021) illustrate these applications on the example of traffic management policies related to car access restrictions and bus frequencies in Hasselt (Belgium) and Bologna (Italy). They started with an activity-based model and calibrated it to reach the consistency of travel mode shares, trip distance and time-of-day distributions with the available aggregate data. The output of this activity-based model was then used as input to MATSim. The corresponding simulation framework, typical for this group of models, is presented in Figure 37.

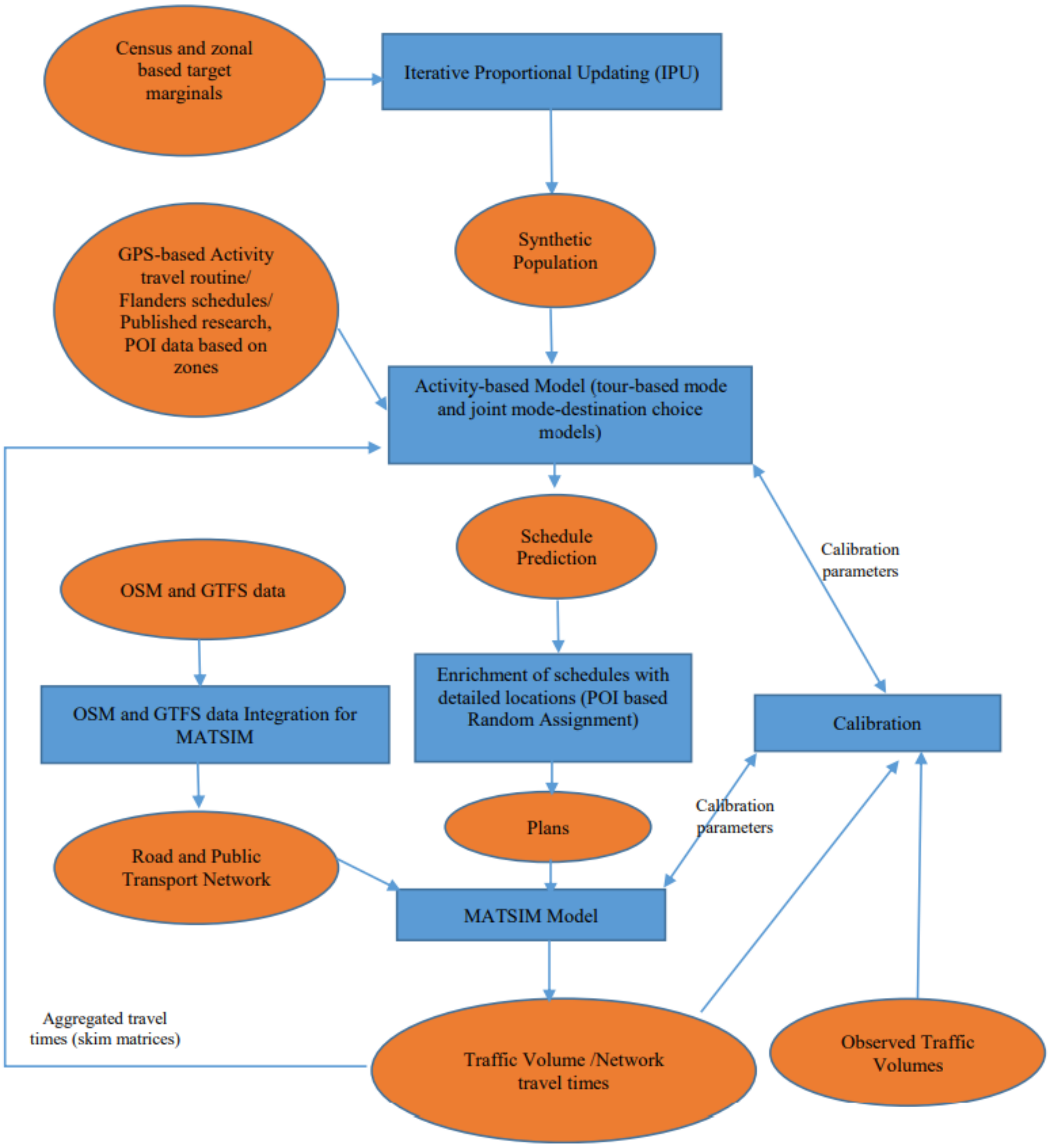

Figure 37: Integrated microsimulation framework for examining impacts of various policies (Adnan, 2021, p. 209)

C.3.3.4 Leisure trips modelling

McArdle et al. (2016) developed a new spatial choice model simulating leisure activities and corresponding traffic flows for the greater Dublin region. They used MATSim and investigated scenario where commuting trips were completed by individuals using private cars over a twenty-four hour period. The effectiveness and accuracy of the approach was validated using hourly data from count stations on main motorways around Dublin.

C.3.3.5 Fleet management

The commercial Immense platform (2021) declares it helps personal traffic providers (including car rental and ride-hailing companies) and package delivery companies to improve their fleet management and support their decisions on future development. For example, it provides a digital replication of real-world operations, allows to identify the optimal configuration of fleet (including volume, allocation logic and drivetrain) and infrastructure requirements (e.g., locations of depots with rapid EV chargers), to model different services, service level agreements and fleet buffer time. It enables to simulate and visualise impact of fleet adaptations across time and space, and consequences of introducing new technologies and business models (e.g., autonomous electric vehicles on a subscription basis in a given region). Addison Lee, a London-based private hire cab and courier company, appreciated the opportunity to explore a range of alternative scenarios, using simulation capabilities that would be difficult to build or access on its own, the improved arrival time accuracy that allows to service customers quicker, satisfy higher demands and provide drivers better balance of jobs. Moreover, it acknowledged the reduction of our vehicles' empty miles and associated emissions and costs.[26]

C.3.3.6 Predicting impacts of urban development

Immense (2020a) presents the case study in which the Immense platform was used to predict the future of England's Economic Heartland, the region with a 5.1 million population and 280,000 business community that is expected to triple in size during the forthcoming 30 years. The developed agent-based models simulated planned housing development and job creation and their impacts on transportation, infrastructure, economy, energy, and environment. They allowed to explore the implications of various scenarios and to assess Mobility-as-a-Service schemes.[27]

C.3.3.7 Infrastructure operations

As one of its key application domains, Immense (2021) names infrastructure operations. Through simulations, the platform helps to understand the consequences of disruption in granular detail and predict future impacts of various scenarios to plan effective mitigation measures. It enables to assess the impact of multiple unplanned incidents, develop strategies to reduce congestion (e.g., rerouting vehicles, changes in signal timing etc.) and thus improving air quality and improve journey time reliability for travellers, and schedule planned works to minimise disruption in the region. For example, the case study Immense (2020b) describes the application of an agent-based model to the improved roadworks planning by the company Transport for London. Various applications of the open platform MATSim related to infrastructure operations (e.g., traffic signals and lanes and parking) are described in the book by Horni et al. (2016).

C.3.3.8 Electromobility simulation

Márquez-Férnandez et al. (2019) present a MATSim (Multi-Agent Transport Simulation) model of Sweden covering the most of long-distance trips nationwide with the aim to simulate various scenarios and analyse interactions between electric vehicles and the charging infrastructure. The model considers individual vehicles and detailed information about all relevant aspects of each trip, including the decision processes related to the charging of the batteries, i.e., when, where and for how long to charge during a long-distance trip depending on the availability of charging infrastructure and its characteristics. The paper demonstrates the usability of a MATSim model for decision making about which type of charging infrastructure suits best

[26] https://immense.ai/wp-content/uploads/2020/02/4531-Immense-Case-Study-AL-v4-Interactive.pdf
[27] https://immense.ai/wp-content/uploads/2020/02/4531-Immense-Case-Study-EEH-v3-Interactive.pdf

the traffic demands at certain locations, and about sizing such infrastructure. Moreover, MATSim simulations have a potential to serve as a basis for other studies such as cost comparisons between different scenarios, assessment of the impact on the power grid, the effect of electricity pricing strategies, the impact of different connected services or even the feasibility of vehicle charging prioritisation schemes under limited resources or emergency situations (Márquez-Férnandez et al., 2019).

CityMoS (2021) declares that its City Mobility Simulator was used to evaluate the electromobility capabilities and charging infrastructure requirements in the Amsterdam metropolitan region.

C.3.3.9 Evaluation of district evacuation scenarios

Klupfel and Lämmel (2016) applied MATSim to model, compare and evaluate various scenarios for the evacuation in the case of a serious flood in Hamburg-Wilhelmsburg. The comparison of individual variants is based on overall evacuation time, clearing time of different cells, i.e., squares in the area that has to be evacuated, and the number of cars using the road network.

C.3.3.10 Solved challenges

Challenges used by multi-agent transport simulation models, possibly integrated with other modules, include:

- Assessment and monitoring of demand responsive transport systems.
- Visualise options with a mix of public/sharing/public modes of transport related to emissions.
- Providing route options with a mix of transport modes taking emissions into account.
- Estimating the emission vehicle profile by routes/areas/vehicle and public parking
- Exploring effects of new mobility modes and policies (e.g., micromobility, park and ride, low emission zones, private vehicle restriction measures, dynamic access restrictions etc.) and external information (weather, public events, …) on public transport and the overall transport network performance.
- Impacts of specific C-ITS enabled traffic management scenarios.
- Identification of more busy public transport stops, more frequent trips, analysis of service quality.
- Improvement of charging infrastructure planning.
- Modelling impacts of unforeseen crisis (e.g., extreme weather, floods, pandemics).

C.3.3.11 Inputs and requisites

Basic inputs and requisites for multi-agent simulation models are listed in the following table.

Table 14: Inputs and requisites for multi-agent simulation models

Elements	Comments
Transport network	A real-world transport network can be extracted using a GIS application using a filter for obtaining components and information relevant for the model, supplemented with further infrastructure elements as charging stations etc.
Land use data	Information on socioeconomic use of land.
Transport supply	E.g., public transit vehicles and their schedules.

Population of agents	Agents can be travellers (e.g., all drivers/citizens living in a considered region, which can be based on a census) or vehicles (of a specific type, size, weight, battery capacity on board, etc.) and the missions that should be fulfilled.
Strategies of agents	Rules guiding various interactions in the environment.
Agent’s activities and missions	Activity schedules, types, locations, mode of travel between activities (for people) etc. This is often a separate module representing an activity-based demand model.

C.3.3.12 Outputs and KPIs

Typical output data include recorded actions of agents, the current state of the population with agent’s plans, a survey of agents arriving, departing or en route (per time unit) in every iteration, a list of the number of trips and their duration for each iteration and each activity pair (e.g., from work to home) and link stats – hourly count values and travel times on every network link in each iteration. The last output is important for the comparison with real-world count data (Horni et al., 2016). The output files that are continuously built up to summarize the complete run are listed in the following table. For more details, see (Horni et al., 2021).

Table 15: Outputs for multi-agent simulation models

Output file	Comments
Log file	Information that may be needed later for an analysis or in case a run crashes.
Warnings and Errors Log File	Warnings and error messages (they may be overlooked in a log file)
Score Statistics	The average best, worst, executed and overall average of all agents’ plans for every iteration (as a picture in a png file, and a text file).
Leg Travel Distance Statistics	Comparable to score statistics, but instead, they plot travel distance (as a picture in a png file, and a text file).
Stopwatch	Computer time (so-called wall clock time) of actions like replanning or the execution of the mobility simulation for every iteration (helpful for computational performance analyses).
Events	Records on every action in the simulation (e.g., activity start or change of network link) and its attributes (e.g., time, ID of the agent triggering the event or link ID where the event occurred).
Plans	At configurable iterations: current state of the population with the agents’ plans; final iteration’s plans.
Leg Histogram	For each iteration and for each transport mode and the sum of all modes: histogram depicting the number of agents arriving, departing or en route, per time unit.

Trip Durations	For each iteration: the number of trips and their durations for each activity pair (e.g., from work to home or from home to shopping).
Link Stats	Hourly count values and travel times on every network link (particularly important for comparison with real-world count data).

Table 16: KPIs for agent-based models

Level	KPI	Impacts		
		Environmental	Economic	Social
Individual/user level	**Total number of trips** made (work trips, leisure trips)	x		x
	Mean travel time, activity duration time, out-of-home time			
	Mean trip distance			
	Total cost per individual/household		x	x
Societal level	**Total distances of vehicles** driven in an area during a day (weekday, week-end day) or per hour (peak hour, off-peak hour,...) by different type of vehicles	x	x	
	Vehicle occupancy (average number of persons per vehicle/day or per vehicle per trip)	x	x	x
	Vehicle fuel efficiency	x	x	
	Fuel/energy consumption	x		
	Fuel mix (the percentage of the share of various fuel types in a given period)	x	x	
	Emissions (CO_2, CO, NO_x, PM; per vehicle-km by vehicle and fuel types or by system user; total emissions for a given time period)	x		
	Share of public transport PKM (person kilometres travelled)	x	x	
	Share of car PKM	x	x	

C.4 Public Transport Management

C.4.1 PTM System

There are more than 50 public transport management (PTM) systems installed across the globe, 15,000 connected vehicles, 5.5 million passengers per day and 500 million monitored kilometres per year (Swarco, 2021). Each PTM system includes a number of smaller sub-systems that allows the management authority at any time to analyse the required data to make certain decisions. These systems include everything from fleet management tools, traffic management and planning, parking and road safety, real-time vehicle tracking to journey planning applications for end users (Ambrož et al., 2016). Some of the elements of PTM integral system include:

- **Fleet management system:** real-time vehicle tracking and location information to enable operators to optimise fleet utilisation and to provide real-time passenger information to overall improve service quality and punctuality.
- **Terminal management system:** optimisation of terminal capacity and utilisation. Drivers are guided all the way in and out of the terminal. Passenger information displays, apps and webservices keep track of arrival and departure times and inform about the bays used by each bus route. Terminal management system also helps to reduce emissions and travel time. In connection with surveillance cameras, safety and security are improved and access control keeps unauthorized traffic away, reducing the risk of disturbances.
- **Real-time passenger information system:** operates on the basis when public transport vehicles transmit information to the central system in real time. This information includes current location, number of passengers and other data that can be used to optimise operations. At the same time, some of this information is shared with passengers, e.g., arrival and departure times and punctuality of the service. This information can be displayed at bus stops and bus terminals, but can also be served to smart phone apps or web applications.
- **Automated fare collection system (AFCS):** a generic term for a ticketing system in public transport where the fare is no longer paid directly but via ticket vending machines, online services, or other methods.
- **Efficient and safe driving system:** continuous improvement of the performance and commitment of drivers, which lead to a more efficient and safer operation, committed to the environment and the quality of the service.
- **Traffic management system:** is composed of a set of application and management tools that aim to improving the overall traffic efficiency and increasing safety of the transportation systems.
- **Public transport priority system:** intends to increase the efficiency of urban traffic management to better handle growing traffic volumes. It makes public transport more attractive due to faster travel times and improved service regularity. Higher passenger satisfaction is complemented by additional benefits including improved energy-efficiency and reduced pollution.
- **Security and Surveillance system:** provides a real-time video observation which has a positive effect on their personal security and helps to reduce criminal activity.

C.4.1.1 Solved Challenges

PTM is a continuous process of integration, analysing and using the big data from different integrated systems for forecasting, communicating, exchanging, and designing public transport solutions. Already many public transport challenges were identified and addressed by the integral PTM, among them:

- **Infrastructure Planning:** identifying where new infrastructure solutions are needed to address public transport user's demand as well as plan new infrastructure to support greener and safer streets.
- **Congestion:** identification of congested areas is an essential element of PTM, but the mechanism to create a prompt response to this issue still need further elaboration.
- **Integration of various transport systems**: degree of integration of passenger public transport system (e.g., fares and ticketing systems, traffic information, etc.) and various carrier from different transportation modes (Prospects, 2003).
- **Safety of VRU:** allow to design the streets multimodal cities for the most vulnerable user (e.g., safer intersections, protected bike lanes, curb extensions, etc.)
- **Standardisation:** unified approach to agree on a consistent, comprehensive, and agreed format for exchanging data (e.g., GTFS) (M. Braga et al., 2014).
- **Travel pattern:** possibility to create a comprehensive and accurate understanding of travel patterns.
- **Public transport pattern:** allow planning for public transport.
- **Parking space:** possibility to receive information on availability of free parking and their control.
- **Fleet size management:** possibility to analyse and plan evolution fleets sizes, in accordance with identified patterns of supply and demand.
- **Curb space management:** planning and prioritising access to curb space to prioritize people and goods.
- **Shared mobility:** allow to analyse and understand the impact of shared mobility in order to efficiently coordinate shared mobility programs with partners to attain safety, equity, and sustainability goals.

C.4.1.2 Inputs and Requisites

Each PTM system operates with mobility data. Mobility data is information about travel that is collected using digitally enabled mobility devices or services. The mobility data is typically recorded as series of latitude/longitude coordinates and collected at regular intervals by smartphones, on-board computers, or app-based navigation systems. With mobility data, public agencies can make more informed decisions about where to place new infrastructure (e.g., kerb loading, scooter parking), ensure that services are equitable (i.e., that they are accessible in historically underserved communities), and determine how new mobility services can be leveraged to reduce congestion and climate impacts. The mobility data may include information about trips, for instance:

- origins,
- destinations,
- trip length,
- trip route,
- start and end times; and

information about the vehicles used, such as:

- vehicle location
- average speed,
- direction,
- sudden breaking,
- emissions.

All mobility data can contain static and dynamic/real-time information. Static information includes:

- routes and schedules;

while dynamic information includes:

- traffic conditions,
- real-time public transport schedules (expected time of arrival),
- information pertaining to bus stops,
- incidents.

In order to be able to manage the routes of public transport vehicles, all infrastructure entities are represented in the system with their geographical properties stored in a GIS database, which is obtained from publicly available data sources. The data is physically stored on a server that provides access to the client applications of different types and roles, based on access permissions (Ambrož at al., 2016). Wireless broadband provides the high-speed connectivity needed and a proven solution that can be deployed at a fraction of the cost and time of fibre or wired connectivity.

C.4.2 Standard data

A critical element of each PTM system is standardizing data sharing specification that helps to improve data comparability as well as reduce administrative burdens related to data sharing. It is of paramount importance to have a comprehensive, consistent, and agreed set of parameters for data to be easily communicated and used.

GTFS stands for "General Transit Feed Specification" which defines a common format for public transportation schedules and associated geographic information. It allows public transport agencies to publish their public transport data in a format that can be used by a variety of software applications. GTFS feeds can be used for trip planning, ridesharing, timetable creation, mobile data, visualisation, accessibility, analysis tools for planning, real-time information, and interactive voice response (IVR) systems.[28] The term GTFS originally stood for "Google Transit Feed Specification" and it led to the first version of Google Transit, back in 2005 (M. Braga et al., 2014). GTFS has become an integral part of the PT data landscape, and some extensions have been proposed as follows:

- **GTFS-Flex**[29] is an extension to enable trip planning for various types of demand-responsive or special transport services for people with disabilities. GTFS-powered feeds are not designed to show demand-responsive service, leaving users in certain areas with an incomplete picture of their options.

[28] https://www.transitwiki.org/TransitWiki/index.php/General_Transit_Feed_Specification
https://gtfs.org/gtfs-background
[29] https://github.com/MobilityData/gtfs-flex

GTFS-Flex remedies this, enabling trip planning software such as OpenTripPlanner[30] to generate trips combining demand-responsive and fixed route service.

- **GTFS-Realtime[31]** allows maps to convey dynamic information about when PT is actually arriving and departing, rather than relying on static, preset schedules. It also allows PT agencies to provide real-time updates about their fleet to application developers.

Alternatives to GTFS and its extensions include the standards GOFS (General On-demand Feed Specification) and REST API/XML. GOFS[32] is developed by MobilityData, a non-profit organisation based in Montreal (Canada). It aims to integrate on-demand services with other mobility options in common platforms for travellers. As an alternative to GTFS-Realtime, REST API/XML, where REST stands for Representational State Transfer (REST), corresponds to an architectural style for Application Programming Interfaces (APIs). There are many alternative data-exchange formats that are compatible with RESTful APIs, including JSON and HTML, but the most used in transportation spaces is eXtensible Markup Language (XML).

Considering that the NeTEx (Network Timetable Exchange) and SIRI (Service Interface for Real-Time Information) standards will be mandatory for all MaaS actors in Europe in 2023, these public transport data standards will be included in the literature review.

- **NeTEx[33]** is a public transport data standard developed under the aegis of CEN (Comité Européen de Normalisation). It provides a means to exchange data for passenger information such as stops, routes timetables and fares, among different computer systems, together with related operational data. It can be used to collect and integrate data from many different stakeholders, and to reintegrate it as it evolves through successive versions. NeTEx is intended to be a general-purpose XML format designed for the efficient, updateable exchange of complex transport data among distributed systems.
- **SIRI**[34] is a protocol that allows exchange of dynamic information about public transport services and vehicles. Just as NeTEx, SIRI is based on Transmodel for public transport information and comprises a general-purpose model and an XML schema for public transport information. SIRI has mainly seen uptake in Europe, but some US agencies, offer real-time information about their services through SIRI. The main benefit of SIRI is that it may convey more details about public transport than GTFS-RealTime.

C.4.2.1 Data specification

The data standardisation can be initiated in two different ways, namely either from “top down” by an influential actor, be it a governmental agency at country, or state, or city level, or from the “bottom up”. This process is initiated by smaller actors who agree to accept the same data specifications. Even organisations that work with highly detailed data internally using standards like NeTEx find GTFS useful to publish data for wider consumption in consumer applications, where GTFS stands out because it was conceived to meet

30 https://www.transitwiki.org/TransitWiki/index.php/OpenTripPlanner
31 https://developers.google.com/transit/gtfs-realtime
32 https://mobilitydata.org
33 http://netex-cen.eu
34 http://www.transmodel-cen.eu/standards/siri

specific, practical needs in communicating service information to passengers, not as an exhaustive vocabulary for managing operational details.

Figure 38 presents a comparison between the GTFS and GTS-Flex models. The GTFS consists of two elements, namely a static component that contains schedule, fare, and geographic transit information and a real-time/dynamic component that contains arrival predictions, vehicle positions and service advisories. The GTFS-Flex extends the GTFS model by including booking rules and locations where a rider may request the pickup or drop off. GTFS-Realtime is based on "protocol buffers", and it uses one of two methods, namely: fetch, which allows Google, or other developers, to retrieve data from a web location; or push, which allows users to upload data programmatically. The specification currently supports the following types of information:

- **Trip updates:** delays, cancellations, changed routes
- **Service alerts:** stop moved, unforeseen events affecting a station, route, or the entire network
- **Vehicle positions:** information about the vehicles including location and congestion level

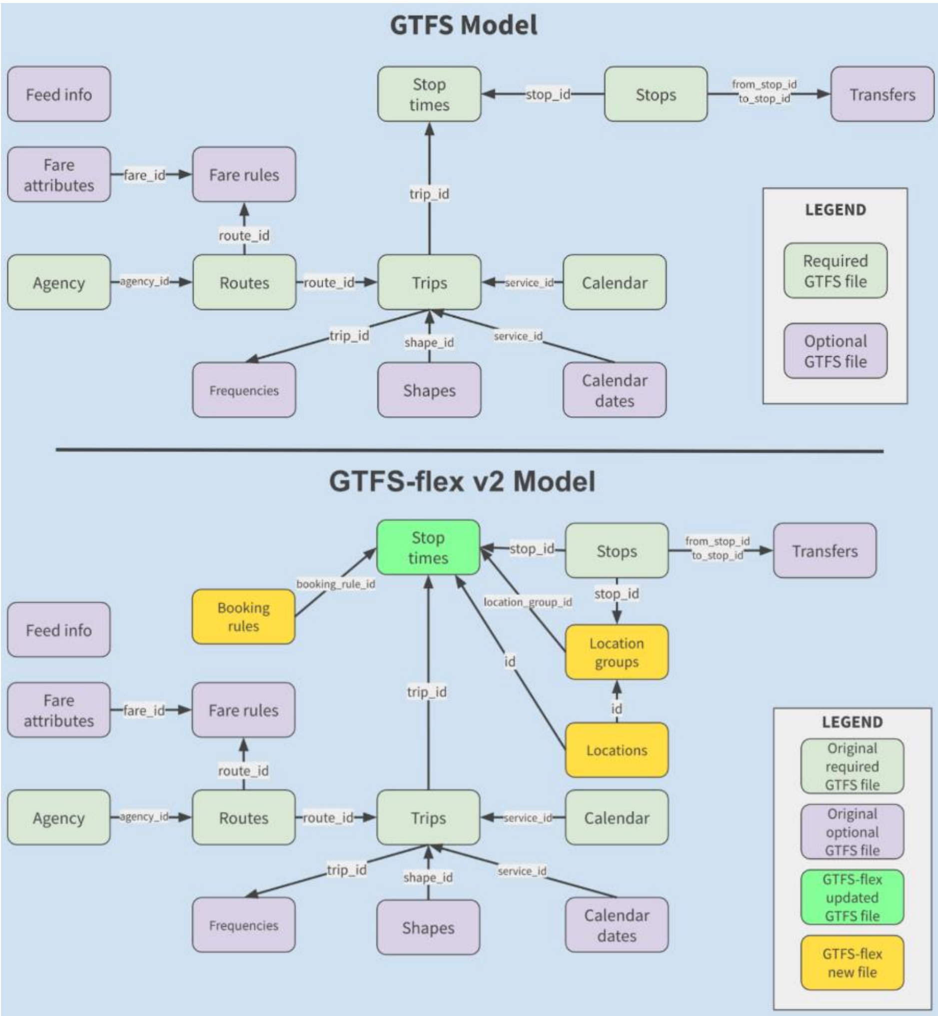

Figure 38: GFTS and GFTS Flex Diagram (source: https://githubmemory.com/repo/MobilityData/gtfs-flex)

REST API/XML is a generalized format and is not necessarily public-transport-specific, though it can be adapted to fit public-transport-specific needs. A RESTful API makes real-time arrival and departure predictions based on when a public transport unit arrives or departs from a specific stop. A RESTful API essentially trades network completeness for reduced data-management requirements and greater object specificity (i.e., a user can request information on a single stop without having to download data on the whole public transport system). In practice, a RESTful API/XML may be more feasible for smaller municipalities (which generally have fewer technical resources), while GTFS-Realtime is better suited to larger cities in scope of our analysis. If a planner wishes to view an entire PT map, however, RESTful APIs require individual requests to fetch stop data one at a time and thus may require more data storage space than GTFS Realtime.

C.4.2.2 Solved challenges

There are several examples of solved challenges that are related to standardizing shared data:

- **Trip planning**: enables trip planning for various types of demand-responsive or paratransit service.
- **Dynamic information about on PT**: conveys information on real-time arrival and departing prediction of public transport.
- **Fleet information**: allows PT agencies to provide real-time updates about their fleet to application developers.
- **Information on a specific segment of a trip**: allows user to request information on a single stop without having to download data on the whole public transport system.
- **Vehicle information**: Information report the real-time information about available vehicles location of a vehicle, vehicle type, and current battery charge.
- **Exchange/integration of information between various systems**: exchanges data for passenger information such as stops, routes timetables and fares, among different computer systems, which can be collected from various stakeholders.
- **Cost reduction**: reduces administrative burdens related to data sharing.
- **Data analysis**: timetable creation, visualisation, analysis tools for planning, real-time information, and interactive voice response (IVR) systems.

C.4.2.3 Inputs and requisites

There is a big number of data that feeds the PTM systems and is collected from various external sources or generated from the analysis of collected data (e.g., for GTFS inputs, see Table 17). However, different PTM systems may use different data for management of PT. Some systems can use a very specific data depending on the transport services they are to support and for other system this specific data may not be relevant at all for their focus is on other transport services. Therefore, here we present the most vital data that ensures the most important functionalities of the PTM system:

- Traveller location
- Start/end of a journey
- Type and modes of transportation used during the trip
- Public transport lines and stations used during the journey
- ICT tools for monitoring the services
- ICT algorithms to combine user requests
- Fleet Information (type, number, location, etc.)
- ICT tools for analysis of travel patterns within a city

- Connected vehicle data
- Data on parked transportation means (vehicle, bikes, etc.)
- Receive alerts for events and infringements
- Data from micromobility riders.

For example, Table 17 lists some of the most common datasets used in GFTS.[35]

Table 17: GFTS Data sets

Field Name	Type	Required	Description
agency_id	ID	Conditionally Required	Identifies a public transport brand which is often synonymous with a public transport agency.
agency_name	Text	Required	Full name of the public transport agency.
agency_url	URL	Required	URL of the public transport agency.
agency_timezone	Timezone	Required	Time zone where the public transport agency is located.
stop_id	ID	Required	Identifies a stop, station, or station entrance.
stop_code	Text	Optional	Short text or a number that identifies the location for riders.
stop_name	Text	Conditionally Required	Name of the location. Use a name that people will understand in the local and tourist vernacular.
stop_lat	Latitude	Conditionally Required	Latitude of the location.
stop_lon	Longitude	Conditionally Required	Longitude of the location.
route_id	ID	Required	Identifies a route.
route_type	Enum	Required	Indicates the type of transportation used on a route. Valid options are: 0 - Tram, Streetcar, Light rail. Any light rail or street level system within a metropolitan area. 1 - Subway, Metro. Any underground rail system within a metropolitan area. 2 - Rail. Used for intercity or long-distance travel. 3 - Bus. Used for short- and long-distance bus routes. 4 - Ferry. Used for short- and long-distance boat service. 5 - Cable tram. Used for street-level rail cars where the cable runs beneath the vehicle, e.g., cable car in San Francisco. 6 - Aerial lift, suspended cable car (e.g., gondola lift, aerial tramway). Cable transport where cabins, cars,

[35] https://developers.google.com/transit/gtfs/reference#file_requirements

			gondolas, or open chairs are suspended by means of one or more cables. 7 - Funicular. Any rail system designed for steep inclines. 11 - Trolleybus. Electric buses that draw power from overhead wires using poles. 12 - Monorail. Railway in which the track consists of a single rail or a beam.
service_id	ID	Required	Identifies a set of dates when service is available for one or more routes.
trip_id	ID	Required	Identifies a trip.
direction_id	Enum	Optional	Indicates the direction of travel for a trip.
wheelchair_ accessible	Enum	Optional	Indicates wheelchair accessibility. Valid options are: 0 or empty - No accessibility information for the trip. 1 - Vehicle being used on this particular trip can accommodate at least one rider in a wheelchair. 2 - No riders in wheelchairs can be accommodated on this trip.
bikes_allowed	Enum	Optional	Indicates whether bikes are allowed. Valid options are: 0 or empty - No bike information for the trip. 1 - Vehicle being used on this particular trip can accommodate at least one bicycle. 2 - No bicycles are allowed on this trip.
arrival_time	Time	Conditionally required	Arrival time at a specific stop for a specific trip on a route.
departure_time	Time	Conditionally required	Departure time from a specific stop for a specific trip on a route.
date	Date	Required	Date when service exception occurs.
start_date	Date	Required	Start service day for the service interval.
end_date	Date	Required	End service day for the service interval. This service day is included in the interval.
fare_id	ID	Required	Identifies a fare class.
price	Non-negative float	Required	Fare price, in the unit specified by currency type.
currency_type	Currency code	Required	Currency used to pay the fare.
payment_method	Enum	Required	Indicates when the fare must be paid. Valid options are: 0 - Fare is paid on board.

			1 - Fare must be paid before boarding.
transfers	Enum	Required	Indicates the number of transfers permitted on this fare. The fact that this field can be left empty is an exception to the requirement that a Required field must not be empty. Valid options are: 0 - No transfers permitted on this fare. 1 - Riders may transfer once. 2 - Riders may transfer twice. empty - Unlimited transfers are permitted.

C.4.2.4 Outputs and KPIs

Depending on the collected data and the PT services that need to be supported by the PTM system, different outputs are obtained and they can be used as the main KPIs. Here we focus on selected outputs since different PTM systems have different purposes to achieve:

- Location of origin and destination information for riders
- Waiting times at the location
- Information on average boarding per PT line
- Information on boarding time at each stop, including specific times throughout the day
- Data on load-factor and estimation of vehicle crowding
- Identification of first/last-mile barriers to ridership
- Information on fleet availability
- Information on transportation means availability (vehicle, bikes, scooter, etc.)
- Breakdown of common line transfers

C.4.3 Mobility data assessment platform

One of the important steps in PTM is not only collection and sharing of the data but also its evaluation that can help for planners and other practitioners to incorporate transportation data into decision making process. There are both proprietary as well as open-source platforms that allow mapping and visualising mobility data. Proprietary platforms typically have more technical and analytical capabilities and tools for assessment, but are costly to use. Relying only on private platforms to gather, store and/or visualise public data may also lead to a troubling precedent. Open-source platforms provide more transparency and accessibility. However, these platforms can be difficult and expensive for public agencies and other not-for-profit entities to maintain.

Moovit[36] is one of those private platforms that provides information about where, when, and how people move around cities worldwide. It is the world's largest repository of public transport data,[37] and through their "Urban Mobility Analytics" tool they combine multiple data sources, including anonymized, aggregated data

[36] https://moovit.com/maas-solutions/urban-mobility-analytics
[37] In August 2019, Moovit has announced that it has reached over half a billion users worldwide and has also opened service in its 3,000th city across 92 countries and is available in 45 languages. https://www.masstransitmag.com/technology/passenger-info/mobile-applications/press-release/21095045/moovit-moovit-reaches-half-a-billion-users-in-3000-cities-around-the-world

from hundreds of millions of Moovit users, with advanced algorithms to provide detailed insights into how people move around cities, therefore supporting them make more informed, data-driven mobility decisions.

Figure 39: Moovit interface (source: Moovit[36])

Moovit tool can provide a very comprehensive and accurate understanding of travel patterns to and from a region, whether it is a city neighbourhood or a particular district. The provided information can be critical for organisations performing a wide variety of planning functions, including improving first/last mile access to stations, aligning timetables to improve network connectivity, building access roads or pathways to a station, and assessing the impact of future public transport changes on riders and local residents.[38]

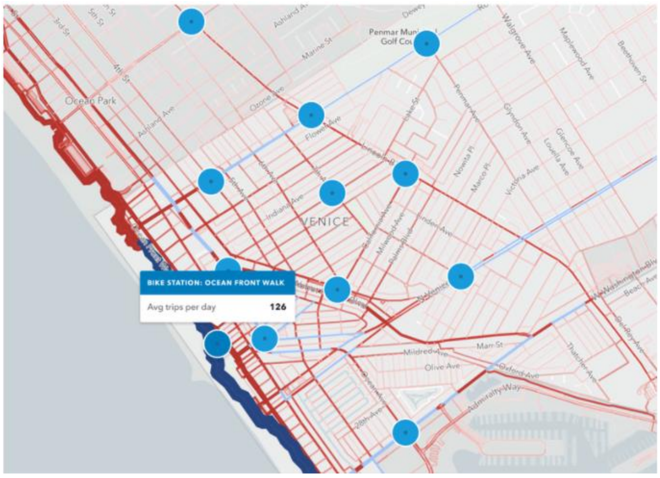

Figure 40: Remix interface (source: Remix[39])

Remix[39] platform provides an integrated set of products that contain public transport, street-specific, and new mobility data, often in real time. It allows to understand who has access to public transport, from where, to where, and how often, in addition to conceptual plans for street-level changes to improve bus speed and reliability.[40] It is a tool that allows planning for public transport, namely design, evaluate, and collaborate all

[38] https://moovit.com/maas-solutions/urban-mobility-analytics
[39] https://www.remix.com
[40] https://medium.com/civic-analytics-2019/remix-shaping-urban-mobility-128d7fa3c13e

in one place. Remix helps to understand the impact of shared mobility, allows to coordinate shared mobility programs with partners to attain safety, equity, and sustainability goals.

C.4.3.1 Solved challenges

As discussed in the previous section, the solved challenges include:

- Identification of city's transportation needs
- Understanding of travel patterns, visualisation of popular routes
- Understanding of patterns of supply and demand
- Control and insight on mobility devices parking
- Receiving alerts for events and infringements
- Support of new infrastructure planning for greener and safer streets
- Streets, curbs, and mobility fleets management using digital solutions
- Evaluation of public transport, support of its design
- Understanding the impact of shared mobility, coordination of its programs

C.4.3.2 Inputs and requisites

The inputs and requisites for a public transport management system can be summarized in few points:

- Input from travellers: regarding location are coming from
- Input from travellers: start their journey
- Input from travellers: modes of transportation that was used during the trip
- Input from travellers: which public transport lines and stations are the most popular

C.4.3.3 Outputs and KPIs

The main KPIs for public transport management have been identified:

- Average boarding and alighting at each stop, including specific times throughout the day
- Typical load-factor and estimation of vehicle crowding
- Identification of first/last-mile barriers to ridership
- Additional descriptive statistics of line riders and their complete journeys
- Average boarding and alighting per line, location, and time
- Waiting times at the location
- Breakdown of common line transfers
- Origin/destination information for riders using the location

C.4.4 ANNEX: Mobility Management Levels

As an equivalent to the levels of MaaS integration topology, an evolution of the levels of Mobility Management is briefly discussed here. This presentation focuses on penetration and contribution of mobility data in each level that corresponds to Maas Integration levels. In total, there are 5 levels, yet since the Level 0 represents no integration or no information, it is not discussed here.

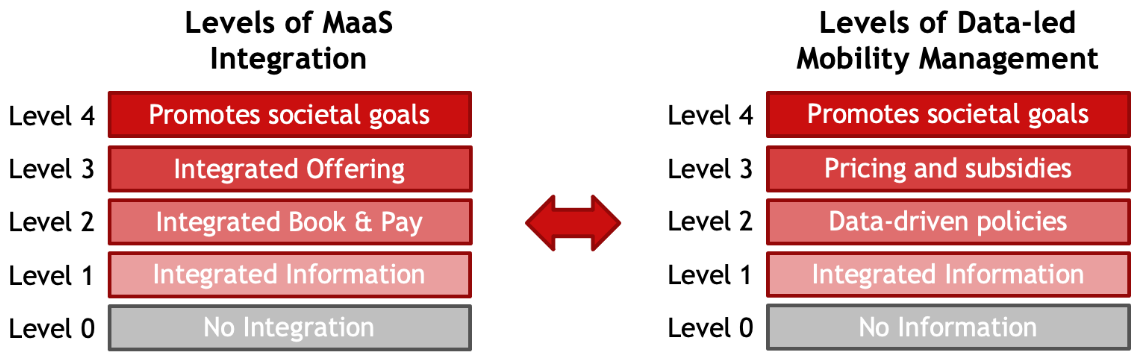

Figure 41: Levels of MaaS integration and data-led mobility management (source: Populus[41])

Level 1: Mobility Data Reporting

In the past years, many cities have achieved Level 1 of Mobility Management, securing access to mobility data from private fleet operators. Public agencies, including city departments of transportation and public transport agencies, need access to mobility data in order to serve as effective mobility managers.

With this data, public agencies can make more informed decisions about where to place new infrastructure (e.g., kerb loading, scooter parking), ensure that services are equitable (i.e., that they are accessible in historically underserved communities), and determine how new mobility services can be leveraged to reduce congestion and climate impacts.

As additional mobility services are introduced in cities, including shared moped, autonomous delivery, and autonomous ride-hailing services, city departments of transportation must have some level of access to data from these services in order to adapt transportation infrastructure and policy to keep up with changing needs of the public right-of-way. Many cities have already reached Level 1 of Mobility Management for shared micromobility, with many having advanced to Level 2.

Level 2: Policies driven/validated with data

Level 2 of mobility management is achieved when cities are able to leverage the data that they receive from mobility operators to set more effective policies. Examples of data-driven policies that might be implemented by cities to manage mobility fleets (that are already implemented for micromobility services) include:

- Parking: Geospatial areas for preferred and restricted parking areas might be communicated to mobility fleets for pedestrian safety or other needs.
- Trips: Routes and specifically no-ride/no-trip paths might be shared to communicate where pedestrians, and micromobility or other types of vehicles have priority on specific paths.

[41] https://www.populus.ai

- Equity: Cities might require or subsidise (see Level 3) fleet service in an area that is historically underserved.
- Fleet size: Cities might set a minimum level of service or maximum fleet size.

Level 3: Pricing to optimise decisions

Level 3 mobility management is achieved when cities effectively leverage pricing strategies, including subsidies, to influence how travellers decide whether to walk, drive, use micromobility, or use public transport. In 2020, many cities overseeing shared micromobility programs began to implement more complex policies for pricing the public right-of-way, including parking fees (applied to restricted parking areas), fines for non-compliance with equity policies, and fees for riding in no-ride zones.

While setting a fair price for access to roads, kerbs, and on/off-street parking is an important mechanism for cities to influence traveller behaviour, also important are subsidies. Public transportation services are typically heavily subsidised because they are viewed as providing a significant public utility - in short, public transport enables cities to more efficiently move more people than would otherwise be possible if they all drove individual vehicles.

Public subsidies must be implemented in the most transparent, cost-efficient, targeted way, and be designed to address Key Performance Indicators included in cities' mobility plans.

Level 4: Multimodal optimisation to Promote societal goals

Nowadays, many cities have completed Level 1, 2, and in some case Level 3 of mobility management: mobility data sharing, data driven policies, and pricing. However, the most sophisticated mobility management solutions that exist today are by and large applied only to micromobility services (e.g., shared bikes and scooters), and generally lacking other transportation modes (e.g., Uber/Ola, carsharing). Platforms like Vianova, Populus, or Remix (discussed earlier) deliver Levels 1 to 3 mobility management solutions for cities to manage multiple shared modes, including shared bikes, scooters, mopeds, and cars

Few cities have implemented mobility management beyond shared electric scooters, and no cities have effectively implemented mobility management to optimise across the multiple transportation modes that exist in many cities (i.e., shared micromobility, Uber/Ola, carsharing, mass public transport, etc.)

With Level 4 mobility management, public agencies will be able to influence how travellers make transportation decisions across modes to promote societal goals: reducing transportation climate impacts, limiting congestion, and expanding equitable access to mobility.

In order to reach Level 4 mobility management, cities will need an access to data from the various transportation services delivered on their public right-of-way in order to make data driven decisions, including the implementation of pricing and subsidies

Level 4 mobility management can more easily be achieved together with Level 4 MaaS solutions. That is, the mechanism through which real-time information about transportation options, and specifically new pricing and subsidies, could be more easily delivered to a large population of travellers through one, or more likely, multiple, MaaS consumer-facing applications.

C.5 Last Mile Logistics

C.5.1 Using drones in the last-mile logistic of medical delivery

The study aims to evaluate the usage of drones in the delivery fleet to deliver medical products in order to reduce congestion and pollution and to overcome the problem of infrastructure limitation in Rotterdam. Drones are introduced in the heterogeneous fleet composition cooperating with vans. The research uses the Vehicle Routing Problem (VRP) optimisation technique to analyse and compare two alternatives: the first one refers to the current situation where fleet is composed only by conventional vans, the other one introduces drones in the heterogeneous fleet composition cooperating with vans (Zubin et al., 2020).

The goal is to define the optimal tour given a set of nodes and a vehicle fleet composition, such that each node is visited once and only once and total costs of operations are minimized, starting, and ending at the pharmacy. Besides data on the current situation, such as vehicle characteristics, fleet characteristics, labour restrictions, delivery agreements, and products demand, drone specifications are added including distance range and time of flight and energy consumption (Zubin et al., 2020).

C.5.1.1 VRP Spreadsheet Solver

VRP Spreadsheet Solver is an open-source tool for representing, solving, and visualising the results of Vehicle Routing Problems. It unifies Excel, public GIS, and metaheuristics. It can solve more than 64 variants of the VRP, based on features related to selective visits to customers, simultaneous pickups and deliveries, time windows, fleet composition, distance constraint, and the destination of the vehicles. Data about the elements of a VRP are kept in different worksheets, and the solver adopts an incremental flow of information (Erdoğan, 2017). Alternatives are tested using a Large-scale Neighbourhood Search (LNS) algorithm, to find quasi-optimal solutions by means of iterations (Zubin et al., 2020).

C.5.1.2 Solved challenges

- Minimize the cost of the tour
- Reduction of the cost per item
- Decreasing the traffic congestion
- Reduction of CO2 emissions

C.5.1.3 Inputs and requisites

- Vehicle characteristics
- Fleet characteristics
- Labour restriction
- Delivery service characteristics
- Demand
- Limitations on distance range and time of flight
- Drones energy consumption rate
- Drones charge power

C.5.1.4 Outputs and KPIs

- Routing sequence

- Total number of stops
- Distance travelled
- Service time
- Vehicle loading
- Cost of operations for each vehicle
- Delivery cost per item
- Fuel / energy consumption
- CO_2 emission
- Cost of power supply
- Payload capacity

C.5.2 Efficiency of parcel lockers – case study of Szczecin

Parcel lockers localization in the city area is one of the most important factors in assessing their efficiency. To evaluate the influence of locations of parcel lockers on their efficiency, an experiment regarding relocation of chosen machines was realized in Szczecin. A set of the most and the least popular machines was prepared based on the monthly number of parcels delivered by each parcel locker. Five underperforming machines were indicated. Several assumptions have been considered to decide better locations for parcel lockers. Furthermore, an analysis of the usability of parcel lockers from the users' point of view has been carried out, using a standardized interview method based on questionnaires (Iwan et al., 2015).

C.5.2.1 InPost parcel lockers

Parcel lockers are unattended delivery machines, located at chosen, in the mostly attended places. It is a system of reception boxes, which enable to both receive and send parcels 24 hours a day, 7 days a week. If the parcel is not collected within 3 days, it will be transported to the nearest branch of InPost. Lockers are placed in monitored stations, such as petrol stations or supermarkets, in order to ensure the safety of both the senders and the consumers.

C.5.2.2 Solved challenges

- Efficient location of parcel lockers
- Increasing the number of delivered parcels

C.5.2.3 Inputs and requisites

- Parcel lockers
- Courier/delivery companies

The most important feature to define the best location of the parcel lockers are:

- High density of population living in the neighbourhood
- High traffic pedestrian areas in the city centres
- Shopping centres and supermarket car parks
- Bus/underground stations next to local commuting hubs
- Petrol station forecourts
- Service station
- Business centres

To analyse the usability of parcel lockers from the users' point of view, the questionnaire asked:

- Overall rating of parcel lockers
- Reasons for parcel lockers' utilisation
- Expectations regarding the location of parcel lockers
- Rating of the current locations of parcel lockers in Szczecin
- Proposal of better locations of parcel lockers

C.5.2.4 Outputs and KPIs

- 600 parcels delivered in one day
- Travel distance of about 70 km instead of 150 km in a traditional delivery system
- Reduction of congestion
- Reduction of unnecessary vehicle mileage due to fail deliveries
- Reduction of CO2 emission (tons per year)
- Less fuel consumption

C.5.3 Monoprix case study in Paris

SAMADA, which is the logistical subsidiary of Monoprix (a large French supermarket chain) established a supply scheme operating since 2007 which consists of combining rail and road vehicles to transport goods from two warehouses outside Paris to stores in the city centre. Pallets are loaded onto a rail shuttle, consisting of about 20 wagons, which every day from Monday to Friday runs about 30 km of line D of the RER to link the two warehouses to the market Gabriel Lamé of the station of Bercy. Then, goods are loaded onto NGVs (Natural Gas Vehicles) and delivered to Monoprix stores. The shuttle leaves at 8 pm at the warehouses and arrives in one hour at the station of Bercy. Trucks deliver goods the day after (Maes & Vanelslander, 2010).

C.5.3.1 Solved challenges

- Traffic congestion
- Reduction of polluting emission
- Less fuel consumption

C.5.3.2 Inputs and requisites

- 26 trucks
- 90 served stores
- 120000 tonnes of goods
- New NGV public station near Bercy station
- New connections between the two warehouses and the railway network
- Agreement for the use of the platform in Bercy

C.5.3.3 Outputs and KPIs

- Reduction of the total distance run by trucks in Ile de France
- Additional costs compared to conventional scheme (only using trucks)

C.6 Rental

C.6.1 Vehicle rental software

A car rental system is a set of software tools designed to automate and control car rental business operations, including fleet management, customer service, reservations management, driver management, vendor management, accounting, payments, inventory management, etc., on a common platform. It brings all the vehicle rental business stakeholders in one place and enables them to perform better by coordinating and sharing information with ease. Online car rental software enables real-time information access and updates to save time and enhance productivity.[42]

An example of a complex all-in-one system is HQ Rental Software[43] that supports all business models and sizes by offering comprehensive customer and fleet management services. This software was appreciated by Investopedia as the best car rental software of 2021.[44] Other complex systems with a high evaluation are RentSyst[45] or MyRent.[46] The following features are described on the basis of HQ Rental Software.

C.6.1.1 Multi-status user management

A rental software allows to create and edit various user roles, e.g., administrator, user, manager, and tour operator. Access control settings allow to determine what various user roles are allowed to manage in the system. A customer profile contains information about the user's name, contacts, driving licence, payment information and reservation history.

C.6.1.2 Accounting & electronic payment

Complex rental systems usually allow the integration with usual accounting systems (e.g., Quickbooks, Xero). A rental company can either use its own invoices, or it can use those compiled by the system, adjusted to its needs. Rental systems allow the company to accept various payment systems (e.g., MasterCard, Visa, PayPal).

C.6.1.3 Mailing services

Rental systems allow sending alerts on orders, invoices, and agreements to customers directly to their Viber, WhatsApp, Telegram or e-mail. A company can inform them about promotions and special offers by mailing via MailChimp.

C.6.1.4 Initial settings

A getting started dashboard guides the system user through all steps necessary to get the system fully running. It allows to insert all necessary inputs specified in part C.6.1.13, customise reservation emails that are sent out by the system to customers (reservation confirmations, payment emails, after-sales emails etc.), integrate the rental system with the company's website, download a mobile app for IOS or Android devices and get in touch with online travel agents.

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[42] https://www.goodfirms.co/car-rental-software
[43] https://hqrentalsoftware.com, https://www.notion.so/Knowledge-Base-b3dc775703154b14b2ba62fad43c7032
[44] https://www.investopedia.com/best-car-rental-software-5091848
[45] https://rentsyst.com
[46] https://www.myrentsoftware.com/en/myrent

C.6.1.5 Rates management

Various available rate structures can be implemented to maximize company's revenue. The system can recalculate rates on an early return or late pickup, it allows to enable per minute rates, seasonal rates, rates per day of the week (e.g., weekday or weekend), decreasing rate structure based on interval (per day or per hour) and various discounts. Moreover, the system allows the company to set rates based on its fleet utilisation to take advantage of high demand. Typical use cases are the following:

- **Rates based on vehicle utilisation:** specific rates for the fleet depending on the availability percentage can be set. For example, with normal availability the rate is 30 EUR per day, with the availability below 10 % the rate is 35 EUR per day.
- **Rates based on vehicle utilisation and days of the week:** specific rates depending on the availability percentage and on the day of the week.

C.6.1.6 Bookings

The system covers the whole reservation process. A company can customise its rental agreements, add specific terms and conditions, link them to confirmation email, set up return receipts, signatures etc. All reservations can be displayed in a calendar with various filter options (vehicle classes, specific vehicles, specific time periods).

C.6.1.7 Fleet management

The system allows to import, modify, and set up various items needed to manage the company's fleet. The company can insert or import information of its vehicles, branches, locations, opening hours, etc. It can also specify how to assign vehicles to open reservations (e.g., automatically or after a confirmation), whether return to other locations is allowed etc. Damages can be displayed on a car drawing and included in a rental contract. The system also provides an overview of the entire fleet and shows which vehicle class attracts the most customers over a selected period of time. Finally, it offers various features related to maintenance.

C.6.1.8 Telematics support

In complex rental systems, a solution for vehicle tracking is integrated. It allows customers to receive directions to the rental station and to a reserved vehicle, together with notifications about the vehicle and the rental process on their smartphone. They can also share their location, e.g., in the case of an accident etc. The rental firm can permanently follow all vehicles on a map directly from the rental software, and optimise rental processes. An A-GPS-based tracking provides a mileage data with an accuracy over 99 % and records a detailed trip history. The rental company receives alerts for harsh acceleration, braking, turn, high revolution, maintenance alerts etc. The tracking system records and analyses driving behaviour, collects fuel consumption data, meter speed (RPM) and engine temperature. An alarm is initiated in the case of an illegal start-up, impact, and rollover. Other features include geofencing, storing breakpoints data in non-volatile memory, shutdown engine and vehicle lock/unlock.

C.6.1.9 Long-term rentals/leasing

Complex rental systems can also be used for vehicle leasing, i.e., for rentals for a period longer than 1 year. In this case, a specification of a return date can be replaced by an automatic contract renewal.

C.6.1.10 Car sharing

Some systems as, e.g., HQ Rental Software, provide an integrated solution for car sharing (see sections 4.3.8 and C.8). It can be used either for on-demand or subscription-based bookings. The former allows to pick up and return a vehicle in a specific location in real time as long as the vehicle appears as available in the moment it is demanded, the latter is convenient for customers that prefer a reservation several days prior to the pick-up.

C.6.1.11 External cooperation and integration

Rental software allows a company to cooperate with various external partners. For example:

- **Tour operators:** external parties (e.g., hotel, sales agent etc.) that can offer the company's services and earn a commission. Tour operators obtain a unique booking link that can be placed on their website and they can also get a restricted access to the backend system to view their own bookings and commissions. The system offers various payment and accounting possibilities for this case.
- **Other vehicle owners** that earn a commission every time their vehicle is used for a rental.
- **Online travel agents:** rental system provides an integration for example with Kayak.com, Skyscanner.com, CarRentalExpress.com, RentCars.com, AirportRentals.com or VehicleRent.com.
- **MaaS providers:** some rental companies have already become part of a MaaS system (for more details, see section 4.3.9).

C.6.1.12 Solved challenges

Several examples of solved challenges that are beyond a standard efficient operation of a rental firm are listed below.

- **Conditions for the reduction of privately owned vehicles:** An accessible offer of rental services, especially if directly integrated into a MaaS system, allows users to satisfy their mobility needs without the necessity to own a private vehicle.
- **User-centric services:** an appropriate rental software is designed as user-centric, intuitive, allowing to satisfy user's needs.
- **Understand service user behaviour:** telematics tools provide accurate mileage and fuel consumption data, record trip history, record and analyse driving behaviour etc. (see section C.6.1.8).

C.6.1.13 Inputs and requisites for a rental software

To make a rental system ready for use, the following inputs should be inserted.

Table 18: Inputs and requisites for a rental software

Elements	Comments
Pick-up and return locations	An arbitrary number of locations can be specified.
Vehicles	The entire fleet can be entered into the system using an Excel file template. Vehicles can also be inserted one-by-one.

Vehicle classes	To determine the rate structure, it is necessary to specify various vehicle classes. It is also possible to add any additional information about a class that will be displayed during the reservation process.
Company logo	Different logos can be assigned to different company's branches.
Seasons	A company can set up different seasons, e.g., peak, and non-peak season, summer, spring etc. Any number of non-overlapping seasons can be created.
Rates	The company can specify its hourly, daily, weekly, or monthly rates. If more seasons were set up, different rates can be specified for different seasons.
Security deposits	If a company has specific rules regarding additional payments, it can set up its security deposit rules.
Additional charges	Any additional services provided to a customer can be specified, e.g., child seats or GPS systems.
System users	The administrator can set up user account for individual employees with the specification of access to the system.
Preventive maintenance	Maintenance check-ups for vehicles can be set up. A period of time or distance before a vehicle needs to undergo maintenance can be set up, a specific user to handle it can be specified.

C.6.1.14 Outputs and KPIs

Car rental systems generate various reports providing an overview of reservations, revenue, vehicle utilisation etc. Examples of these outputs are listed in Table 19.

Table 19: Outputs contained in various reports provided by car rental software

Feature	Comments
Revenue based on returns	Overview of revenues based on completed reservations (returned vehicles).
Revenue per payment option	Overview of revenues per payment option.
End of the day / monthly overview	Overview of revenues until end of the day / per month.
Daily manifest	A daily report of all pickups, returns, overdues and scheduled repairs.
Location performance	Overview of reservations in a selected time period.
Sales tax	A sales tax report of all reservations.
Cancellations	Overview of cancelled reservations.

Expenses overview	Overview of expenses per vehicle or payment option.
Vehicle profitability	Overview of revenue, expenses, and profits per vehicle.
Vehicle depreciation	Overview of depreciation per vehicle.
Vehicle utilisation	Overview of utilisation rates per vehicle.

Since rental systems represent a core of rental services, the following table presents selected key performance indicators related to car rental in general.

Table 20: KPIs for car rental service (Engels et al., 2017; Kamargianni et al., 2017; Fink & Reiners, 2006)

Level	KPI	Impacts		
		Environmental	Economic	Social
Individual/user level	**Total number of trips** made	x		x
	Satisfaction against the expectations (of users or providers)		x	x
	Perceived accessibility to the service		x	x
	Total cost per individual/household		x	x
	Perceived security when using the service			x
Business/organisational level	**System usage** (bookings, rentals, deliveries, users, passengers) in a given unit of time		x	
	Customer segments (men/women, young/old, ...)		x	x
	Collaboration/partnership in value chain		x	
	Revenues/turnover		x	
	Capital investment costs for purchase of equipment and vehicles (total or average)		x	
	Operating costs including personnel costs, fuel, electricity, and maintenance costs for vehicles (total or average), etc.		x	
	Fleet utilisation	x	x	
	Organisational changes, changes in responsibilities		x	

Societal level	**Total distances of vehicles** driven in an area during a day (weekday, week-end day) or per hour (peak hour, off-peak hour,...) by different type of vehicles	x	x	
	Vehicle occupancy (average number of persons per vehicle/day or per vehicle per trip)	x	x	x
	Vehicle fuel efficiency	x	x	
	Fuel/energy consumption			
	Fuel mix (the percentage of the share of various fuel types in a given period)	x	x	
	Emissions (CO_2, CO, NO_x, PM; per vehicle-km by vehicle and fuel types or by system user; total emissions for a given time period)	x		
	Citizens accessibility (physical, operational, economic) to rental services			x
	Modification of vehicle fleet (electrification, automation, etc.)	x		
	Transport safety (number of transport accidents, number of people killed and seriously injured, percentage of vehicles in a given region exceeding the posted speed limit)			
	Legal and policy modifications	x	x	x

C.6.2 Fleet and revenue management – modelling and simulation tools

Oliveira et al (2016) provides a detailed literature overview and a conceptual framework for issues related to car rental fleet and revenue management, including decisions on clustering locations that share the same fleet, decisions on the fleet size and composition, distribution of the fleet amongst rental stations, decisions on prices, selecting which reservations to accept, and assigning these reservations to individual vehicles. The following sections mention several examples of problems solved by mathematical modelling and simulation tools.

C.6.2.1 Pricing and capacity decisions

Oliveira et al., (2018) propose a novel mathematical model of a specific dynamics of rentals based on the relationship between inventory and pricing and several further realistic requirements from the car rental business, such as upgrades. The developed solution procedure using a genetic algorithm is able to solve real-sized instances within a reasonable time, and the authors prove that integrating capacity (including decisions on fleet size, mix, acquisitions, and deployment) and pricing decisions has a positive impact on profit. In principle, the model allows the extension to free floating fleet, i.e., to car-sharing systems.

C.6.2.2 Logistics performance improvement

Fernandez et al., (2020) describe two different methods leading to the improvement of the operation process related to the allocation of cars in parking facilities before and after their preparation for the rental, reduction of transport costs and subsequently increasing customers' satisfaction. One method involves the shortest path determination, the other one the maximum flow determination. Both approaches were simulated in MATLAB and analysed as a global decision support model.

C.6.2.3 Short-term car rental logistics problem

Fink and Reiners (2006) model and solve the problem of short-term decisions about the transportation and deployment of cars to optimise fleet utilisation while maintaining a high service level. The solution is based on the minimum cost network flow optimisation under consideration of necessary practical needs such as multi-period planning, a country-wide network, customised transportation relations, fleeting and defleeting, and car groups with partial substitutability.

C.6.2.4 Simulation of various levels of car class upgrades

Alabdulkarim (2018) developed a discrete event simulation (DES) tool that allows large car rental companies to input their historical data into the system and analyse the effects of different pricing policies for each car class for their specific operations. The simulation is created in ExtendSim (2018) and it concentrates especially on the influence of upgrades provided by rental companies in the case that the car class reserved by the customer is not available.

C.6.2.5 Discrete event simulation tools

Alabdulkarim et al (2019) present a modified discrete event simulation (DES) tool that allows a rental company to determine the best pricing strategy to achieve the highest revenue for same-location pick-up and drop-off of rentals.

C.6.2.6 Solved challenges

As the previous sections suggest, solved challenges include:

- Solution of logistics problems
- Modelling various pricing strategies
- Maximization of the rental company's profit and fleet utilisation

C.6.2.7 Inputs and requisites

Inputs for the above-mentioned models include the information on the available fleet, various rental types, rental locations, costs, etc.

C.6.2.8 Outputs and KPIs

Relevant KPIs listed in Table 3 are especially revenue and fleet utilisation and user's satisfaction.

C.7 Micromobility

C.7.1 Standard data

The Mobility Data Specification (MDS), a project of the Open Mobility Foundation (OMF) and used by more than 100 regulatory agencies around the world, is a set of Application Programming Interfaces (APIs) focused on dockless e-scooters, bicycles, mopeds and carshare. The goals of MDS are to provide a standardized way only for municipalities or other regulatory agencies to ingest, compare and analyse data from mobility service providers, and to give municipalities the ability to express regulation in machine-readable formats (MDS, 2021a). Although MDS data is not public, it is related to public data through the General Bikeshare Feed Specification (GBFS) standard, a project of the MobilityData / NABSA (North American Bikeshare Association), which is being used by over 500 shared mobility systems worldwide. GBFS provides real-time or semi-real-time docked and dockless (but GBFS do not fully support the latter) bikeshare and scooter share data in a uniform format with an emphasis on findability, such as stations and station information, available bikes, and system operating information (GBFS, 2021a).

C.7.1.1 Data specification

How the specification is used depends on a variety of factors: transportation goals, existing services and infrastructure, and the unique needs of the cities' communities. MDS is comprised of six distinct APIs, with multiple endpoints under each API (MDS, 2021a), as seen in Figure 42. It is important to notice that all MDS compatible Provider endpoints feeds must also expose a public GBFS feed as well. Moreover, the Provider, Agency, and Policy API specifications contain data standards for *Mobility as a Service* providers.

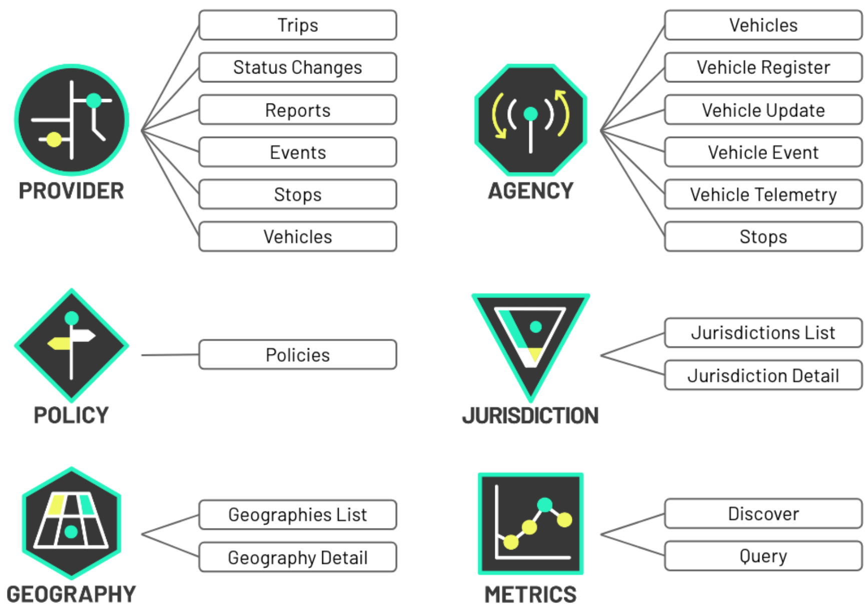

Figure 42: Different APIs for the Mobility Data Specification (MDS, 2021a)

In the case of GBFS, the specification is defined by a set of different types of files and data. A selection of relevant type of files is presented in Table 21.

.

Table 21: GBFS relevant specification (GBFS, 2021b)

File Name	Required/Optional	Defines
system_information.json	Yes	Details including system operator, system location, year implemented, URL, contact info, time zone.
vehicle_types.json *(added in v2.1)*	Conditionally REQUIRED	Describes the types of vehicles that System operator has available for rent. REQUIRED of systems that include information about vehicle types in the free_bike_status file. If this file is not included, then all vehicles in the feed are assumed to be non-motorized bicycles.
station_information.json	Conditionally REQUIRED	List of all stations, their capacities, and locations. REQUIRED of systems utilising docks.
station_status.json	Conditionally REQUIRED	Number of available vehicles and docks at each station and station availability. REQUIRED of systems utilising docks.
free_bike_status.json	Conditionally REQUIRED	*(as of v2.1)* Describes all vehicles that are not currently in active rental. REQUIRED for free floating (dockless) vehicles. OPTIONAL for station based (docked) vehicles. Vehicles that are part of an active rental MUST NOT appear in this feed.
system_hours.json	OPTIONAL	Hours of operation for the system.
system_calendar.json	OPTIONAL	Dates of operation for the system.
system_regions.json	OPTIONAL	Regions the system is broken up into.
system_pricing_plans.json	OPTIONAL	System pricing scheme.
system_alerts.json	OPTIONAL	Current system alerts.
geofencing_zones.json *(added in v2.1)*	OPTIONAL	Geofencing zones and their associated rules and attributes.

C.7.1.2 Solved challenges

- **Establishing an open data standard:** municipalities interact with companies who operate dockless scooters, bicycles, mopeds and carshare in the public right-of-way through MDS, while GBFS focus on real-time or semi-real-time findability of docked and dockless bikes and scooters.

C.7.1.3 Inputs and requisites

For MDS, the Provider API is intended to be implemented in situations when a municipality queries information from a mobility provider. Relevant sets are trips and routes (see Table 22), and status changes (the status of the inventory of vehicles available for customer use older than 2 weeks, see Table 23). Other endpoints include events (similar to status changes but younger than 2 weeks), stops (see

Table 24), and vehicles (see Table 25).

Table 22: Inputs and requisites for trips and routes (MDS, 2021c)

Field	Required/Optional	Comments
provider_id	Required	A UUID for the Provider, unique within MDS. See MDS provider list.
provider_name	Required	The public-facing name of the Provider
device_id	Required	A unique device ID in UUID format
vehicle_id	Required	The Vehicle Identification Number visible on the vehicle itself
vehicle_type	Required	See vehicle types table
propulsion_types	Required	Array of propulsion types; allows multiple values
trip_id	Required	A unique ID for each trip
trip_duration	Required	Time, in Seconds
trip_distance	Required	Trip Distance, in Meters
route	Required	See Routes detail below
accuracy	Required	The approximate level of accuracy, in meters, of Points within route
start_time	Required	
end_time	Required	
publication_time	Optional	Date/time that trip became available through the trips endpoint
parking_verification_url	Optional	A URL to a photo (or other evidence) of proper vehicle parking
standard_cost	Optional	The cost, in the currency defined in currency, that it would cost to perform that trip in the standard operation of the System (see Costs & Currencies)
actual_cost	Optional	The actual cost, in the currency defined in currency, paid by the customer of the *Mobility as a Service* provider (see Costs & Currencies)
currency	Optional, USD cents is implied if null.	An ISO 4217 Alphabetic Currency Code representing the currency of the payee (see Costs & Currencies)

Table 23: Inputs and requisites for status changes (MDS, 2021c)

Field	Required/Optional	Comments
provider_id	Required	A UUID for the Provider, unique within MDS. See MDS provider list.
provider_name	Required	The public-facing name of the Provider
device_id	Required	A unique device ID in UUID format
vehicle_id	Required	The Vehicle Identification Number visible on the vehicle itself
vehicle_type	Required	see vehicle types table
propulsion_types	Required	Array of propulsion types; allows multiple values
vehicle_state	Required	See vehicle state table
event_types	Required	Vehicle event(s) for state change, allowable values determined by vehicle_state
event_time	Required	Date/time that event occurred at. See Event Times
publication_time	Optional	Date/time that event became available through the status changes endpoint
event_location	Required	See also Stop-based Geographic Data.
event_geographies	Optional	**Beta feature**: *Yes (as of 1.1.0)*. Array of Geography UUIDs consisting of every Geography that contains the location of the status change. See Geography Driven Events. Required if event_location is not present.
battery_pct	Required if Applicable	Percent battery charge of device, expressed between 0 and 1
trip_id	Required if Applicable	Trip UUID (foreign key to Trips API), required if event_types contains trip_start, trip_end, trip_cancel, trip_enter_jurisdiction, or trip_leave_jurisdiction
associated_ticket	Optional	Identifier for an associated ticket inside an Agency-maintained 311 or CRM system

Table 24: Inputs and requisites for stops (MDS, 2021c)

Field	Required/Optional	Comments
stop_id	Required	Unique ID for stop
name	Required	Name of stop
last_reported	Required	Date/Time that the stop was last updated
location	Required	Simple centrepoint location of the Stop. The use of the optional geography_id is recommended to provide more detail.
status	Required	Object representing the status of the Stop. See Stop Status.
capacity	Required	Number of total places per vehicle_type
num_vehicles_available	Required	How many vehicles are available per vehicle_type at this stop?
num_vehicles_disabled	Required	How many vehicles are unavailable/reserved per vehicle_type at this stop?
provider_id	Optional	UUID for the Provider managing this stop. Null/undefined if managed by an Agency. See MDS provider list.
geography_id	Optional	Pointer to the Geography that represents the Stop geospatially via Polygon or MultiPolygon.
region_id	Optional	ID of the region where station is located, see GBFS Station Information
short_name	Optional	Abbreviated stop name
address	Optional	Postal address (useful for directions)
post_code	Optional	Postal code (e.g., 10036)
rental_methods	Optional	List of payment methods accepted at stop, see GBFS Rental Methods
cross_street	Optional	Cross street of where the station is located.
num_places_available	Optional	How many places are free to be populated with vehicles at this stop?

Field	Required/Optional	Comments
num_places_disabled	Optional	How many places are disabled and unable to accept vehicles at this stop?
parent_stop	Optional	Describe a basic hierarchy of stops (e.g., a stop inside of a greater stop)
devices	Optional	List of device_ids for vehicles which are currently at this stop
image_url	Optional	Link to an image, photo, or diagram of the stop. Could be used by providers to help riders find or use the stop.

Table 25: Inputs and requisites for vehicles (MDS, 2021c)

Field	Required/Optional	Comments
provider_id	Required	A UUID for the Provider, unique within MDS. See MDS provider list.
provider_name	Required	The public-facing name of the Provider
device_id	Required	A unique device ID in UUID format, should match this device in Provider
vehicle_id	Required	The Vehicle Identification Number visible on the vehicle itself, should match this device in provider
vehicle_type	Required	See vehicle types table
propulsion_types	Required	Array of propulsion types; allows multiple values
last_event_time	Required	Date/time when last state change occurred. See Event Times
last_vehicle_state	Required	Vehicle state of most recent state change.
last_event_types	Required	Vehicle event(s) of most recent state change, allowable values determined by last_vehicle_state.
last_event_location	Required	Location of vehicle's last event. See also Stop-based Geographic Data.
current_location	Required if Applicable	Current location of vehicle if different from last event, and the vehicle is not currently on a trip. See also Stop-based Geographic Data.
battery_pct	Required if Applicable	Percent battery charge of device, expressed between 0 and 1

The Agency API endpoints are intended to be implemented by regulatory agencies and consumed by mobility providers. The most relevant sets are those for vehicle data (returns a specified vehicle or a list of known vehicles, see Table 26), including telemetry data (Table 27), and stops (for agency to register city-managed stops, or a mobility provider to register self-managed Stops).

Table 26: Inputs and requisites for vehicles data (MDS, 2021d)

Field	Comments
`device_id`	Provided by Operator to uniquely identify a vehicle
`provider_id`	Issued by Agency and tracked
`vehicle_id`	Vehicle Identification Number (vehicle_id) visible on vehicle
`vehicle_type`	Vehicle Type
`propulsion_types`	Array of Propulsion Type; allows multiple values
`year`	Year Manufactured
`mfgr`	Vehicle Manufacturer
`model`	Vehicle Model
`state`	Current vehicle state. See Vehicle State
`prev_events`	Last [Vehicle Event][vehicle-event]
`updated`	Date of last event update
`provider_id`	A UUID for the Provider, unique within MDS. See MDS provider list.

Table 27: Inputs and requisites for telemetry data (MDS, 2021d)

Field	Required/Optional	Comments
`device_id`	Required	ID used in Register
`timestamp`	Required	Date/time that event occurred. Based on GPS or GNSS clock
`gps`	Required	Telemetry position data
`gps.lat`	Required	Latitude of the location
`gps.lng`	Required	Longitude of the location
`gps.altitude`	Required if Available	Altitude above mean sea level in meters

Field	Required/Optional	Comments
gps.heading	Required if Available	Degrees - clockwise starting at 0 degrees at true North
gps.speed	Required if Available	Speed in meters / sec
gps.accuracy	Required if Available	Accuracy in meters
gps.hdop	Required if Available	Horizontal GPS or GNSS accuracy value (see hdop)
gps.satellites	Required if Available	Number of GPS or GNSS satellites
charge	Required if Applicable	Percent battery charge of vehicle, expressed between 0 and 1
stop_id	Required if Applicable	Stop that the vehicle is currently located at. Only applicable for *docked* Micromobility. See Stops

The Policy API endpoints is implemented to enable regulatory agencies to create, revise, and publish machine-readable policies, as sets of rules for individual and collective device behaviour exhibited by both *Mobility as a Service* providers and users. Relevant sets include policy (Table 28), and rules (Table 29).

Table 28: Inputs and requisites for policy (MDS, 2021e)

Field	Required/Optional	Comments
name	Required	Name of policy
policy_id	Required	Unique ID of policy
provider_ids	Optional	Providers for whom this policy is applicable; empty arrays and null/absent implies all Providers. See MDS provider list.
description	Required	Description of policy
currency	Optional	An ISO 4217 Alphabetic Currency Code representing the currency of all Rules of type rate.
start_date	Required	Beginning date/time of policy enforcement. In order to give providers sufficient time to poll, start_date must be at least 20 minutes after published_date.
end_date	Optional	End date/time of policy enforcement
published_date	Required	Timestamp that the policy was published

Field	Required/Optional	Comments
`prev_policies`	Optional	Unique IDs of prior policies replaced by this one
`rules`	Required	List of applicable Rule objects
`device_id`	Required	ID used in Register

Table 29: Inputs and requisites for rules (MDS, 2021e)

Field	Required/Optional	Comments
`name`	Required	Name of rule
`rule_id`	Required	Unique ID of the rule
`rule_type`	Required	Type of policy (see Rule Types)
`geographies`	Required	List of Geography UUIDs (non-overlapping) specifying the covered geography
`states`	Required	Vehicle state to which this rule applies. Optionally provide a list of specific [vehicle events][#vehicle-events] as a subset of a given status for the rule to apply to. An empty list or `null`/absent defaults to "all".
`rule_units`	Conditionally Required	Measured units of policy (see Rule Units)
`vehicle_types`	Optional	Applicable vehicle types, default "all".
`propulsion_types`	Optional	Applicable vehicle propulsion types, default "all".
`minimum`	Optional	Minimum value, if applicable (default 0)
`maximum`	Optional	Maximum value, if applicable (default unlimited)
`rate_amount`	Optional	The amount of a rate applied when this rule applies, if applicable (default zero). A positive integer rate amount represents a fee, while a negative integer represents a subsidy. Rate amounts are given in the `currency` defined in the Policy.
`rate_recurrence`	Optional	Recurrence of the rate (see Rate Recurrences)
`start_time`	Optional	Beginning time-of-day when the rule is in effect (default 00:00:00).
`end_time`	Optional	Ending time-of-day when the rule is in effect (default 23:59:59).

Field	Required/Optional	Comments
`days`	Optional	Days `["sun", "mon", "tue", "wed", "thu", "fri", "sat"]` when the rule is in effect (default all)
`messages`	Optional	Message to rider user, if desired, in various languages, keyed by language tag (see Messages)
`value_url`	Optional	URL to an API endpoint that can provide dynamic information for the measured value (see Value URL)
`device_id`	Required	ID used in Register

The Geography API contains descriptions of geographical information, for example multi-polygons, currently represented via GeoJSON, useful for municipal boundaries, locations for pick-up and drop-off zones, etc. The Jurisdiction API is intended for a collection of agencies when they need to coordinate and share relevant data between one another when their jurisdictions overlap.

In the case of GBFS, relevant type of files are: “vehicle_types.json” (Table 30), “station_information.json” (Table 31), “station_status.json” (Table 32), “free_bike_status.json” (Table 33), and “system_pricing_plans.json” (Table 34).

Table 30: Inputs and requisites for vehicle types (GBFS, 2021b)

Field Name	Required/Optional	Defines
`vehicle_types`	Yes	Array that contains one object per vehicle type in the system as defined below.
`vehicle_type_id`	Yes	Unique identifier of a vehicle type. See Field Types above for ID field requirements.
`form_factor`	Yes	The vehicle's general form factor. Current valid values are: • `bicycle` • `car` • `moped` • `scooter` • `other`
`propulsion_type`	Yes	The primary propulsion type of the vehicle. Current valid values are: • `human` *(Pedal or foot propulsion)* • `electric_assist` *(Provides power only alongside human propulsion)* • `electric` *(Contains throttle mode with a battery-powered motor)* • `combustion` *(Contains throttle mode with a gas engine-powered motor)*

Field Name	Required/Optional	Defines
		This field was inspired by, but differs from the propulsion types field described in the Open Mobility Foundation Mobility Data Specification.
`max_range_meters`	Conditionally REQUIRED	If the vehicle has a motor (as indicated by having a value other than `human` in the `propulsion_type` field), this field is REQUIRED. This represents the furthest distance in meters that the vehicle can travel without recharging or refueling when it has the maximum amount of energy potential (for example, a full battery or full tank of gas).
`name`	OPTIONAL	The public name of this vehicle type.

Table 31: Inputs and requisites station information (GBFS, 2021b)

Field Name	Required/Optional	Defines
`stations`	Yes	Array that contains one object per station as defined below.
`station_id`	Yes	Identifier of a station.
`name`	Yes	The public name of the station for display in maps, digital signage, and other text applications. Names SHOULD reflect the station location through the use of a cross street or local landmark. Abbreviations SHOULD NOT be used for names and other text (e.g., St. for Street) unless a location is called by its abbreviated name (e.g., “JFK Airport”). See Text Fields and Naming. Examples: • Broadway and East 22nd Street • Convention Centre • Central Park South
`short_name`	OPTIONAL	Short name or other type of identifier.
`lat`	Yes	Latitude of the station in decimal degrees. This field SHOULD have a precision of 6 decimal places (0.000001). See Coordinate Precision.
`lon`	Yes	Longitude of the station in decimal degrees. This field SHOULD have a precision of 6 decimal places (0.000001). See Coordinate Precision.
`address`	OPTIONAL	Address (street number and name) where station is located. This MUST be a valid address, not a free-form text description. Example: 1234 Main Street
`cross_street`	OPTIONAL	Cross street or landmark where the station is located.

Field Name	Required/Optional	Defines
`region_id`	OPTIONAL	Identifier of the region where station is located. See system_regions.json.
`post_code`	OPTIONAL	Postal code where station is located.
`rental_methods`	OPTIONAL	Payment methods accepted at this station. Current valid values are: • `key` (e.g., operator issued vehicle key / fob / card) • `creditcard` • `paypass` • `applepay` • `androidpay` • `transitcard` • `accountnumber` • `phone`

`is_virtual_`
`station`
(added in v2.1)
	OPTIONAL	Is this station a location with or without physical infrastructures (docks)?
		
		`true` - The station is a location without physical infrastructure, defined by a point (lat/lon) and/or `station_area` (below).
		`false` - The station consists of physical infrastructure (docks).
		
		If this field is empty, it means the station consists of physical infrastructure (docks).
		
		This field SHOULD be published in systems that have station locations without standard, internet connected physical docking infrastructure. These may be racks or geofenced areas designated for rental and/or return of vehicles. Locations that fit within this description SHOULD have the `is_virtual_station` boolean set to `true`.

`station_area` *(added in v2.1)*	OPTIONAL	A GeoJSON multipolygon that describes the area of a virtual station. If `station_area` is supplied, then the record describes a virtual station. If lat/lon and `station_area` are both defined, the lat/lon is the significant coordinate of the station (e.g., dock facility or valet drop-off and pick up point). The `station_area` takes precedence over any `ride_allowed` rules in overlapping `geofencing_zones`.
`capacity`	OPTIONAL	Number of total docking points installed at this station, both available and unavailable, regardless of what vehicle types are allowed at each dock. If this is a virtual station defined using the field `is_virtual_station`, this number represents the total

Field Name	Required/Optional	Defines
		number of vehicles of all types that can be parked at the virtual station. If the virtual station is defined by `station_area`, this is the number that can park within the station area. If `lat`/`lon` are defined, this is the number that can park at those coordinates.
`vehicle_capacity` *(added in v2.1)*	OPTIONAL	An object used to describe the parking capacity of virtual stations (defined using the `is_virtual_station` field), where each key is a `vehicle_type_id` as described in vehicle_types.json and the value is a number representing the total number of vehicles of this type that can park within the virtual station. If the virtual station is defined by `station_area`, this is the number that can park within the station area. If `lat`/`lon` is defined, this is the number that can park at those coordinates.
`vehicle_type_capacity` *(added in v2.1)*	OPTIONAL	An object used to describe the docking capacity of a station where each key is a `vehicle_type_id` as described in vehicle_types.json and the value is a number representing the total docking points installed at this station, both available and unavailable for the specified vehicle type.
`is_valet_station` *(added in v2.1)*	OPTIONAL	Are valet services provided at this station? `true` - Valet services are provided at this station. `false` - Valet services are not provided at this station. If this field is empty, it is assumed that valet services are not provided at this station. This field's boolean SHOULD be set to `true` during the hours which valet service is provided at the station. Valet service is defined as providing unlimited capacity at a station.
`rental_uris` *(added in v1.1)*	OPTIONAL	Contains rental URIs for Android, iOS, and web in the android, ios, and web fields. See examples of how to use these fields and supported analytics.

Table 32: Inputs and requisites for station status (GBFS, 2021b)

Field Name	Required/Optional	Defines
`stations`	Yes	Array that contains one object per station in the system as defined below.
`station_id`	Yes	Identifier of a station see station_information.json.

Field Name	Required/Optional	Defines
`num_bikes_available`	Yes	Number of functional vehicles physically at the station that may be offered for rental. To know if the vehicles are available for rental, see `is_renting`. If `is_renting` = `true`, this is the number of vehicles that are currently available for rent. If `is_renting` =`false`, this is the number of vehicles that would be available for rent if the station were set to allow rentals.
`vehicle_types_available` *(added in v2.1)*	Conditionally REQUIRED	This field is REQUIRED if the vehicle_types.json file has been defined. This field's value is an array of objects. Each of these objects is used to model the total number of each defined vehicle type available at a station. The total number of vehicles from each of these objects SHOULD add up to match the value specified in the `num_bikes_available` field.
`vehicle_type_id` *(added in v2.1)*	Yes	The `vehicle_type_id` of each vehicle type at the station as described in vehicle_types.json. This field is REQUIRED if the vehicle_types.json is defined.
`count` *(added in v2.1)*	Yes	A number representing the total number of available vehicles of the corresponding `vehicle_type_id` as defined in vehicle_types.json at the station.
`num_bikes_disabled`	OPTIONAL	Number of disabled vehicles of any type at the station. Vendors who do not want to publicize the number of disabled vehicles or docks in their system can opt to omit station capacity (in station_information.json, `num_bikes_disabled`, and `num_docks_disabled` *(as of v2.0)*. If station `capacity` is published, then broken docks/vehicles can be inferred (though not specifically whether the decreased capacity is a broken vehicle or dock).
`num_docks_available`	Conditionally REQUIRED *(as of v2.0)*	REQUIRED except for stations that have unlimited docking capacity (e.g., virtual stations) *(as of v2.0)*. Number of functional docks physically at the station that are able to accept vehicles for return. To know if the docks are accepting vehicle returns, see `is_returning`. If `is_returning` = `true`, this is the number of docks that are currently available to accept vehicle returns. If `is_returning` = `false`, this is the number of docks that would be available if the station were set to allow returns.
`vehicle_docks_available` *(added in v2.1)*	Conditionally REQUIRED	This field is REQUIRED in feeds where the vehicle_types.json is defined and where certain docks are only able to accept certain vehicle types. If every dock at

Field Name	Required/Optional	Defines
		the station is able to accept any vehicle type, then this field is not REQUIRED. This field's value is an array of objects. Each of these objects is used to model the number of docks available for certain vehicle types. The total number of docks from each of these objects SHOULD add up to match the value specified in the `num_docks_available` field.
`vehicle_type_ids` *(added in v2.1)*	Yes	An array of strings where each string represents a `vehicle_type_id` that is able to use a particular type of dock at the station.
`count` *(added in v2.1)*	Yes	A number representing the total number of available vehicles of the corresponding vehicle type as defined in the `vehicle_types` array at the station that can accept vehicles of the specified types in the `vehicle_types` array.
`num_docks_disabled`	OPTIONAL	Number of disabled dock points at the station.
`is_installed`	Yes	Is the station currently on the street? `true` - Station is installed on the street. `false` - Station is not installed on the street. Boolean SHOULD be set to `true` when equipment is present on the street. In seasonal systems where equipment is removed during winter, boolean SHOULD be set to `false` during the off season. May also be set to false to indicate planned (future) stations which have not yet been installed.
`is_renting`	Yes	Is the station currently renting vehicles? `true` - Station is renting vehicles. Even if the station is empty, if it would otherwise allow rentals, this value MUST be `true`. `false` - Station is not renting vehicles. If the station is temporarily taken out of service and not allowing rentals, this field MUST be set to `false`. If a station becomes inaccessible to users due to road construction or other factors this field SHOULD be set to `false`. Field SHOULD be set to `false` during hours or days when the system is not offering vehicles for rent.
`is_returning`	Yes	Is the station accepting vehicle returns? `true` - Station is accepting vehicle returns. Even if the station is full, if it would otherwise allow vehicle returns, this value MUST be `true`.

Field Name	Required/Optional	Defines
		`false` - Station is not accepting vehicle returns. If the station is temporarily taken out of service and not allowing vehicle returns, this field MUST be set to `false`. If a station becomes inaccessible to users due to road construction or other factors, this field SHOULD be set to `false`.
`last_reported`	Yes	The last time this station reported its status to the operator's backend.

Table 33: Inputs and requisites for free bike status (GBFS, 2021b)

Field Name	Required/Optional	Defines
`bikes`	Yes	Array that contains one object per vehicle that is currently stopped as defined below.
`bike_id`	Yes	Identifier of a vehicle. The `bike_id` identifier MUST be rotated to a random string after each trip to protect user privacy *(as of v2.0)*. Use of persistent vehicle IDs poses a threat to user privacy. The `bike_id` identifier SHOULD only be rotated once per trip.
`system_id` *(added in v3.0-RC)*	Conditionally REQUIRED	Identifier referencing the `system_id` field in system_information.json. REQUIRED in the case of feeds that specify free (undocked) bikes and define systems in system_information.json.
`lat`	Conditionally REQUIRED *(as of v2.1)*	Latitude of the vehicle in decimal degrees. *(as of v2.1)* This field is REQUIRED if `station_id` is not provided for this vehicle (free floating). This field SHOULD have a precision of 6 decimal places (0.000001). See Coordinate Precision.
`lon`	Conditionally REQUIRED *(as of v2.1)*	Longitude of the vehicle. *(as of v2.1)* This field is REQUIRED if `station_id` is not provided for this vehicle (free floating).
`is_reserved`	Yes	Is the vehicle currently reserved? `true` - Vehicle is currently reserved. `false` - Vehicle is not currently reserved.
`is_disabled`	Yes	Is the vehicle currently disabled? true - Vehicle is currently disabled. false - Vehicle is not currently disabled. This field is used to indicate vehicles that are in the field but not available for rental. This may be due to a mechanical issue, low

Field Name	Required/Optional	Defines
		battery etc. Publishing this data may prevent users from attempting to rent vehicles that are disabled and not available for rental.
`rental_uris` *(added in v1.1)*	OPTIONAL	JSON object that contains rental URIs for Android, iOS, and web in the android, ios, and web fields. See examples of how to use these fields and supported analytics.
`vehicle_type_id` *(added in v2.1)*	Conditionally REQUIRED	The `vehicle_type_id` of this vehicle as described in vehicle_types.json. This field is REQUIRED if the vehicle_types.json is defined.
`last_reported` *(added in v2.1)*	OPTIONAL	The last time this vehicle reported its status to the operator's backend.
`current_range_meters` *(added in v2.1)*	Conditionally REQUIRED	If the corresponding `vehicle_type` definition for this vehicle has a motor, then this field is REQUIRED. This value represents the furthest distance in meters that the vehicle can travel without recharging or refueling with the vehicle's current charge or fuel.
`station_id` *(added in v2.1)*	Conditionally REQUIRED	Identifier referencing the `station_id` field in station_information.json. REQUIRED only if the vehicle is currently at a station and the vehicle_types.json file has been defined.
`pricing_plan_id` *(added in v2.1)*	OPTIONAL	The `plan_id` of the pricing plan this vehicle is eligible for as described in system_pricing_plans.json.
vehicle_type_id *(added in v2.1)*	Conditionally REQUIRED	

Table 34: Inputs and requisites for system pricing plans (GBFS, 2021b)

Field Name	Required/Optional	Defines
`plans`	Yes	Array of objects as defined below.
`plan_id`	Yes	Identifier for a pricing plan in the system.
`url`	OPTIONAL	URL where the customer can learn more about this pricing plan.
`name`	Yes	Name of this pricing plan.
`currency`	Yes	Currency used to pay the fare. This pricing is in ISO 4217 code: http://en.wikipedia.org/wiki/ISO_4217 (e.g., CAD for Canadian dollars, EUR for euros, or JPY for Japanese yen.)

Field Name	Required/Optional	Defines
`price`	Yes	Fare price, in the unit specified by currency. If string, MUST be in decimal monetary value *(added in v2.2).* Note: v3.0 may only allow non-negative float, therefore future implementations SHOULD be non-negative float. In case of non-rate price, this field is the total price. In case of rate price, this field is the base price that is charged only once per trip (e.g., price for unlocking) in addition to `per_km pricing` and/or `per_min_pricing`.
`is_taxable`	Yes	Will additional tax be added to the base price? `true` - Yes. `false` - No. `false` MAY be used to indicate that tax is not charged or that tax is included in the base price.
`description`	Yes	Customer-readable description of the pricing plan. This SHOULD include the duration, price, conditions, etc. that the publisher would like users to see.
`per_km_pricing` *(added in v2.2)*	OPTIONAL	Array of segments when the price is a function of distance travelled, displayed in kilometres. Total price is the addition of `price` and all segments in `per_km_pricing` and `per_min_pricing`. If this array is not provided, there are no variable prices based on distance.
`start` *(added in v2.2)*	Yes	The kilometre at which this segment rate starts being charged *(inclusive)*.
`rate` *(added in v2.2)*	Yes	Rate that is charged for each kilometre `interval` after the `start`. Can be a negative number, which indicates that the traveller will receive a discount.
`interval` *(added in v2.2)*	Yes	Interval in kilometres at which the `rate` of this segment is either reapplied indefinitely, or if defined, up until (but not including) `end` kilometre. An interval of 0 indicates the rate is only charged once.
`end` *(added in v2.2)*	OPTIONAL	The kilometre at which the rate will no longer apply *(exclusive)*, e.g., if `end` is `20` the rate no longer applies at 20.00 km. If this field is empty, the price issued for this segment is charged until the trip ends, in addition to following segments.
`per_min_pricing` *(added in v2.2)*	OPTIONAL	Array of segments when the price is a function of time travelled, displayed in minutes. Total price is the addition of `price` and all segments in

Field Name	Required/Optional	Defines
		`per_km_pricing` and `per_min_pricing`. If this array is not provided, there are no variable prices based on time.
`start` *(added in v2.2)*	Yes	The minute at which this segment rate starts being charged *(inclusive)*.
`rate` *(added in v2.2)*	Yes	Rate that is charged for each minute `interval` after the `start`. Can be a negative number, which indicates that the traveller will receive a discount.
`interval` *(added in v2.2)*	Yes	Interval in minutes at which the `rate` of this segment is either reapplied indefinitely, or if defined, up until (but not including) end minute. An interval of 0 indicates the rate is only charged once.
`end` *(added in v2.2)*	OPTIONAL	The minute at which the rate will no longer apply *(exclusive)*, e.g., if end is `20`, the rate no longer applies after 19:59. If this field is empty, the price issued for this segment is charged until the trip ends, in addition to following segments.
`surge_pricing` *(added in v2.2)*	OPTIONAL	Is there currently an increase in price in response to increased demand in this pricing plan? If this field is empty, it means these is no surge pricing in effect. `true` - Surge pricing is in effect. `false` - Surge pricing is not in effect.

C.7.1.4 Outputs and KPIs

For MDS, reports (see Table 35) are information that mobility providers can send back to municipalities containing aggregated data that is not contained within other MDS APIs, like counts of special groups of riders.

Table 35: Outputs and KPIs for reports (MDS, 2021c)

Name	Comments
StartDate	Start date of trip the data row, ISO 8601 format, local timezone
Duration	Value is always P1M for monthly. Based on [ISO 8601 duration]()
Special Group Type	Type that applies to this row
Geography ID	ID that applies to this row. Includes all IDs in /geography. When there is no /geography then return null for this value and return counts based on the entire operating area.
Vehicle Type	Type that applies to this row

Name	Comments
Trip Count	Count of trips taken for this row
Rider Count	Count of unique riders for this row

The Metrics API is intended to be implemented by regulatory agencies and their partners for requesting historical calculated core metrics and aggregations of MDS data, possibly for situations of compliance, program effectiveness, and alignment on counts.

C.7.2 Vehicle location and information tools

The most common type of tool related to micromobility – except private apps of micromobility operators – is for locating stations, vehicles and possibly displaying some information about them. Such tools are either: a) specific apps for finding stations and vehicles of different micromobility operators (see Figure 43); or b) single apps that include not only micromobility but also many other use cases like multimodal route planning.

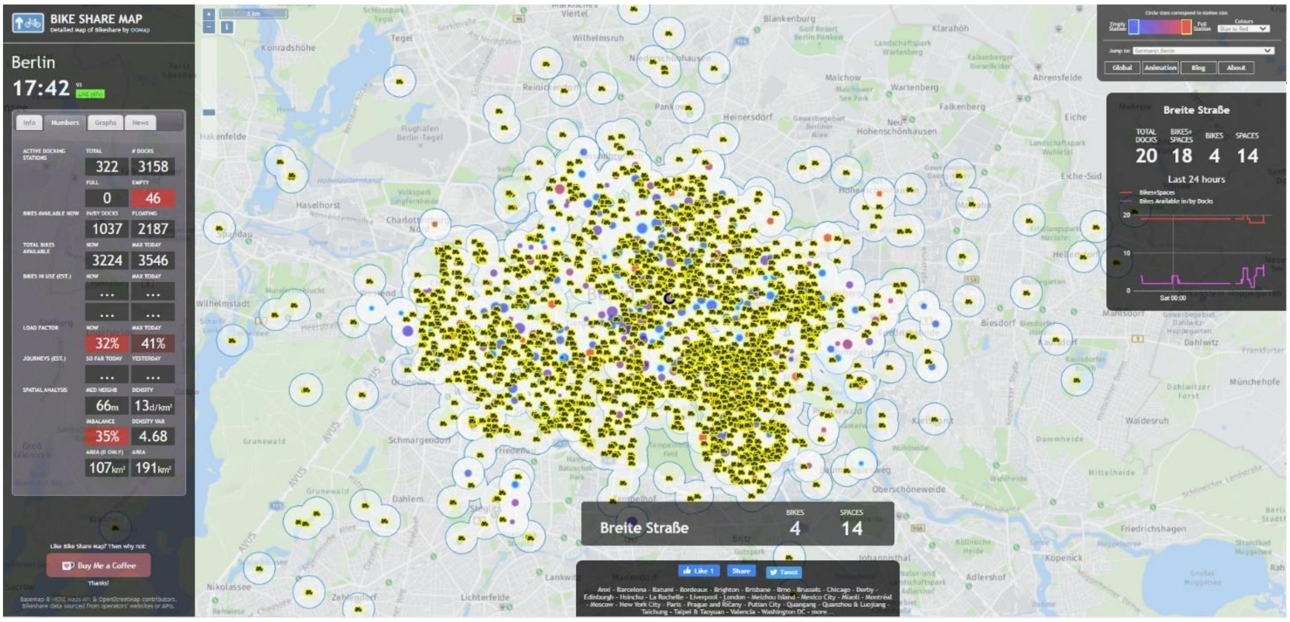

Figure 43: User interface of bikesharemap.com

C.7.2.1 Solved challenges

- **Public Availability of Devices:** Allow the public (individuals, apps, services) to see where vehicles are available for use.

C.7.2.2 Inputs and requisites

This category of tools usually retrieve data from different websites and APIs of micromobity operators (usually via GBFS or MDS). Examples of specific apps and their inputs are described on Table 36. They always require information about stations, including:

- identification name,
- number of empty spaces/slots,

- number of available vehicles,
- position,
- status (e.g., available, or unavailable),
- if temporary or not,
- and some extra info.

Some of them support the location of flee-floating vehicles (dockless systems) and sometimes also vehicle attributes, such as:

- type (manual bicycle, e-bike, scooter, moped),
- battery level,
- micromobility operator.

Table 36: Specific apps for finding micromobility vehicles and their inputs

Tool	Station Info	Vehicle Attributes	Support of Free-Floating Vehicles
Bike Share Map[47]	Yes	No	Yes
City Bikes[48]	Yes	No	No
Data Flow (Fluctuo)[49]	Yes	Yes	Yes
Bestmap API Bikes[50]	Yes	Yes	Yes

For the case of single apps, they all provide station information, vehicle attributes and they also support free floating vehicles. There are three main apps in this category: Bestmap,[51] CityMapper[52] and Moovit[53].

C.7.2.3 Outputs and KPIs

As this category of tools focus only on finding vehicles, it is usually not offered any KPI. The exception is the app Bike Share Map[1], which calculate simple real-time statistics such as (see Figure 43):

- number of active stations (including those full and empty),
- number of free-floating vehicles,
- estimated in use and journeys,
- load factor,
- density and variation of docks,
- and imbalance (%).

[47] https://bikesharemap.com
[48] https://citybik.es
[49] https://fluctuo.com/data-flow
[50] https://bestmap.net/api_bikes
[51] https://bestmap.net
[52] https://citymapper.com
[53] https://moovit.com

C.7.3 Data analysis tools

Recently, several companies (including micromobility operators) are taking advantage of the data sharing trend by offering specialised analytics and platform services to cities. One reason for this is that many cities now require data sharing as a requirement to concede permit to shared mobility operators. Another contributor to this is that as new data sharing standards are developed, analytics tools and platforms are well seen by municipalities to improve outcomes and decide whether or not to sign contracts. For instance, e-scooter sharing operator Voi Technology offers its City Data Dashboard, which provides current and historical vehicle trip. Another example is the micromobility operator Helbiz, which offers a Mobility Analytics platform that provides daily operations metrics and fleet usage, tracking of missing vehicles, and suggested deployment areas (Guidehouse Insights, 2021).

The New Urban Mobility Alliance (NUMO) micromobility data analysis tool enable municipalities to track general usage of their shared mobility systems such as who is using the service, where, and how often. The main contributions focus on trip patterns, modal shift, how to provide safe spaces, equitable access, and the real environmental impacts of micromobility (New Urban Mobility Alliance, 2021a).

SharedStreets Mobility Metrics is an open-source command line interface and frontend for ingestion and analysis of Mobility Data Specification (MDS) mobility data for aggregating useful & privacy-protecting metrics for long term storage and analysis (SharedStreets, 2021).

The Shared Mobility Software of Remix[54] digitizes policies like caps and equity into dashboards, visualising corridors and where people are travelling, comparing with existing bike networks and encourage mode shift from single-occupancy vehicles, identify risk areas, creating geospatial policies, such as no-parking zones, and easily communicating them to all provide.

City Dive[55] is a tool that tracks the use of shared mobility services, providing dashboard to monitor fleets, trips, usage patterns such as: number of vehicles available, density of vehicles available per area, number of trips, analysis of trips patterns per hour and per day, origins/destinations.

Urban Sharing[56] understand day-to-day user behaviour, redistribute to meet user-demand profile-placeholder, and predict fleet's maintenance needs.

Populus[57] provides digital solutions to manage shared mobility services (e.g., bikes and scooters), and commercial delivery operators. The Populus platform ingests and visualises data in real-time that allow cities to create and communicate policies, monitor parking, and analyse routes. By processing a large amount of GPS data, the platform provides an insight on parked vehicles and trip patterns. Populus also enables a visualisation of popular micromobility routes, compare them with current infrastructure, and plan for new, safe infrastructure.

Vianova[58] uses connected vehicles to visualise in real-time anonymized locations of vehicles, as well as mobility operators' deployments. It can also monitor the evolution of fleets sizes, services utilisation, and

[54] https://www.remix.com/solutions/streets-shared-mobility
[55] https://fluctuo.com/city-dive
[56] https://urbansharing.com
[57] https://www.populus.ai
[58] https://www.vianova.io

number of trips, by providers as well as receive alerts for safety hazards and send service request. It also easily allows retrieval of historical data and insight within city own tools to perform travel behaviour analysis and mobility planning.

C.7.3.1 Solved challenges

- **Vehicle caps:** determine total number of vehicles per operator in the right of way (e.g., "Minimum 500 and maximum 3000 scooters within city boundaries" or "Up to 500 additional scooters are permitted near train stations")
- **Distribution requirements:** ensure vehicles are distributed according to equity requirements.
- **Injury investigation:** investigate injuries and collisions with other objects and cars to determine roadway accident causes.
- **Restricted area rides:** find locations where vehicles are operating or passing through restricted areas (e.g., "No scooters are permitted in this district on weekends").
- **Infrastructure planning:** determine where to place new bike/scooter lanes and drop zones based on usage and demand, start and end points, and trips taken.
- **Parking area performance:** location and performance of all designated parking areas.
- **Monitor vehicle condition and lifespan:** percentage of deployed vehicles in good working condition, and average lifespan by vehicle model and number of vehicles stolen or lost.
- **Enforcement:** tracking safety and improper parking incidents.
- **Measure accessibility:** such as access to grocery stores, healthcare, and education facilities in an x-minute micromobility ride, or access to micromobility vehicle within an x-minute walk.

C.7.3.2 Inputs and requisites

Inputs and requisites of the New Urban Mobility Alliance (NUMO) tool is found on Table 37.

Table 37: Inputs and requisites for NUMO micromobility data (New Urban Mobility Alliance, 2021b)

Field	Description	Source
propulsion_type	The propulsion system of a vehicle.	Mobility Data Specification (MDS)
trip_distance	The distance of a trip, in meters.	Mobility Data Specification (MDS)
trip_duration	The duration of a trip, in seconds.	Mobility Data Specification (MDS)
device_id	A unique identification number for each device.	Mobility Data Specification (MDS)

Field	Description	Source
end_time	The date and time a trip ended.	Mobility Data Specification (MDS)
start_time	The date and time a trip started.	Mobility Data Specification (MDS)
vehicle_type	The type of vehicle used for a trip.	Mobility Data Specification (MDS)
“route” start	The start location of an individual trip.	Mobility Data Specification (MDS)
“route” end	The end location of an individual trip.	Mobility Data Specification (MDS)
actual_cost	The actual cost paid by the customer of the Mobility as a Service provider.	Mobility Data Specification (MDS)
event_type	The type of status change event that occurred.	Mobility Data Specification (MDS)
event_time	The date and time that the status change event occurred at.	Mobility Data Specification (MDS)
event_location	The location a status change event took place.	Mobility Data Specification (MDS)
event_type_reason	The reason for a status change.	Mobility Data Specification (MDS)

C.7.3.3 Outputs and KPIs

Outputs and KPIs of the New Urban Mobility Alliance (NUMO) tool can be found in Table 38, and SharedStreets are presented in Table 39.

Table 38: Outputs and KPIs for NUMO micromobility data (New Urban Mobility Alliance, 2021b)

Field	Description	Source
Population data	The population data of the jurisdiction including demographic information such as age, sex, race/ethnicity, etc.	Census
Average rides per user	The average number of rides per user as reported by an operator. *(Cities should account for users that may patronize multiple services.)*	Vendor Data
Fleetwide average life span	The fleetwide average life span in days/months and miles/kilometres of a micromobility vehicle as reported by an operator. *(By mode – the value that occurs most frequently in a given set of data.)*	Vendor Data
Citation data	Citations for vehicles in motion issued by law enforcement or city enforcement team. *(Local regulations and methods for reporting will vary by city.)*	City Enforcement Team
Average lifespan by model	The average lifespan in days/months and miles/kilometres of a micromobility vehicle as reported by an operator.	Vendor Data
Code enforcement data	Parking, safety, and other code violations cited by a city or agency enforcement team. *(Local regulations and methods for reporting will vary by city.)*	City Enforcement Team
Time of incident	The time of an incident as reported by local law enforcement.	Law Enforcement Crash Reports
Date of incident	The date of an incident as reported by local law enforcement.	Law Enforcement Crash Reports
Cause of injury	The cause of an injury involving a micromobility vehicle as reported during a hospital visit.	Hospital Data
Crash severity	The severity of an injury resulting from a crash as reported by local law enforcement.	Law Enforcement Crash Reports
Crash contributing factor	The factor(s) contributing to a crash as reported by local law enforcement.	Law Enforcement Crash Reports

Field	Description	Source
In-app education awareness survey responses	How well a user understands the rules of the road and how to operate and park safely as reported during a user survey. *(Cities and operators should work together to develop survey criteria.)*	User Survey
Education awareness survey responses	How well users and non-users understand how to access and use the service, the rules of the road and how to interact with micromobility vehicles as reported during a survey. *(Cities and operators should work together to develop survey criteria.)*	User Survey
Average daily users	The average amount of daily users as reported by an operator. *(Cities should account for users that may patronize multiple services.)*	Vendor Data
Operator vehicle mileage by vehicle type	The total mileage driven by each vehicle type by an operator or their contractor during non-revenue operational activities.	Vendor Data
Unique monthly users	The total number of unique users as reported by an operator. *(Cities should account for users that may patronize multiple services.)*	Vendor Data
Unfulfilled trips	The total number of trips that have been unfulfilled as reported by an operator.	Vendor Data
Communities of concern spatial file	A spatial file containing the geographic community boundaries within a jurisdiction, as determined by the city or agency using local criteria, that have been designated as disadvantaged, vulnerable, or historically underserved.	City Open Data
Trip purpose satisfaction survey responses	How well the micromobility service served the purpose of a specific trip as reported during a user survey. *(Cities and operators should work together to develop survey criteria.)*	User Survey
Average cost per mile of other available modes	The average cost per mile of other available modes in a city. *(Cities and agencies will need to determine appropriate distance values to use for other modes. This variable could be based on the average micromobility trip distance or a different distance value could be used for each mode based on likely distance given the modal choice. Additionally, dynamic pricing or rush hour fares should also be accounted for with transit modes.)*	Various
Trip purpose survey responses	The purpose of a specific micromobility trip as reported during a user survey. *(Cities and operators should work together to develop survey criteria.)*	User Survey
count "trip_id"	A count of all the unique identification numbers assigned to an individual trip.	Mobility Data Specification (MDS)

Field	Description	Source
Transit stops	The latitude and longitude of all transit stop locations for a transit agency.	GTFS (General Transit Feed Specification)
Average distance to a vehicle at app open	The average distance to a micromobility vehicle when an operator's app is opened by a potential user.	Vendor Data
Average cost per mile by vehicle type	The average cost of a mile for a user for each micromobility vehicle type as reported by an operator.	Vendor Data
Total kwh	The total number of kilowatt hours (kWh) used as reported by an operator.	Vendor Data
Total eligible individuals for low-income plan	Based on thresholds determined in local regulations, how many residents that are eligible for low-income discounts using available census data.	Census
Street spatial file with roadways speeds	A spatial file containing all the roads and streets in a jurisdiction along with their related speed information.	City Open Data
Service area spatial file	A spatial file containing the geographic boundaries where companies may operate in a jurisdiction.	City Open Data
Safety issue observations	Safety issues with vehicle hardware observed during random spot checks by city or agency observation team.	City Observation Team
Rider frequency survey responses	How frequently a rider uses a micromobility service as reported during a user survey. *(Cities and operators should work together to develop survey criteria.)*	User Survey
Propensity to ride survey responses	The reason a user chooses to use a micromobility service as reported during a user survey. *(Cities and operators should work together to develop survey criteria.)*	User Survey
Healthcare locations spatial file	A spatial file containing all the locations of healthcare facilities in a jurisdiction.	City Open Data
Grocery stores locations spatial file	A spatial file containing all the locations of grocery stores in a jurisdiction.	City Open Data

Field	Description	Source
Government facilities locations spatial file	A spatial file containing all the locations of government institutions in a jurisdiction.	City Open Data
Education locations spatial file	A spatial file containing all the locations of educational institutions in a jurisdiction.	City Open Data
City specific places of interest spatial file	A spatial file containing all the places of interest in a jurisdiction determined important for analysis by the city or agency.	City Open Data
Parking facility spatial file with capacity information	A spatial file containing all the micromobility parking facilities in a jurisdiction along with their related capacity information.	City Open Data
Observational count data	The results of a city or agency observation team in the field observing micromobility use and parking. *(Local methods for observation and reporting will vary by city.)*	City Observation Team
Trips booked using cash	The number of trips booked with a micromobility service using cash as reported by an operator.	Vendor Data
Trips booked through non-digital methods	The number of trips booked with a micromobility service through non-digital means as reported by an operator.	Vendor Data
Neighbourhood spatial file	A spatial file containing all the existing neighbourhood boundaries in a jurisdiction.	City Open Data
Monthly vehicle removal from service by reason	A monthly report detailing why micromobility vehicles were removed from service by an operator.	Vendor Data
Mode-shift survey responses	Which other mode a user would have taken if not using a micromobility vehicle as reported during a user survey. *(Cities and operators should work together to develop survey criteria.)*	User Survey
Marital status demographic data	Marital status of a user as reported during a user survey. *(Cities and operators should work together to develop survey criteria.)*	User Survey
Maintenance monthly report	A monthly report detailing the repairs and maintenance performed on micromobility vehicles in service by an operator.	Vendor Data

Field	Description	Source
Maintenance issue observations	Maintenance issues observed during random spot checks by city or agency observation team.	City Enforcement Team
Vehicle type	The form factor of a vehicle involved in a crash as reported by local law enforcement.	Law Enforcement Crash Reports
Land-use spatial file	A spatial file containing all the existing land-use delineations in a jurisdiction.	City Open Data
Jobs locations spatial file	A spatial file containing all the locations of jobs in a jurisdiction.	City Open Data
Age demographic data	Age of a user as reported during a user survey. *(Cities and operators should work together to develop survey criteria.)*	User Survey
Household income demographic data	Household income of a user as reported during a user survey. *(Cities and operators should work together to develop survey criteria.)*	User Survey
Home location demographic data	Home location of a user as reported during a user survey. *Note: cities will need to determine how best to survey home location to avoid creating disparities with other analyses they perform using census tract, neighbourhood, or zip code data. (Cities and operators should work together to develop survey criteria.)*	User Survey
Gender demographic data	Gender of a user as reported during a user survey. *(Cities and operators should work together to develop survey criteria.)*	User Survey
Event data (e.g., address, date, number of attendees)	The event specific information reported by operators after hosting local safety and education events. *(Local regulations and methods for reporting will vary by city.)*	Project Manager Records Vendor Data
Ethnicity/race demographic data	Race or ethnicity of a user as reported during a user survey. *(Cities and operators should work together to develop survey criteria.)*	User Survey
Employment demographic data	Level of employment of a user as reported during a user survey. *(Cities and operators should work together to develop survey criteria.)*	User Survey
Education demographic data	Level of education attained by a user as reported during a user survey. *(Cities and operators should work together to develop survey criteria.)*	User Survey

Field	Description	Source
Adaptive daily utilisation rate of adaptive or alternative vehicles	The average daily utilisation of adaptive or alternative vehicles as reported by an operator. *(Cities or agencies will need to account for multiple operators.)*	Vendor Data
Discount plan users by month	The number of users signed up for a discount plan as reported by an operator.	Vendor Data
Discount plan recipient demographic data	Whether or not a user is a discount plan receipt as reported during a user survey. *(Cities and operators should work together to develop survey criteria.)*	User Survey
Desired vehicle availability satisfaction survey responses	Survey data reflecting a user's satisfaction with the form factors of available vehicles. *(Cities and operators should work together to develop survey criteria.)*	User Survey
Crash location	The latitude and longitude of a crash as reported by local law enforcement.	Law Enforcement Crash Reports
Complaint data	Complaints reported to the city by residents through 311 or another method. *(Local regulations and methods for reporting will vary by city.)*	311
Community engagement results	The results of direct, personal engagement with local residents who are digitally disconnected. *(Local methods for engagement and reporting will vary by city.)*	Project Manager Records
TIGER/Line Shapefiles	A spatial file containing the boundaries of geographic areas and features such as census blocks, landmarks, and roads.	Census
Bike facility spatial file with capacity information	A spatial file containing all the bicycle facilities in a jurisdiction along with their related capacity information.	City Open Data
Average daily availability of adaptive or alternative vehicles	The average daily availability of adaptive or alternative vehicles as reported by an operator. *(Cities or agencies will need to account for multiple operators.)*	Vendor Data

Table 39: Outputs and KPIs for SharedStreets data (SharedStreets, 2021)

Field	Description
Total vehicles	Total number of vehicles that were on the street at any time during the specified day. This includes all vehicles that were available, unavailable, or reserved according to the event types specified here.
Active vehicles	Total number of vehicles that completed at least one trip during the specified day. (Trips)
Total trips	Total number of trips taken throughout the specified day.
Total trips distance	Total miles travelled by any vehicles throughout the specified day. (trip_distance)
Vehicle Utilisation	Percentage of vehicles that were active over the course of a day.
Average distance per vehicle	Total trips distance, divided by active vehicles.
Average trips per active vehicle	Total trips, divided by active vehicles.
Average trip distance	Total trips distance, divided by total trips.
Average trip duration	Total trips duration, divided by total trips.
Available fleet	Vehicles deployed and ready to be activated by a rider
Unavailable	Vehicles deployed but unable to start a trip (awaiting maintenance, depleted battery, etc.)
Reserved	Vehicles actively engaged in a trip
Trip Volume	The number of vehicles that moved over a street or in a zone during the time window specified.
Availability	The maximum number of vehicles that were available to users during the time window specified.
On-street	The maximum number of vehicles that are on the street and available or unavailable during the time window specified.
Pickups	The total number of trips that began during a time window.
Drop-offs	The total number of trips that ended during a time window.
Flows	The number of trips that went from one area of the city to another area of the city, sometimes referred to as origin/destination data or “O/D pairs”.

C.8 Car Sharing

C.8.1 Data visualisation platform

With the use of visualisation platforms of online data the Municipality of Milan could have a real-time reaction to anomalies on transit or irregular parking and could eventually give prompt feedback to the operators to solve the issues that had been identified. Likewise, offline information can be used to retrieve historical data useful for transportation planning purposes. The Municipality of Milan is currently employing two platforms: Bluesystems and Vianova. Those platforms are also in use in other European cities such as London (Bluesystems) and Stockholm (Vianova).

One of the ways in which data collection within sharing mobility operation can be achieved is by pairing up public administration agencies with technological partners in charge of providing data visualisation tools. As an example, the Municipality of Milan is currently working with two platforms which serve the purpose of data collection and visualisation for real-time and offline information retrieved directly or indirectly from all operators of sharing mobility present in the city.

C.8.1.1 Solved challenges

Data visualisation platform helps cities in constantly monitors the usage of the car-sharing services in order to identify real-time malfunctioning or improper uses. Policy makers can make use of the historical data to take decision on future improvements of the service.

The platforms allow:

- Real-time data collection
- Offline data collection.
- Real-time reaction to anomalies on transit or irregular parking.

C.8.1.2 Inputs and requisites

The platform receives as input all the information sent by each shared vehicle. The platform gathers that information from different sources and publishes it as output.

C.8.1.3 Outputs and KPIs

Some examples of real-time data that the platform updates periodically (e.g., for the Municipality of Milan) are:

Table 40: Examples of real-time data updated by the platform

Real-time availability of devices and stations. Real-time GPS localization of vehicles and stations.	
Station_information.json	List of all stations, their capacities and location
Station_status.json	Number of bikes/cars available in each station and station status
Free_car_status.json	Cars that are available for rent

Moreover, some examples of the offline data that can be visualised on the platform (e.g., visualised by the Municipality policy makers) are:

Table 41: Examples of offline data visualised on the platform

Aggregate history on travel routes and usage behaviours
• Anonymous user code natural person • Anonymous user code legal entity • Number of device that performed the rental • Rental start date and time • Date and time of end of rental • Pick-up station • Drop-off station • Number of kilometres covered during the rental, in whole number format • Total number of full minutes of rental • Number of full minutes the device is in "moving" mode • Number of full minutes the device is in "stationary" mode • User's use of the pre-booking system • Percentage of the battery charge level at the moment of starting the rental • Percentage of the battery charge level at the time of conclusion of the rental • Unique trip identifier ("trip_id") • Identifier UUID of the Provider ("provider_id") • Provider name ("provider_name") • Type of the vehicle ("vehicle_type") • Type of propulsion ("propulsion_types") • Starting point coordinates ("route[first]" "geometry ") • End point coordinates ("route[last]" "geometry ")

C.8.2 Relocation models

In one-way car-sharing network, the vehicles distribution needs to be rebalanced through relocation models which can serve operational or strategic aims. Many of this models are only considered once a day in order to reset the initial vehicle balance, so called static relocations (Illgen & Höch, 2018).

C.8.2.1 Mixed-Integer Programming models (MIP models)

Many approaches to solve the vehicle relocation problem revolve around optimisation models that maximize profit for providers and customers or minimize costs are modelled by means of mixed integer programming models (MIP).

It offers optimal solutions to the redistribution issue but it is limited to manageable problem size and smaller numbers of considered variables due to computational restrictions (Illgen & Höch, 2018).

C.8.2.2 Solved challenges

- Optimizing vehicle depot location
- Describing how demanded customer trips are merged with available vehicles
- Trade-off between customers' advantages and operators' profits
- Staffs relocation
- Vehicles relocation (Illgen & Höch, 2018)

C.8.2.3 Inputs and requisites (aggregated from all tools)

A relocation model requires the following inputs according to (Gambella et al., 2017).

- Number of cars
- Number of relocators
- Stations (only for station based)
- Number of charging for station (for electric vehicles)
- Battery charge level (for electric vehicles)
- Spots per station
- Node set
- Arch set

C.8.2.4 Outputs and KPIs

The relocation model provide as output the optimal vehicle relocation suggestion (Illgen & Höch, 2018), the models suggest to the service operator the relocation configuration that maximize its profit (Gambella et al., 2017).

C.8.3 Decision Support System for the Optimisation of Electric Car Sharing Stations

Sonneber et al., presented in 2015 a Decision Support System that provide strategic optimisation of location, number, and size of stations for electric vehicles with a specific charging infrastructure, station-based car sharing in a two-way mode.

To support decision, a mathematical model that optimises an electric car-sharing network and maximizes the organisation's profit as objective function was developed. The model was designed with a critical overview of the data availability and implemented to provide valuable insight for real-life decision makers.

C.8.3.1 Set of tools

The Decision Support System is based on a dataflow that include five tools as shown in Figure 44.

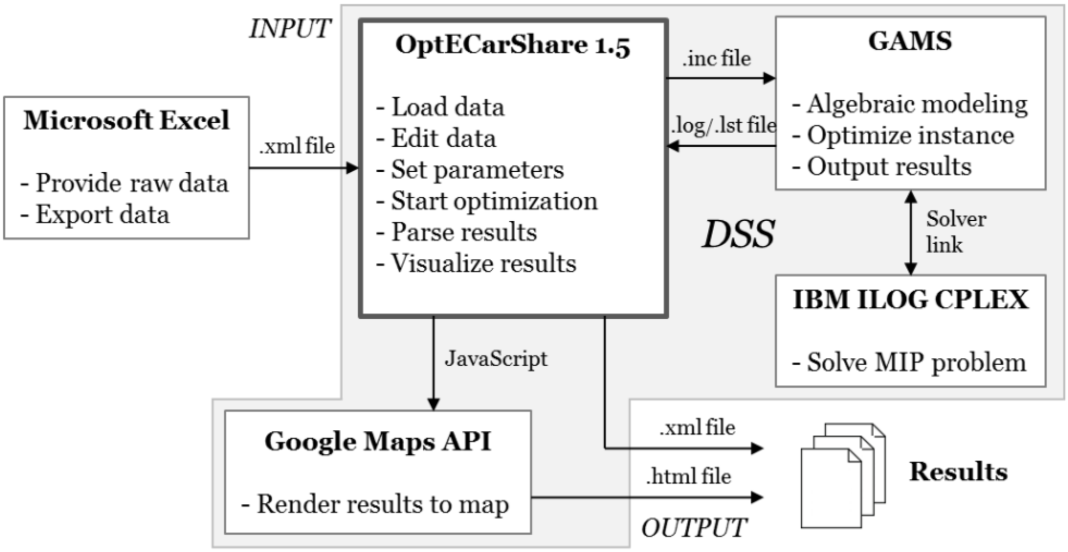

Figure 44: Dataflow for the Decision Support System (Sonneberg et al., 2015)

The core of the optimisation is performed by the OptECarShare module a research artifacts developed by the authors.

C.8.3.2 Solved challenges

The model optimises:

- the location of an electric car-sharing station network
- the car-sharing organisation's profit

C.8.3.3 Inputs and requisites

The optimisation model is based on the basic model from Rickenberg, Gebhardt, and Breitner (2013) and maximizes the annual profit of a car-sharing organisation. The following assumptions form the basis of the optimisation model:

- The object in consideration is the classic two-way car-sharing scheme. Every vehicle has its designated parking lot, meaning vehicles have to be picked up and returned to the same location.
- The objective of the optimisation model explicitly concerns strategic planning of a car-sharing network; operational aspects are not considered.
- Stochastic and normal distributed demand points for car sharing exist.
- The demand points are allocated within the investigation area and are provided on a punctual basis by geographic coordinates.
- The demand has to be fulfilled completely to reach the maximum customer satisfaction.
- Possible supply points in the form of car-sharing stations are spread over the specific investigation area to satisfy the demand. These points are also characterized by exact geographic coordinates.

- For each of the potential stations, a maximum limit of parking lots is defined to reflect local land-use conditions in the surroundings of the respective station.
- Annual leasing costs for vehicles, parking lots, and stations are introduced. These contain all incidental expenses, and explicitly not only the initial costs.
- Subject matter is electric vehicles, which are completely battery powered and require trip-dependent charging cycles.
- Two different options of the charging process can be simulated for the otherwise homogenous fleet. Firstly, regular charging can be used through the conventional local grid-connection. As an alternative, more efficient fast chargers via special 50 kW DC charging elements can be chosen. Depending on the option, different charging times and adjusted leasing costs are being considered.
- The implementation of electric vehicles into the car-sharing fleet requires additional parameters. Charging condition and influencing elements such as range, average speed, and power consumption are therefore considered. The power consumption depends on the duration of a trip and the distance driven. Hence, these are integrated as trip-dependent parameters and modelled stochastically by a normal distribution.
- A maximum number of possible trips per day results from the choice of trip-dependent parameters and the corresponding fast or regular charging times.
- The charging time is linearly correlated to the travel time. This means that one hour of travel time is always associated with a fixed time to recharge the battery.
- Variations in demand typically do not represent a part of a strategic, i.e., long-term problem. To grant decision makers a certain degree of variation, the suggested model allows the demand to be varied throughout the week by determining peak and off-peak weekdays. An additional variation of the demand (e.g., throughout the day or year) is not expected to add further value to the strategic allocation of stations and vehicles and should rather be included in operative approaches.

The model makes then use of the following parameters.

Table 42: Parameters used in the optimisation model

Sets	
Station_information.json	List of all stations, their capacities and location
Parameters	
Normal distributed demand [rents/week] Revenue for renting [USD] Average energy consumption [kwh/km]	Expected duration of a rent [min] Expected distance driven [km] Energy price [USD/kwh]
Leasing cost of a vehicle [USD] Leasing cost of regular charger [USD] Leasing cost of a station [USD]	Leasing cost of a parking lot [USD] Leasing cost of a fast charger [USD]
Possible trips regular [units]	Possible trips fast

Demand of busiest interval [rents/day]	
Max lots per station Distance between station I and demand point j [km]	Max lots with fast charger Max distance between i and j [km]

C.8.3.4 Outputs and KPIs

The output of the optimisation model is the value of the following decision variables.

Table 43: Decision variables and their values

Decision variables	
Number of vehicles regular charged at station i	Stations built [0,1]
Number of vehicles fast charged at station i	Demand location served by stations [0,1]

C.9 Mobility as a Service (MaaS)

C.9.1 MaaS platforms

The MaaS platform is a collection of components which perform integral functions such as data import, data storage, journey planning, optimisation, ticketing, payment, and communication (Signor et al., 2019). MaaS platforms allow the planning of door-to-door trips by aggregating all the public and private means of transport available in the city and allowing for the payment of the service through a monthly subscription or based on use (Canale et al., 2019). The International Association of Public Transport UITP (2019) distinguishes MaaS systems based on a platform provided by a commercial MaaS integrator (e.g., the app Whim in Helsinki, developed by the private company MaaS Global and started in 2016, or Zipster, Asia's first integrated MaaS app launched in Singapore in September 2019), or on an open back-end platform set up by a public entity with rules determined by a public authority (e.g., the app WienMobil that was launched by Upstream, a subsidiary of Wiener Linien and Wiener Stadtwerke, in June 2017).

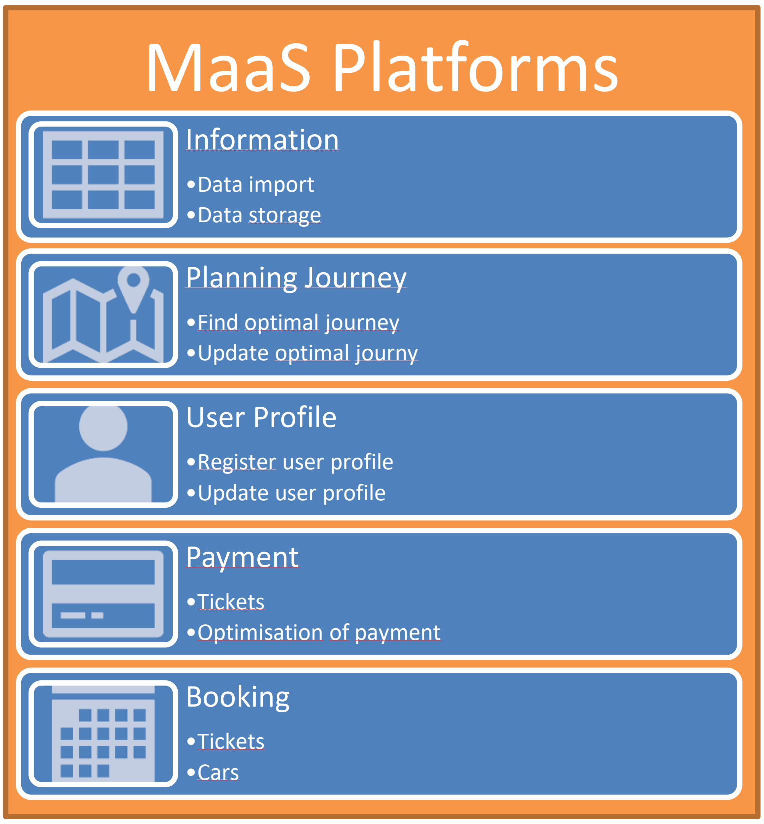

Figure 45: MaaS platforms (source: own elaboration)

The open platform serves as a public infrastructure on which different actors can build a MaaS solution, all mobility services have to open up their API's. The following groups of use cases are described according to the integrated open platform developed withing the project MaaS4EU (Georgakis, 2019; Chatzigiannakis & Bravos, 2020).

C.9.1.1 Manage user profile & subscription

Use cases related to the creation and management of a user's account include (Georgakis, 2019):

- Register user
- Generate user profile
- Update user profile
- Evaluate journey
- Receive package configuration recommendations

C.9.1.2 Plan trip

Use cases that facilitate the planning and monitoring of a journey using different mobility services (Georgakis, 2019):

- Generate multi-modal routes
- Receive personalised multi-modal routes
- Store selected route
- Monitor trip progress

C.9.1.3 Analyse supply and demand

Use cases for managing services at a system level – supply and demand analysis (Georgakis, 2019):

- Monitor service supply
- Monitor service demand
- Inform traveller

C.9.1.4 Manage booking, ticketing, and payment

Use cases for enabling support services for a journey include (Georgakis, 2019):

- Book service
- Generate ticket
- Accept subscription payment
- Register tap

C.9.1.5 Receive data reports

Use case for MaaS operators, mobility service providers and public transport authorities (Georgakis, 2019), allowing to vie aggregated data and reports related to the usage of the mobility services by travellers.

C.9.1.6 Solved challenges

The following key challenges that any MaaS solution is expected to address were identified by Trafi (2020) and Zöschinger (2019).

- **Sustainability:** MaaS scheme significantly improves air quality and avoids emissions of hazardous pollutants – especially in highly dense urban areas. It also notably reduces transport-related GHG-emissions, and thus contributes to the climate change mitigation.
- **Effectiveness of the mobility network:** MaaS contributes explicitly to increase of transport network effectiveness. It helps to overcome the road congestion and public transport bottlenecks. It reduces car-dependency and simultaneously assures to cover all mobility needs – in the city and in its suburban areas.
- **Safety:** Advanced tools allow for tracking safety and improper parking incidents (see also the note on micromobility).
- **Equity:** Implemented services cover all societal groups and are accessible by anyone – in terms of economic, physical, geographical, and skill-related issues.
- **Connectivity:** Services such as car and ride-sharing or ride-hailing increase mobility for citizens to reach destinations otherwise inaccessible by public transport, walking or biking.
- **Livable public space:** MaaS accounts for facilitating conversion of transport related urban space towards liveable neighbourhoods and housing.
- **Flexibility:** MaaS adapts to increasingly flexible living and working conditions without restricting convenience and service quality.

C.9.1.7 Inputs and requisites

Inputs related to **data analytics** are data related to a user profile (Georgakis, 2019):

- Mode use
- Package purchase
- Socio-economic characteristics
- Attitudes towards mobility
- Travel preferences[59]
- Inputs received from the traveller (journey origin and destination)
- Other data generated from other components of the platform

[59] For the general discussion on the relation between attitudes and preferences see (Schmitt, 2015). In the decision-making theory, a preference order is defined within the space of alternatives, while attitudes are related to the different attributes of alternatives, together with attributes of other decision makers, social norms, and rules.

C.9.1.8 Outputs and KPIs

Outputs related to data analytics are aggregated visualised results (Georgakis, 2019).

To assess the impact of MaaS, Kamargianni et al. (2017) proposed the following KPIs. Since a MaaS platform represents the main tool through which this service is implemented, the same KPIs can also serve for the assessment of this tool.

Table 44: KPIs for MaaS (Kamargianni et al., 2017)

Level	KPI	Impacts		
		Environmental	Economic	Social
Individual/user level	Total number of trips made	x		x
	Modal shift (from car to PT, to sharing, ...)	x		
	Number of multimodal trips	x		
	Attitudes towards PT, sharing, etc.	x		
	Perceived accessibility to transport			x
	Total travel cost per individual/household		x	x
Business/organisational level	Number of customers		x	
	Customer segments (men/women, young/old, ...)		x	x
	Collaboration/partnership in value chain		x	
	Revenues/turnover		x	
	Data sharing		x	
	Organisational changes, changes in responsibilities		x	
Societal level	Emissions	x		
	Resource efficiency (roads, vehicles, land use, ...)	x	x	
	Citizens accessibility to transport services			x
	Modification of vehicle fleet (electrification, automation, etc.)	x		
	Legal and policy modifications	x	x	x

C.9.2 Standard Data

MaaS platforms face the challenges of standardizing interfaces and data between different mobility operators who must interface via APIs with each operator, and these operators will potentially have different repositories and data structures from one another. Today, various initiatives are already present at regional scale (Capgemini Invent & Autonomy, 2020). A good example is the Mobility Data Specification (MDS), the project of the Open Mobility Foundation (OMF), initially developed by the Department of Transportation to manage micromobility services in Los Angeles – see also the note on micromobility. MDS is comprised of a set of APIs that enable a standardized two-way communication between cities and private companies to share information about their operations, and that allow cities to collect data that can inform real-time traffic management and public policy decisions to enhance safety, equity, and quality of life (Smart Dublin, 2019). It is used by more than 50 cities in the USA and by numerous cities in other parts of the world, including e.g., Lisbon.

In Europe, a common standard for designing digital transport services based on European legislature is the aim of three projects funded under the H2020 Mobility for Growth Programme, namely: MyCorridor, MaaS4EU and IMOVE. In this framework, MaaS API (Application Programming Interface) is under development by MaaS Alliance,[60] a public-private partnership with the ambition to provide the foundations for a common approach to MaaS, unlock the economies of scale needed for successful implementation and take-up of MaaS in Europe and beyond.[61] MaaS API defines a common approach to designing a transport service Application Programming Interface (API) including the use of communication protocol and data format to security standards, basic methods and service calls, responses and general behaviour of an API.[62]

Within a specific platform, a component “API of APIs” is responsible for the integration of services through a single interface. It exposes different APIs from various sources following various standards and protocols under a singular API governed by the CIM (Common Information Model) following the REST (request and/or response) schema (Georgakis, 2019). For instance, TOMP-API (where TOMP stands for Transport Operators and MaaS Providers) is being developed by the Transport Operators and MaaS Providers (TOMP) Working Group, including public and private stakeholders. It aims at facilitating the implementation of MaaS and the corresponding exchange of data in Europe. The TOMP-API describes a full MaaS journey, including operator information, planning, booking, support, payments, and trip execution. Although the NeTEx (Network Timetable Exchange)[63] and SIRI (Service Interface for Real-Time Information)[64] standards will be mandatory for all MaaS actors in Europe in 2023 – see also the note on public transport management – it is important to realize that there is no one-size-fits-all solution for all regions or environments. There exist different types of solution and APIs. Frequently used basic scenarios are (ERTICO – ITS Europe, 2019):

- **Private Integrators** where each of individual MaaS providers has bilateral agreements with transport operators. The APIs and data can be open to third parties.
- **Open Back-End Platform** where a public authority or another neutral party stands between mobility service providers and MaaS providers. All data are shared without discrimination and all players have the same access to integrated data.

[60] https://maas-alliance.eu
[61] https://maas-alliance.eu/2019/01/24/eu-projects-explore-common-standard-for-digital-mobility-services
[62] https://maas.guide/ and https://github.com/maas-alliance
[63] http://netex-cen.eu
[64] http://www.transmodel-cen.eu/standards/siri

- **Public Transport as the Integrator** where the MaaS provider is the provider of public transport. There is only one MaaS provider and the choices of transport types can be limited because there is no competition between providers.

Finally, other standards may be useful for MaaS, such as the AIDX (Aviation Info Data Exchange)[65]. Developed by IATA (a short for the International Air Transport Association), the standard uses the global XML messaging standard for exchanging flight data between airlines, airports, and any third party consuming operational data. Because intercity, air travel is in the scope of MaaS, thus included into this deliverable.

C.9.2.1 Data Specification

This use case and the solution proposed by MDS was already discussed in section C.7.1. The specification of the provider API endpoints contains a data standard for Mobility as a Service providers.[66] APIs for the integrated open platform developed withing the project MaaS4EU are described in the report by Chatzigiannakis and Bravos (2020).

For the TOMP-API standard, the main purpose of this API is to provide a generic and open interface between Transport Operators and MaaS Providers, enabling an open ecosystem. Since the focus lies on sharing asset information, both the asset information from free-floating systems and the information from station or fixed-route systems mobility hubs or station-dependent transportation can be shared through the functional descriptions. The TOMP-API specification holds much promise for creating a common standard for MaaS applications, but it cannot be the sole interface in which to develop and build a shared mobility ecosystem.

C.9.2.2 Solved challenges

Data standards help cities interact with companies that operate various modes of transport included in MaaS and contribute to the solution of challenges listed in section C.7.1.2.

C.9.2.3 Inputs and requisites

Inputs and requisites are discussed in section C.7.1.3.

C.9.2.4 Outputs and KPIs

For outputs, see section C.7.1.4, KPIs are listed in Table 35.

C.9.3 Methodology for mobility packages creation

Esztergár-Kiss and Kerényi T. (2020) propose a methodology for the creation of mobility packages for the MaaS system users that allow to determine the convenient price and specify the modes of transport included in a package (and to which extent).

[65] https://www.iata.org/en/publications/info-data-exchange
[66] https://github.com/openmobilityfoundation/mobility-data-specification/tree/main/provider

C.9.3.1 Creating a mobility package

The method elaborated by Esztergár-Kiss and Kerényi T. (2020) takes into account various city specific parameters (e.g., demography, cost of living, modal split, weather conditions, environmental friendliness). It assigns package levels to cities involving different transportation modes, such as public transport, bike sharing, car sharing and taxi. The authors considered 15 European cities with specific parameters and created the most suitable mobility packages for them.

C.9.3.2 Solved challenges

The mentioned methodology helps to solve the problem of providing suitable mobility packages for the users to support the efficient development of the MaaS concept, and overcome the lack of knowledge on how the plans should be created and what local aspects could be taken into account. It helps to specify what kind of transportation modes are included, to what extent the specific modes should be offered, and what circumstances may have an effect on the package structure (Esztergár-Kiss and Kerényi T., 2020).

C.9.3.3 Inputs and requisites

As the quantifiable characteristics of cities, the following aspects are considered:

- **The general climate of the cities** characterized by sunshine hours and rainfall.
- **Financial information**, i.e., the average monthly salary, cost of living, public transport pass price and taxi tariffs.
- **Specific indexes** to receive information about the transportation in the cities (traffic index, travel time index, PT satisfaction).
- **The modal split of transportation modes** received from the size of the agglomeration compared to the size of the city.
- **Density of the city**, i.e., inhabitants per squared kilometre.
- **Environmental awareness of the citizens** measured on the basis on the amount of waste and commitment to prevent climate change.
- **The median age and male/female ratio** to define general socio-demographic features.

C.9.3.4 Outputs and KPIs

All inputs are normalized to be expressed by a number between 0 and 1, and for different transport modes, they are assigned different weights. The final set of mobility packages is created from the level of packages, which provides individualised combination for each city. The following transport modes and package levels are considered:

- **Public transport:** pay-as-you-go / 10 days / 20 days per month / unlimited / unlimited with agglomeration
- **Bike-sharing:** not used / pay-as-you-go / one hour / three hours free per day / unlimited
- **Car sharing:** not used / pay-as-you-go / one hour / three hours free per day / unlimited
- **Taxi:** not used/pay-as-you-go/10 km/20 km / 50 km free per day

C.9.4 Simulation tools

An interesting example of a tool that integrates macro, meso, micro and hybrid simulations is the software Aimsun. MaaS can be modelled and analysed by Aimsun´s simulation platform Aimsun Ride oriented to new demand-responsive transportation services.[67] Here, the demand-responsive vehicles are an overlay on regular traffic and interact fully with other road users. Aimsun Ride provides dynamic simulation of various kinds of transportation services that allows to demonstrate impacts of congestion and various policies on them.

C.9.4.1 MaaS dynamic simulation

Aimsun Ride allows to model individual vehicle-to-vehicle interaction or use aggregate representations of a transportation network and demand, test and refine stakeholder's fleet management algorithms by connecting them with Ride's API. It is also possible to work with travel requests based on individual agents with customizable parameters based on anything from age, gender, eco-friendliness, or economic status. The simulation helps to understand how stakeholder's offering fits into the mobility space and how it is likely to combine with and compete against alternative modes, namely walking, public transportation (rail, metro, bus, tram...), taxi and ride-hailing operators and on-demand buses and mini buses.

Aimsun Ride allows to identify patterns in travel demand, replay simulations to check the fleet's movements in the network, extract network statistics for every user-defined interval and review individual requests and how they were served.

C.9.4.2 Solved challenges

MaaS simulation tools as e.g., the mentioned Aimsun Ride allow to set up models of any size for testing various kinds of scenario, including for example:

- Fixed routes, semi-fixed routes, or completely free 'taxi-style' routing
- Fixed timetables or purely on-demand requests, real-time or pre-booked
- Physical stops, virtual stops, or stop-anywhere
- Different fleet types and configurations
- Rides offered in isolation or combined with public transport as part of a holistic transportation model
- Algorithms for managing routes, scheduling departures, offering, and operating user-pooling, and fleet redistribution
- Algorithms for generating different offers, pricing models, and target service levels
- Attractiveness levels of different types of service
- Competition between different providers or services
- Sensitivity to key input parameters, e.g., running multiple simulations with different assumptions on behavioural parameters

[67] https://www.aimsun.com/aimsun-ride

C.9.4.3 Inputs and requisites

The input data required by Aimsun is a simulation scenario, and a set of simulation parameters that define the experiment. The scenario is composed of the following types of data:

- Network description: information about the geometry of the network, turning movements, layout of links and junctions, location of detectors along the network.
- Traffic control plans: description of phases and their duration for signal-controlled junctions, the priority definition for unsigned junctions, the ramp-metering information.
- Traffic demand data: traffic volumes at the input sections, turning proportions and the initial state of the network, or an OD matrix containing number of trips going from every origin centroid to any destination one. In the first case.
- Public transport plan comprises the definition of bus lines (routes and bus stops) and the timetables for each line, including stop times.

C.9.4.4 Outputs and KPIs

The outputs provided are a continuous animated graphical representation of the traffic network performance, both in 2D and 3D, statistical output data (flow, speed, journey times, delays, stops), and data gathered by the simulated detectors (counts, occupancy, speed). Both the statistical and detection data can be graphical (plots) or numerical, the latter can be stored in ASCII files or database Access or ODBC (TSS, 2003).

C.10 C-ITS and CAV integration

C.10.1 Strategic planning tools

Strategic transport planning involves the identification of future needs within a transport system as well as the of the most proper solutions enabling a safer, faster, more comfortable, convenient, economical, and environmental-friendly movement of people and goods. Strategic transport planning relies on a variety of tools, ranging from simple data analysis tools (sketch planning tools) to advanced mathematical models (Furnish & Wignall, 2009). A widely utilised approach for serving strategic transport planning's objectives is the use of macroscopic modelling tools that are based on the traditional "four step" model (McDonald, 1988), which includes: a) the number of trips generated within and attracted by each transport analysis zone (TAZ), b) how these trips are distributed among the TAZs, c) by which transport mode are these trips served, and d) which of the available routes are selected by travellers. Macroscopic modelling tools, relying on the "four-step" model, alternatively known as trip-based models, have received criticism regarding: a) the use of static factors (e.g., time-based trip generation rates not taking into account travellers' attitude to adapt their travel behaviour or activities according to prevailing traffic conditions), b) the fact that the only step (apart from route choice) that is based on behavioural decision-making theory is the third one (i.e., mode choice), c) the absence of information concerning whether trips originate from or end up in home or non-home locations, d) the inability to define in a precise manner the spatial extent of TAZs, d) the inability to account for time-of-day shifts to travel demand and land-use interactions (Stabler & Brinckerhoff, 2012). However, trip-based models are considered advantageous in terms of data requirements as well as providing an aggregated analysis on topics such as land use changes and their impact of transport system.

The rise of C-ITS and CAV technologies and the increasing penetration rate of automated vehicles and connected vehicle services are expected to have significant implications, among others, on the beforementioned steps. For that reason, there is a need to reconsider the relevant parameters and assumptions of existing macroscopic modelling techniques.

Potential implications on trip distribution

- The possibility offered to travellers by automated vehicle to disengage from driving and complex navigation tasks and spend in-vehicle time relaxing or working is expected to alter their perception concerning in-vehicle value of time. Thus, travellers may choose to execute more distant trips.

Potential implications on mode choice

- A number of travellers currently using public transport services may prefer to make use of shared automated vehicles for comfort-related reasons (Milakis et al., 2017).
- A number of travellers/drivers currently using private vehicles or active transport modes may prefer to make use of automated vehicles for both safety- and comfort-related reasons (Milakis et al., 2017).

Potential implications on traffic assignment

- Descriptive and prescriptive advises targeting (users of) connected vehicles are expected to alter their route choice behaviour (Wang et al., 2018).

- The penetration of automated vehicles at their current level of maturity is expected to affect several traffic-related parameters, taken into account by macroscopic models (free flow speed, travel times, capacity of supply side elements) (Milakis et al., 2017).

It is noted that macroscopic models are in general iterative rather than serial, which needs to be taken into account by the newly developed tools to capture the impacts of C-ITS and CAV technologies on the mode choice step.

Apart from the abovementioned implications, C-ITS and CAV technologies are expected to affect vehicle ownership and ridership, as well as the extent of urban sprawl due to the increase in average trip length resulting from the disengagement of travellers from the driving task. Moreover, assuming the existence of shared autonomous vehicles, the need for parking spaces within urban centres is expected to reduce.

Another class of models that overcome several limitations of the traditional trip-based models mentioned above are the so-called activity-based models (ABM). In these models, it is assumed that travel demand is a product of people's need to engage in non-home-based activities. ABM's goal is to replicate whether, where, when, and how people decide to travel, thus incorporating behavioural decision-making processes (in the sense of utility maximization) in several steps of travel demand analysis, including trip generation, spatial distribution of trips, and mode choice. Moreover, in these models travel demand is not modelled at an aggregated TAZ level but at a disaggregated person- or household-level, while the concept of trips is often substituted with that of tours (i.e., a series of trips beginning and ending at home or non-home locations). On top of that, time and space constraints are considered (Stabler & Brinckerhoff, 2012). Time constraints imply the scheduling of activities that may occur only in available time windows. In this respect, ABM are more readily capable of evaluating the effects of policies enforced by transport authorities, including intelligent pricing policies, and behavioural modification programs (Delhoum et al., 2020). ABM typically involve a pre-travel computation stage, where individuals (pre)schedule their activities in a manner that satisfy their needs as well as a travel computation stage, where revisions, additions, and deletions are accomplished following unforeseen consequences of (pre)scheduling, new demands, or unexpected events (Axhausen & Gärling, 1992).

C.10.1.1 Integration of automated vehicles into macroscopic models

Existing approaches for capturing the impacts of automated vehicle technologies are mainly based on microscopic simulation environments (Sala & Soriguera, 2020). However, there are a few attempts to integrate automated vehicles and their foreseen implications into macroscopic models. Friedrich at al. (2018) present three alternatives for adjusting macroscopic models for estimating the impacts of automated vehicles on the performance of a transport network. Performance is understood as the delay time per vehicle. According to the first alternative, capacity of supply side elements (i.e., links and nodes) is assumed constant, while demand is adapted using a different passenger car unit factor for automated vehicles. The passenger car unit factor corresponding to automated vehicles may be constant or varying so as to account for the effect of different penetration rates. According to the second alternative, passenger car unit factors are not modified but capacity is assumed to depend on specific headways between vehicle types. According to the last alternative, capacity is assumed to be a constant value associated with the available time to travel through a supply element, while demand is assumed to be the time required by a specific traffic composition to travel through a supply element scaled to one hour.

Obaid and Torok (2021) suggest a method to estimate the impact of automated vehicles on traffic parameters. As such are understood the daily vehicle travelled kilometres and the everyday vehicle travelled hours taking into account three passenger (conventional cars, automated cars, and taxis) and four heavy (light, medium, buses/coaches, and heavy vehicles) vehicle car classes. The methodology relies on a PTV VISUM model, wherein the Passenger Car Unit (PCU) capacity modification factor is adjusted to account for the positive effect of automated vehicles (assumed to be connected) on road capacity and saturation. For modelling the saturation reduction, parameters related to following distance and headway between vehicles is lowered.

Friedrich at al. (2018) also propose a methodology for adjusting macroscopic models for estimating the impacts of automated vehicles on travel demand. In this methodology, the utility function used to estimate travellers' mode choice behaviour is adjusted to account for properties and opportunities offered by automated vehicles (e.g., reduced value of time). Two variations of the methodology are presented based on the inferred level of vehicle automation. The main assumptions made for fully automated vehicles (SAE Level 5) are that no "captive users" exist, car travellers do not need to take their car back to the origin of the trip, and the existence of fleets of shared automated vehicles are expected to trigger new mobility options (e.g., car- or ridesharing).

C.10.1.2 Integration of automated vehicles into activity-based models

Several researchers motivated by the debate concerning the potential implications of automated vehicles on transport systems and mobility (some of which mentioned above) have attempted to utilise ABM to analyse these implications. Childress et al. (2015), for instance, attempt to assess the impacts of automated vehicles in the Puget Sound region (Washington) in the context of four scenarios. These scenarios are analysed with the use of the region's activity-based travel model comprised of a travel demand component coded in DaySim software and a travel choice component coded in SoundCast. The first scenario involves the assessment of the effects of increased roadway capacity, building upon the premise that automated vehicles will use existing facilities more efficiently (e.g., V2V coordination technologies are expected to enable lower headways). This scenario was assessed by increasing the hourly capacity of freeways and major arterials by 30%. The second scenario complements the first one by assuming that automated vehicle users will perceive in-vehicle time spent as less negative than in conventional vehicles. A basic assumption of this scenario is that automated vehicles will be initially used by higher-income households. Therefore, travel time is perceived as the 65% of its actual value only for household trips corresponding to high Value of Time (VoT), i.e., greater than $24/h. The third scenario builds upon the previous two as well as the premise that all cars are self-driving and non-shared. Therefore, in this scenario travel time is perceived as the 65% of its actual value for all trips, since it is assumed that all travellers have access to automated vehicles. Moreover, parking costs are reduced to 50% to account for the possibility offered by self-driving vehicles to self-park in cheaper locations or better utilise existing parking lots. The fourth scenario, resembling long-term conditions, involves a situation in which it is assumed that automated vehicles are shared and commonly used by all travellers, following a vehicle usership scheme. Moreover, it is assumed in this scenario that all costs of driving (incl. internal and external ones)[68] are defrayed by travellers. To this end, a rate of $1,65/mi was deemed appropriate to reflect the beforementioned assumption. Finally, in this scenario no capacity increase is assumed to reflect a situation in which enforced traffic regulations limit capacity gains. The first three

[68] Parking, vehicle maintenance, infrastructure maintenance, accidents, road construction, congestion, air pollution, and global warming cost.

scenarios (related with increased capacity) resulted in increased Vehicle Miles Travelled (VMT) compared to the base case scenario, while only the second resulted in increased Vehicle Hours Travelled (VHT). This is attributed to the fact that capacity increase in the first two scenarios counteracts additional VMT (caused by the increased number of trips per person and the increased length of trips), which is not the case for the third scenario wherein the reduction of parking costs resulted in a great demand increase and considerable systemwide delays. In the fourth scenario, average trip length appears to be reduced as considerably does the modal share of single occupancy vehicles. System-wide delays are also significantly reduced.

Vyas et al. (2019) also attempt to assess the implications of automated vehicles by utilising ABM. Specifically, they make use of the Columbus' region model through which five scenarios are analysed. The parameters on which these scenarios rely include productivity bonus associated with the changed perception on travel time, roadway capacity improvement, and parking cost. According to the derived results, the total number of person trips are reduced mainly due to decreased school escorting trips, but the total vehicle trips appear to be increased as a result of empty car repositioning and the increased use of automated vehicles by school-age children instead of school buses. Moreover, productivity bonus is associated with a moderate increase in vehicle trips and VMT. Roadway capacity improvement results in higher speeds as well as in reduced system-wide delays that, in turn, lead to increased vehicle trips and VMT. The increase in parking cost results in more empty car trips, which is associated with a moderate increase in the total number of number of trips.

C.10.1.3 Solved challenges

The adjustment of strategic planning tools in order to be able to capture the implications of C-ITS and CAV technologies will significantly support transport planners to assess the impacts of such technologies, including new mobility options and associated policies. Moreover, transport planners will be able to evaluate and support the prioritization of investments in these technologies and support the design of new policies making use of these technologies taking account of emerging mobility patterns, their effects in the level of service of transport systems, as well as changes in travel demand. Thus, they will support policy makers to take evidence-based decisions. Researchers will be given the opportunity to test the validity and further enhance the developed models through, among others, the utilisation of Big Data.

C.10.1.4 Inputs and requisites

Step 1 – Trip generation

- Person group data (e.g., income level-, employment rate-, household structure-, and car availability-related)
- Activity patterns

Step 2 – Trip distribution

- Land-use data
- Data concerning the attributes of specific locations (e.g., number of employees at a working location)

Step 3 – Mode choice

- Vehicle availability
- Accessibility of specific locations via different modes of transport
- Structure of population

- Value of time
- Generalized cost of transport

Step 4 – Traffic assignment

- Supply data
- Intersections, including nodes and main nodes
  - Turn restrictions
  - Links
  - Traffic analysis zones
  - Count locations
  - Signalization
- Public transport network supply data
- Demand data
  - OD matrices per mode
- Other data and parameters
  - Volume Delay Function parameters
  - Solution algorithm convergence parameters

C.10.1.5 Outputs and KPIs (aggregated from all tools)

- Volume at link level
- Volume at path level
- Volume at subnetwork level
- Volume at network level
- All post-processed indicators based on the above

C.10.2 Microscopic simulation environments

The aim of microscopic simulation is to replicate traffic flow by modelling the behaviour of individual vehicles, encompassing the representation of travel demand, and driving behaviour. The representation of travel demand is based on the so-called route choice models, while driving behaviour representation is based on acceleration, lane-changing and gap-acceptance models (Toledo, 2005). In these models, cars/drivers are conceived as separate entities complying to special rules.

Route choice models support the identification of the paths that vehicles follow in the network and may be discerned into path-based and link-based. According to the former, each vehicle selects between alternative routes by comparing the attributes of entire paths, while based on the latter vehicles make their decisions considering the next link to follow. While path-based route choice models are computationally more expensive, they are viewed to lead to more realistic and non-cyclic route choices (Toledo, 2005). In these models, the effects of traffic guidance and routing information is captured through travel timetables that are updated based on the specifications of the traffic guidance or routing information system. Vehicles having access to such information use updated travel timetables that are aware of prevailing traffic conditions, while drivers not having access to such information use habitual link travel timetables (Toledo, 2005). Driving behaviour models aim to replicate the manner in which vehicles perform accelerations and decelerations and change lane within a traffic stream given certain traffic conditions. Acceleration and deceleration models take account of free-flow, car-following and emergency behaviour, and conditions. On the other hand, lane-changing may be mandatory or discretionary. The former applies in situations where a vehicle must change a lane in order to follow its path or to avoid an obstacle/road blockage. The latter applies in situations where vehicle perceives the prevailing traffic conditions in another lane as preferable. Each vehicle after deciding to perform a lane change evaluates whether existing gap in the target lane is acceptable or not. Important parameters considered by gap acceptance models include the available lead and lag space gaps.

The use of microscopic simulation to replicate the behaviour of automated vehicles and assess the impacts of C-ITS is an increasingly addressed use case in both industry and the academia, as well as in the context of several R&D initiatives. However, at the current state existing attempts mostly relate to specific road segments and/or intersections, while the use of microscopic simulation for assessing C-ITS and CAV technologies within real-world large-scale networks is limited. Moreover, there is a lack of real-world data concerning CAV's ADAS features resulting to uncertainty due to lack of validation inputs.

C.10.2.1 Integration of CAV technologies into microscopic simulation

The development of microscopic models is a mature research area of Transportation Engineering. However, the automation and communication capabilities of contemporary vehicles imply new requirements for microscopic models. As Ahmed (2021) states there two approaches for integrating automated vehicle capabilities into microscopic models. The first involves the modification of driving model parameters associated with human drivers, while the second involves the development of new smart logics for vehicle cooperation and communications. Irrespective of the adopted approach, a car-following model is required to replicate the behaviour of automated vehicles in the longitudinal direction, i.e., to state their behaviour in terms of a keeping a safe distance from their preceding vehicles, cruising at a desired velocity, or choosing the acceleration from the desired limits.

The list of adopted car-following models in the relevant practice is rich. Existing models, according to Ahmed et al. (2021) and based on their utilised logic, can be divided into three main classes. The first class includes the Gazis-Herman-Rothery (GHR) model. The main assumption of this model is that the acceleration of the following vehicle is based on the spacing and relative speeds between this vehicle and its leading one (Al-Jameel, 2009). The second class includes the safety-distance model according to which the following vehicle always keeps a safe distance to the leading vehicle. The third class include the psychophysical models, which use threshold values based on which vehicle adjust their reactions. Threshold values relate to speed difference and spacing between following and leading vehicles.

There are several micro-simulation packages available either commercially or non-commercially for modelling either drivers or automated vehicles behaviour. These include, for instance, PTV VISSIM, AIMSUN, CORSIM, PARAMICS, and SUMO. According to Vrbanić et al. (2021), the most widely used ones for modelling CAVs are AIMSUN, VISSIM, and SUMO.

AIMSUN utilises the Gipps' safety distance model and its heavily used within Europe to address use cases, such as dynamic traffic assignment, incident management and ITS applications, including ramp metering and route guidance (Ahmed, 2021). Its microscopic simulation logic may be considered as a time-slice simulation with an additional event calendar (Barcel & Casas, 2005). In essence, at each time step, the simulator updates the scheduling list including events that do not depend on the termination of other activities, i.e., the so-called "unconditional events" (e.g., traffic light changes). Afterwards, several nested loop structures start to update the status of all network component, i.e., road sections and intersections, and vehicles. Having updated the last entity, the simulator inputs new vehicles and collects new data.

Zhang et al. (2019) utilise AIMSUN to optimise the C-ITS enabled lane-changing advisory in the context of scenarios relating to lane drops leading to reduced capacity. Within the simulation testbed and considering that lane-changing causes voids in the traffic stream, the authors considered acceleration rate as an important parameter to be calibrated. In addition, gap and clearance parameter are also considered for calibration. The former influences the vehicle headway, while the latter influences the minimum distance between stopped vehicles. Similarly, Zhou et al. (2019) utilise AIMSUN to propose a trajectory planning strategy for enabling cooperative mainline facilitating and on-ramp metering maneuvers. In particular, AIMSUN is used in second class of simulation performed, wherein the effect of the aforementioned strategy at a traffic flow level is assessed. The authors assume mixed traffic conditions and various penetration rates for CAVs in their simulations. The structure of the proposed simulation platform includes a close interaction of AIMSUN package, through a Python-based API, with a MATLAB based algorithm wherein a model predictive control and constant time gap car-following controller is implemented. AISUM is used to generate all vehicles and to simulate the movements of human-driven vehicles. At each simulation step AIMSUN reports to the MATLAB code vehicle states to enable the calculation of desired speed. The value of desired speed is, in turn, reported back to AIMSUN package for calculating the necessary metrics oriented to assess from an efficiency and safety point of view the proposed trajectory planning strategy. Finally, Ntousakis et al. (2015) provide a framework to integrate Adaptive Cruise Control (ACC) into AIMSUN simulation package. This is achieved by overriding the default car-following model, a possibility offered by this package, by the control law suggested by Rajamani et al. (2005).

VISSIM is a microscopic traffic simulation package worldwide. Its architecture is comprised of three main building blocks (Fellendorf & Vortisch, 2010). The first building block involves the modelling of physical transport infrastructure, including roads, tracks, public transport stops, parking lots, sign posts, detectors. The second building block involves the modelling of vehicles technical features, the generation of typically at link entries, and models for assigning traffic to the network (routing models) and describing traffic flow-related parameters. The third building block involves all the necessary elements for controlling traffic. This may involve definitions for four-way stops, priority rules associated with gap acceptance, and control options of traffic signals. Apart from the aforementioned building blocks, there is an additional building block, which involves, among others, the generation/visualisation/animation of the final results. VISSIM make use of a psychophysical car-following model and is relying on the logic of random numbers, statistical distributions, and stochastic variations to capture the varying vehicle behaviour in each simulated time-step (Ahmed, 2021). It also allows users to modify according to their needs the parameters of the underlying fundamental models for car-following, lane-changing and gap acceptance (Ahmed, 2021).

VISSIM has been used extensively in the relevant practice and academia in relation to CAVs and their functionalities. A class of studies have attempted to adjust car-following model integrated in VISSIM package to render it capable of better capturing CAVs behaviour. A typical example constitutes the study Zeidler at al. (2019) in which several parameters related to longitudinal movement of automated vehicle are proposed to make the model better reflect the behaviour of such vehicles in two specific use cases, involving a manual driven vehicle, which is the leading vehicle, and two following vehicles operating in an autonomous driving mode. The first use case assumes that following vehicles are equipped with Cooperative Adaptive Cruise Control (CACC) functionalities, while the second use case assumes that following vehicles are equipped with functionalities enabling a fallback CACC strategy (degraded CACC). Another class is by itself the EU-funded

CoEXist project that was aimed to lay the ground for the transition to automated mobility, assuming the co-existence of conventional and automated vehicles within road networks. The project has provided simulations for automated vehicles in four cities of Europe, namely Milton Keynes, Stuttgart, Gothenburg, and Helmond. It resulted, among others, to the enrichment of the final version of VISSIM with new parameters to better capture automated vehicle behaviour. Such parameters may be classified as communication and cooperation-related, automated vehicle functions-related, and distributions-related. Communication and cooperation-related parameters have been adjusted in an effort to support the creation of two driving modes, namely “cooperative lane-change” and “advanced merging”. According to the former, trailing vehicles in the target lane provide room to the lane-changing vehicles. According to latter, lane-changing vehicles initiate their manoeuvre earlier so as to disrupt to a lesser degree traffic flow in the target lane. Both driving modes are achieved my modifying headway-related parameters. The adjustment of automated vehicle-related parameters was made with aim of reducing randomness in vehicle behaviour building upon the rational assumption that automated vehicle’s behaviour will more closely resemble deterministic driving behaviour. Finally, another class of studies focuses on the development of future AV car-following models exploiting the VISSIM DLL-APIs and COM Interface. DLL-APIs being an add-on module enable users to integrate into VISSIM developed external applications relating, for instance, to driver models, emission models, and signal control, and V2V or V2I capabilities. On the other hand, the COM Interface allows VISSIM to interact with different applications providing these applications access to vehicles’ attributes, such as position, acceleration, etc. Through this approach the possibility of replacing VISSIM’s car-following models is enabled.

SUMO constitutes an open-source, high-portable, and computationally efficient microscopic traffic simulator, which enables users to develop and integrate new algorithms. SUMO supports use cases encompassing both urban transport networks and highway traffic networks, enabling, inter alia, the simulation of C-ITS services, such as GLOSA, platooning modes for CAVs (e.g., SIMPLA mode), as well as V2V and V2I networks through VEINS framework. An integral component of SUMO package is TraCI (Traffic Control Interface), which constitutes a Python-based API allowing users to interact with on-going simulations and control vehicle parameters (Porfyri et al., 2018). The car-following model on which SUMO relies is a modified version of Krauss model, which constitutes a safety-distance car-following model. Within SUMO each vehicle is defined explicitly through a minimum set of parameters, including its identifier, departure time and followed route. Additional parameters may be used to describe the maximum velocity, the used lane, or the position of each vehicle. SUMO includes a set of tools to support the definition of vehicle (Behrisch et al., 2011; Lopez et al., 2018). For instance, “od2trips” converts OD tables to single vehicle trips by selecting an edge intersecting with each TAZ as the depart/arrival position. In addition, “jtrrouter” utilises turn percentages at an intersection for computing or adjusting routes within the network. On the other hand, “dfrouter” uses loop detectors to compute vehicle routes. Simulation in SUMO is executed in a time-discrete manner with a predefined simulation step corresponding to 1 second. SUMO outputs include measure of induction loops placed within the road network, single vehicle positions for each defined time step, information about each vehicle trip, aggregated measures along a specific edge or edge lane, and so on.

SUMO has been widely utilised to address CAV-related use cases. Porfyri et al. (2018) integrated two car-following models reflecting ACC and CACC behaviour into SUMO to assess traffic-related metrics, such as speed fluctuation and traffic flow within a freeway stretch and a single-lane ring-road, assuming various penetration rates for ACC and CACC technologies. Mena-Oreja and Gozalvez (2018) present PERMIT, a SUMO enabled simulation platform for platooning maneuvers in mixed traffic conditions. PERMIT’s architecture is comprised of three main components: a) SUMO the scope of which is to simulate the road network and traffic demand, b) Plexe that enable the implementation of new car-following models for the longitudinal dynamics of vehicles equipped with ACC or CACC technologies through the simulation of IEEE 802.11 p-based C-ITS information exchange between vehicles, and c) TraCI used to retrieve vehicle variables required by ACC and CACC controllers.

Two newer microscopic "modelling frameworks", developed however for different purposes than the ones mentioned above, include FLOW and CARLA. FLOW constitutes an open-source simulation framework that links deep reinforcement learning libraries (i.e., rllab and RLlib) with SUMO with aim of enabling the analysis of complex traffic control problems within mixed and connected traffic environments (Kheterpal et al., 2018). The aim of CARLA, standing for "Car Learning to Act", is open-source simulation environment that has been developed to support training, prototyping, and validation of autonomous driving models, encompassing both perception and control tasks of such autonomous vehicles. CARLA includes a rich list of urban layouts, vehicle models, building infrastructure, pedestrian, street signs. It also enables training of driving strategies through a flexible setup of sensor suites (Dosovitskiy et al., 2017).

C.10.2.2 Solved challenges

The integration of connected and automated vehicle technologies into microscopic traffic simulators, despite not having been implemented covering use cases involving large-scale real-world road networks, constitutes an important step towards the replication of CAV behaviour within mixed traffic environments and the assessment of traffic management scenarios making use of CAV and C-ITS technologies. Moreover, in this respect, the deployment-related gap of utilising vehicular communication capabilities explicitly for the operation of ADAS without links to the operational management of traffic will be filled in. Therefore, planners will be equipped with a valuable set of tools for assessing the impacts of CAV technologies within urban road networks and highways. Policy makers, on the other hand, by having access to enhanced information on the impacts of CAV technologies, will take evidence-based decisions on the allocation of resources for further deploying such technologies but also in the introduction of new legislation related to the use of these technologies. Finally, researchers by exploiting the advancements in the field of data analytics and Artificial Intelligence will have the chance to develop predictive models for CAV-related impacts that will build upon a wide range of scenarios analysed though CAV-informed microscopic traffic simulation platforms.

C.10.2.3 Inputs and requisites

The main inputs of microsimulation models may be discerned into the following categories:

- Road network data
- Vehicle data
- Demand data
- Detector and output configuration data
- Public transport data

C.10.2.4 Outputs and KPIs

Traffic-related

- Trajectories
- Median speed
- Average speed
- Average delay
- Number of stops
- Number of trips
- Distance travelled
- Travel time
- Density
- Throughput
- Capacity
- Level of Service
- Congestion
- Macroscopic fundamental diagrams (MFD)
- Parking spaces

Safety-related

- Near crash situations
- Crash probability
- Maximum speed
- Average speed
- Extreme maneuvers
- Brake intensity
- Headway
- Acceleration range
- Crash occurrence
- Crash avoidance
- Number of lane changes
- Number of crashes
- Vehicle stability
- Reaction time to incidents
- Queue clearance time

Public transport-related

- Travel time
- Speed Variation
- Travel time
- Delay punctuality
- Level of service
- Dwell time

- Vehicle occupancy rate
- Cost per vehicle km
- Passenger waiting time

Vehicle operations-related

- Number of emergency deceleration
- Minimum time headway
- Maximum time headway
- Longitudinal acceleration
- Lateral acceleration
- Spatial distance
- Gap acceptance
- Speed variation
- Lateral position variation
- Minimum gap intersections
- Minimum gap lane changes
- Minimum distance headway
- Mean distance headway

Mobility-related

- Number of trips
- Mode share
- Mode choice
- Total distance travelled
- Total time travelling
- Route choice
- Travel time savings

Environment-related

- GHG
- Pollutants
- Fuel consumption
- Energy consumption

C.10.3 Optimisation tools

The proliferation of new technologies within transport systems and the increased competition resulting from the emergence of new actors involved in transport systems operations along with the need to plan and operate such systems in a sustainable and resource optimal manner have led to an increased need for applying optimisation techniques. Optimisation of transport systems translates to the identification of the proper strategies and solutions oriented to handle multiple, often conflicting, objectives that should be fulfilled over time. Optimisation theory provides the means for serving the aforementioned purposes. This scientific domain has evolved for several decades and may be divided into several sub-fields, including among others linear, non-linear, dynamic, stochastic, constrained, and unconstrained optimisation (Floudas & Pardalos 2020; Dasgupta et al., 2006).

Common applications of optimisation theory in the field of transport engineering constitute the optimisation of traffic signalling, route planning, and the design of mobility services. The rest of this section provides an overview of tools and methods oriented to serve the needs of these applications.

C.10.3.1 Traffic signals optimisation

LISA+ is a proven traffic engineering software for planning and evaluation of traffic signal lights developed, updated, and commercialized by the German company Schlothauer & Wauer[69]. The scope of the software is to create traffic signal controls for individual intersections, roundabouts, and progressive systems, evaluate controls based on current guidelines, plan, test and simulate traffic-actuated controls and upload data to controllers directly and remotely. Moreover, LISA+ is possible to work with unsignalized intersections or roundabouts. Target groups for LISA+ are traffic engineering companies, municipal administrations, signal manufacturers and universities. Examples of Key Performance Indicators (KPIs) that are used for software process efficiency evaluation are the average waiting times, the flow, the capacity per cycle, the capacity per hour, the effective green time, the flow ratio, the average number of vehicles arriving at an intersection per cycle, the average tailback length at the end of green, the average tailback length at the end of red, the level of service, the fuel consumption, and the carbon monoxide emissions.

TRANSYT, commercially available by TRL[70], is a software suite containing a macroscopic traffic model, signal optimiser and also a simulation model, for the purpose of evaluation design and optimisation, ranging from isolated road junctions up to large signal-coordinated networks. TRANSYT is primarily used for the study and determination of optimum fixed time, coordinated, traffic signal timings in any road network, for which the average traffic flows are known. TRANSYT is also used for the assessment of single isolated signal-controlled junctions, signalized roundabouts, partially signalized roundabouts and for any network of non-signalled and signal-controlled junctions. The TRANSYT optimisation method has two main elements, i.e., the traffic model and the signal optimiser. The model represents traffic behaviour in a network of streets, in which one or more junctions are controlled by traffic light signals. The model predicts the value of a 'Performance Index' for the network, for any fixed-time plan and set of average flows that is of interest. The Performance Index is a measure of the overall cost of traffic congestion and is usually a weighted combination of the total amount of delay and the number of stops experienced by traffic. The optimisation process adjusts the signal timings and checks, using the model, whether the adjustments reduce the Performance Index or not. The outputs provided by TRANSYT include the mean delay per vehicle, the mean maximum queue, the saturation flow, the level of service, the fuel consumption, the wasted time starvation, the weighted cost of stops, the weighted cost of delay, and the capacity.

[69] https://www.schlothauer.de/en/software-systems/lisa
[70] https://trlsoftware.com/products/junction-signal-design/transyt

C.10.3.2 Route planning

Route planning involves the use of shortest path algorithms, for computing optimal paths among selected origins and destinations in any network, based on various optimality criteria (e.g., time, distance, or others) and for one or more modes of transport.

Route planning is utilised in several models (e.g., for planning purposes) and services (e.g., for operational purposes). Within the C-ITS and CAVs domain, route planning is among others used for the provision of the Day 1.5 C-ITS smart routing service, building upon the knowledge of prevailing traffic conditions (Lu et al., 2018). Furthermore, route planning is a component of smart mobility services, such as MaaS (Hietanen, 2014).

A family of routing algorithms, suitable in terms of computational efficiency, are the “contraction hierarchies” algorithms. Contraction hierarchies routing algorithms identify shortest (least-cost) routes for origin and destination pairs by following a preprocessing approach, which identifies the importance of each node in a (network) graph. In this respect, they enable the pre-identification of shortcuts that in essence constitute the shortest paths between nodes of high importance. Having identified these shortcut, unimportant nodes are skipped during shortest path queries, thus significantly speeding up the process (Geisberger, 2008).

C.10.3.3 Network design and Bi-level optimisation

The design of mobility services and networks, e.g., public transport services, is a multi-faceted process involving many subprocesses, such as the design of routes, the determination of service frequency, the development of timetables, and scheduling of fleet components (Kepaptsoglou & Karlaftis, 2011). Solving problems of such kind involve the optimisation of specific objectives, either related to business-as-usual operational conditions (i.e., performance-based design) or exceptional circumstances (i.e., robust design). The former are typically associated with the minimization of the costs of the system or the maximization of the provided level of service. The latter may involve the minimization of network efficiency assuming the manifestation of several events disrupting normal operations. In addition to objectives, in this kind of problems several constraints are taken into consideration, such the available budgetary resources and the maximum fleet size (Kepaptsoglou & Karlaftis, 2011). These problems are typically bi-level optimisation problems, which are divided into two optimisation problems that are solved simultaneously. The upper-level problem is typically associated with the objectives of a policy-making authority, while the lower-level problem is typically associated with travellers’ behaviour and their reactions to imposed policy measures (e.g., route choice). Existing achievements in this field (e.g., achievements on optimizing the operational performance of public transport services) provide a solid knowledge foundation for optimizing the operation of transport systems, including innovative mobility technologies. Pinto et al. (2020) suggest a bi-level programming formulation and a solution approach for solving the problem of resource allocation between transit services and the operation of shared mobility services relying on highly automated (autonomous) vehicles. Delle Site (2021) considers a pricing scenario for CAVs, assuming a mixed traffic environment, wherein only CAVs are considered for charging. The rationale of this scenario builds upon the premise that CAVs can be managed as individual vehicles, as a fleet of vehicles, or according to a social planning perspective, which affects the behavioural characteristics taken into consideration.

C.10.4 Operational tools

The main purpose of operational tools in CCAM domain is to incorporate relevant services into operational Dynamic Traffic Management (DTM). Kotsi et al. (2020b) present a C-ITS enabled DTM system developed in the context of the C-MobILE project. The rationale of this system relies on a well-defined framework of control strategies that is operationalized through traditional DTM services (e.g., traffic signal adaptation) as well as C-ITS services.

C.10.4.1 C-ITS enabled DTM system

The system is comprised of three main building blocks. The first one constitutes the policy set by a road authority. A policy provides a description regarding the importance and function of road network elements as well as quantitative thresholds for links and route parts. The second building block include the available road network as defined by a road authority. In this respect, each element of the role of each element of the road network should be declared (i.e., choice/control/regular nodes, control segments, and route parts). The third building block includes the control strategies operationalized through the various DTM services. These strategies are the following: 1) Inform traffic, 2) Enlarge the outflow, 3) Reduce the inflow, 4) Reroute traffic.

Before the deployment of the C-ITS enabled DTM system it is required to relate each of the available DTM services to each of the control strategies. DTM services are discerned into C-ITS services (C-ITS) and traditional traffic management services (TTM). The next table presents such relations.

Table 45: Relations between DTM and control strategies

Service	Service category	Primary objective	Inform traffic	Enlarge the outflow	Reduce the inflow	Reroute traffic
Motorway Parking Availability	C-ITS	Publish information on facilities at and occupancy of truck parking areas	-	-	x	x
Urban Parking Availability	C-ITS	Publish information on facilities at and occupancy of truck parking areas	-	-	x	x
Green Priority	C-ITS	Reduce delay time at traffic light for designated vehicles	-	x	-	-
Flexible Infrastructure	C-ITS	Control available road capacity	-	x	x	-
In-Vehicle Signage (road section)	C-ITS	Present dynamic road sign information for road sections in the vehicle (personalized and extrapolated)	x	x	x	-

In-Vehicle Signage (route)	TTM	Present route and travel time information in the vehicle (personalized and extrapolated)	x	-	-	x
Mode and Trip Time Advice	C-ITS	Multi-modal travel and departure time advice (MaaS-like concept, by incentives)	x	-	-	x
Shockwave damping	TTM	Inform drivers about appropriate velocity in traffic flow	x	x	x	-
Metering	TTM	Facilitate other traffic by metering	-	-	x	-
Modify traffic lights	TTM	Redistribute the green split at the intersection	-	x	x	-

The next step is the identification of the applicability of each C-ITS service to each choice/control node and control segment. This is a process that should take into account the availability of provided services in the area in which the C-ITS enabled DTM system is to be applied.

Having complete the aforementioned step, the system can be deployed. Its operational logic rely on a) the fusion of data from multiple sources in order to gain a deep understanding on prevailing traffic conditions, b) the use of KPIs, trigger values, and target values in order to enable the most appropriate DTM services, and c) the visualisation of derived results supporting ex-post refinements and adaptations.

C.10.4.2 Solved challenges

The C-ITS enabled DTM system presented in this section contributes to the incorporation of C-ITS into operational traffic management, disrupting the practice of using C-ITS mostly as ADAS. In this respect, road authorities (urban or highways) are equipped with a state-of-the-art solution for effectively managing traffic with profound benefits on the sides of traffic efficiency, road safety, and environmental conditions. Moreover, such a system enables the realization of sustainable urban mobility goals and the promotion of cooperation between different actors of the mobility ecosystem based on new business models. In addition, transport planners are given access to a knowledge base that can provide significant input to the improvement of their models. In this respect, transport planning is getting closer to the operational management of traffic. Finally, researchers can extend the C-ITS enabled DTM system and improve its efficacy by using AI-based techniques and new methods and tools for microscopic and macroscopic traffic flow modelling.

C.10.4.3 Inputs and requisites

- Traffic flow related KPIs
    - Speed
    - Flow
    - Density
    - Travel times

- Traffic signals data
- Vehicle data (FCD)
- Weather-related KPIs

C.10.4.4 Outputs and KPIs

- Dynamic traffic management scenario
    - C-ITS services related to drivers' information
    - C-ITS services related to drivers' guidance
    - Other common ITS services (VMS messages, Traffic signals' plans)

C.10.5 Other methods & tools

Macroscopic Fundamental Diagrams (MFD) have proven their value for traffic management and control. Their rationale relies on examining the relationship between traffic flow, traffic density and vehicle speed. A more elementary form of MFDs is the so-called Fundamental Diagrams (FDs) which also strive to assess traffic by examining the relationship between the aforementioned variables along specific road segments and not at the level of a whole transport network or specific parts of its that represent homogeneous traffic conditions, which is the case for MFDs. An important contribution to the field of MFDs has been made by Geroliminis and Daganzo (2007) and Daganzo and Geroliminis (2008), who have identified some important properties for MFDs, including:

- MFDs are a property of transport infrastructure itself and not of demand (i.e., the average traffic flow in a network or part of it is maximum for the same value of traffic density irrespective of time varying nature of OD tables).
- The impact of spatial distribution of congestion is an important factor towards for the definition of a robust MFD (i.e., traffic-related variables shall be aggregated for homogeneous partitions of a transport network).
- MFDs can be reproduced under homogeneous traffic conditions even in the case that traffic variables along specific segments of a transport network represent significant dispersion.

The above evidence highlights the value of MFD for assessing traffic following a scenario-based approach. These scenarios may include variations in transport supply, the enforcement of traffic management strategies, or the introduction of new mobility services within the same transport network. MFDs can be estimated both using real-world data (e.g., Floating Car Data) or a microscopic simulation environment.

Several researchers have attempted to utilise MFDs to study the effect of technologies relating to CAVs. Lin et al. (2017) have used MFDs and a simulation-based approach to identify the oversaturated congestion state of a road network. Following that, they estimated the effect of two flow control strategies (i.e., boundary control and boundary control with limiting queue strategy) on the average queue lengths, average delay time, and average stop times at each intersection, assuming oversaturated network conditions. Similarly, Lu et al. (2020) adopted a simulation-based approach to study the effects of different penetration rates of autonomous vehicles on urban traffic by utilising MFDs.

C.11 Electric Infrastructure Management

C.11.1 Electric Infrastructure Management Tools

There have been many reports of specific computational tools for energy market analysis, EV design, traffic modelling, power network analysis, renewable and/or EV integration in distributed energy systems, etc. Mahmud and Town (2016) identified 125 and analysed 67 simulation tools for modelling and managing the impact of electric vehicles on power distribution networks, and associated applications. Typical applications of the tools included vehicle system analysis and control, renewable energy and vehicle-to-grid integration and impact analysis, energy market behaviour and charge scheduling, vehicle energy management, and traffic system simulation. Unfortunately, no tool from the analysed set covers areas that would be necessary for municipalities, as the tools concentrate e.g., either on the power grid analysis, or solely on the V2G analysis, or on the transportation analysis.

Many methodologies for locating charging stations (CS) have been developed in the last few years. Pagany et al. (2019) report on approximate 120 recent publications describing methods for planning charging station locations. Their analysis concentrates solely on a pool of scientific publications and does not include any potential planning tools that could be used by municipalities. They propose a classification scheme regarding modelling theory and empirical application; further on, models are analysed, distinguishing between users, route or destination centricity of the approaches and outcomes. In a second step, studies in the field of explicit spatial location planning are reviewed in more detail, that is, in terms of their target criteria and the specialisation of underlying analytical processes. One divergence of these approaches lies in the varying level of spatial planning, which could be crucial depending on the planning requirements.

Current EU projects concentrate mostly on fast charging (ELECTRIC) and on building fast-charging stations networks (EUROP-E, ULTRA-E, NEXT-E), with the exception of eCharge4Drivers (2021) project that aims to provide a planning tool to guarantee the optimum mix of charging options to cover users' needs, recommendations for legal and regulatory harmonisation, and guidelines for investors and authorities for the sustainability of charging infrastructure and services.

At the European level, the METIS mathematical model provides analysis of the European energy system for electricity, gas, and heat. It simulates the operation of energy systems and markets on an hourly basis over a year, while also factoring in uncertainties like weather variations. It can, for example, analyse the hour-by-hour impact of using more renewable energy. While the model can be used at national or regional level, the model apparently cannot be used for modelling a fine-grained domain as a city or a city district (European Commission, 2019).

In the U.S., an Electric Vehicle Infrastructure Projection Tool (EVI-Pro, 2018) together with its web-based counterpart EVI-Lite (2018) are offered by the National Renewable Energy Laboratory to provide guidance on plug-in electric vehicle (PEV) charging infrastructure to regional/national stakeholders to (i) reduce range anxiety as a barrier to increasing EV sales, and (ii) ensure effective use of private/public infrastructure investments into charging infrastructure. The tool uses only travel data, i.e., it disregards power grid parameters, identifying only perspective locations to place public chargers.

As already mentioned in Section 4.3.11.4, currently only the city of Stockholm seems to use a tool to support electric infrastructure planning, related to their business model for charger installation. In Stocholm, private companies apply for one or more pre-selected locations displayed on a publicly available map (see Figure 46), and after obtaining all permits, they install charging points at their own expense, and cover service and maintenance costs. In exchange, the operators are granted free access right agreements for the charging point. This solution provides benefits for both parties and avoids imposing a financial burden on local authorities. The “tool” in question is in fact a regularly updated heatmap that displays an overview of all locations where an installation of a public charger is possible at the given time. The installation process still requires that the applicants send an application to the city authorities, which is then manually reviewed by the traffic office and grid operator; the speedup for all stakeholders lies in the fact that the installation places are already preselected and hence the approval takes a shorter time.

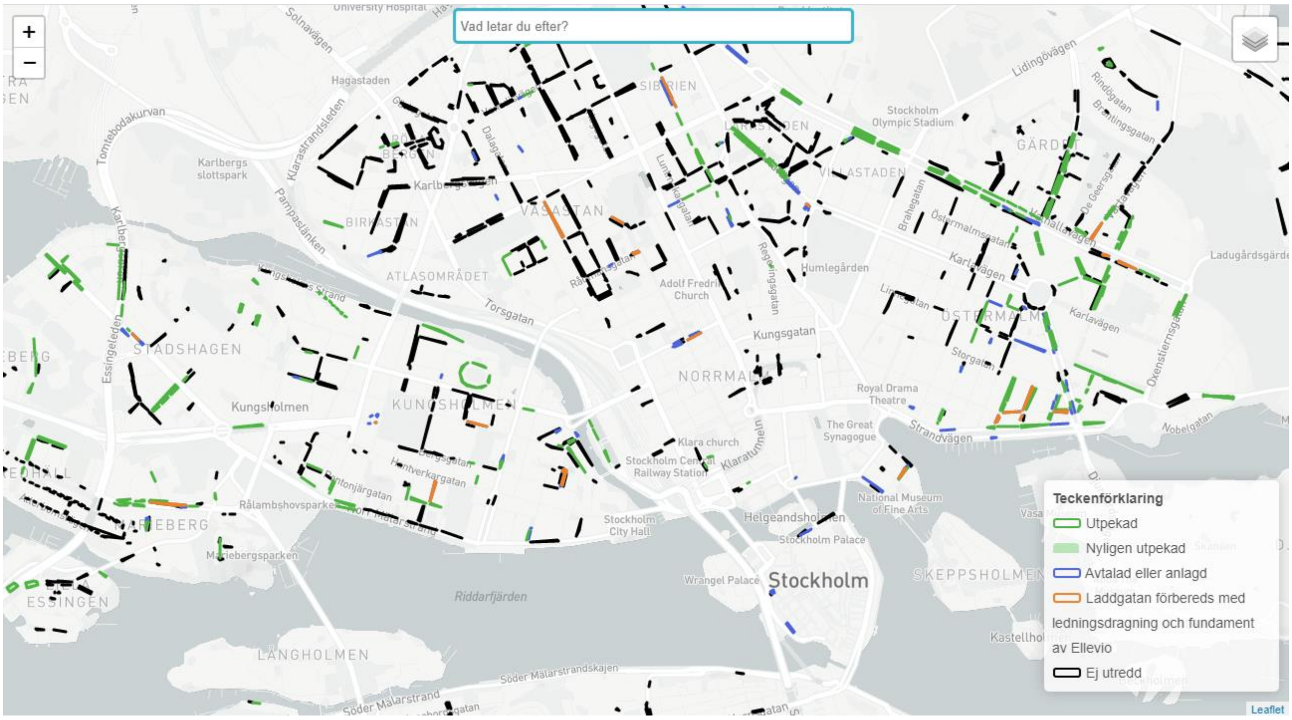

Figure 46: Stockholm map of charger locations (source: https://stockholmladdgator.sweco.io)

C.11.1.1 Solved challenges

The typical challenges to be solved when proposing changes to charging infrastructure are:

- Predicting the density of charging demand
- Determining the suitable charger type for given location (AC/DC) and its charging capacity
- Ensuring adequate state-of-charge (SOC) of charged EVs (not necessarily 100% when the vehicle may be charged cheaply elsewhere)
- Minimising the cost of building the charger and time needed for building it
- Minimising the total cost of ownership (maintenance, cleaning, recycling)
- Ensuring stable loading of charging stations
- Eliminating load peaks in the distribution grid

The challenges related to transition of public transport service to e-busses or battery-trolley buses are not so extensive and they overlap in part with the challenges of charging infrastructure planning:

- Selecting appropriate system (depot charging, opportunity charging, in-motion charging)
- Selecting appropriate fleet structure (vehicle capacities, battery capacities)
- Planning the infrastructure (building chargers, overhead wires)
- Minimising the total cost of ownership (maintenance, cleaning, recyclation)

C.11.1.2 Inputs and requisites (aggregated from all tools)

As our review did not identify any tools that would facilitate electric infrastructure management in a way suitable for nuMIDAS project, we summarize here the inputs and requirements that such a tool may require from the stakeholders' perspective.

From the transportation point of view:

- Population statistics (e.g., census data)
- Travel diaries or similar surveys
- Travel data of existing EVs
- Usage data from AC and DC chargers
- Number of EVs and FCEVs (prognosis)
- Street passport (determines where chargers may be installed)

From the infrastructure owner point of view:

- Distribution grid blueprints
- Grid capacity at charging and possible connection points
- Allowed charging concurrency
- Price plans (e.g., for smart charging)

From the public transport operator:

- Vehicle capacity needed to service particular lines
- Number of vehicles needed
- Distance travelled and elevation profile of the lines, to estimate energy consumption

C.11.1.3 Outputs and KPIs

Typical KPI categories in this area can be found in Table 4: List of KPIs of GreenCharge Project Deliverable: D5.1 & D6.1., which is reprinted here.

Table 46: List of KPIs of GreenCharge Project (Natvig et al., 2019).

Indicator	Sub-category	KPI
Category: Transport System		
GC5.1: Number of EVs	eMobility	EVs
GC5.2: Number of parking spaces with charging plug	eMobility	Impact Aspect
GC5.3: Utilisation of charging points	eMobility	Charging availability
GC.15 car share e-cars per capita	eMobility	Charging availability
Category: Energy		
GC5.4 Share of battery capacity for V2G	eMobility	V2G
GC5.4 Share of battery capacity for V2G	eMobility	V2G
GC5.5 Charging availability	eMobility	Charging availability
GC5.9 Energy mix	Fuel consumption	Share of energy from local RES in neighbourhood grid
GC5.13 Charging flexibility	eMobility	Flexibility
GC5.10 Peak to average ratio	Fuel consumption	Burden on grid
GC5.14 Self Consumption	Fuel consumption	Share of energy from local renewable energy source in neighbourhood grid
Category: Economy		
GC5.6 Average operating costs for charging infrastructure	Cost	Operating costs
GC5.7 Capital investment costs	Costs	Investment for acquiring and installing equipment
GC5.8 Average operation revenue of charging service		
GC5.11 Savings Benefits Increase savings using local produced energy with smart charging	Benefits	Operating revenues

Category: Environment		
GC5.12 CO2 emissions	Pollution/Nuisance	Emissions
Society-people		
GC6.1 Awareness level	Acceptance	Awareness
GC6.2 Acceptance level	Acceptance	Acceptance level
GC6.3 Perception of level of (physical) accessibility of service	Accessibility	(Physical) accessibility of service
GC6.4: Operational barriers	Accessibility	Operational accessibility to (transport) services
GC6.5: Relative cost of the service	Accessibility	Economic accessibility of (transport) services
GC6.6: Shared e-vehicles and stations/operators per capita	Accessibility	Vehicles availability
GC6.7: Average number of trips per person	Mobility demand	Total travel demand/need

C.12 Parking Management

C.12.1 Parking Management Systems

Parking management systems continuously monitor an area to relay information on parking space availability. They combine various equipment and software solutions (cameras, parking meters, sensors, and automatic gates) in order to improve the security of parked vehicles and reduce adverse impacts on traffic caused by vehicles in search of a parking lot (Gautam, 2019). These systems are more commonly associated with off-street parking management. Table 47 provides a survey of commercial applications designed for different types of parking fields (Capterra, 2021; G2, 2021).

Table 47: Parking management platforms

Field	Parking software	Focus
Smart offices, company parking, staff parking	ParkOffice	Automation and optimisation of employee parking
	Parkalotu	Manage parking spaces online by setting parking rules
	Parkable	Allowing for shared/reserved parking, payments, gate access and automated problem resolution
Cloud-based full-stack parking management	Premium Parking	Cost reduction without the need for gate parking control equipment
Web-based parking mobility	SpotHero	Helps individuals and businesses manage vehicle spot reservations, tickets and more
Enterprise visitor management	Traction Guest	Access Controls, Alerts, Audit Management and more
Car park booking	EVA Check-in	Manage parking demand in large areas, workplaces and at events
Apartments & HOAs	Parking Boss	Allows guests to register their vehicle 24/7 from any connected device in seconds
	Reliant Parking	Controls for management & apps for everyone
Web-based government Management	GovPilot	Powers efficiency, employee productivity and constituent engagement
Parking operators	SecurePark	Helps to achieve optimal parking enforcement and compliance

Beside the commercial applications, Barone et al. (2014) suggested IPA (Intelligent Parking Assistant). It is an architecture for public and off-street parking management (see Figure 47).

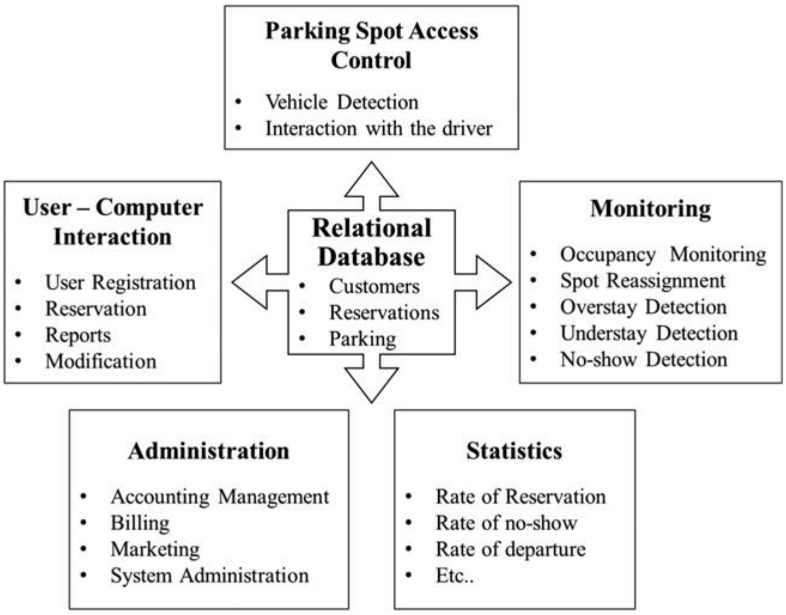

Figure 47: Functional organisation of the server-side of the IPA parking software (Barone et al., 2014)

C.12.1.1 Use Cases: Administration & Operation

Parking management generally consists of two high-level actions (Lin, 2017), administration and operation, considering that municipality is involved in both. Figure 48 and Figure 49 illustrate all possible actors and their functions within a parking management system.

It is evident that an important role in parking management plays parking data. They represent a source for services which are implemented in order to achieve the parking management goals. Parking data should be also used for the continuous evaluation of currently set parking policy.

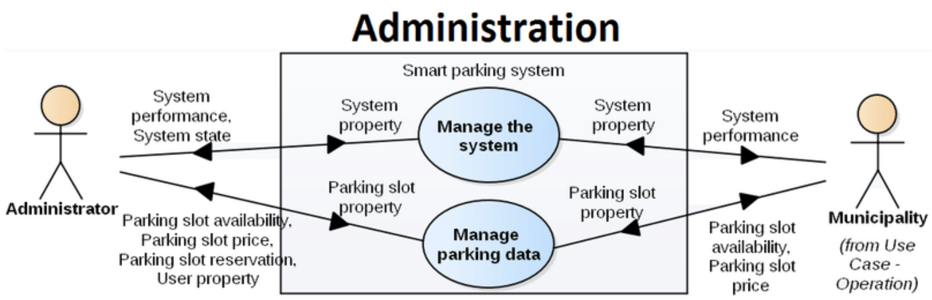

Figure 48: Administration use case of parking management (Lin, 2017)

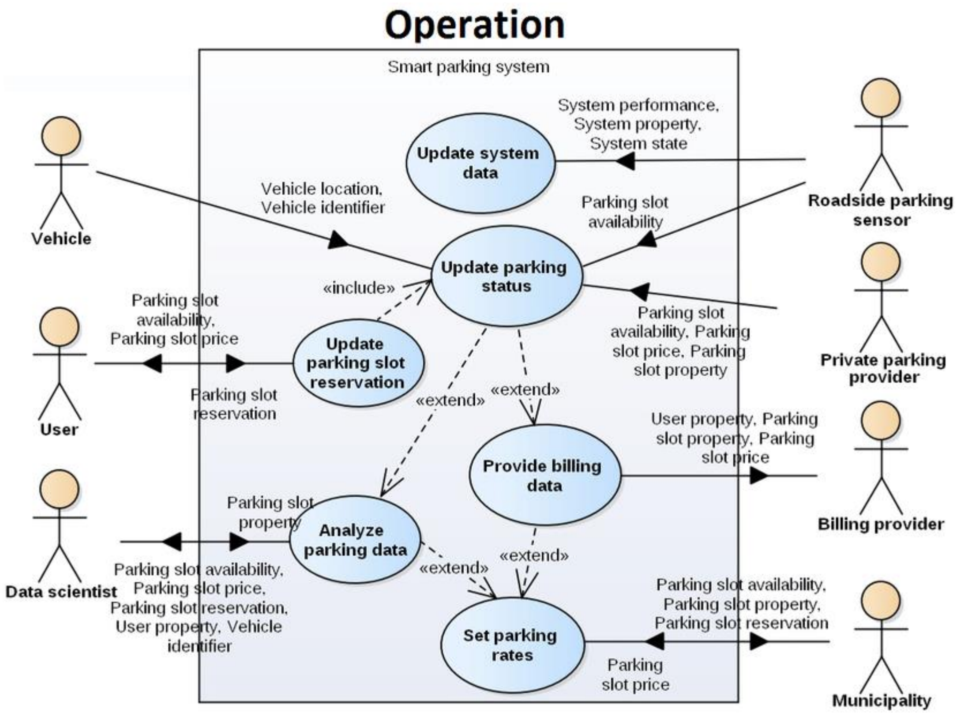

Figure 49: Operation use case of parking management (Lin, 2017)

C.12.1.2 Solved challenges

As mentioned above, Barone et al. (2014) suggested IPA (Intelligent Parking Assistant) which represent an architecture for public parking management offering solution for the off-street parking. Then Grimaldi & Fernandez (2019) present the usage of IoT and describe a project for on-street smart parking smart parking in Nice. Such systems commonly solve the following challenges:

- **Parking spot access control:** define who has the right to use the parking spot.
- **Spot reservation and monitoring:** monitor the occupancy, spot assignment and reservations to vehicles, as well as detection of understay, overstay, and no-show.
- **Accounting, billing, and marketing**
- **Reports and statistics of parking:** provide an overview of the parking situation and usage patterns.

For Barter (2016), the most efficient policy instrument in parking management is pricing. Parking management systems enables the gathering of necessary data for properly pricing according to the author:

- **Individual pricing:** based on vehicle category (personal vehicle, taxi, delivery vehicle, etc.), vehicle owner (resident, customer, visitor, etc.), and parking time (time limits, parking hours).
- **Parking management systems** aid to solve the following challenges described by McDonald (2010): **Encourage drivers to use P&R (Park and Ride) systems and enter to the city centre by public transport.** They are achievable by pricing.
- **Surveillance system to control the compliance with the rules:** blue zones are often restricted to residents only.
- **Information about parking availability**: provided either via VMS (Variable Message Signs) or a mobile application (McDonald, 2010).

C.12.1.3 Inputs and requisites

The inputs and requisites for a parking management system can be summarized in few points:

- Analysis of basic parking data and facilities
- Definition of target area and user groups
- Identification of differentiated tariff system
- Political and legal approval
- Installation of associated infrastructure
- Control and enforcement concept of the measures
- Marketing and promotion

If we consider the inputs according to different actors, it would be as follows:

- Inputs from users: reservation, demand
- Inputs from sensors: state (availability)
- Authorities: pricing policy

C.12.1.4 Outputs and KPIs

The main KPIs for parking management have been identified:

- Occupancy (occupied spaces/total spaces)
- Availability (empty spaces/total spaces)
- Revenue per space
- Average transaction value
- Operational efficiency: seek time, dwell time, transactions per hour/per permit
- Emissions' reduction

C.13 Ride-Hailing and Ride-Sharing

C.13.1 CleverShuttle

CleverShuttle is a sharing ride-hailing service which, based on an ICT platform, used as a complementary service to local public transport especially in peripheral urban areas. The service is present in some German cities (Leipzig and Düsseldorf), in Phoneix (USA) and in Boston Bay (Inclusion Project, 2019). It is a ride-hailing service where the vehicle is shared with other people traveling on the same route.

The user, using the smartphone application, enters the following data:

- The desired destination, that must be in the operating area of the service
- The pickup location
- The number of the required seats

After that, the user confirms the booking and follows on the application the icon of the van that is going to pick him/her up.

C.13.1.1 Optimisation

CleverShuttle uses optimisation software capable of matching a user's request with the availability of the driver closest to the user's location.

C.13.1.2 Solved challenges

- Provide multi-modal combination
- System monitoring
- Optimisation of cost and vehicles occupancy

C.13.1.3 Inputs and requisites

- ICT tools for monitoring the service
- ICT algorithms to combine user requests on the one hand and route optimisation for drivers on the other

C.13.1.4 Outputs and KPIs

- Availability of drivers
- Frequency of runs
- Optimisation of the match between transport supply and demand

C.13.2 Simulation modelling

In order to analyse the effects of taxi sharing both for taxi drivers and for users, and to evaluate the functioning of the taxi sharing service, Ferreira and d'Orey (2014) proposed to use a Simulation Modelling Approach. Their study took data relating to taxis operating in the city of Porto as a starting point. The simulation shows good results both for taxi operators such as the reduction of fuel consumption, and therefore of costs, and for users such as the reduction of fares. Furthermore, the study shows that, as seen from the simulation results, as the use of taxi sharing increases, the service improves its performance (Ferreira and d'Orey, 2014).

C.13.2.1 Microscopic traffic model and Taxi operation model

The study authors used DIVERT, microscopic traffic simulator open-source software based on Intelligent Driver Model. Moreover, the lane changing is based on the Minimizing Overall Braking decelerations induced by lane changes (MOBIL) (Ferreira and d'Orey, 2014).

A taxi operational model simulates both the taxi rides with traditional service (one paying customer per trip), the taxi sharing trips (several paying customers per trip) and any other hybrid format (Ferreira and d'Orey, 2014).

C.13.2.2 Solved challenges

- Implementation of algorithm in a realistic and large-scale simulation platform using data from taxi operation.
- Coupled use, in the same simulation platform, of microscopic traffic model and taxi operation model.

C.13.2.3 Inputs and requisites

- Dynamic taxi-sharing algorithm
- Operational data of taxis
- Realistic Passenger demand parameters (O/D points)

C.13.2.4 Outputs and KPIs

- Reduction of operational costs (less fuel consumption, less maintenance costs)
- Increase of revenue per distance.

C.13.3 DRT Simulator

In order to evaluate the effectiveness of the introduction of a demand-responsive transport (DRT) service in the territory of the Municipality of Milan, simulations of the service were conducted to quantitatively estimate the indicators in relation to the quality of service for users and production costs.

C.13.3.1 Taxi sharing service simulator

The objective of the simulations was to assess the optimal operating conditions of the service in relation to the coverage area, the service hours, and the most suitable fleet in relation to the number and type of vehicles.

C.13.3.2 Solved challenges

A simulator of the DRT service has been used by the Municipality of Milan to define the optimal operating conditions of the service

C.13.3.3 Inputs and requisites

On the basis of an origin-destination matrix, the simulator generates movement requests in the area covered by the service, assigns these requests to the vehicles in service and simulates their movement on the road network.

C.13.3.4 Outputs and KPIs (aggregated from all tools)

From the simulation it is possible to obtain data:

- on the quality of the service for users in relation to both the waiting time of the means of transport and the entity of the deviation from the shortest route;
- on the efficiency of the service in relation to the load factors of the vehicles and the number of users served per hour by each vehicle.

Appendix D Stakeholder role descriptions and categorisation

In this appendix, the stakeholders from the business model radars presented in chapter 4.3 are described in more detail. The descriptions contain their role in the specific business model and includes recent or expected changes in the described role.

D.1 Transportation Data Analysis

Municipality (Customer)

A municipality can request support from data analysts in order to have a better insight into data on which base its activity. Municipality should detail his request by defining KPIs of interest.
In the future, municipalities could have the possibility to make decisions, in the mobility sector, also thanks to constantly updating data. A basic skill of data analysis and dashboard querying could become required for policymakers. They operate at a strategical and tactical level.

Traveller (Customer)

A traveller could use the data analysis results, implemented in a mobile app, to better plan his/her trip in the future. Travellers, thanks to new technologies, could increase their role as data collectors. Traveller operates at an operational level.

Mobility service operator (Customer)

The mobility service operator could request data analysis results from a data analyst as evaluation feedback of the level of the transport service. In this way, mobility service operator could monitor its service and solves promptly any problem. Data analysis could also help service operators in planning the future development of their service. In the future, mobility service operators could make some actions more efficient, for example: real-time fleet management, accuracy on waiting time, management of flows on board, etc. Mobility service operator operates at strategic and operational time frames.

App developer (Customer)

An app developer could get data analysis results or analyse raw data to provide information to travellers with a mobile app. In the future app developers will manage a growing amount of big data and respond to a growing demand for real-time transport data. App developer operates at tactical and operational time frames.

Data analysts (Focal organisation)

Data analysts are professional figures who can respond to customers' requests by performing data analysis and design specific algorithms for this purpose. They can also help customers in designing KPIs to be retrieved from data analysis. The potential of data analysis is evolving thanks to higher computing speed, greater data availability in terms of quality and quantity. They operate at strategic, tactical, and operational time frames.

Research and technology centres (Core partner)

They collect and store data from heterogeneous sources and provide data to the other actors (Data Analysts, App developers). Moreover, they could provide open-source tools for data analysis or develop data visualisation platforms (i.e., dashboard) that help end users of data analysis to visualise KPIs. They operate at a tactical and operational level.

nuMIDAS/Intermediary (Future partner)

This is a future partner operating at the strategic, tactical, and operational levels that may monitor and evaluate the system and relevant policies as an impartial body between the Municipality and service providers.

D.2 Transportation Policy and Design

Citizen/ traveller (Customer)

Citizens are affected by the transport policies implemented by the municipality on many levels. As a traveller, those policies will directly determine their mobility behaviour by incentivizing certain modes of transportation (e.g., public transportation, electric vehicles) through the improvement of infrastructure, implementation of subsidies and information campaigns, while restricting others (e.g., fuel-based vehicles) through the application of tolls, taxes, and low emission areas. Hence, the choices the traveller takes will depend on the efficiency, cost and quality of the mobility network shaped by transport policies. In addition, citizens who are not travelling at a given time are also affected by transport policy as it can have an effect on other urban systems such as housing, economic activity, etc. Their value-in-use is the data they generate on their daily activities which are used to inform policy. Traditionally travellers/ citizens have played a passive role in policy design but are increasingly becoming active stakeholders throughout the policy design process through co-creation (Eltis, 2021). Hence, another value-in-use is their knowledge as travellers. Travellers usually operate on an operational timeframe.

Municipalities (Focal organisation)

Municipalities are the focal organisation in this business model radar as they are a stakeholder in charge of designing transport policies, both in the form of short-term actions or mid to long-term strategies. They provide the analytical capacity in decision making, the resources (human and financial) and the capacity to coordinate with other stakeholders to ensure the correct implementation of a given transport policy. In addition, municipalities can manage the infrastructure that will be affected by a given policy and also can be in charge of providing concessions for public transport operators.

Currently, data collection, storage, processing, and analysis presents a new challenge for municipalities, they will need to increase their investment in equipment and talent or outsource some of these tasks. Municipalities can operate on an operational, tactical, and strategical timeframe.

Metropolitan/ regional governments (Core partner)

Metropolitan and regional governments are core partners in the implementation, as they will implement the policies in coordination with the municipality. Their value-in-use is the competencies to act in a wider jurisdiction and manage pieces of infrastructure/ services relevant to the transport system. Wider competencies allow the homogenization of relevant policies at a metropolitan level (e.g., Low emission zones). As metropolitan areas become more relevant in the planning and management of transport, there could be an increasingly important role in designing policies for the metropolitan and regional governments. Metropolitan/ regional governments operate on an operational, tactical, and strategical timeframe.

Public transit operators (Core partner)

Public transport operators are key partners in implementing new mobility policies concerning public transportation. In some cases, they will also be involved within the policy design process itself. Their value-in-use is their competencies over the public transport system. Public transit operators operate on an operational, tactical, and strategical timeframe.

Universities/research centres (Enriching partner)

Researchers in universities and research centres collect information, knowledge, and experiences in many projects and multi-disciplinary platforms and feed projects that are applicable and scalable (Carbonnell, 2019). Through this research, they accelerate the development of innovative technological solutions and methodologies which can be adopted by governments seeking to improve transport policy making or the private sector. They can receive financing in the form of grants or through participation in applied research projects. Universities operate on a tactical and strategical timeframe.

Technology companies (Enriching partner)

Technology companies can provide to the public and private sector smart city applications in the form of cameras, sensors and platforms used to collect data and transfer data between devices through IoT and also can create standards for data exchange between IoT applications and products. In addition, software companies can provide to municipalities the analysis and visualisation software that enables the use of data in decision making in policy design. They are continuously improving the functions and accuracy of their tools, as open data becomes more available, start-ups, and technology enthusiasts will increasingly engage in developing more smart city services and applications.

Private data owners (Core partner)

Technological and service companies collect, store, and sell data that is relevant to inform transport policymaking. There is an increasing number of private companies which are entering this market and profiting from data, while technological giants are consolidating their power through the control of massive amounts of data. Unless open data policies are enforced, these stakeholders will acquire more power and leverage within the mobility field. They operate at an operational level and strategical timeframe.

D.3 Travel Demand Modelling

Citizen / traveller (Customer)

Traditional key actors related to travel demand modelling are citizens who are living and travelling in the considered region and whose interests should be taken into consideration. They act at an operational level, generating and sharing data on their daily activities. If travel demand models are constructed and applied properly and lead to an improved decision making and planning by the municipality, improved traffic management and operation of traffic management centre, and operation and service optimisation of mobility providers, citizens benefit from improved mobility, planning and environment. Models are also used by navigation providers to advise a convenient route or multimodal trip together with the estimation of travel time. Costs may be reflected in taxes and prices of mobility services.

Municipality (Core partner)

Municipalities implement policies, collect, and analyse data, and contribute to market regulations with the aim to provide a high-level, efficient, reliable, accessible and safe, but also clean and sustainable transport system. Travel demand models support their decision-making, allowing for the evaluation of various future scenarios and showing the effects of different policies, restrictions, control decisions, investments, etc. They help them to improve planning and forecasting, and hence also the overall transport system and environment. However, construction and exploitation of these models, similarly to data collection, processing, and analysis, requires additional costs for equipment and training employees or outsourcing some of the work. Municipalities operate mainly at strategical and tactical, but also operational levels.

Traffic management centre (Core partner)

A traffic management centre of a city usually provides central monitoring of the traffic situation, central coordinated traffic management and control, and verified real-time traffic information. Its control system processes all available information and automatically reacts to the current traffic situation by invoking various traffic management scenarios, changing the status of telematics devices such as traffic lights or variable message signs to improve the traffic flow. An important and necessary component of this system is a travel demand model of the given city or region. A traffic management centre operates at all levels – operational, strategical, and tactical.

Mobility providers (Core partner)

Other core partners of the business model are providers of particular mobility services. They contribute to data collection, sharing and analysis, and thus to the improvement of the corresponding travel demand model, which helps them to improve the offered services and to achieve or at least approach fleet and operation optimisation. Mobility providers operate at operational, strategical, and tactical levels.

Research and technology centres (Enriching partner)

Tools for travel demand modelling and optimisation and necessary technology are being developed by various research and technology groups based in universities, other public institutions or private companies, or the cooperation of several of these entities. These stakeholders also carry out data processing and analysis and work on more general methods for modelling and optimisation. The tools they offer range from commercial to free and open-source software. Even in the last case, their vendors can gain ground in the marketplace by providing software maintenance and support, training employees of municipalities and transport-related companies or directly building models for specific cities using the developed software. Non-commercial activities of researchers can be subsidised by various research grants, they also often participate in various applied research projects. Research and technology centres usually operate on a tactical level and strategical timeframe.

nuMIDAS/Intermediary (Future partner)

This is a future partner operating at the strategic, tactical, and operational levels that are expected to monitor and evaluate the system and relevant policies as an impartial body between the municipality and service providers. It will be aimed at collecting data from different sources, its processing and distribution, helping to understand their meaning and playing a role of an independent intermediary that can facilitate data sharing between different stakeholders. It will allow the assessment of the correctness of transport modelling tools. As a result, customers can benefit from improved transport policies and mobility services, and nuMIDAS from new knowledge and capabilities.

D.4 Public Transport Management

Traveller / end-user (Customer)

The traveller or the end-user of the public transport is a focal point of the service who creates the value-in-use by providing real-time data on the location, itinerary with a final point of destination, use of public transport type, as well as data that helps to build a traveller's mobility pattern. The data is collected from the devices used by the end-users and is consequently used by the service provider. The user's data is combined with other information from other stakeholders to create an optimal travel scenario for the traveller. In this case, the value proposition from the end-user of the public transport is real-time data, which is created via the efficient use of services. In case the services that provide key data are not used, then the value-in-use is decreased. The main benefits for the traveller are shorter time of a journey, less waiting time for a public transport, comfort, less stress, reliable information on itinerary, the possibility of cheaper fare ticketing, etc. As for the cost, the traveller will have to pay some fees for using the services.

Service provider (Focal organisation)

The service provider is the main orchestrator in this business model. He is responsible for offering optimised trip advice to all users, taking into account real-time end-users data, floating traffic data, transport operator data, fleet manager and data from MaaS services provider. The service provider is responsible for the integration of data from all stakeholders by generating and proposing the best transport solutions for the traveller. Handling such a big amount of data requires that it is treated carefully regarding its privacy and security. The main value proposition of the service provider is therefore to provide integration, information, and security on the privacy of the data. This value proposition is offered through the co-production activity of managing and integrating the various streams of data. The service provider receives an operating fee for providing the service, whereas platform operating costs are incurred to operate the service.

Public transport operator (Core partner)

In the PTM business model, the public transport operator is responsible for transporting the travellers to the final destination. The value proposition of the public transport operator is therefore free relocation without minimum disturbances during the itinerary. The public transport operator also ensures that the end-user will have a comfortable and efficient travelling experience. The increase of public transport efficiency will stimulate more travellers to opt for its services. It will stimulate benefits from increased revenues and increased customers, which in turn may benefit the image of public transport as a suitable and reliable travelling alternative. The public transport operator will incur increased operational costs. However, some more disturbance (e.g., late arrivals, crowdedness) may be generated in public transport due to transporting more customers than usual.

Traffic manager (Core partner)

The traffic manager is one of the key stakeholders in the PTM radar business model. The responsibility of the traffic operator lies in generating and synchronizing traffic data, which should be integrated with real-time end-user's data to provide optimised trip advice. Therefore, the value proposition of the traffic operator is the assembling and management of all types of traffic data (real-time and historic data), which is conducted through the co-production activity of managing the traffic data. The main benefits for the traveller are that the itinerary is without interruption, waiting time for the public transport is reduced, comfort is increased, frequency of public transport is not impacted as well as management of public transport data is not distorted. The traffic operator incurs operational costs yet for generating and synchronizing traffic data.

MaaS provider (Future partner)

Other mobility services such as relocation of commuters from a parking space to travel location or micromobility solutions that include a range of light-weight devices or mini-vehicles (i.e., bicycles, scooters, skateboards, segways and hover-boards, which can be human-powered or electric and are either privately owned or shared) (Dia, 2019), also can be included in the public transport management through the mobility provider. In this case, the user can be provided with the service to book or receive a ride at a certain location and time, as well as allowing the traveller to indicate the final destination. It is also possible to integrate an intermodal booking option for the end-user. By using a single channel for booking and ticketing for all types of public transport in one service, MaaS providers can accommodate the end-user's journey request by combining various modes of transport to find the most optimal travel solution. This information can be handed to the mobility provider who can accordingly plan a suitable ride for the commuter. It is likely that the costs of these rides are covered in a similar manner as using public transport. The mobility provider will consequently benefit from revenues that are accrued from relocating commuters as a part of fees paid for the service.

Municipality (Core partner)

The municipality will benefit from the service solutions offered in this business model through decreasing of congestion, which will lead to a decrease of pollution, improving traffic flow and road safety. Moreover, it will also impact the attractiveness of the city which can be beneficial to gain some extra benefits. These benefits largely depend on the financial feasibility of the services that come from a stimulus from the city to use public transport. The municipality can promote the public transport services by using some incentivising financial schemes, namely lower price ticketing scheme for public transport for specific users, the introduction of extra fees for parking private cars in certain areas of the city, creating areas for public transport use only, subsidies for the acquisition of a green fleet, etc. Therefore, the value proposition of the municipality is to offer financial feasibility of the services, which is conducted through subsidizing the services. The municipality will pay subsidies as costs for supporting the business model. It will create a favourable environment for the development of optimal public transport management for the traveller.

D.5 Last Mile Logistics

Retailer (Customer)

Retailer or online shop uses delivery companies to deliver parcels to customers. Their role is at the operational level. Depending on the good that they sell, they can require special delivery needs such as specific time windows or specific vehicles (e.g., refrigerated vehicles).

Buyer (Customer)

Buyers are the final users of the service. They buy online and they receive the parcels at home or pick them up at a pick-up point or from a locker nearby their home. In the chain of events, they operate at an operational level. They can influence the delivery process by choosing specific requirements for their deliveries, e.g., time windows.

Delivery company (Focal organisation)

The delivery company picks parcels from retailers and delivers them to the customer. In some cases, the delivery companies work as a warehouse for retailers. It is the Focal organisation of this business model and operates at all levels: operational, tactical, and strategic. Delivery companies can vary depending on the size of the fleet, type of goods delivered, type of vehicles, delivery options (e.g., the use of pick-up points as automated lockers). In recent years food delivery companies are significantly rising in many cities. Most food delivery companies operate with bikes to reduce costs and environmental impacts as required by many cities.

In addition, traditional delivery companies are evolving to reduce costs and environmental impacts by introducing more eclectic vans or bikes in their fleet and adopting optimisation tools to manage their fleet. In the future, the introduction of autonomous vehicles could be a disruptive factor for delivery companies.

Municipality (Core partner)

The municipality regulates the deliveries in cities by introducing policies and rules to contain the impact of the vehicles and favour transition towards sustainability. Policies could concern time access restrictions, parking regulation, environmental restrictions, and size/load access restrictions.

Municipality operates at the strategic and tactical level. Since environmentally sustainable matters are rising in importance, especially in cities, municipalities will need to increase their regulatory role on deliveries.

Model/Software developer (Core partner)

Model and software developers provide to the delivery companies the optimisation software required to improve the efficiency of their service. This actor could be in some cases within the delivery company, depending on its size. Model/software developer works at operational level providing parcels/vehicles matching and route optimisation. They can also help delivery companies in their strategic and tactical operations, especially in evaluating the possibility of introducing new emerging technologies or service models.

Pick-up shop (Enriching partner)

The pick-up shop is an alternative location where the delivery company can deliver the package. It accomplishes a role similar to the locker and operates at the operational level.

Micro hub/Warehouse (Core partner)

The micro hub or the warehouse is the place where the delivery company stores all the parcels to deliver, and it is the starting and ending point of all the vehicle paths. This solution is emerging as a new possibility for cities to increase the use of bikes or small vehicles for the actual last mile. It can operate at tactical and operational levels.

Vehicle manufacturers / OEMs (Enriching partner)

Vehicle manufacturers and OEMs provide vehicles to delivery companies. Given the emerging need for smaller and low impacts vehicles for delivering in cities, new vehicle manufactures are emerging and traditional car industries are evolving and designing new specific products. These actors operate at strategic, tactical, and operational levels. The evolution of vehicles for urban deliveries will have a disruptive change when autonomous vehicles will be available and will be allowed to run within cities.

D.6 Rental

Traveller (Customer)

Customers use and pay for rental services. They include tourists, business travellers or people who prefer not to own a car either for convenience, cost reduction or sustainability. The choice to use this service depends on the origin and destination of the planned trip, on time, price, accessibility of rental service and other mobility alternatives, reliability, and personal preferences. They operate in an operational timeframe.

Municipality (Core partner)

The aim of the municipality is to provide a high-level, efficient, reliable, accessible, and safe, but also clean and sustainable transport system. For example, some restrictions on the quality of the fleet for the rental service may be stated to reduce pollution (CIVITAS, 2020). It is desirable to support car rental and car-sharing services as alternatives to car ownership, but it should not be at the expense of public transport. Municipalities operate at a strategical and tactical level.

MaaS provider (Future partner)

Where MaaS already operates, it provides a platform integrating all included services into a single service, allowing travellers to plan, buy and carry out multimodal seamless trips. Integrating rental services into multi-modal transport including MaaS packages allows to reduce the number of privately owned cars further (Kamargianni et al., 2018), but it can also bring new customers to rental companies. MaaS providers operate at all levels – operational, strategical, and tactical.

Rental company (Focal organisation)

A rental company provides rental services to customers. Its activities also include daily operations, fleet maintenance, growth, and allocation, analysing new car points, marketing, scheduling management, balancing pricing and vehicle availability, etc. The most substantial costs are related to car fleets, car's maintenance, insurance, fuel, parking, IT platform and human resources. Revenue comes from rent fees (either per hour or per distance or based on membership). Rental companies operate on an operational and partly also tactical level.

Other mobility providers (Enriching partner)

The cooperation of rental companies with other mobility providers is usually mutually profitable. For example, the availability of cars for a rental at a railway station (for a reasonable price) allows for replacing a travel by an own car with a combination of a train trip with car rental to get to a destination that is not simply accessible via public transport.

nuMIDAS/Intermediary (Future partner)

This is a future partner operating at the strategic, tactical, and operational levels that may monitor and evaluate the system and relevant policies as an impartial body between the Municipality and service providers.

D.7 Micromobility

First/last mile traveller (Customer)

The customer uses the service provided by the micromobility operator. The choice of using micromobility is a classic travel behaviour choice, dependent on time, money, relative comfort of using available modes and personal preference. The choice of using micromobility may be made each individual trip or maybe part of a habit. The customer relies on the availability of vehicles, especially for irregular trips for which an owned vehicle is not an option (e.g., after using PT). Travellers are operating at an operational (day to day travel choice) and tactical (longer-term travel choice) timeframe. The role is of travellers, while based on strong habits, is always changing slowly, as innovations or other influences (e.g., environmental, or financial issues) may drive new desires for customers.

Municipality (Core partner)

The municipality wants to provide a high level of safe and clean mobility for people within the city, without confiscating too much public space for parking vehicles. They are responsible for providing the environment for both the customer and micromobility providers in terms of infrastructure (e.g., providing dedicated parking space, separated bike lanes, etc.) and policies (e.g., requiring a driving license, restricted parking areas, etc.). By regulating parking space usage, restricting the fleet size, and controlling the number of micromobility operators with licenses, municipalities can orchestrate their local micromobility market. Since micromobility is a quite new concept, municipalities are still trying to find their exact role in this. How much has to be regulated? What rules are required? The involved policy instruments are presented in the State-of-the-art review. With these policy instruments, the municipality operates at a strategical timeframe.

Micromobility operator (Focal organisation)

A core partner, as this actor provides the vehicles and the platform, facilitates pick-up and drop-off of vehicles and manages the fleet. They are responsible for maintaining a well-distributed fleet to maximize the availability of vehicles for customers. As round trips of customers are not always symmetrical, or customers park vehicles in an undesired spot redistribution of vehicles is often required. However, operators can also create incentives to park vehicles in the desired spot. This is done by dynamic pricing, assigning dedicated parking spots with a geofence, or even by giving discounts for parking in a certain area[71]. Another important aspect is managing the fuel levels of vehicles since many vehicles require some sort of energy to operate.

As can be seen from these examples, most can be categorised under an operational level. However, due to regulations, a strong tactical layer is required as well.

ESO's (Enriching partner)

As micromobility is still a relatively new topic, there is no standardisation on a European strategic level. Local governments all have their own regulations. Current standardisation mostly focuses on vehicle safety. In the future, this will also entail a role in standardising rules for micromobility operations and MaaS platforms, which may make it possible to facilitate MaaS EU-wide. For good integration into MaaS platforms, ESO's can develop data exchange standards for micromobility vehicles.

nuMIDAS/Intermediary (Future partner)

The intermediary organisation is a future partner of this micromobility business case. The intermediary will be able to function as a central data platform and monitor and evaluate the functioning of the micromobility system. By doing so, this organisation will be able to evaluate the functioning of relevant policies made by the relevant governmental authorities. In the European SOCRATES 2.0 project, an example has been set of how such an organisation can function impartially between public authorities and private service providers. The intermediary organisation will likely operate at an operational, strategical, and tactical timeframe.

MaaS provider (Future partner)

MaaS is still in development, therefore not much is known about this actor yet. The role of the MaaS provider will be to offer a single platform where all services are combined into a single service. Information on PT and vehicle availability, as well as a centralised payment system, will result in a seamless travel experience inside and between municipalities or even countries. At this moment, there are third parties present (like Scooter Map) that combine the available maps for each micromobility service in a city for customers, as well as chargers, which makes them able to find the nearest vehicle more easily. Google Maps also attempted this but is limited to Lime scooters. MaaS operators will build a new transport ecosystem, which will contain strategic, tactical, and operational choices along the way.

D.8 Car Sharing

Service operators (Focal organisation)

The service operator is the focal organisation in this business model. It provides the service including the vehicle to be shared by users and the app that allows users to register, find, reserve, and use the cars. The service operators aim at providing vehicles in high demand areas and time windows and so have interest in relocating vehicles towards high demand areas. Service operators operate at operational, strategic, and tactical time frames.

[71] https://stadszaken.nl/artikel/2926/elektrische-deelscooter-zegen-of-last

Traveller (Customer)

Travellers are customers of the service. They can rent cars for short term use and pay for the actual use (generally based on a distance/time tariff). Proper use of the service (e.g., parking in right locations, keeping the vehicles clean), according to the rules, is fundamental for the good operation of the service. Travellers operate at an operational time frame.

Municipality (Core partner)

Municipalities define rules and provide licences for car-sharing services. Rules must be well balanced in order to offer the best service to the citizens but also guarantee economical sustainability to all the service operators that compete in the market. This is why municipalities need to carefully design the calls for tenders for new operators. Main rules regard the number of cars to share, the service area, the time windows of operation, the parking. Municipality operates at a strategic time frame.

MaaS/service aggregator (Core partner)

Software development companies that provide to users an app that allows the visualisation on a map of the entire sharing offer within a city. In some cases, also the reservation/car opening/ payment can be done with an aggregator app. Service aggregators get information from service operators via API, providing them with more visibility towards users. MaaS/service operator operates at a tactical time frame.

Ancillary companies (Relocators, Car fix) (Enriching partner)

Companies that provide ancillary services to focal organisations in case they prefer to focus only on their core business. Services can be car relocation, car cleaning, car fixing and maintenance. They operate at an operational time frame.

Car industry (Enriching partner)

Vehicles are the base of a car-sharing service. Car industries provide vehicles and can be interested in gaining advertisement through shared mobility. Testing users responses to new trends (e.g., electric vehicles) is also in the interest of the car industry.

Research and Development (Enriching partner)

Research and development test new possible service models such as service for specific users with specific vehicles. They operate at a strategic time frame.

User operators (P2P) (Core partner/customer)

In a P2P business model, the actual owners of the shared vehicles are private citizens. In this business model user operators are at the same time the core partner of the service because they provide the car and the customer with the matching platform. They operate at an operational time frame.

Matching platform operator (P2P) (Core Partner)

In a P2P business model, the service operator is focused on the platform that matches the offer and demand of shared vehicles. Fundamental is the provision of insurance to car owners and users. Matching platform operators operate at operational and tactical time frames.

nuMIDAS/Intermediary (Future partner)

This is a future partner operating at the strategic, tactical, and operational levels that may monitor and evaluate the system and relevant policies as an impartial body between the Municipality and service providers.

D.9 Mobility as a Service

Traveller (Customer)

The customer uses services provided by the MaaS. The choice to use this service depends on time, price, accessibility, reliability, relative comfort, and personal preferences. Travellers act at an operational (day to day travel choice) and strategical (longer-term travel choice) timeframe. Their roles are changing together with the evolution of transport modes offers included in the MaaS system, innovations, etc.

Municipality (Core partner)

The aim of the municipality is to provide high-level, efficient, reliable, accessible, and safe mobility. At the same time, it endeavours to improve the urban environment including better air quality, noise reduction, quiet zones, green spaces, safe streets etc., which requires a clean and sustainable transport system, parking regulations and other necessary actions. By using policy instruments, municipalities can support the MaaS system and orchestrate the overall mobility market. As Inland Transport Committee (2020) point out, such orchestration may be important, as MaaS might bring disruptive changes to urban mobility, which, if simply left to market forces, may hinder the expected benefits for some actors. Municipalities can operate at various timeframes, namely operational, strategical, and tactical.

MaaS provider (Focal organisation)

A MaaS provider offers a single platform integrating all included services into a single service, allowing travellers to plan, buy and carry out multimodal seamless trips. It can be either a private company or a public authority. It coordinates individual services, settles a provision and pricing policies (including commissions on ticket sales and subscription packages), supports and assists MaaS customers, runs marketing activities, gathers, analyses, and interprets customer data, communicates with the municipality, implements its policies and regulations and provides data to authorities, gets APIs from mobility service providers, etc. The operation of a MaaS provider covers operational, strategical, and tactical levels.

Mobility providers (Core partner)

A key role is played by public transport operators. However, achieving the stated MaaS value proposition requires the involvement of other mobility providers that allow to extend the existing public transport network and provide individualised travel solutions. These actors include providers of shared mobility (car sharing, bike and scooter sharing, carpooling, ride-hailing etc.), taxi providers and car rental companies (Tsirimpa et al., 2018). They operate at an operational and strategical level.

Mobility providers can benefit from the opportunity to access a wider market and to reach customers quickly and efficiently without the need to invest into their own platform. They can also profit from the access to data from other mobility operators and from the increased negotiation power for discussions with governmental institutions (Blanco & Esmaeilzadeh, 2020). Moreover, the MaaS provider can optimise demand and supply, especially in peak hours when some transport operators run on full capacity and it is desirable to redirect demand to other transport operators to avoid passenger dissatisfaction (Kamargianni & Matyas, 2017).

Infrastructure providers (Core partner)

Successful implementation of MaaS requires a reliable and safe overall infrastructure (roads, EV charging infrastructure, parking facilities, ICT infrastructure, etc.) to carry out mobility operations by individual users and transportation firms, including a smooth transfer between different modes of transport (Dimitriou et al., 2019). Infrastructure providers responsible for this task play therefore an important role in the MaaS ecosystem and the corresponding business model. Their activities include asset management (activities aimed at keeping specific infrastructure in the desired condition), traffic management (activities aimed at controlling traffic parameters and influencing them, and also cooperation with traditional and new mobility providers), EV charging management, etc. The infrastructure contributes to traveller's value creation by influencing travel time, costs, and comfort. The importance of its providers increases further as they use various IT solutions for collecting and disseminating data that are crucial for effective and efficient mobility and route planning (Inland Transport Committee, 2020).

nuMIDAS/Intermediary (Future partner)

This is a future partner operating at the strategic, tactical, and operational levels that is expected to monitor and evaluate the system and relevant policies as an impartial body between the municipality and service providers. It will be aimed at collecting data from different sources, its processing and distribution, helping to understand their meaning and playing a role of an independent intermediary that can facilitate data sharing between private stakeholders involved in a MaaS system. Moreover, it will provide a toolkit using this data to support evidence-based decisions and impact assessment. As a result, customers can benefit from improved transport policies and mobility services, and nuMIDAS from new knowledge and capabilities.

D.10 C-ITS and CAV Integration

Traveller (Customer)

The traveller will be the main customer for C-ITS and CAV integrated technologies. Using this the commute will get safer, as well as more time-efficient. Current users of the public transport system will be able to make use of shared automated vehicles. They can provide more comfort and a more personalised travel plan to the traveller. This development may also attract current users of a private car, for convenience reasons or reduced costs. Current users of private vehicles will travel more time-efficient, as they will encounter less standing traffic. Next to this, they will be able to do other things during their commute, making their travel time more valuable. The traveller is operating at an operational (day to day travel choice) and tactical (longer-term travel choice) timeframe. The role of the traveller will change with technological and service innovations, or due to other external factors that influence the travellers' priorities.

Municipality (Core partner)

The municipality will be involved in the implementation of the necessary road infrastructure for C-ITS and CAV integration. They are responsible for designing a safe and liveable city. The development of new vehicles can be expected to change the approach of municipalities to this issue. The municipality will also be involved in the exploitation of the services that the service providers will provide. They currently have the responsibility to make sure that everyone can make use of public transport. For example, public transport operators have to run less profitable bus lines because they are used less if they want to exploit public transport in a certain area. After all, the municipality wants to make sure that people in the less dense areas have access to public transport as well. If C-ITS and CAV integration changes the way shared transport is offered, the municipality will need to make sure that the new forms of shared mobility are also accessible to everyone. The municipality is operating at a strategical and tactical timeframe.

Service provider (Focal organisation)

Service providers will make use of C-ITS and CAV integration to operate fleets of vehicles to provide personalised transport to travellers. The service providers use connected technologies to monitor vehicle status, the functioning on the road, and operate a service infrastructure to maintain the vehicles. For example, they will have to make sure that vehicles are charged or fuelled, or get their servicing done to ensure safe operation on the road. These main tasks will not be very different from the current tasks of a public transport provider. However, it can be expected that the part that data plays in the way this service provider operates will only increase with more technology built into the vehicles. The service provider will predominantly be operating at an operational timeframe.

OEM (Core partner)

The equipment manufacturing OEMs will be involved with developing the communication technologies that will be placed in, and enable, connected and automated vehicles. They will be an important factor to determine what technologies and information exchange standards will be used. In turn, this will require cooperation with the road authority, and in order to make sure that all vehicles will be able to communicate with the other vehicles in the network. This cooperation will also be needed by the car manufacturing OEMs that are also involved with the development of communication technologies and data/information exchange systems. The car manufacturing OEMs can also become a service provider, as they might want to diversify their portfolio from selling cars to selling mobility solutions. The OEMs will be operating at an operational and strategical timeframe.

C-ITS standards organisation (ETSI, CEN) (Enriching partner)

To make the best use of interconnected vehicles and infrastructure, it is desirable that all vehicles and infrastructure can communicate with each other. In Europe, the responsibility for the development of C-ITS standards and specifications that will enable this interoperability is on the European Telecommunications Standards Institute (ETSI) and the European Committee for Standardisation. Standards organisations will operate at the strategical and tactical timeframe

Insurance agencies (Enriching partner)

Insurance agencies will be involved as liabilities for the vehicles will likely change. In autonomous vehicles, there will be no longer a driver that can be held accountable for an accident. It is still unsure where the liability will be placed in the future. The car manufacturers might be held accountable if their product may not function properly. But it could also be that their product has passed a test that allowed it to be used on the road. The service providers could be held accountable if they have not maintained the vehicles as prescribed by the manufacturer. Another option could be that there will be a national fund that users of the vehicles will pay for, which will be used to cover damages. At this moment there is no proof that vehicles with autonomous driving capabilities, like Tesla Autopilot, are in fact less involved in accidents. This indicates that during the transition period where there are enough vehicles on the road that are not autonomous it is not likely that there will be significant changes to the current insurance system. The insurance agencies are therefore operating at a strategical timeframe.

nuMIDAS / intermediary (Future partner)

The role of the intermediary organisation is still unsure. It can provide a neutral assessment of the functioning of the C-ITS and CAV system by operating independently from service providers and public authorities. Such a cooperation model is developed in the European SOCRATES 2.0 project. Common goals by the collaborating organisations will be set, like fewer accidents on the road network, less travel time lost due to heavy traffic. The intermediary organisation can, by receiving data from all organisations on accidents registered, or average travel times for a road section, determine whether the cooperation is achieving its goals. It will operate at the operational, strategical, and tactical timeframe.

D.11 Electric Infrastructure Management

Customer

Customers are residential, commercial, or industrial. Small residential customers charge their vehicles mainly at home or work (Hall & Lutsey, 2020) and often pay regulated rates. Large customers negotiate a supply contract with suppliers. The share of the public charging segment is expected to increase substantially during the following decade, driven by customers living in households without home charging options and an increasing range of electric vehicles.

Municipality (Core partner)

Municipalities can support the development of the charging infrastructure by the following actions. They can conduct baseline electric vehicle and charging assessments to obtain relevant data for proper infrastructure planning. Furthermore, they can design infrastructure plans to strategically match future electric vehicle growth targets, consult stakeholders to identify infrastructure barriers, revisit and refine charging infrastructure action plans. They can also influence driver's behaviour through convenient transportation policies, e.g., congestion pricing, public transport, parking restrictions, and private hire vehicle licensing. Moreover, local governments can provide incentives for charging infrastructure for particular applications with high costs, or where the private market is less likely to invest (e.g., subsidies for residential or public charging stations). Municipalities operate at a strategical and tactical level (Hall & Lutsey, 2020).

Charging system providers (Focal organisation)

Charging system providers denote the actors who handle the operation and maintenance of charging points. They supply all necessary elements except energy. They also include providers of software that allows for standardized payment solutions and interfaces. Many vehicle manufacturers entered into a partnership with charging system providers or established their own charging network to make electric vehicles more attractive and drive their sales. Similarly, energy suppliers often run a charging business, too. With the increasing range capabilities of electric vehicles, customers are more inclined to drive long distances, which increases the demand for public charging points. Their activities include construction, operation and maintenance of charging stations, electrical connection of the charging system with the grid (also bidirectional for V2G services), acquisition and operation of IT systems for energy management and service billing management. Charging system providers operate at an operational, tactical, and strategical level.

Power and grid providers (Core partner)

In countries where electric energy distribution and supply have been unbundled, final customers buy energy from the energy supplier, who procures the energy and pays to the distribution system operators (DSO) regulated charges for grid services and other system costs. Many energy suppliers also act as charging system providers. Power and grid providers operate at an operational, strategical, and tactical level.

Location owners (Core partners)

Within public charging infrastructure, traditional fuel stations often cooperate with charging system providers and offer their location for the installation of a charging point. Moreover, various retail and food service providers rent, sell, or partner with charging service providers to a charging service to their customers, in addition to the present service offering. Besides a rental fee, they benefit from increased consumption in their stores. However, this model is beneficial also for charging customers who are offered access to existing infrastructure and a natural stopping point. Location owners usually operate at a tactical level.

nuMIDAS / Intermediary (Future partner)

This is a future partner operating at the strategic, tactical, and operational levels that may monitor and evaluate the system and relevant policies as an impartial body between the municipality and service providers.

D.12 Parking Management

Customer

Customers (including private drivers and organisations booking parking on behalf of clients and business partners) use parking services, they book a place, purchase parking tickets or passes, provide feedback and recommendations. The parking system allows them to find the most cost-effective parking space nearby the desired location. They can automatically reserve the space and receive guided navigation towards it. They also profit from the elimination of wandering around to find a free parking space. Customers operate in an operational timeframe.

Municipality (Core partner)

The aim of the municipality is to provide a high-level, efficient, reliable, accessible, and safe, but also clean and sustainable transport system. In the field of parking, they make decisions on the price, parking restrictions and conditions. For example, a convenient pricing policy may promote parking cars away from city centres. They also benefit from the reduction of city traffic and pollution from needles wandering cars. Municipalities operate at a strategical and tactical level.

Parking system provider (Focal organisation)

The smart parking system provides a dynamic pricing solution for parking (respecting given requirements and policies of municipalities and other owners of offered parking spaces) along with a booking facility for renting and finding available parking spaces based on real-time sensing of parking spaces. Its provider facilitates connecting parking space providers with the driver. His activities include platform administration, data collection and elaboration, booking and revenue sharing. Parking system provider operates at an operational, strategical, and tactical level.

Parking space providers (Core partner)

Providers of parking spaces (on-street spaces, lots, garages, individual parking spaces) include parking space operators, private households and household companies, retail companies, outdoor areas and parks, and other providers such as sports arenas and museums, which resources are parking spaces with the necessary equipment (i.e., sensors, cameras) allowing the detection of vacant parking positions and the involvement in the Internet of things. The smart parking system also allows individuals who pay for a parking space to offer it for parking when it is free. The revenue then decreases their total parking costs.

Activities of parking space providers include operations management, equipment operation and maintenance, parking passes validation, real-time follow-up, providing data, etc. They profit from the better utilisation of parking spaces at a competitive price, and the system allows them to avoid the hassle of contract agreements directly with the parking operators. They operate at operational, strategical, and tactical level.

Location and navigation technology provider (Enriching partner)

Location and navigation technology provides the customer with the optimal route with guided navigation to selected and reserved parking spaces. Their providers act at an operational timeframe.

nuMIDAS/Intermediary (Future partner)

This is a future partner operating at the strategic, tactical, and operational levels that may monitor and evaluate the system and relevant policies as an impartial body between the municipality and service providers.

D.13 Ride-Hailing and Ride-Sharing

Ride-Sharing

User A (Customer)

User A uses the ride-sharing platform to offer a ride in exchange for sharing the expenses. He/she operates at an operational time frame. Its role is not expected to change in the future.

User B (Customer)

User B chooses from a platform or a mobile app, the trip that she/he considers most suitable for her/himself. He/she operates at an operational time frame. In the future, instead of planning the trip, the user may require a ride even on the spot.

Municipality (Core partner)

The municipality could introduce policies that favour ride-sharing (preferential lanes, reserved parking spaces at modal change nodes). Municipality operates at a strategic time frame. In the future, with the implementation of MaaS platforms, the role of the Municipality could change.

Ride-Sharing App/platform provider (Focal organisation)

Ride-Sharing platform provider provides and manages the web platform where user A and user B "meet" each other. This platform operates at a tactical and strategic time frame. In the near future, these platforms could implement other forms of mobility internally, effectively providing a multimodal mobility service.

Navigation provider (Enriching partner)

The navigation provider implements a useful service to User A (the driver), showing him/her, the best route for the journey. In this way, the driver can avoid traffic jams and given that, reduce the travel time. Moreover, the navigation app could indicate, to the driver (User A), with more accuracy the position of the User B (Google,2018). The navigation provider operates at tactical and operational time frames.

MaaS provider (Future Partner)

MaaS provider implements a platform integrating all included services into a single service, allowing travellers to plan, buy and carry out multimodal seamless trips, in a vision of reducing car dependency and car ownership. MaaS providers operate at operational, strategical, and tactical time frames.

nuMIDAS/Intermediary (Future partner)

This is a future partner operating at the strategic, tactical, and operational levels that may monitor and evaluate the system and relevant policies as an impartial body between the Municipality and service providers.

Ride-Hailing

Customer

The customer uses the services provided by the ride-hailing operator. He/she operates at an operational time frame. Its role is not expected to change in the future.

Driver (Core partner)

The driver, to whom a fee is paid, makes his car available to transport the customer. The driver operates at an operational time frame. The role of the driver can certainly change in the future as with the spread of autonomous vehicles in the coming decades, his role could be almost completely removed.

Municipality (Core partner)

The municipality could encourage forms of ride-hailing by banning private cars from entering city centres. Municipality operates at a strategic time frame. In the future, municipalities in collaboration with taxi companies could create taxi sharing services capable of providing, with the same taxi, a public service to several customers at the same time instead of one customer at a time.

Ride-Hailing operators (Focal organisation)

Ride-hailing operators provide and manage the web platform where customers find a car with a driver. They operate at a tactical, strategic, and operational time frame. In the near future, these platforms could implement other forms of mobility internally, effectively providing a multimodal mobility service

Navigation provider (Enriching partner)

The navigation provider implements a useful service to the driver, showing him/her the best route for the journey. In this way, the driver can avoid traffic jams and given that, reduce the travel time. Moreover, the navigation app could indicate, to the driver, with more accuracy, the position of the customer (Google,2018). The navigation provider operates at tactical and operational time frames.

MaaS provider (Future partner)

MaaS provider implements a platform integrating all included services into a single service, allowing travellers to plan, buy and carry out multimodal seamless trips, in a vision of reducing car dependency and car ownership. MaaS providers operate at operational, strategical, and tactical time frames.

nuMIDAS/Intermediary (Future partner)

This is a future partner operating at the strategic, tactical, and operational levels that may monitor and evaluate the system and relevant policies as an impartial body between the Municipality and service providers.

D.14 Stakeholder categorisation

While some stakeholders, such as a traveller or a municipality, are represented in many of the services, some stakeholders only occur in a few services. Additionally, some of the stakeholders are service-specific, but perform a similar role to a stakeholder in a different service. These organisations that perform similar functions in different services are categorised together into a general category. To keep the number of categories low, while keeping categories clear, stakeholders that can only be found once in all the services are deemed too specific for this overview and are therefore not included in the categorisation or taken further into the summary.

The categories based on the business model radars, and the descriptions of their roles given in previous sections, are presented in Table 48 below.

Table 48: Stakeholder categorisation

Stakeholder category	Combines	Description
Traveller	Traveller, citizen, end-user	A person who travels by using an available mobility service
Municipality	Municipality, policy maker	City government, which is responsible for, among others, local policies, and urban development.
(Mobility) service provider	(Mobility) service provider / operator, platform provider, parking system provider, public transport provider	Private or public company responsible for organising the related service, which also includes other activities such as fleet management, platform development, data collection, payment systems, etc.

Research organisation	Research organisation, technology centre	Private or public company/entity focused on academics or scientific research.
Standardisation organisation		The organisation which is responsible for management of related standards and the standardisation process.
Navigation provider		A company that provides an app used for navigation. These parties can be seen as service providers as well.
Traffic manager		A party that works with real-time and historic data to manage and improve the (current) traffic-flow.
Tech company	App developer, tech company, software developer	A software company that works on the development of the front or backend of systems used by other parties in the service.
MaaS provider		A service provider that integrates various modes of transport into a single platform, with a single payment system and multimodal trip-advice to the end-user.
Infrastructure provider	Parking space provider, power & grid provider, charging system provider	A party that is responsible for providing (data of) the infrastructure supporting the mobility system and service.
OEMs	OEMs, car industry	Original Equipment Manufacturers of vehicles or other transport-related products
Intermediary		A party that stands between two or more stakeholders to provide better collaboration between them, increase trust, reduce costs, and ensure security of transmitted transport/private data. nuMIDAS may fulfil this role in later stages of the project.

Appendix E Survey analysis

E.1 Introduction

The survey was carried out in four languages, namely English, Greek, Italian and Spanish. In total, 119 responds from 15 countries were delivered. Some of the surveys were not completely filled in, so we further divide the submitted surveys into full, partial, and incomplete. The numbers of surveys and the overview of their state are given in the following tables.

Table 49: Returned surveys by language

Language	N	Percent
English	59	49.58
Greek	14	11.76
Italian	31	26.05
Spanish	15	12.61

Language	Full (Percent)	Partial (Percent)	Incomplete (Percent)
English	40.68	13.56	45.76
Greek	35.71	14.29	50.00
Italian	29.03	6.45	64.52
Spanish	20.00	26.67	53.33

Table 50: Returned surveys by country

Country	N	Percent
Belgium	2	1.68
Croatia	1	0.84
Czech Republic	7	5.88
France	1	0.84
Germany	11	9.24
Greece	18	15.13
Hungary	1	0.84
Italy	33	27.73
Malta	1	0.84
Netherlands	24	20.17
Poland	2	1.68
Slovakia	1	0.84
Slovenia	1	0.84
Spain	15	12.61
United Kingdom	1	0.84

Country	Full (Percent)	Partial (Percent)	Incomplete (Percent)
Belgium	0.00	50.00	50.00
Croatia	100.00	0.00	0.00
Czech Republic	28.57	14.29	57.14
France	0.00	100.00	0.00
Germany	36.36	18.18	45.45
Greece	33.33	11.11	55.56
Hungary	100.00	0.00	0.00
Italy	30.30	6.06	63.64
Malta	100.00	0.00	0.00
Netherlands	50.00	8.33	41.67
Poland	0.00	0.00	100.00
Slovakia	0.00	100.00	0.00
Slovenia	0.00	0.00	100.00
Spain	26.67	20.00	53.33
United Kingdom	100.00	0.00	0.00

E.2 Analysis of quantitative results

E.2.1 Importance of different challenges

The survey contained two groups of questions with numerical answers related to 24 different challenges in the domain of transportation. In the first group, respondents were asked:

What is the importance of the following challenge for the urban mobility sector?

For each challenge, the task was to rate the topic from 1 (not important) to 5 (very important).

Table 51: Importance of challenges for the urban mobility sector – overall mean rates and mean rates by domain

	Mean rate	Academy/Research (20 %)	Government (38 %)	Transport companies (12 %)	Other/unknown (30 %)
Privacy	3.74	3.80	3.68	4.00	3.67
Ethics	3.62	3.60	3.74	3.50	3.53
(Cyber)security	4.31	4.33	4.42	4.00	4.29
Analysing (Big) data	4.16	4.56	4.26	3.50	4.07
Data standardisation	4.38	4.67	4.53	3.60	4.27
Open data platforms	4.31	4.33	4.47	4.20	4.13
Real-time information	4.52	4.78	4.58	4.40	4.33
Use of algorithms/AI	3.96	4.00	4.05	4.20	3.73
Disruptive technologies	3.36	3.56	3.19	3.60	3.33
Excessive information	3.00	3.44	3.16	2.25	2.69
Impact assessment	3.73	3.89	3.74	4.20	3.47
Digital gap / inclusiveness	3.71	3.89	3.74	4.00	3.47
Co-creation	3.26	3.38	3.26	3.80	3.00
Technocracy vs. liveability	3.58	3.38	3.74	3.60	3.46
Business models	3.73	3.78	3.58	4.00	3.80
Legislation and policies	4.06	4.00	4.00	4.20	4.13
IT-infrastructure	4.10	4.44	4.16	3.80	3.93
Road infrastructure	3.69	3.33	3.84	3.40	3.80
Electrification	3.81	4.22	3.58	3.40	4.00
Interoperability of systems/organisations	4.44	4.33	4.63	4.40	4.27
Urban space management	4.44	4.44	4.58	4.60	4.20
Sustainability	4.50	4.44	4.47	4.60	4.53
Funding	4.10	4.56	4.00	3.60	4.13
Toughening/changing of environmental requirements	4.11	4.33	3.95	4.00	4.21

Besides information on countries, IP addresses allowed to identify several domains in which participants were working, namely domain of academy and research (universities, research institutes etc.), government (from local to state levels), companies working in the field of transportation, and other/unknown. Mean rates for individual challenges together with mean rates for different domains are given in Table 51.For a better orientation in the values, the blue-red scale was used, where the dark red colour denotes the highest value and dark blue the least one. Mean rates by countries from which quantitative answers were obtained are listed in Table 52.

Table 52: Importance of challenges for the urban mobility sector – overall mean rate and mean rate by country

	Mean rate	Belgium	Croatia	Czech Republic	France	Germany	Greece	Hungary	Italy	Malta	Netherlands	Spain	United Kingdom
Privacy	3.74	4.00	5.00	4.33	3.00	3.50	4.33	4.00	3.00	3.00	4.00	3.75	2.00
Ethics	3.62	3.00	5.00	4.00	3.00	3.00	3.67	2.00	3.64	5.00	3.92	3.25	2.00
(Cyber)security	4.31		4.00	5.00	4.00	4.75	4.67	3.00	3.70	5.00	4.69	3.50	3.00
Analysing (Big) data	4.16	5.00	4.00	3.67	3.00	4.75	4.33	2.00	4.70	5.00	3.77	4.25	3.00
Data standardisation	4.38	4.00	5.00	5.00	4.00	4.50	3.89		4.60	5.00	4.46	4.00	4.00
Open data platforms	4.31	3.00	5.00	4.67	4.00	4.25	4.22		4.60	5.00	4.08	4.25	5.00
Real-time information	4.52	3.00	5.00	4.67	3.00	4.75	4.56		4.90	5.00	4.08	5.00	5.00
Use of algorithms/AI	3.96	3.00	4.00	4.33	3.00	3.50	4.22		4.30	2.00	3.85	4.25	3.00
Disruptive technologies	3.36		4.00	4.00	4.00	3.50	3.56		3.00	2.00	3.08	3.75	3.00
Excessive information	3.00	4.00	4.00	3.00	2.00	3.67	3.00		2.56	4.00	3.08	3.00	2.00
Impact assessment	3.73	4.00	5.00	4.00	2.00	3.50	3.78		3.80	5.00	3.54	4.00	3.00
Digital gap / inclusiveness	3.71	4.00	4.00	4.33	2.00	3.25	4.00		3.60	5.00	3.54	4.00	3.00
Co-creation	3.26	3.00	3.00	4.00	4.00	3.67	3.67		2.70	5.00	3.23	2.75	2.00
Technocracy vs. liveability	3.58	4.00	3.00	4.00	5.00	3.00	3.33		3.33	5.00	3.77	4.00	2.00
Business models	3.73	4.00	5.00	5.00	4.00	4.25	3.44		3.60	5.00	3.31	3.75	4.00
Legislation and policies	4.06	2.00	3.00	4.33	4.00	4.25	4.11		3.80	5.00	4.08	4.75	4.00
IT-infrastructure	4.10	2.00	4.00	4.00	3.00	4.25	4.44		3.90	5.00	4.15	4.50	3.00
Road infrastructure	3.69	4.00	1.00	4.00	4.00	4.50	3.44		3.90	5.00	3.23	4.00	5.00
Electrification	3.81	5.00	5.00	3.67	4.00	4.75	3.89		4.30	5.00	2.77	4.00	4.00
Interoperability of systems/organisations	4.44	4.00	4.00	5.00	4.00	4.75	4.67		4.30	5.00	4.38	4.00	4.00
Urban space management	4.44	5.00	4.00	4.33	4.00	4.25	4.67		4.70	5.00	4.15	4.50	4.00
Sustainability	4.50	5.00	5.00	4.67	4.00	4.50	4.44		4.40	5.00	4.38	4.75	5.00
Funding	4.10	2.00	5.00	4.67	5.00	3.50	4.11		4.20	5.00	3.85	4.75	4.00
Toughening/changing environ. requirements	4.11		3.00	4.33	5.00	4.00	4.44		3.70	5.00	4.08	4.25	4.00

We can notice that the most important are considered real-time information, sustainability, interoperability of systems and organisations, urban space management, data standardisation, (cyber)security and open data platforms.

E.2.2 Attention paid to various challenges

The second group of questions with numerical answers was related to same challenges, and the respondents were asked:

Do you think the current attention to these problems is sufficient?

As before, the task was to rate the challenge from 1 (we should pay no attention) to 5 (we should pay more attention), with 3 being we are paying the right amount of attention).

Mean values sorted by domain and country are provided in Table 53 and Table 54.

Table 53: Attention paid to challenges for the urban mobility sector – overall mean rate and mean rate by domain

	Mean rate	Academy/Research (20 %)	Government (38 %)	Transport companies (12 %)	Other/unknown (30 %)
Privacy	3.61	2.20	3.40	4.25	4.67
Ethics	3.69	3.30	3.40	4.00	4.29
(Cyber)security	4.06	3.60	3.85	4.50	4.53
Analysing (Big) data	3.59	3.30	3.60	3.75	3.73
Data standardisation	3.82	3.80	3.75	4.25	3.80
Open data platforms	3.80	3.70	3.80	4.25	3.73
Real-time information	3.73	3.40	3.75	4.00	3.87
Use of algorithms/AI	3.57	3.40	3.45	4.00	3.73
Disruptive technologies	3.34	3.14	3.22	3.75	3.47
Excessive information	2.87	2.78	2.72	3.50	2.93
Impact assessment	3.53	3.40	3.30	3.75	3.87
Digital gap / inclusiveness	3.59	3.30	3.45	3.75	3.93
Co-creation	3.11	2.44	2.74	3.50	3.87
Technocracy vs. liveability	3.13	3.20	2.76	3.25	3.47
Business models	3.39	2.70	3.50	4.25	3.47
Legislation and policies	3.80	3.60	3.65	4.25	4.00
IT-infrastructure	3.71	3.30	3.65	4.75	3.80
Road infrastructure	3.59	3.30	3.60	4.25	3.60
Electrification	3.22	3.30	3.00	4.00	3.27
Interoperability of systems/organisations	3.90	3.70	3.60	4.50	4.27
Urban space management	3.94	4.00	3.65	4.00	4.27
Sustainability	3.98	3.60	4.05	3.75	4.20
Funding	3.86	3.30	3.65	4.25	4.40
Toughening/changing environ. requirements	3.79	3.11	3.70	4.25	4.20

Table 54: Attention paid to challenges for the urban mobility sector – overall mean rate and mean rate by country

	Mean rate	Belgium	Croatia	Czech Republic	France	Germany	Greece	Italy	Malta	Netherlands	Spain	United Kingdom
Privacy	3.61	2.00	3.00	3.33	4.00	3.25	4.11	3.00	5.00	3.69	4.40	3.00
Ethics	3.69	2.00	3.00	3.33	4.00	3.50	3.78	3.78	5.00	3.77	3.80	3.00
Cybersecurity	4.06	3.00	3.00	5.00	4.00	4.25	4.33	3.80	5.00	4.15	3.60	3.00
Analysing (Big) data	3.59	3.00	1.00	4.00	3.00	4.00	3.44	4.50	5.00	3.00	3.60	3.00
Data standardisation	3.82	4.00	2.00	4.33	3.00	4.25	3.33	4.60	5.00	3.54	3.40	4.00
Open data platforms	3.80	2.00	2.00	4.67	3.00	3.75	4.00	4.40	5.00	3.15	4.00	4.00
Real-time information	3.73	2.00	3.00	3.67	3.00	3.75	3.89	4.50	5.00	3.08	4.20	3.00
Use of algorithms/AI	3.57	3.00	1.00	4.00	4.00	3.75	3.22	3.80	5.00	3.54	3.80	3.00
Disruptive technologies	3.34		1.00	4.00	5.00	3.75	3.11	3.50	5.00	3.08	3.40	3.00
Excessive information	2.87		1.00	3.50	2.00	3.25	3.00	2.67	5.00	2.92	2.40	3.00
Impact assessment	3.53	4.00	1.00	3.67	3.00	4.00	3.56	3.80	5.00	3.31	3.20	4.00
Digital gap / inclusiveness	3.59	4.00	1.00	4.00	4.00	4.00	3.89	3.60	5.00	3.08	4.00	3.00
Co-creation	3.11		1.00	3.33	3.00	3.33	3.44	2.60	5.00	3.23	3.00	3.00
Technocracy vs. liveability	3.13	4.00	2.00	3.00	4.00	3.00	3.22	3.11	5.00	2.85	3.50	3.00
Business models	3.39	2.00	2.00	4.00	5.00	4.00	3.00	3.20	5.00	3.31	3.80	3.00
Legislation and policies	3.80	3.00	1.00	4.00	5.00	3.50	3.56	4.10	5.00	3.77	4.20	3.00
IT-infrastructure	3.71	3.00	3.00	4.33	4.00	3.75	3.67	3.70	5.00	3.46	4.20	3.00
Road infrastructure	3.59	4.00	5.00	4.00	4.00	4.25	3.33	3.90	5.00	2.85	4.00	3.00
Electrification	3.22	5.00	3.00	2.67	2.00	3.75	3.11	3.80	5.00	2.62	3.40	3.00
Interoperability of systems/organisations	3.90	4.00	1.00	4.67	2.00	4.50	3.67	4.10	5.00	3.92	3.60	4.00
Urban space management	3.94	4.00	2.00	4.67	3.00	4.00	4.22	4.20	5.00	3.54	4.00	3.00
Sustainability	3.98	4.00	3.00	4.67	4.00	4.50	4.00	4.10	5.00	3.69	3.80	3.00
Funding	3.86	3.00	3.00	4.67	4.00	3.25	3.89	4.20	5.00	3.54	4.20	3.00
Toughening/changing environ. requirements	3.79		3.00	4.00	3.00	4.00	3.89	3.80	5.00	3.77	3.60	3.00

According to the respondents, more attention deserve especially (cyber)security, sustainability, urban space management, interoperability of systems and organisations and funding. Notice that the respondents from transport companies call for a higher attention paid to the most of considered challenges, compared to participants from the academical and governmental fields.

E.3 Analysis of qualitative results

E.3.1 Current trends in the urban mobility sector

Twelve open-ended questions were aimed at trends and the related issues and challenges identified by respondents in the urban mobility sector at present and those expected to come up in the next 10 years, separately for four different categories: services, policies, traffic management and other. The first group of these questions asked: **What trends can you currently identify in the urban mobility sector?**

Services

The issues that emerged most in the survey were: Micromobility, Mobility as a Service (MaaS), Autonomous vehicles, Sharing Mobility. In particular, micromobility is seen as "the only component of sustainable mobility that is clearly on the horizon". Special attention should be paid to data and its use to make decisions in the field of urban mobility. Specifically, one of the objectives of the European Socrates 2.0 project was cited as a good practice. Socrates 2.0 mission of this project was to align "public and private data and strategies in (private) services''. Furthermore, two other trends emerged from the survey: the first is the use of real-time data for dynamic traffic management (i.e., traffic lights "to promote the flow of various modalities (bicycles, freight traffic, public transport, car traffic"). The second, on the other hand, concerns the cooperative systems and specifically the implementation of Connected, Cooperative, and Automated Mobility (CCAM).

Policies

Answers in the survey mentioned especially policies related to traffic calming and less accessibility for cars in inner cities (low-speed zones, low emission zones, traffic restricted areas, limited parking requirements). In particular, in Greece "the introduction of Low Emission Zones is very close to being adopted as a policy tool, especially if the studies related to Sustainable Urban Mobility start to be operationalized in practice". These policies have as their final objective the reduction of car dependence with the possibility of reusing the space left by cars for other forms of mobility (such as walkability and cycling). In conclusion, as it was stated in another answer: "Cars become less important in the city. With physical, dynamic, or virtual means, (sub-)areas are increasingly closed off, sometimes for certain periods, sometimes for specific target groups (old vehicles), sometimes for all vehicles. This will increase to better guarantee road safety, health and quality of life".

Traffic management

The results have returned a very heterogeneous situation, which includes issues concerning the regulation of active mobility (bicycles, pedestrians), centralisation of traffic lights, smart roads, road safety, etc. In particular, reference is made to the prioritization of public transport, cycling and pedestrian accessibility over private transport (cars). However, an answer to this question of the survey has outlined an interesting starting point: "Cycling, walking and public transport are becoming more important and will therefore be given more priority in urban areas. The resources are still very much focused on the car. How do we reach those other target groups?"

Specifically, it can be noted that other forms of mobility, especially after the COVID pandemic, are increasingly important, generating flows that begin to be very significant at an urban level. The challenge is therefore to know how to combine the limited financial resources with the need to be able to travel safely the forms of mobility alternative to the car (bikes, kick scooters, pedestrians, etc.).

Other

Only five answers mentioning other current trends in the mobility sector were recorded:

- Urban furniture, integrated urbanism interventions
- More space for healthy mobility and focus on multi mobility solutions for users
- Local traffic manager
- Local traffic managers feel short of resources
- 10-minute city concept
- Exploitation of license plate camera data for the definition of environmental policies.

Reference is made to the need to integrate transformations in the mobility sector (multimodal solutions, active mobility) with those in the urban area, also through the implementation of new urban paradigms such as "15 minutes city". Moreover, another interesting issue is the use of data from cameras that identify vehicle license plates in order to implement environmental zones in some parts of the city.

E.3.2 Trends expected to come up in the next 10 years

The second group related to trends in the mobility sector asked: **What trends do you expect to come up in the next 10 years in the urban mobility sector?**

Services

What emerges from the survey is that the future of mobility will be electric (kick scooters, mopeds, cars, buses), shared and connected to a smart and cooperative system (MaaS). Also, from the management point of view, there will be greater coordination between the public and private sectors, also thanks to the dissemination and sharing of data. The way in which the last mile of freight transport will be covered will also be important, thanks also to the application of smart logistics practices. Finally, some answers hinted at the possible implementation of the use of drones in the urban mobility sector.

Policies

It is useful to start from an answer provided by the survey to understand what the policies relating to urban mobility may be in the future:

"Public investments in ITS and C-ITS should be oriented towards projects public interests, i.e., projects that will contribute to improve traffic control and the flow of traffic, contribute to better road safety, to improve incidents management and further to improve public transport safety and its accessibility as well as to improve logistic processes for consignments which required a special surveillance (e.g., transport monitoring of heavy and oversized loads)".

In this sense, policies must use technological innovations to solve the main problems of the transport sector, introducing restrictions and limitations aimed at improving both accessibility and inclusiveness by other forms of mobility (pedestrians, cyclists) and environmental conditions (i.e., air quality).

For example, useful practices to achieve these goals are:

- pay per use,
- pay per space,
- toll system,
- more extensive and restrictive low emission zones.

Traffic management

Although no issues were cited in a definite way by the answers, it can be highlighted how the need emerges to have traffic management tools capable of also managing the new flows due both to the increase in active mobility and to the circulation of autonomous and connected vehicles. Specifically, the goal is to have smart roads able to transmit information between vehicles, travellers, and infrastructures. Another hypothesis is the one advanced by a compiler of the survey who referred to some output solutions of the Socrates project: use "road KPI driven management instead of basic condition/action-based traffic management".

Other

The following answers are reported:

- access for all at any cost,
- new players on the market, old (dominant) players disappear,
- users revolt about the fact that their personal data generates money for others; this can lead to different revenue models compared to user data in which the user is also involved, or to less enthusiasm for using the services with certain target groups.

The last answer focuses on the question of selling data and the need to involve users who could benefit from selling their data in new business models.

E.3.3 Other important issues/challenges

In the last group of questions related to trends, the respondents were asked:

Are there any important issues/challenges that you would like to mention regarding some of the trends?

Services

Three major challenges were highlighted. The first one is the need for data sharing and their relative problems. For example, a survey compiler wrote:

"In the Netherlands we see that some mobility data is stored at the appropriate National Access Point, while other data is stored at some private party. For instance, all data is at the NAP's (National Access Point), except for logistics, road signs and intelligent traffic light data. This is a bad situation: I think we should store relevant mobility data at the appropriate national access point. Private parties can have a role in the management of the data and access point, but it should be under governmental control. This is a common data good".

The second one is the necessary coordination and cooperation between the public and private sectors to involve every stakeholder that works in the mobility sector. The last one is related to the regulation of micromobility, in fact "the relative lack of legislation and regulations on micro-mobility may be a reason for the limited use of micromobility modes".

In the end, one responder mentioned an ethics problem that represents an interesting starting point for the future of mobility: "Should you want to make money if it doesn't contribute to an improvement?"

Policies

The answers provided were very heterogeneous, so much so that it is not possible to define what the greatest challenges are. On the one hand, there is a need for a change in urban mobility ("Tough and unpopular decisions need to be made to speed up the mobility transition (e.g., spatial development follows mobility policies)"). On the other hand, there is a lack of cooperation between the various actors in sharing and publishing data ("Governments are increasingly mandated to create data, but there is no implementation mandate for private parties, even though these parties have an increasingly bigger impact on the mobility ecosystem"). Finally, a final challenge is the participation of citizens in the planning of urban transformation processes that also affect mobility.

Traffic management

One of the main arguments is the need to integrate road safety practices, real-time traffic information with a change in behaviour and a cultural change starting especially from the new generations ("Important to start educating right from young age to bring about cultural change"; "Integration with MaaS and behavioural change. Not just route-navigation, but live-navigation.") Furthermore, the risk of cybersecurity and privacy related to the collection and management of big data relating to traffic also emerged.

Other

The following answers are reported:

- keeping smaller entities connected/involved,
- lack of skilled labour,
- growing aggression between specific groups of road users (drivers vs. cyclists),
- Financing of local public transport services.

These answers open the way to very interesting reflections such as the need to train people (workers) able to specialise in activities strictly related to new forms of mobility, or the requirement of a change in behaviour that highlights how in addition to motorists there are other users on the roads.

E.3.4 New types of stakeholders expected in the urban mobility sector

Three open-ended questions asked about new types of stakeholders observed within the urban mobility sector, the change of the role of traditional stakeholders during the past few years, and the expected additional shift in their roles in the next 10 years. The first of these questions ran:

What new types of stakeholders do you observe within the urban mobility sector (may or may not be related to the previously mentioned trends) (i.e., micromobility operators, MaaS operators)?

New stakeholders have been identified that are closely correlated with the new mobility trends. In particular, the following were mentioned (the most frequently cited stakeholders are in italics):

- *micromobility service providers*
- *data providers*
- *MaaS providers*
- *technology companies*
- ***citizens' movements and residents' groups to promote sustainable urban mobility***
- right of use of public space sellers
- mobility assets managers
- intermediary Role between private and public
- data brokers
- telecommunications operators
- urban logistics operators
- social media groups.

E.3.5 Change of traditional stakeholders' roles during the past years

The second question aimed at stakeholders in the urban mobility sector asked:

How has the role of the traditional stakeholders in the urban mobility sector changed during the past few years (i.e., policy makers, service operators, traffic managers, users, legislation, OEM, insurance company, etc.)?

Several interesting points emerge from the answers to the questionnaire. The first is the rise of the private sector within urban mobility, with the consequent weakening of public road authorities. This can hide the risk of losing the public interest of the mobility sector in the face of multiple private interests.

The second concerns the different data sources where users can find information. Indeed: "Road users have many new ways to get information about their trips and new ways to interact. Events use social media to steer their visitors, navigation services are everywhere. This means that governments need to compete with these parties for the attention of the road users". This can, in turn, question the role of governments at all levels (national, regional and local), indeed a compiler wrote: "Traditional public transport operators have to fight for their position on the market much more, because of new possibilities of transportation currently being offered to potential passengers. Traditional stakeholders have to follow technological trends affecting/disrupting "old school" models of mobility to stay in touch with progressive private companies."

The last issue, as already seen for the previous questions, concerns the role of users, which is currently only passive, i.e., they are seen as only data generators, without them being put into a participatory planning process. Their role will therefore need to be rethought in the future.

E.3.6 Expected additional shift in stakeholders' role in the next 10 years

The respondents were asked:

Do you expect an additional shift in the role of certain stakeholders in the next 10 years?

The majority of the respondents (about 70%) expect an additional shift in the role of certain stakeholders in the next 10 years. They suggest mainly shifts in the role of mobility operators, public authorities, policy makers, and travellers. New/smart mobility operators are increasing in importance and are becoming relevant stakeholders that road authorities and policy makers need to consider. In the next years and with new technologies (e.g., flying taxis) their importance and role could further change.

Road authorities and policy makers will need to set more policies to adapt to new actors as micromobility and shared automated mobility. The public sector will have to find a compromise between regulation and economic sustainability for these new actors. To have a more data-driven decision making, public governments will need to develop their own data/IT platforms.

Mobility users show quick reactions to new services and will be the key stakeholders. People want more and quickly, but the government and legislation can't be that fast. Respondents see the need for more collaboration between different stakeholders (e.g., data sharing) especially between private and public sectors.

Traditional companies such as fuel companies, lease companies and insurance will have to significantly adapt their role to the change of technologies and services.

E.3.7 Mobility-related tools nowadays available for policy makers

Further, the survey contained 7 questions directed at mobility-related tools. The first one asked:

What mobility-related tools are available for policy makers nowadays (e.g., simulation models, dashboards, etc.)?

Data collection/storing tools are fundamental for policy maker. Respondents listed tools such as drones, cameras, sensors for recording and collecting traffic Big Data, satellite, incident detection tools. Surveys are also an important tool to retrieve user opinions. Data should be stored in open data platforms with open APIs, with particular attention to real-time data availability.

Data analysis tools need to process big data, including video and images.

Simulation models (macroscopic and microscopic simulation of urban transport systems) are also fundamental for policy makers to evaluate alternative future scenarios. Forecast of traffic conditions in a network and tools in dynamic traffic management are also relevant.

Dashboards and visualisation platform are fundamental for a proper use of data analysis results in relation to traffic management, asset management, real-time monitoring, and strategic, tactical, and operational decision support systems. Real-time data dashboard can also be important, especially for control rooms.

Respondents reported also other tools as software packages for transport system design or software for mobility managers.

Tools for training are also reported: the lack of skilled personnel in public and private office could benefit from those.

Most of the stakeholders (75%) observed improvements in the existing mobility related tools and emergence of new tools.

E.3.8 Main gaps in which the existing tools do not meet policy makers' expectations or needs

The next question was:

What are the main gaps in which the existing tools do not meet policy makers' expectations or needs?

Respondents mentioned the following gaps.

Several gaps concern data. Data are often not available, not up-to-date, difficult to recover and lack of integration. Open data are still limited. There is a disconnect between real-time data, strategic information needs and tactical data use. Data are often not recorded to build a history of events.

Data on origins and destinations of trips is not yet accurate and there is not enough information about current travel motive per trip.

Tools should be easy to use since there is a lack of specific skills. Tools should provide policy makers with appropriate KPIs to show insights of policies performance. Tools may meet technical needs but do not always align with policy objectives, as an example dashboards on high-level goals like inclusiveness, liveability, accessibility, sustainability are not available.

Respondents listed several gaps of the available tools:

Effects of smart mobility solutions on local level.

System dynamics approach on mobility to get more insight in complex systems (interaction, spatial development, behaviour, prices, etc. on mobility choices).

Integration of Micromobility and public autonomous transport modes in simulation tools.

Social cost-benefit analysis.

Respondents stressed widely on gaps in stakeholders' skills and highlighted the need for more training for a proper use of the available tools. There is a lack of specialised scientific staff in policy makers and civil servants. A gap needs to be overcome concerning the ability to "read" models and dashboards. The ability to compare model results and dashboard indicators with political 'desired' indicators and associated action perspectives must be learned. Nowadays it is still not easy for cities to approach the available tools, especially because the involvement of local communities in policy-making cannot be achieved through existing tools.

Another gap concerns the costs of tools. Specific tools and their implementation for public offices, including the training of personnel, can have a significant cost.

E.3.9 The most critical challenges/risks

The respondents were asked:

Please indicate at least two challenges/risks that are, in your opinion, the most critical and can impact existing methodological tools supporting transport/mobility researchers, planners, and policy makers.

The following issues were mentioned in the answers.

The actual use of the results of the tools is often limited. This happens for several reasons: tools often don't provide results easy to interpret, a unimodal approach seems very limited, there is lack of skilled personnel in public offices and there are difficulties in understanding and accepting scientific results by policy makers.

An important challenge is the change in demand for mobility day by day, as well as getting insights in the impact of shared and MaaS mobility. There is a lack of knowledge about the effects of smart mobility.

The quality of data and the tools that process data still have to be improved. Mobile phones do not provide sufficiently robust data and there is not enough data standardization and integration. Excess of unverified or unverifiable information is an important risk to consider. Available data are often commercial; there is not yet enough public/open data available.

Tools to process big data still have to improve. Too much attention is given to nice visualisations instead of well-developed (and complex) transport models.

Modelling travellers behaviour and choice seems quite challenging, the focus cannot be only on travel times and costs.

A significant risk for policy makers is a mechanistic decision-making process based solely on data, outside a human-cantered framework for public space and transport planning. The risk is to focus on technical and efficient solutions instead of the mobility and environmental needs.

A correct management of privacy and NDAs is still a challenge, with the risk of delays on the technical procedures. Cyber security is also a risk to be considered, especially when dealing with private and personal data.

A main challenge is also the application of a holistic approach, with the risk of thinking that the solution to a problem is only technological or political without thinking about heuristics, configurations, modelling, management, maintainability, and impacts. Future traffic management will require lots of data of any stakeholder, and all of this needs to be included in the models.

E.3.10 New types of mobility-related data that should be collected

The respondents were asked:

What new types of mobility-related data should be collected to support data driven policy making?

Answers included the following formulations.

Data about Public Transport are fundamental for monitoring and planning of the service (e.g., data from electronic ticketing to monitor get on/get off and how full is a bus).

One of the trickiest data to collect is about characteristics of travellers (home address, job, hobbies, habits, use of existing mobility assets). Those data are important to model travel demand and ODs, as well as the reasons to choose a way of transportation and travellers behaviour in general.

Performance evaluation data and satisfaction from service users and non-users represent a significant feedback for transport companies and policy makers. Social media data could also help in define travellers profiles.

Data about the environmental impacts of mobility are rising in importance (e.g., environmental footprint of urban transport systems in relation to the land use, the air quality, the climate change)

Roads and transport infrastructure need to be monitored to retrieve data about road safety, real-time data on traffic, on-street/off-street parking, disabled accessibility, use of charging station.

The vehicles are also a fundamental source of data to support data driven policy making. Relevant information are types of fuel, consumption, vehicle tracking, floating vehicle data and connected vehicle data.

Qualitative data collected with surveys and respondents are also important to provide policy makers with the opinion of stakeholders, including in particular travellers and mobility service operators.

E.3.11 New KPIs needed or expected from policy makers

Finally, new KPIs and new types of mobility-related data supporting data-oriented policy making were inquired, together with their benefits on policy making. The first question was:

What new key-performance indicators (KPIs) do policy makers need or will they focus on?

Respondents reported several KPIs grouped by costs/benefits, environment, traffic, social behaviour/user experience, transport infrastructure and services.

Costs/benefits

- Total trip unitary cost (including all actors),
- Benefits from exploiting the public space
- Local economy (Number of trips ending along main street / total trips)

Environment

- CO2 and NOX emissions
- Spatial impact indicators
- Noise pollution
- Climate (Lifecycle carbon footprint of micro-mobility vehicle by passenger km/mile)
- Environmental costs per journey

Traffic

- Cars to park at the edge of the city and then move further by bus or bike
- Connectivity (e.g., Share of micro-mobility trips combined with public transport)
- Reduction of motorized mobility or even mobility at all in an area
- Travel time

Social/user experience

- Accessibility to all (age, gender, financial status)
- Safety
- Accessibility
- Inclusiveness
- Equity in mobility offer
- Employment
- Social costs per journey
- Happiness of people living near the roads
- Comfort (convenience, travel time, flexibility etc.)
- Which % of passengers is willing to change modes of transport and under which conditions?
- The factor of decreasing the modal split of the car

Service/infrastructures

- Number of bicycle lanes per road kilometre
- Rate of usage of new mobility services
- Combination of transport modes
- Utilisation of public transport means

- Percentage of roads which are capable for automated vehicles or which are covered by sensors enabling individual traffic management

E.3.12 Benefits of the aforementioned data and KPIs for policy making

What benefits would the aforementioned data and KPIs have on policy making?

A correct use of KPIs could help policy makers in better planning and selecting of more realistic transport modes answering to the needs of the city. It is important that decisions are justified by data and analysis.

A wide spectrum of KPIs can help policy makers to consider more balanced choices between safety, flow, environment and land use, and steer towards more long-term effects for society instead of short-term effects for individual travellers.

KPIs can be used to monitor the solutions already in place and also to evaluate possible alternative solutions to be implemented. A constant monitoring and KPIs update provide more flexible and quicker reaction time for optimizing policies and measures.

Policy makers with a wide knowledge provided by KPIs would show higher efficiency in public spending and in service provision for the citizen.

Respondents stressed the importance of understanding behaviour and motivation of travellers, and consequently adopting a user-cantered design approach to develop mobility services and infrastructure. The interaction with travellers should be continuous to adjust regulation and services to users' needs. The traveller must be central and must have that feeling. The provision of mobility services should evolve from supply-oriented to demand-oriented.

KPIs on environmental impacts of mobility cannot be avoided by modern policy makers to assess the effects of the implementation of carbonation policies in the urban environment, to evaluate the quality of the public space of the city and to measure the impacts of mobility in terms of emissions.

E.3.13 Additional suggestions

Do you have anything to add that may benefit our project, or things we may have forgotten?

The stakeholders who responded to the surveys provided few final suggestions:

- More attention to the subject is needed, more money to explore it
- Excessive information is only a problem if you are not able to channel it.
- Standardization is overrated these days, getting the data in any format should have a much higher priority.
- Business models must be found that allow identifying the value proposition for the various mobility operators in integrating the various services
- Best to see what trends exist in different age groups and gender and address those.

E.4 Survey questions

LimeSurvey

Section A: Trends

A1. What trends can you currently identify in the urban mobility sector? Please answer for each of the following categories (about three answers per topic is sufficient).

Other

Services (e.g. micromobility, MaaS, C-ITS and CAV Integration)

Policies (e.g. environmental zones, accessibility, inclusiveness, congestion charge)

Traffic management (e.g. bicycle priority at intersections, road safety, traffic scenarios)

A2. What trends do you expect to come up in the next 10 years in the urban mobility sector? Please answer for each of the following categories (about three answers per topic is sufficient):

Services (e.g. micromobility, MaaS, C-ITS and CAV Integration)

Policies (e.g. environmental zones, accessibility, inclusiveness, congestion charge)

Traffic management (e.g. bicycle priority at intersections, road safety, traffic scenarios)

Other

Section B: Challenges

B1. What is the importance of the following challenges for the urban mobility sector? Please rate the following topics from 1 (not important) to 5 (very important):

	1	2	3	4	5
Toughening/changing of environmental requirements	☐	☐	☐	☐	☐
Funding	☐	☐	☐	☐	☐
Sustainability	☐	☐	☐	☐	☐
Urban space management	☐	☐	☐	☐	☐
Interoperability of systems/organisations	☐	☐	☐	☐	☐
Electrification	☐	☐	☐	☐	☐
Road infrastructure	☐	☐	☐	☐	☐
IT-infrastructure	☐	☐	☐	☐	☐

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	1	2	3	4	5
Legislation and policies	☐	☐	☐	☐	☐
Privacy	☐	☐	☐	☐	☐
Ethics	☐	☐	☐	☐	☐
(Cyber)security	☐	☐	☐	☐	☐
Analysing (Big) data	☐	☐	☐	☐	☐
Data standardisation	☐	☐	☐	☐	☐
Open data/platforms	☐	☐	☐	☐	☐
Real-time information	☐	☐	☐	☐	☐
Use of algorithms/AI	☐	☐	☐	☐	☐
Disruptive technologies	☐	☐	☐	☐	☐
Excessive information	☐	☐	☐	☐	☐
Impact assessment	☐	☐	☐	☐	☐
Digital gap / inclusiveness	☐	☐	☐	☐	☐
Co-creation	☐	☐	☐	☐	☐
Technocracy vs. liveability	☐	☐	☐	☐	☐
Business models	☐	☐	☐	☐	☐

B2. Do you think the current attention to these problems is sufficient? Please rate the following topics from 1 (we should pay no attention) to 5 (we should pay more attention), with 3 being we are paying the right amount of attention):

	1	2	3	4	5
Toughening/changing of environmental requirements	☐	☐	☐	☐	☐
Privacy	☐	☐	☐	☐	☐
Ethics	☐	☐	☐	☐	☐
(Cyber)security	☐	☐	☐	☐	☐
Analysing (Big) data	☐	☐	☐	☐	☐

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	1	2	3	4	5
Data standardisation	☐	☐	☐	☐	☐
Open data/platforms	☐	☐	☐	☐	☐
Real-time information	☐	☐	☐	☐	☐
Use of algorithms/AI	☐	☐	☐	☐	☐
Disruptive technologies	☐	☐	☐	☐	☐
Excessive information	☐	☐	☐	☐	☐
Impact assessment	☐	☐	☐	☐	☐
Digital gap / inclusiveness	☐	☐	☐	☐	☐
Co-creation	☐	☐	☐	☐	☐
Technocracy vs. liveability	☐	☐	☐	☐	☐
Business models	☐	☐	☐	☐	☐
Legislation and policies	☐	☐	☐	☐	☐
IT-infrastructure	☐	☐	☐	☐	☐
Road infrastructure	☐	☐	☐	☐	☐
Electrification	☐	☐	☐	☐	☐
Interoperability of systems/organisations	☐	☐	☐	☐	☐
Urban space management	☐	☐	☐	☐	☐
Sustainability	☐	☐	☐	☐	☐
Funding	☐	☐	☐	☐	☐

B3. Are there any important issues/challenges that you would like to mention regarding some of the trends?

Other

Services (e.g. micromobility, MaaS, C-ITS and CAV integration)

Policies (e.g. environmental zones, accessibility, inclusiveness, congestion charge)

Traffic management (e.g. bicycle priority at intersections, road safety, traffic scenarios)

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Section C: Stakeholders

C1. **What new types of stakeholders do you observe within the urban mobility sector (may or may not be related to the previously mentioned trends) (i.e. micromobility operators, MaaS operators)?**

C2. **How has the role of the traditional stakeholders in the urban mobility sector changed during the past few years (i.e. policy makers, service operators, traffic managers, users, legislation, OEM, insurance company, etc.)?**

C3. **Do you expect an additional shift in the role of certain stakeholders in the next 10 years?**

Yes ☐

No ☐

C4. **Please elaborate briefly.**

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Section D: Tools

D1. **What mobility-related tools are available for policy makers nowadays (e.g. simulation models, dashboards, etc.)?**

D2. **Have you observed any positive shift (improvements) in the existing mobility related tools or emergence of any new tools?**

Yes ☐

No ☐

D3. **What are the main gaps in which the existing tools do not meet policy makers' expectations or needs?**

D4. **Please indicate at least two challenges/risks that are, in your opinion, the most critical and can impact existing methodological tools supporting transport/mobility researchers, planners, and policy makers.**

Challenge/risk

Challenge/risk

Challenge/risk

Challenge/risk

Challenge/risk

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Section E: Data

E1. **What new types of mobility-related data should be collected to support data driven policy making?**

E2. **What new key-performance indicators (KPIs) do policy makers need or will they focus on?**

E3. **What benefits would the aforementioned data and KPIs have on policy making?**

Section F: Concluding remarks

F1. **Do you have anything to add that may benefit our project, or things we may have forgotten?**

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Section G: Contact information (optional)

G1. Personal information:

Company/organisation

Name

E-mail

G2. What best describes your organisation?

- Policy maker
- Service operator
- Service provider
- Researcher/engineer
- Consultant
- Traffic manager
- Other

Other

G3. Are you interested in receiving our half-yearly nuMIDAS newsletter with updates on our progress, reports containing our research results, announcements of upcoming workshops, etc.?

- Yes
- No

We sincerely thank you for filling in this survey, feel free to contact us if you have any questions!