ULTIMO

Advancing Sustainable User-centric
Mobility with Automated Vehicles

DELIVERABLE

D3.7 Open Modular System Requirements, Architecture and Tools

First version

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Acronyms

ADS	Automated Driving Systems
AI	Artificial Intelligence
AM	Automated Mobility
AMB	Automated Minibus
API	Application Protocol Interface
AV	Automated Vehicle
BMM	Business Modelling Manager
CAV	Connected and Automated Vehicles
CB	Consortium Body
CERN	European Organization for Nuclear Research
D7.1	Deliverable 7.1
DC	Demonstration Coordinator
DI	The department of infrastructure (Swiss Canton of Geneva)
DMP	Data Management Plan
DTU test track	Technical University of Denmark test track
EAB	External Advisory Board
EC	European Commission
ECSEL	Electronic Components and Systems for European Leadership
EM	Exploitation Manager
EU	European Union

EUCAD	European Conference on Connected and Automated Driving
F2F	Face to face meeting
FEDRO	(Swiss) Federal Roads Office
FM	Fleet Management
FOT	(Swiss) Federal Office of Transport
GDPR	General Data Protection Regulation
GIMS	Geneva International Motor Show
GNSS	Global Navigation Satellite System
HARA	Hazard Analysis and Risk Assessment
IPR	Intellectual Property Rights
IT	Information Technology
ITU	International Telecommunications Union
LaaS	Logistics as a Service
LIDAR	Light Detection and Ranging
MaaS	Mobility as a Service
MEM	Monitoring and Evaluation Manager
MT	MobileThinking
OCT	General Transport Directorate of the Canton of Geneva
ODD	Operational Domain Design
OEDR	Object and Event Detection and Response

PC	Project Coordinator
PEB	Project Executive Board
PGA	Project General Assembly
PRM	Persons with Reduced Mobility
PTA	Public Transport Authority
PTO	Public Transportation Operator
PTS	Public Transportation Services
QRM	Quality and Risk Manager
QRMB	Quality and Risk Management Board
RN	Risk Number
SA	Scientific Advisor
SAE Level	Society of Automotive Engineers Level (Vehicle Autonomy Level)
SAN	(Swiss) Cantonal Vehicle Service
SDK	Software Development Kit
SLA	Sales Lentz Autocars
SMB	Site Management Board
SoA	State of the Art
SOTIF	Safety Of The Intended Functionality
SWOT	Strengths, Weaknesses, Opportunities, and Threats.
T7.1	Task 7.1
TM	Technical Manager
TPG	Transport Publics Genevois
UITP	Union Internationale des Transports Publics (International Transport Union)

V2I	Vehicle to Infrastructure communication
WP	Work Package
WPL	Work Package Leader

Executive Summary

This document describes the proposed system architecture and provide a first version of the policy requirements of the PTOs, based on the defined use cases and ODDs for each operator and deployment site. The deliverable is based on the work performed in T3.5 and T3.6.

In view of the fact that each operator and has a different service model and architecture already in place for its public transport service, our target is to provide a modular architecture able to allow the integration of AVs to a MaaS system, in the most economically and technically optimal method.

We start by describing the existing systems of the PTO/PTAs, related to the past deployments of AVs and the target policies for the (to come) AVs services, taking also into account results and experience from past projects.

This deliverable provides the first, starting point for the detailed definition of the ULTIMO modular architecture.

Introduction

During the past few years many projects and initiatives were undertaken deploying and testing Automated Vehicles (AVs) for public transportation and logistics. However in spite of their ambition, all of these projects stayed on the level of elaborated experimentation and never reached the level of a large-scale commercial deployment of transport services. The reasons for this are many, the most important being the lack of economically viable and commercially realistic models, the lack of scalability of the business and operating models, and the lack of user oriented services required for large end-user adoption of the solutions.

The ULTIMO project will create the very first economically feasible and sustainable integration of AVs for MaaS public transportation and LaaS urban goods transportation. ULTIMO aims to deploy in three sites in Europe 15 or more multi-vendor SAE L4 AVs per site. A user centric holistic approach, applied throughout the project, will ensure that all elements in a cross-sector business environment are incorporated to deliver large-scale on-demand, door-to-door, well-accepted, shared, seamless-integrated and economically viable CCAM services. We target the operation without safety driver on-board, in a fully automated and mission management mode with the support of innovative user centric passenger services.

ULTIMO's innovative transportation models are designed for a long-term sustainable impact on automated transportation in Europe, around the globe and on society. The composition of the consortium ensures the interoperability between multiple stakeholders by making adoption of new technology at minimum costs and maximum safety. The integration of the ongoing experiments of previous AV-demonstrator projects ensures highest possible technical and societal impacts from the very beginning of the project, as well as during the project lifetime and even long after its completion.

1.1 On-demand Mobility

Public transportation is a key element of a region's economic development and the quality of life of its citizens. Governments around the world are defining strategies for the development of efficient public transport based on different criteria of importance to their regions, such as topography, citizens' needs, social and economic barriers, environmental concerns, and historical development. However, new technologies, modes of transport and services are appearing, which seem very promising to the support of regional strategies for the development of public transport.

On-demand transport is a public transport service that only works when a reservation has been recorded and will be a relevant solution where the demand for transport is diffuse and regular transport is inefficient.

On-demand transport differs from other public transport services in that vehicles do not follow a fixed route and do not use a predefined timetable. Unlike taxis, on-demand public transport is usually also not individual. An operator or an automated system takes care of the booking, planning and organization.

It is recognized that the use and integration of on-demand Automated vehicles has the potential to significantly improve services and provide solutions to many of the problems encountered today in the development of sustainable and efficient public transport.

1.1.1 Fully Automated Vehicles

A self-driving car, referred in the ULTIMO project as a **Fully Automated Vehicle** (**AV**), is a vehicle that can sense its environment and moving safely with no human input on the vehicle.

The terms *automated vehicles* and *autonomous vehicles* are often used together. The Regulation 2019/2144 of the European Parliament and of the Council of 27 November 2019 on type-approval requirements for motor vehicles defines "automated vehicle" and "fully automated vehicle" based on their autonomous capacity:

An "automated vehicle" means a motor vehicle designed and constructed to move autonomously for certain periods of time without continuous driver supervision but in respect of which driver intervention is still expected or required.

"Fully automated vehicle" means a motor vehicle that has been designed and constructed to move autonomously without any driver supervision.

In ULTIMO we operate ***Fully Automated mini and micro shuttles for shared public transportation***. In relation to the SAE levels, the ULTIMO project will operate SAE Level 4 vehicles.

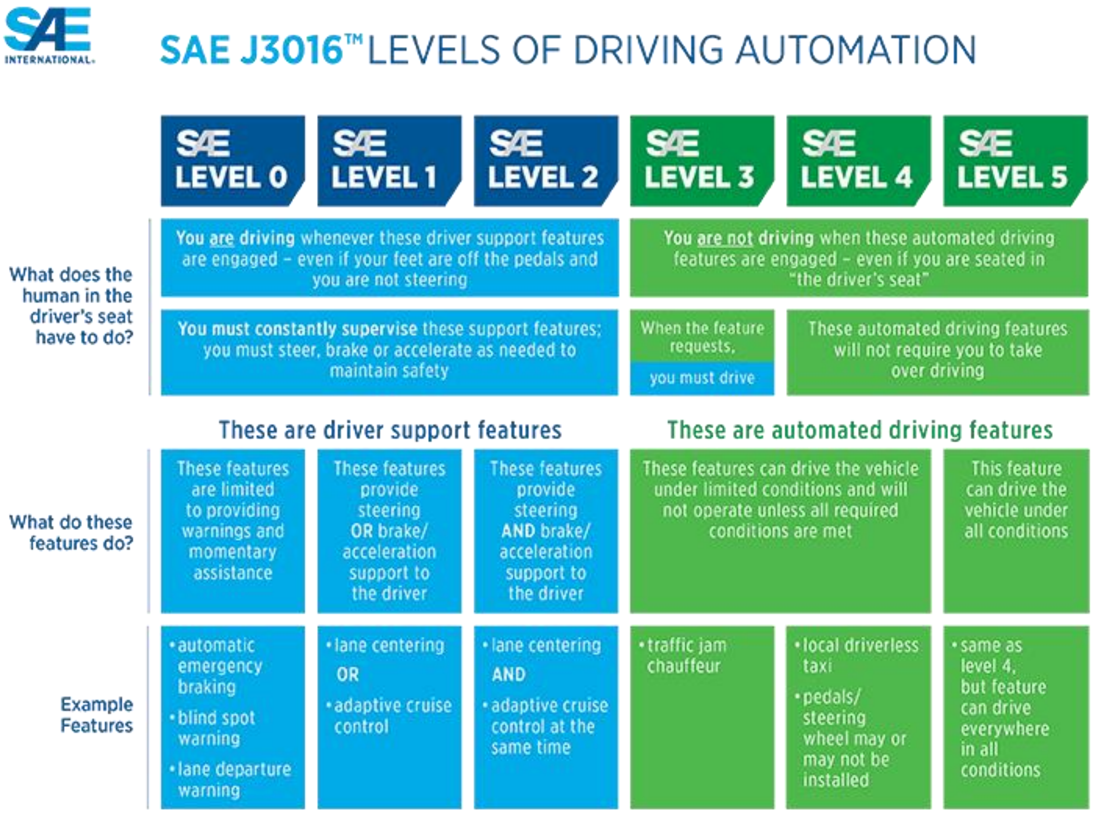


Figure 1: SAE Driving Automation levels (©2020 SAE International)

1.2 The ULTIMO dream for public transportation

Our city has a population of 700.000, and the local PTO (Public Transport Operator) deploys 3.000 Km of public transportation services' routes, with 4 backbone tram lines, 8 backbone large bus/trolley lines, and 340 fully automated multi-manufacturer mini and micro-shuttles in an on-demand, door-to-door shared public transport service. The fleet of the 340 automated mini-busses is composed of different vehicle generations and models from different manufacturers, as it was purchased in different batches during the last 12 years (it all started with the first 15 bought by a European project in 2023/24, called ULTIMO). It is today composed of the first 15 twelve-years old vehicles from manufacturer A, 160 eight-years old vehicles from manufacturer B and 160 two-years old vehicles from manufacturer A, which are the new generation of manufacturer's A vehicles. These last 160 vehicles re-placed the last 70 old, driver based, thermic diesel busses that reached the end of their life after 18 years in operation. The change from driver large busses to automated mini-buses and from fixed line service to on-demand, door-to-door, for the last area of the city, was decided 6 years ago, and was based to the great success of the already deployed AV-based ser-vices in the other parts of the city.

The integration of new vehicles in the PTO fleet was done within just a few days, thanks to the now standardised APIs of the automate vehicles' connection with the AV fleet management and orchestration service, that allows a plug-and-operate functionality, but also enables the combination of AVs with all other means of transport, offering a seamless citizen centric journey to the users. Similarly, the now standardized High Definition (HD) maps between the vehicle manufacturers, allowed us to reuse the maps created in the past for the 3.000 Kms of routes of the city, with small adaptations for the new vehicle capabilities. At the same time of the purchase of the last 160 AVs, we also switched to a new AV fleet management and orchestration service, from another provider, which offers more precise trip time estimations, considering also traffic jams in the city and weather conditions (that affect traffic in the city). The replacement was made within just two weeks, thanks to the new standardised interfaces between AV fleet management and PTO MaaS services.

Passengers are now able to reserve, via their mobile phone app, on the fly or book with pre-reservation trips from one side of the city to another, using the optimal transport mode available for them, with a combination of different transport modes, and having the automated vehicle arriving next (or almost) to their door entrance and bringing them to their final destination or to a backbone transport connection and back. All trips are offered with highly reliable and accurate transport and arrival times, based on real time, dynamic route changes of the vehicles, responding to the passenger needs. Many passenger services are available in the AVs via a mobile phone app, adapted to all passengers' needs, from special needs passengers (visually impaired, wheel-chair users, pregnant women, elderly, children), to persons transporting suitcases or a baby-stroller, providing adapted information of their trip (where to get-off, PTO general information, and even infotainment, like city related information and historical facts and anecdotes, related to their current journey and actual position).

With the full suppression of on-board operators, automated in-vehicle monitoring provides a multitude of passenger services and infotainment, which were, and are developed with a continuous collaboration and innovation between users and the PTO. An on-board unit identifies locally (that is, in the bus) incidents and events, like aggressions, vandalism, forgotten objects, littering, accidents, etc., and raises incident alarms to the PTO back-office immediately. The PTO officer at the back-office evaluates the incident and decides, based on the operator policies, what action to take: dismiss the incident, or stop the vehicle and call one of the intervention teams to go to collect the vehicle and take the required action. The back-office operator, based on the number of incidents and intervention time legal obligations, can deploy any of the 15 intervention teams available in the city, ready to reach within a few minutes any AV. At the back-office, service operators are able, with one set of screens linked to the fleet management, to follow the vehicle status, trip reservations, routes chosen, open and closed road segments (due to works, accidents, etc. thus adapting dynamically the trip routings), while in a second set of screens, the back-office operators can follow the passenger services' incidents and the status and location of the intervention teams. The two systems, although independent, are linked so that the back-office operator can intervene and transfer incidents to intervention teams and turn-on, when possible and under the local legal re-strictions, video connection to systematically inspect the incident.

The public transport services are operating 24/7 with different active vehicles, depending on passenger transport demands. The PTO, being eco-sensible, has defined that the vehicle must have an average occupancy of at least 3 passengers. This of course has implications, especially in off-peak hours, in the transport delays, but it is fully justified for an optimal and eco-responsible operation. Exceptions are made for people with special needs or when the passenger is ready to pay an additional price.

While at peak-hours the full 340 strong fleet of AVs is in service for public transportation, in the off-peak and night hours, due to the reduced transportation needs, part of the fleet is not serving passenger transportation. However, because having a vehicle waiting idly is a waste of resources, the PTO has signed an agreement with Logistics as a Service (LaaS) Service providers. During the off-peak hours the unused vehicles are dynamically chartered by the different LaaS providers to be used for other types of incidental transport of goods or even non-public transportation of passengers. Local retailers, shops and enterprises use the service, on demand with dynamic reservation, to offer home delivery of on-line purchases, or B2B delivery of goods from an urban consolidation center to the distribution center (hub, many to one or one to many [7], or even transport their VIP customers directly to their offices or exposition centers. This way they can deliver the goods to their customers in the city, with a delay of just 60 minutes with affordable prices, as the last mile is the most inefficient part of the goods delivery chain. The goods sent can include books from local bookshops or libraries, supermarket bags or even documents exchanged between companies or waste. The local shops are even using the service in the early hours (5 o'clock in the morning) for re-provisioning their shops for the day. The so chartered AVs are "returned" to the PTO for public transport at the peak-hours automatically, at the end of the chartered time period.

1.3 Preamble – Towards an open architecture

WP3 contributes to the definition of the overall system and services that need to be implemented for the creation and deployment of the target public transportation services.

The target of this deliverable series (D3.7, D3.8, D3.9) is to define the overall architecture of the platform and the transport services' policy requirement and their impact to the architecture. This first version of the deliverable describes the proposed system architecture and provides a first version of the policy requirements of the PTOs, based on the defined use cases and ODDs for each operator and deployment site. The deliverable is based on the work performed in T3.5 and T3.6.

During the explorative phase it has become apparent that the 3 pilot sites not only have different starting point in terms of dealing with on-demand transportation, but also have different models on how the business is structured. This means that this first delivery on the work performed in T3.5 and T3.6 has focused on describing the existing architecture and the individual target architecture of the 3 pilot sites.

The following deliverables 3.8 and 3.9 will focus on finding common architectural elements that will help to standardize the way "on-demand" will be operated and thus how it will help standardizing the Ultimo API for on-demand operation with AV vehicles.

2 Project Operators' status

The ambition of the ULTIMO project is to create an economically realistic and viable, large-scale and AV-based shared public transport service in different regions in Europe. It is obvious that the different PTOs and PTAs in Europe do not have neither the same needs, requirements and legal circumstances, nor same or even similar IT systems managing their existing public transportation services. For this reason, the architecture the project aims to propose must be modular and open, allowing it to be adapted and integrated in diverse existing PTO/PTA systems and environments.

Based on the above, we first defined the starting point for the architecture, and namely the description of the existing systems and architectures of the project operators.

2.1 Ruter (PTA) transportation architecture

2.1.1 Existing DRT architecture

Ruter# has been running DRT services for a number of years, and has over time introduced more services into the offering. The current DRT service implemented using the fleet orchestration software from Voyagerr, handles 3 types of trips.

All non-emergency trips in Norway are booked by **Pasientreiser**, which services all 17 regions in Norway. Execution of the trips are handled by the various operators that have contract with the regions. As such Ruter# through their subsidiary Koncentra# executes the trips in the Oslo areas. Pasientreiser is using a variant on the SUTI standard they call Nissy, it works and operates the same way as SUTI with minor special attributes and telegrams.

The Nissy gateway is a two way interface, that sends over the trips and will get confirmation on PUDO, location, vehicle doing the trip, ETA etc., which they use to keep their clients informed of the progress of their booking. Besides the local trips, some trips going to and from the hospitals in Oslo can be several hundred kilometers in length.

Special education **schooltrips** is managed in a separate Voyagerr system, that delivers travelpatterns for schoolchildren that needs special transportation or lives in locations that are not feasible to include in regular public transportation. These schooltrips are included in the pooling and matching algorithms of the fleet orchestration together with the other types of trips.

The last types of trips that are pooled together is **TT trips**, this service allows disabled citizens to book leisure trips within a individually allocated allowance.

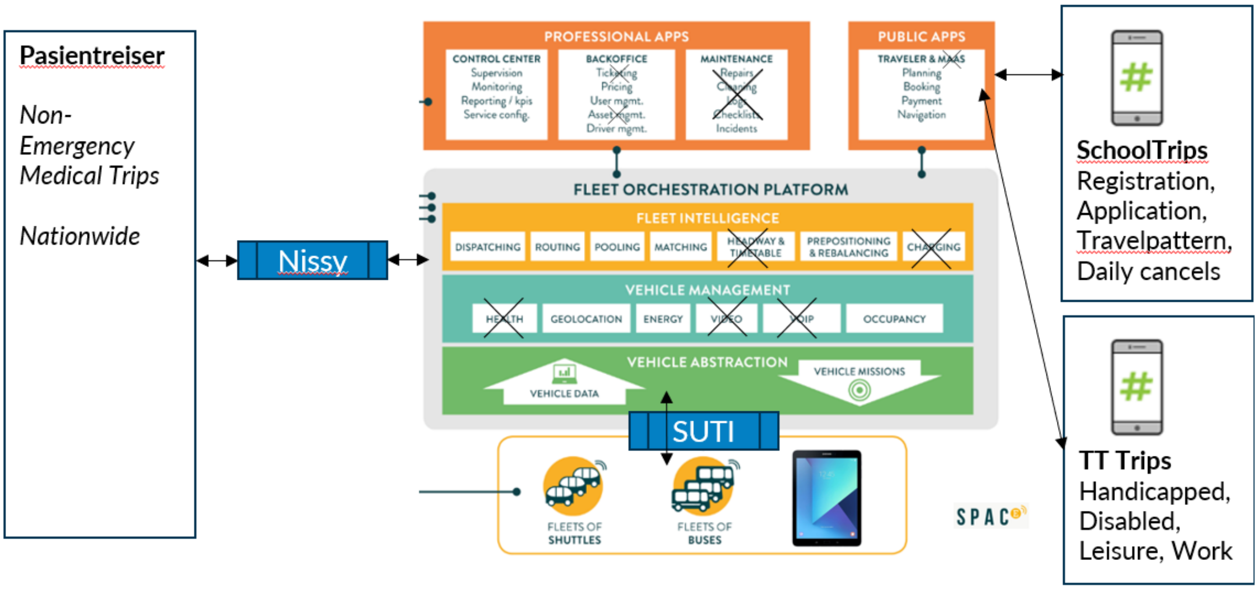


Figure 2 - Ruter's existing DRT architecture

Using the SPACe architecture, figure 2 depicts the components that are currently part of the DRT service running at Ruter#. From the control center the supervisors can monitor the execution of the trips on the street as the PUDO's are performed. Incidents can be handled by rescheduling to other vehicles or moving entire sections to a spare vehicle.

Clients booking schooltrips and TT trips, can monitor and manage their bookings through webpages and apps.

The fleet orchestration system optimizes pooling of the trips on the fleet of vehicles that is available. Availability does not mean that the actual vehicles are known, just that between 6:30 and 9:00 there is X vehicles with capacity Y from a specific operator. At the time of dispatch, the SUTI order (Mission) is sent to the operator. At that time they accept receival of the order and sometime later the assigned vehicle will be confirmed. When the vehicle is confirmed the fleet orchestration will be tracking the vehicle location and be able to send alterations and / or deviations to the assigned order.

The whole communication is done using the SUTI protocol, this allows the actual execution on the street being done independently once a mission has been assigned. Through SUTI the fleet orchestrations system keeps track of execution, possible alterrations and needed interventions.

The SUTI protocol is primarily used in the on-demand services, and as such in a closed environment. However, Ruter# as a PTA also administers regular public line based transportation and would like to have a combined overview of their services. To this end Ruter# has created the ADT digital services. The ADT is a middle layer in which SUTI- and public transportation data flows is to be captured, enabling combined monitoring of both On-Demand and Line based operations.

Ruter’s contract on digital services ADT

What is “ADT”?

A well-designed digital services agreement facilitates the specification of data requirements towards suppliers and operators. Ruter’s Digital Services Agreement (“Avtale om Digitale Tjenester” - ADT) regulates the exchange of data between a Service Provider, usually an operating company for mobility services, and Ruter. Upon entering a Transport Services Contract (TSC), a Service Provider undertakes to provide data in accordance with the Digital Services Agreement. In order for the Service Provider and the Service Recipient to be able to produce the best possible services in cooperation, the agreement regulates quality requirements for the data production/exchange between the Service Provider and the Service Recipient.

How ADT works:

- Ruter's transport service contracts require that operators sign this contract.
- ADT runs independently of the transport service contracts.
- ADT is versioned and deployed for the entire transport service portfolio.
- Operators commit to keeping up with new versions.

Functional levels

Some variations in functionality between different modes of transport and vehicle categories make it necessary to set different requirements for different vehicles. Therefore, service recipient transport service contracts may include a description of the functionality level that each vehicle type should provide. If the vehicle is expected to deliver multiple types of functions, it should fulfil all data points collectively described in the functionality level table. Service recipient transport service contracts may contain a description of the functionality levels to be met. Complete sets of functions apply unless otherwise defined.

		Schedule-based transport				On demand transport			
Category	**Protocol**	Bus	Tram	Boat	Mini	Pluss	Mini	M2Y (B2B)	Y2M
Vehicle login and log-off	MQTT	•	•	•	•				
Position	MQTT	•	•	•	•	•	•		
Odometer	MQTT	•	•		•	•			
Passenger count	MQTT	•	•	•					
Temperature data	MQTT	•	•	•					
Door status	MQTT	•	•	•	•				
Stop signal	MQTT	•	•		•				
Windshield wiper status	MQTT	•							
Accelerometer	MQTT	•				•			
Energy consumption	MQTT	•	•	•		•			
Battery level (SOC)	MQTT	A		A		•			
Charging status	MQTT	A		A					
Internal display	MQTT*	•	•	•	•				
Automatic announcement	MQTT	•	•	•	•				
Sale of tickets & validation of travel rights	MQTT*	•	G	•	•	•			
External signs	MQTT	•	•	•	•	•			
Event reporting API	HTTP	•	•	•	•	V	V	V	V
Assignments and plan-data API	HTTP	•	•	•	•				
Driving direction	MQTT		B	B					
Assignment exchange and reporting						C	C	D	E

A – For electric or hybrid electric vehicles/vessels

B – For vehicles/vessels with alternating directions

C – Assignment execution is confirmed and verified through the driver app

D – Assignments are transferred and confirmed via SUTI

E – Reports and assignment reporting through Y2M interface

G – Validation of travel rights

V – Optional

Figure 3 - Categories and functional levels of Ruter's ADT

The image shows a table that lists the different types of transportation. The table is divided into two columns: Scheduled Transportation and On-Demand Transportation.

2.1.1 Current On-demand Transport in Ruter[1]

Why Does Ruter Offer On-demand Transport?

A central element of today's public transport offering is that the main lines in the transport network should have high frequency and high capacity. By shifting attention from individual lines and modes of transport to networks with high frequency and great flexibility, more people have received an ever-better public transport service. Good accessibility for vehicles is important for a good travel network. The mobility network consists of fixed lines, On-demand transport where there is no market for fixed lines, car sharing, private car and micromobility including cycling and walking.

On-demand transport or other flexible services are being explored as a new offer to customers in sparsely populated areas, however it will not be possible to cover all transport needs with fixed lines.

On-demand transport needs to be booked in advance and picks up customers at home, at a stop or at another agreed nearby location. The departure follows a fixed route or within a pre-defined area. Some transport services run at fixed times, while other times the service has flexible departure times within fixed intervals or days. On-demand transport is adapted for wheelchairs and walkers.

A line can have multiple roles, for example, school bus can be combined with flat coverage in sparsely populated areas. In some areas, where the market is too small to have an offer with fixed lines, it may be most appropriate to establish on-demand transport. The public transport network must be built up in a way that ensures good interaction between fixed and flexible lines and between the passenger's needs.

Minimum Frequency

In Oslo, the minimum frequency is two departures per hour, but in areas with low market demand, a bus line with one departure per hour to the nearest city, station town, or larger hub should normally be a lower limit. Where the market demand does not justify maintaining this minimum frequency in the base route, alternatives such as on-demand transport, carpooling, or other flexible and more cost-effective solutions should be considered. Further development of various on-demand transport concepts and flexible lines can provide new insights and eventually change the principle of minimum frequency.

The Interaction between Fixed Lines and Flexible Services

For society, it is an advantage that as many people as possible travel by public transport, as this is both good for the environment, mobility-, energy- and and space-efficient. In addition to covering the major travel flows, Ruter must provide an offer to people living outside the major public transport routes and areas.

The offer must cover the needs for passengers of several categories: work trips and other trips, such as shopping, services, and leisure activities. An offer to people who do not get a good offer through the fixed lines, either because they live or work in areas where there is not a

[1] (*Ruters veileder for planlegging av linjenettet*, 2021)

large enough customer base, or because they have needs that cannot be met with fixed lines, can be solved with other more flexible transport services like private mobility suppliers or taxi.

Ruter is running several pilots to explore proactively different concepts for flexible services. The goal of the pilots is to gain knowledge and information that can be used to develop a toolbox for further planning and implementation of flexible services. As experience is gained from the pilots, it will be possible to develop its own principles for the development of flexible services.

Key Concepts

- **On-demand transport** is a service that only runs when there is a market need. Customers must book their trips in advance. The service may have a fixed route or operate freely within a limited geographical area. On-demand transport can provide some more flexibility with regards to the utilization of vehicles and drivers, as well as the departure time for passengers.
- **Public transport** is a mode of transportation that can accommodate many people traveling at the same time in the same vehicle. The vehicles are traditionally organized into lines that stop at predetermined places, called stops, and follow a predetermined route. In recent years, more flexible forms of public transport, such as on-demand transport, have also become part of the public transport offer.
- **Mobility network** consists of everything that makes it possible to move around in a given area. In addition to the public transport network, which consists of fixed lines and on-demand transport, the mobility network includes the possibility to rent transport vehicles such as car sharing, bicycles, or electric scooters.

  A mobility network is built up of physical components such as rails, roads, stations, bus stops and terminals, vehicles, as well as labor and plans for the mobility offer.

Existing On-demand («DRT») services in Ruter

Existing DRT services are best described in the latest tender description for minibus services in Romerike.[2] The service describes the following:

- On-demand transport in general
- School transport
- Sub-areas for the agreement
- Minibus types ("XXL" - "XL" - "L")
- Minimum compensation
- Hire times
- Distribution of full-time and part-time hire
- Booking app for customers
- Vehicle schedule
- Driver app

[2] (*Oppdragsbeskrivelse - Minibusstjenester Romerike 2023*, 2023)

- Requirements for implementation
- Digital customer experiences - on-board information, external information
- Requirements for drivers - training, customer contact, safety, language skills, geographic competence, uniforming
- Cleaning and maintenance
- Lost and found

Mandatory Services

School Transport

School bus lines transport school children to and from school. This is the only form of public transport that is obligatory in Norway. School buses may be open to other passengers, but they often have limited competitiveness against cars because the departures are few and they are adapted to student transport. Note that in urban areas, most students will travel by regular public transport to and from school.

The purpose of the school bus is to fulfill the rights of the students according to the Education Act and guidelines for school bus transport in connection with waiting and travel time, setting of school days, etc. given by Viken County Municipality.

All trips on special school bus and on-demand transport are pre-booked and planned by the school secretary's booking reception. Trips can be booked, canceled, and changed up to the travel time. The Ordering Party coordinates, plans, and mediates the vehicle runs for special school bus and On-demand transport to the individual Operators. The Ordering Party organizes and plans the booked trips into the minibuses' vehicle runs. The minibus's vehicle schedule is made available digitally.

«TT-transport»

«TT-transport» is an offer of alternative transport for people who cannot use public transport due to a disability or illness. This is a mandatory service that must be provided by public transport operators in Norway.

Ruter has the responsibility to arrange transport for people who, due to a disability, cannot travel with the ordinary public transport offering. The scheme is not based on rights in the law and operates alongside other rights-based schemes, such as the patient transport scheme for doctor's visits and treatment (patient travel), or work and education travel.

Figure 4 - TT-transport

Other On-demand (DRT) Services

«Age-friendly transport»[3]

The DRT service that was tested in Oslo starting in September 2017 and was — and still is — an age-friendly DRT service for people aged above 67. The main goal of the pilot was to provide an age-friendly transportation model that will ease the challenge for elderly to get out and socialize. Many elderly are lonesome and have problems with running errands and being part of a social life, without help for transportation. The customers were transported door-to-door within a given geographical area and they could book their trip in real time or up to a week in advance. The service was available from 10 a.m. to 6 p.m., Monday through Saturday. If there were several passengers going in the same directions, they will be picked up and dropped off along the way, which will optimize the driving logistics. The pilot ran with pink minibuses with the capacity of 15 passengers and one wheelchair. The customers booked their trip by an app or a phone call to the operation center. This concept was tested in the city center of Oslo. The pilot started in the district of Nordre Aker in 2017, followed by Sagene (2018), Vestre Aker (2019) and Ullern in 2020.

Figure 5 - Age-friendly transport

Pilot Nes[4]

Ruter started a new DRT pilot in the municipality of Nes in Viken (former Akershus) county. Nes municipality was selected based on geographical conditions, the fact that it is a low population area with scattered population, and travels constitute fairly long travel routes, and existing public transport in the area has a low customer satisfaction score. Nes is a rural municipality, and the population is clustered together in different areas. 2/3 of the citizens live in these clusters, and 1/3 of the citizens live outside of these clusters in even more rural areas.

Pilot Nes started in November 2019. The business model of Pilot Nes was inspired by the pilot for elderly in Oslo, which also aimed to enable elderly people to socialize and take control of their own lives without help from others. The pilot offered a door-to-door service with flexible routes for people above the age of sixty-seven. The passengers were picked up and dropped off where they wanted, within a predefined area in Nes municipality. If there were several

[3] (*Konseptevaluering - Ruter Aldersvennlig transport*, 2021)

[4] (*Sluttrapport - Pilot Nes*, 2022)

passengers going in the same directions, they will be picked up along the way which optimized the driving logistics. The bookings was done in real time or up to a week in advance through the app or by calling the operation center. The transportation service was available from 9 a.m. to 5 p.m., Monday - Saturday. The customers could book their trip one week prior to their trip. The customer could also reserve trips with a fixed interval (e.g., every Monday at 10 a.m.).

DRT Expansions and pilots

Activity Transport[5]

The DRT service that was tested in Bærum municipality was started in January 2018, and the pilot period ended in December 2019. From August 2020 we started a new pilot in the same area and included more activities, more schools, and more children. The service was for 2nd - 5th graders that run organized sports activities after school. The children were picked up at school and driven to the sports arenas and returned home afterwards. When the child “subscribed” to this transport, all bookings were made for the following semester. New customers could start using the service during the semester if needed. This pilot included 12 schools, around 330 children and 20 minibuses. By organizing the transport like this, we gathered many passengers in the same vehicle and minimized the need for private cars. The pilot aimed to reduce the need for private cars, as well as make children develop good travel habits at an early age. The service ran Monday-Friday, and the children were picked up from their schools so that they arrived in time for practice at 2.30 p.m. Practice ended at 4 p.m. and the children were then driven home.

Pilot Oppegård[6]

The DRT service tested in Oppegård municipality, started in September 2019, and takes costumers from virtual stops that can be their home address, sports arenas or other social meeting areas. Bookings are made in real time in a service specific application. Pilot Oppegård is uses a fully automatic solution for planning and booking. The main goal for the pilot is to test the digital plan system solution for booking and route planning. The service is open to everyone, but the main target group is young technologically adept users, aged between 8-12 that need transport for their sport activities. Customers book their trip through the app and the bus arrives within a few minutes, with an estimated waiting time between 4 and 8 minutes. The pilot’s opening hours are between 4 p.m. to 9 p.m.

[5] (*Evalueringsrapport - Aktivitetstransport - Pilot Stabæk - Pilot VIF - Pilot Fet*, 2019)
[6] (*Midtveisrapport - Pilot Oppegård*, 2020)

Figure 6 - Activity transport

Today's service offered in Viken does not meet the mobility needs of the residents, and to solve this, Ruter must offer a user-adapted and individualized offering that makes public transport an attractive alternative to the private car.

Scaling up DRT – a Concept and KPIs[7]

On-demand transport is considered a key element for meeting future needs and for achieving strategic goals for Ruter. Based on learning from previous pilots, a new concept for On-demand transport in Viken has been developed.

Today's mobility solutions are facing major changes driven by the desire for more sustainable solutions, technological development, new business models, and changing customer expectations.

Electrification: The transition to renewable and sustainable energy
Self-driving transport: Automation and autonomy
Intelligent interaction: Interactive intelligent transport systems
New business models: Individual-oriented business models tailored for sharing mobility services

These trends provide opportunities for shared mobility and a blurring of the current sharp distinction between private transport and public transport. This can also provide new opportunities for residents to live without owning a car, but it also means that the position of public transport companies can be challenged by other companies that adopt new technology and become able to offer services that match or are better than the services that public transport companies offer today.

2.1.2 Ruter needs and target MaaS service

Introduction

Public transport today consists of many different travel modes, e.g., fixed-line train, bus, and ferries as well as more dynamic modes e.g., DRT shuttles and taxi. Traditional journey planners

[7] (Heidi Aakre Juvik & Andresen, Madeleine Bundli, 2022)

are often able to propose journeys across some different modes, e.g., train and bus, but these are typically based on static information such as schedule datasets, or at best, a snapshot of the state of the transport network at the time of booking. Once the booking is made, the proposed trip plan remains fixed, regardless of any delays, broken connections, etc. Integration of dynamic DRT services is also often lacking, preventing true intermodal planning with DRT in any of the journey legs.

To offer a more seamless journey experience, the entire transport network, including both DRT services and the fixed-line network, could be treated as a (large) dynamic multimodal DRT service. This requires an overarching *orchestrator* to continuously monitor the state of the entire transport network across all modalities, and the validity of all proposed journeys. In case of delays or broken connections, updated journey proposals are provided.

Ruter aims to evolve its backend IT architecture to support such dynamic multi-modal planning, (including on-demand operations with autonomous vehicles) and has ideated a multi-modal and multi-operator model that can be used as a basis when developing a target architecture. This document describes the model and its parts and serves as guidance in further dialogue between Ruter stakeholders e.g., IT architects, and key technology suppliers e.g., DRT system suppliers.

Computing shortest paths with Orchestrator and Soloists

To manage the computational complexity of treating an entire transport network as a dynamic and multimodal DRT service, Mobility Research has proposed a multi-level and graph-based approach where an overarching *orchestrator* handles planning at the highest level, but delegates detailed and local planning to the individual modalities, here referred to as *soloists*[8].

Examples of soloists are DRT services with human or autonomous drivers, fixed-line bus networks, or fleets of city bikes. Several soloists can also be of the same transport mode but serve different geographical areas. The *Orchestrator* has information about all soloists and their connectivity at a macro level and can compute an optimal sequence of soloists to get from point A to B. Figure 7 shows examples of multimodal paths from A to B via sequences of soloists, coordinated by an orchestrator.

[8] Detti A, Tropea G, Blefari Melazzi N, Kjenstad D, Bach L, Christiansen I, Lisi F. Federation and Orchestration: A Scalable Solution for EU Multimodal Travel Information Services. Sustainability. 2019; 11(7):1888. https://doi.org/10.3390/su11071888

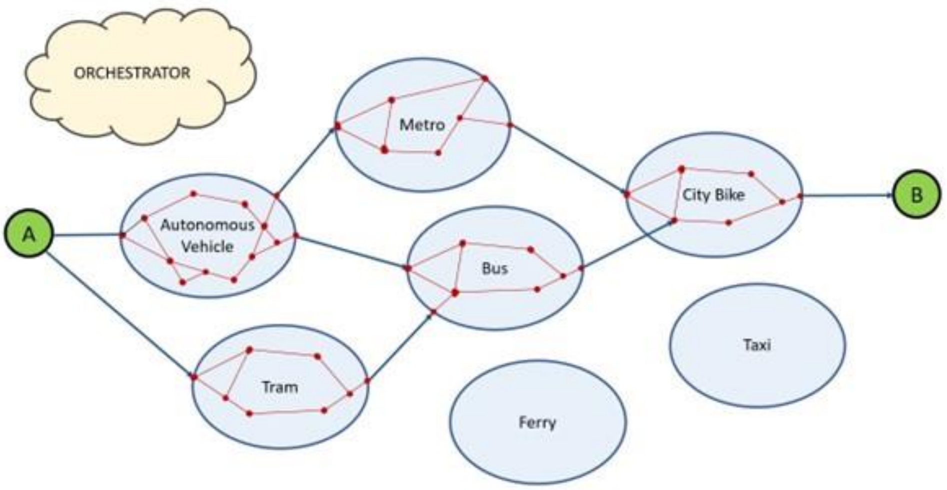


Figure 7 - Multimodal paths via sequences of soloists (blue) are coordinated by an orchestrator (yellow). Local paths (red) are computed locally by the soloists.

Multi-Modal and Multi-Operator Model

Below figure shows a model proposed by Ruter to realize dynamic multimodal journey planning with the orchestrator-soloist pattern. Parts of the model are inspired by UITP's target architecture for operations with autonomous vehicles, see Appendix. A central orchestrator coordinates multimodal planning at the top level and delegates detailed local planning to soloists, which could be several separate transport operators/providers (PTO).

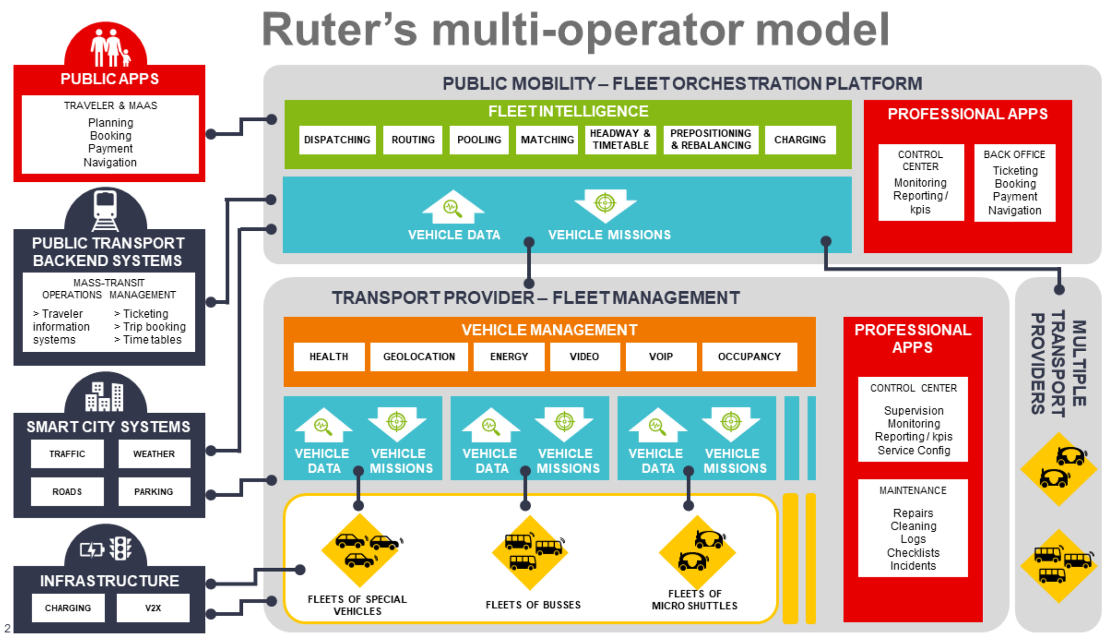


Figure 8 - Ruter's multi-operator model with a central fleet orchestration platform, and multiple transport operators/providers.

Definitions

This section describes the different parts of the multi-operator model shown in Figure 8.

Public Apps

Public Apps are available for download from e.g., Google Play or AppStore for smartphone use, or accessed directly on the web. They are intended for end-users and include functionality for ride search and planning, navigation, bookings, payment, ticketing, etc. Public apps can be developed in-house or provided as a white-label solution by a 3rd party supplier.

Public Transport Backend Systems

Public Transport Backend Systems manage timetables, bookings, and ticketing for a line- and schedule- based mass-transit public transport network, typically including trains, trams, buses, and ferries.

Smart City Systems

Smart City Systems leverage Internet of Things (IoT), data analytics, sensors, and connectivity to collect and analyze data, enabling cities to make informed decisions and improve various aspects of urban living. A central fleet orchestration platform can improve its optimizations and predictions by leveraging real-time smart city data e.g., traffic flows, weather, road conditions, and parking.

Infrastructure

Infrastructure relates to physical installations supporting the transport operations, such as charging and maintenance depos, robust and high-speed wireless networks, and communication between vehicles and roadside sensors, traffic signal systems, as well as other vehicles (V2X).

Fleet Orchestration Platform

The Fleet Orchestration Platform has access to and maintains updated real-time information about the current state of all transport modalities, including schedules and delays, ride requests, vehicle GPS positions, fuel- and charge levels, as well as maintenance needs. With this information, it can enable bookings, holistic analysis, predictions, and optimizations across the entire transport network, including traditional line-based and scheduled transport, as well as dynamic DRT services, both with human driven and autonomous fleets.

The Fleet Orchestration Platform can submit vehicle-missions with capacity demands, time and place for pickup and drop-off to one or multiple transport providers, and the transport provider(s) responds back with proposed solution(s). The orchestrator then evaluates all responses and confirms/books and orchestrates the preferred solution.

As part of, or closely integrated with the Fleet Orchestration Platform, a Mobility integrator integrates multiple Mobility (e.g., micro-mobility) and DRT systems while presenting a single API gateway to the orchestrator, see example architecture in Figure 3. The Mobility integrator can also contain an availability prediction model to minimize the blocking of vehicles while users consider proposed journeys, which is the case in most DRT systems today. Such availability prediction typically requires a fleet of at least 100's of DRT vehicles to function well. Lastly, personal data such as user's names can be hashed/anonymized in the requests to the (often cloud-hosted) DRT systems for data privacy compliance.

Transport Provider

A Transport Provider manages and operates human driven and/or autonomous On-demand fleet(s). It manages everything to keep the fleet operational, including vehicle cleaning and maintenance, incident response, fleet monitoring and remote assistance of autonomous vehicles.

The transport provider receives vehicle-missions with time and place for pickup and drop-off from the fleet orchestration platform and responds back with proposed solution(s). The orchestrator then accepts a preferred solution or rejects the proposal(s). The transport provider also continuously makes available real-time vehicle data to the orchestrator.

Professional Apps

Professional Apps support various business-related tasks and processes, such as user management, maintenance management, traffic monitoring, payments, etc. Professional apps can be developed in-house or by a 3rd party supplier.

Differences between AV systems and traditional DRT operators

The communication patterns between DRT and AV systems resemble those between DRT systems and traditional DRT operators. Differences exist, however.

Since there is no human driver present that can manage onboard emergencies e.g., a passenger getting sick, or a passenger requesting an emergency stop, a set of prioritized message patterns must be established to support such emergency situations.

For autonomous vehicles, no established messaging standards such as SUTI[9] exist today, it is an important area for future work. Today, AV suppliers typically implement their own protocols, and DRT system suppliers make ad-hoc adaptations. To manage the lack of standards, an AV integrator module/middleware can serve as an adapter between the DRT and AV management systems based on standards to the largest extent possible, see example architecture in Figure 9.

Finally, AV systems maintain a high definition (HD) map of the operational area including not only the geography of the road network, but also locations of traffic signs, road markings, etc. Such maps are needed for the AVs to operate robustly and safely. During operation, the autonomous vehicles continuously collect data to keep the HD map updated. The DRT system also maintains a map for routing optimization, with less details than the HD map. Real-time updates from the AV management systems on changes in the road network (e.g., construction work, blockage of a road, etc. detected by the vehicles out on the roads) should be fed back continuously to the DRT system to keep the routing map and HD maps in sync.

Example Use-Case of Multi-Modal and Multi-Operator booking

We here exemplify the fleet-orchestrator, multi-modal, and multi-operator concepts presented in the previous sections with a use-case. To clarify the use-case Figure 9 shows an example of an architecture based on the multi-operator and multi-modal model, with data flows between the parts shown as arrows numbered 1-29. Each data flow is defined and

[9] www.suti.se

exemplified in Table 1. Each request or data transfer in the use case refers to their respective data flow number.

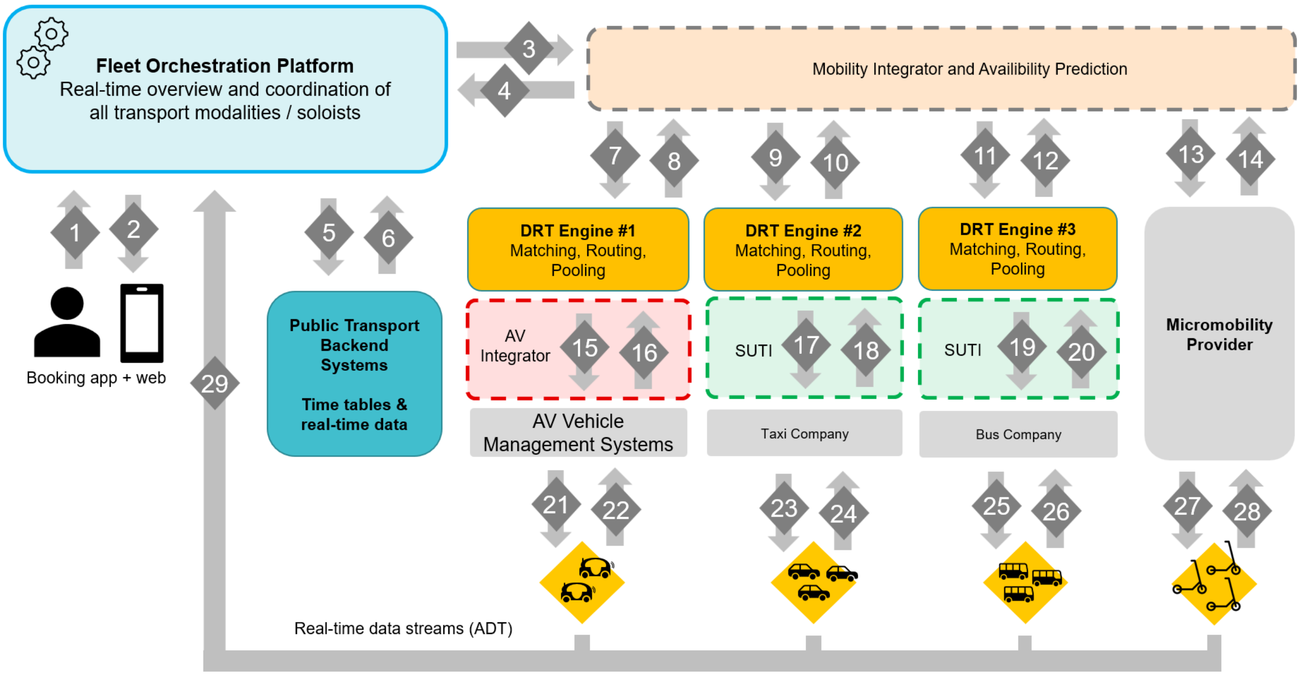


Figure 9 - Example of a multi-modal and multi-operator architecture with a fleet-orchestrator. Data flows are shown as arrows numbered 1-25.

Use Case Description

- A user logs into the booking app (or web) and requests a journey from his home address to the local shopping center. The request is sent to the fleet orchestration platform (1).
- The orchestrator makes a top-level routing to identify the chain of modalities/soloists involved in taking the user from his home to the shopping center. It finds a possible journey chain starting with a shared autonomous vehicle (SAV) ride, followed by a ride with the metro.
- The orchestrator delegates the detailed within-modality planning to the metro (5) and DRT soloists (3) for their respective journey legs.
- The Mobility integrator (DRT soloist) receives the request (3) and responds that from experience it can provide an SAV to fulfil the request with 95% confidence (4). It does this without interaction with the integrated DRT services, and without booking/locking any vehicle.
- The metro soloist receives the request (5) and confirms it can fulfil the request (6).
- The orchestrator proposes the detailed multi-modal journey to the user (2).
- The user confirms the journey and books the ticket (1).
- As the user confirms the booking, a booking confirmation is passed from the orchestrator to the Mobility integrator (3), which passes it on an SAV operator (7).

- It turns out that despite the 95% confidence, the SAV operator responds that this time no SAV is available (8). The Mobility integrator then instead passes the request on to a taxi service (9), where vehicles are available, and a booking confirmation is returned to the Mobility integrator (10) and on to the orchestrator (4).
- Updated information is presented to the user (2) who starts waiting for the taxi.
- The taxi picks up the user.
- Real-time information about vehicle position is continuously made available to the fleet orchestration platform (25) and shown in a live map in the user app (2).
- Halfway to the metro, the orchestrator receives updated information about significant delays on the metro line serving the last leg of the journey (6).
- The orchestrator determines that the optimal path is now via the ongoing taxi to a bus stop, where a bus will take over and serve the last leg. The user would have missed the bus according to the schedule, but the orchestrator knows the bus is five minutes late and will fit perfectly with the arrival of the taxi.
- The user gets an update (2) and prepares to get on the bus instead of the metro.
- The user gets on the bus, which takes the user to the end destination.

Data Flow #	Description	Example data / signal
1	**Fleet orchestrator from User App & web**	Booking request
2	**Fleet orchestrator to App & web**	Journey proposals, booking confirmation
3	**Fleet orchestrator to Mobility integrator**	DRT requests
4	**Fleet orchestrator from Mobility integrator**	DRT preliminary booking confirmations (based on predictions), DRT final booking confirmations
5	**Fleet orchestrator to Public transport backend systems**	Routing requests within fixed line modalities / soloists e.g., metro.
6	**Fleet orchestrator from Public transport backend systems**	Routing proposals, real-time delay updates.
7	**Mobility integrator to DRT engine #1**	Booking requests, routing requests
8	**Mobility integrator from DRT engine #1**	Booking confirmations, booking rejections, routing proposals
9	**Mobility integrator to DRT engine #2**	Booking requests, routing requests
10	**Mobility integrator from DRT engine #2**	Booking confirmations, booking rejections, routing proposals
11	**Mobility integrator to DRT engine #3**	Booking requests, routing requests
12	**Mobility integrator from DRT engine #3**	Booking confirmations, booking, rejections, routing proposals
13	**Mobility integrator to Micromobilty provider**	Booking requests, routing requests
14	**Mobility integrator from Micromobilty provider**	Booking confirmations, booking, rejections, routing proposals

Data Flow #	Description	Example data / signal
15	**DRT engine #1 to AV vehicle management systems**	Vehicle missions, i.e., drive passenger from A to B. Signals are passed via an AV Integration layer compatible with multiple AV suppliers' management systems.
16	**DRT engine #1 from AV vehicle management systems**	Real-time vehicle telemetric data, e.g., vehicle position. Real-time map updates e.g., construction work, or other blockages. Completion of vehicle missions. Signals are passed via an AV Integration layer compatible with multiple AV suppliers' management systems.
17	**DRT engine #2 to Taxi company #1**	Vehicle missions, i.e., drive passenger from A to B. Signals are passed using the SUTI standard.
18	**DRT engine #2 from Taxi company #1**	Real-time vehicle telemetric data, e.g., vehicle position. Signals are passed using the SUTI standard.
19	**DRT engine #3 to Bus company #1**	Vehicle missions, i.e., drive passenger from A to B. Signals are passed using the SUTI standard.
20	**DRT engine #3 from Bus company #1**	Real-time vehicle telemetric data, e.g., vehicle position. Signals are passed using the SUTI standard.
21	**AV management systems to Autonomous Vehicles**	Vehicle missions.
22	**AV management systems from Autonomous Vehicles**	Real-time vehicle telemetric data, e.g., vehicle position, battery level, maintenance need.
23	**Taxi company #1 to Vehicles**	Vehicle missions. Messages to driver.
24	**Taxi company #1 from Vehicles**	Real-time vehicle telemetric data, e.g., vehicle position. Messages from driver.
25	**Bus company #1 to Buses**	Vehicle missions. Messages to driver.
26	**Bus company #1 from Buses**	Real-time vehicle telemetric data, e.g., vehicle position. Messages from driver.
27	**Micro mobility to central hub**	Micro missions. Messages to central hub.
28	**Micro mobilty from central hub**	Messages from central hub to fleet management platform.
29	**Autonomous Vehicles, Taxi, Buses, and Micro mobility to Fleet Management Platform**	Real-time telemetric vehicle data e.g., position, battery level, maintenance need, number of passengers in vehicle. The data adheres to Ruter's data specification ADT.

Table 1 - Data flows

2.1.3 Policies for public transportation

Today's transport solutions are facing major changes driven by the desire for more sustainable solutions, technological development, new business models, and changing customer expectations. In order to continue to offer a good and stable mobility offering in the greater Oslo region, Ruter must adapt to these changes.

Ruter's vision is to create sustainable mobility in the greater Oslo region. We are an important societal actor that contributes to making the greater Oslo region an attractive area to live, work, and vacation in. In order to succeed in the future, we must supplement traditional public transport with new services and solutions. We develop these in collaboration with customers and partners.

Ruter sees shared self-driving vehicles, door-to-door transport, and other green mobility forms as an important part of the future mobility offering and therefore wants to take a forward-looking and active role in developing an attractive and customer-oriented shared booking service based on self-driving.

If Ruter does not take responsibility for how shared autonomous vehicles should be integrated as part of public transport, trends indicate that ride-hailing apps and private autonomous vehicles in the future will lead to increased car use, more traffic congestion, and more traffic noise.

A commercial offer will probably not stimulate carpooling, but will reinforce the "Robotaxi" business model.

Private, self-driving vehicles will increase the burden on our roads due to empty driving. There is reason to fear that car use in such a scenario will be significantly higher than where public transport takes most of the urban transport.

2.1.3.1 Regulatory Framework for Public Transportation in Ruter’s Operational Area

Ruter operates under a «central planning with route-by-route contract tendering» model. This means that Ruter plans and oversees the public transportation network, but it contracts private companies to operate the individual routes.

- Ruter is responsible for planning and overseeing the public transportation network. This includes determining the routes, frequencies, and fares of public transportation services.
- Ruter contracts private companies to operate the individual routes. These companies are responsible for providing the vehicles and drivers necessary to operate the services.
- Ruter monitors the performance of the private companies and takes action if they are not meeting their contractual obligations. This may include issuing fines or terminating contracts.

- Ruter is funded by a combination of fares, subsidies from the government, and advertising revenue.

2.1.3.2 Main Differences in Regulatory Framework[10]

Public-Private Partnerships (PPPs)

PPPs can be used to combine the strengths of the public and private sectors to deliver public transportation services. In a PPP, the government typically retains ownership of the infrastructure, while a private company is responsible for operating and maintaining the system. PPPs can be an effective way to finance new infrastructure and improve the efficiency of public transportation services.

Public Company

A public company is a transportation provider that is owned and operated by the government. The government has direct control over the company's operations, including its routes, fares, and service levels. This type of ownership structure can be beneficial because it allows the government to ensure that public transportation is accessible and affordable for all citizens. Additionally, public companies can be more accountable to the public and more likely to invest in long-term infrastructure improvements.

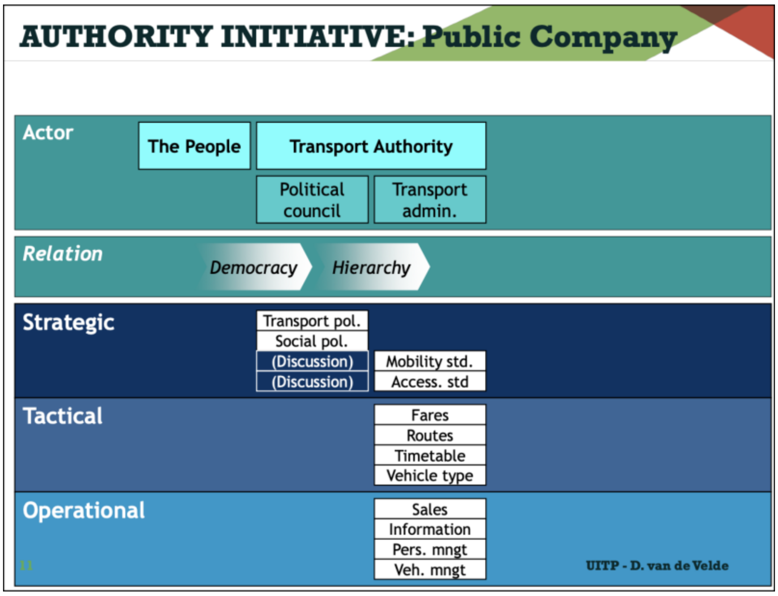


Figure 10 - Public company regulatory framework

Central Planning with Route-by-Route Contract Tendering

Under central planning with route-by-route contract tendering, the government plans and oversees the public transportation network, but it contracts private companies to operate the

[10] Information from (Velde, Didier van de, 2016)

individual routes. This approach can be more efficient than running a public company because it allows the government to take advantage of the expertise and economies of scale of private sector operators. Additionally, it can give the government more flexibility to adjust service levels and routes in response to changing demand.

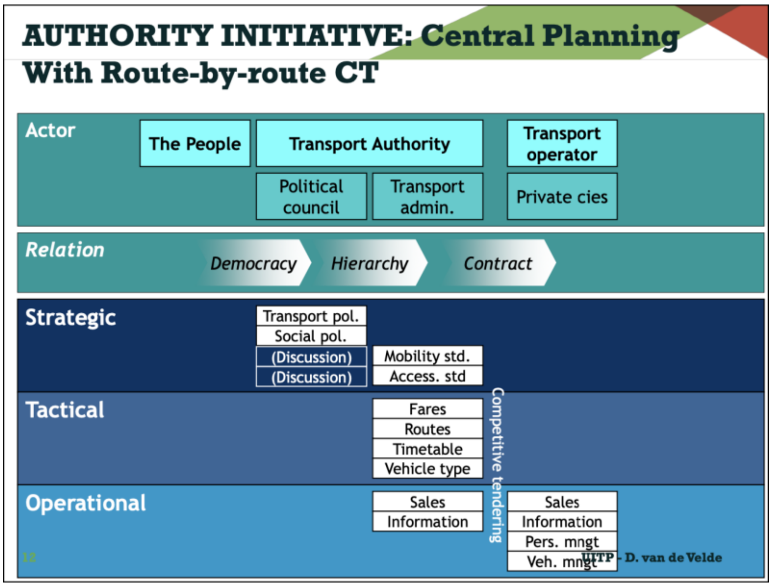


Figure 11 - Regulatory framework for Central Planning with route-by-route CT

Comparison of the Two Approaches

Feature	Public Company	Central Planning with Route-by-Route Contract Tendering
Ownership	Government	Private
Control	Government	Government (planning) and private (operations)
Accountability	Public	Private (to government)
Investment incentives	Can be more likely to invest in long-term infrastructure	May be more focused on short-term profits
Efficiency	Can be less efficient due to government bureaucracy	Can be more efficient due to private sector expertise
Flexibility	Can be less flexible due to government oversight	Can be more flexible due to private sector autonomy

Table 2 - Comparison of regulatory frameworks

2.2 DB Regio (PTO) transportation architecture

Deutsche Bahn (DB) is pursuing ambitious growth targets with its Strong Rail, DB's overarching strategy (DSS). Integrated rail and road services are essential for this, in order to enable easy-to-use, door-to-door mobility in line with demand.

With DB Regio Bus and other owned software companies focusing on relevant mobility services, user applications and background systems, DB has the necessary core components to make these services accessible quickly and across the country. The aim is a targeted market development of DB's road-based units through closer integration (MaaS) and common objectives as well as an overall focus on the For Strong Rail target of 300 million additional passengers through new forms of mobility.

All road-based activities are bundled under the umbrella of "DB Regio Straße". This enables future-oriented and effective cooperation between the Regio Bus and software units, utilizing the support and governance functions of DB Regio's headquarters.

The joint business model will be geared towards the development and operation of integrated mobility solutions. The cooperation will be structured along the business and governance processes of the joint strategic business model for integrated mobility solutions in order to combine a standardized approach in the market ("acting like one company") and a higher operational speed with short decision-making paths.

The transport industry in Germany is undergoing substantial change. In view of the climate crisis, there is an urgent need to shift to climate-friendly modes of transport. To this end, a targeted expansion of public mobility services is unavoidable.

At the same time, new technologies are driving an expansion of mobility services and the increasing importance of digitalisation in the transport industry. The necessary modal shift will also be accelerated by the introduction of the Deutschlandticket[11].

The key to improving transport services is the greater integration of rail and road services. In order to achieve this and finance the improvements in services, significant increases in efficiency through innovation and digitalisation are required - including the expansion of demand-oriented transport. Given the disruptive effect of the Deutschlandticket on existing contractual relationships and financing instruments and the inadequate instruments for financing road-based mobility, there is also a clear need for further development of the existing financing regime.

This is where the DB Regio business unit (BU) sees the opportunity and need to actively shape market development and position itself as THE provider of integrated everyday mobility.

DB Regio is building on an integrated market perspective for rail and road within the BU. In addition to targeted, overarching market and industry communication, the BU focuses on

[11] The Deutschlandticket is a monthly or season ticket for regional and local passenger transport valid throughout Germany. It is valid for second-class travel on all local transport in Germany, such as regional trains, suburban trains, underground trains, trams and local buses. Source: https://de.wikipedia.org/wiki/Deutschlandticket

customer-centric innovations and consistently exploits the opportunities offered by digitalisation, thus becoming a driver of change in the mobility market - with new growth potential and entirely in the interests and for the benefit of passengers. The aim is to actively develop the market into an integrated public transport market for rail and road.

DB Regio is a public transport company that offers public transport services with its own vehicles. In addition to a central organisational unit, DB Regio AG, based in Frankfurt and Berlin, rail and bus operations are divided into independent regional and local companies with own local and regional IT departments. These operate in very different framework conditions (requirements of the passenger transport authorities – also on digital services, status of digitalisation in the companies, etc.).

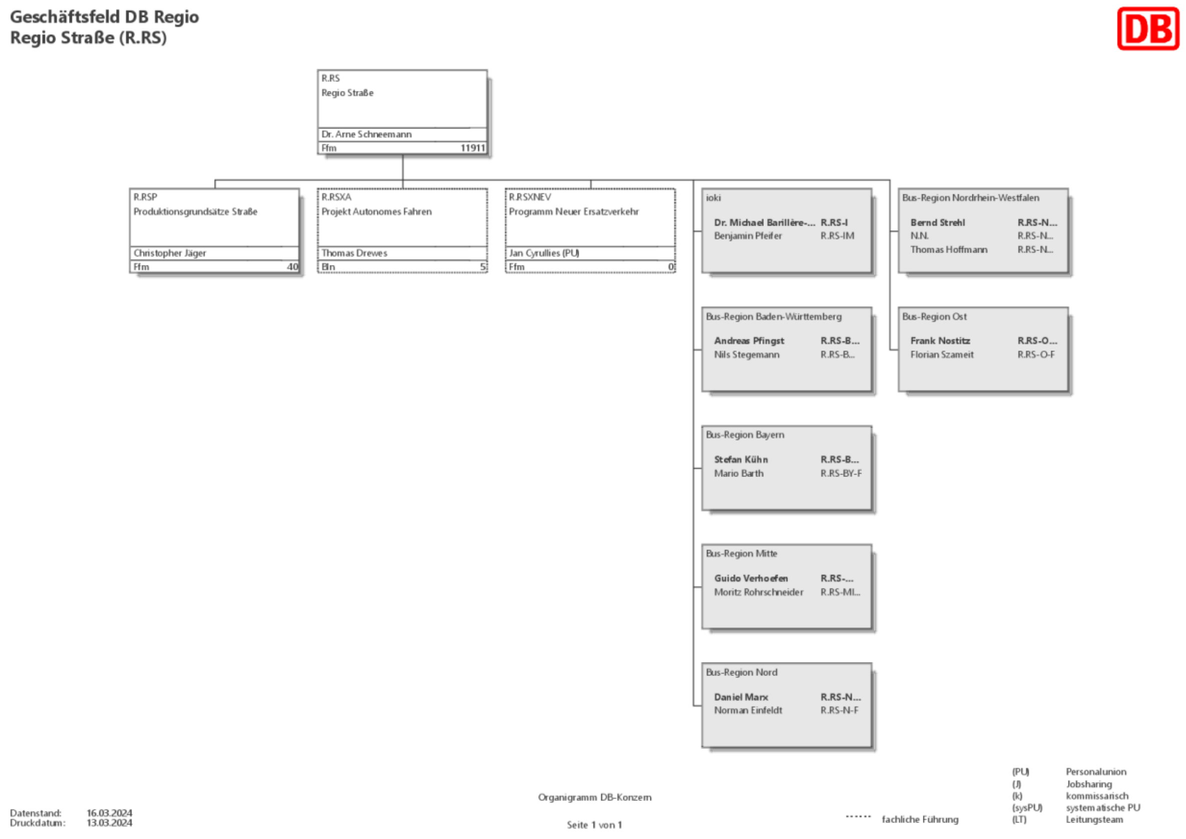


Figure 12 - Organisational Chart DB Regio Straße

The transformation and future process for DB, which started in 2022, means that the integration of automated vehicles into operations is at the very beginning. There is no harmonised concept and requirements at either strategic or operational level. Let alone a harmonised and uniform system architecture. However, the Ultimo project has now set this development process in motion and a project initialisation is currently underway to drive forward product and IT development in parallel with our project. The demo site in Herford is therefore perfect for testing the transformation of a regional bus operating unit in Ultimo as an example.

The Herford region is a special case from DB Regio Bus's point of view, as we act as a PTO for the bus operations of various passenger transport authorities in both the city and the administrative district. In collaboration with our local branch of DB Regio Bus we integrate the

Ultimo Shuttles in the existing public transport system as well as other available mobility services to reach the project goal of AV in MaaS.

After a quarter of a year of initial project work at the Kronach site, we have decided to look for another test area that better meets the requirements of the Ultimo project (described in more detail in the project management report), so we are currently in the middle of the project start phase with the local stakeholders. We are in the route and operating form determination phase and are in the process of gathering information on the local IT systems. We can therefore only provide an initial rough overview below.

The description of the planned forms of operation and services have not yet been agreed with all stakeholders and are initially proposals from the core project team of DB Regio.

DB Regio target service will be to offer AV in MaaS in the end of 2025 or beginning of 2026. At the start of the test phase in autumn 2024, one or two mini-buses (depending on the purchase or rental price) with level 2 to 3 automated driving will start operating on a route in the urban area around the hospital in order to introduce the population and all other stakeholders to this new technology and to gather initial findings for the development of a level 4 fleet and new developments for operation within Ultimo (technical remote monitoring, etc.). The manufacturer selection and tendering process is currently underway.

2.2.1 DB Regio existing architecture

Due to the very fragmented public transport system in Germany with very different requirements of the local and regional PTAs, DB Regio Straße has not yet had a standardized and comprehensive system architecture. Work is currently underway to standardize and modernize the IT systems, at least at federal state level. Both on the part of DB Regio and the passenger transport authorities of the federal states. Individual solutions have also been developed and used in previous research and funding projects to operate AVs and make on-demand transport services bookable for passengers. Below is an architectural concept that was developed in the first DB Regio research project for automated driving in Bad Birnbach. It is an on-demand system for connecting the center of Bad Birnbach with a medical and health center next to a thermal spa on the outskirts of the town.

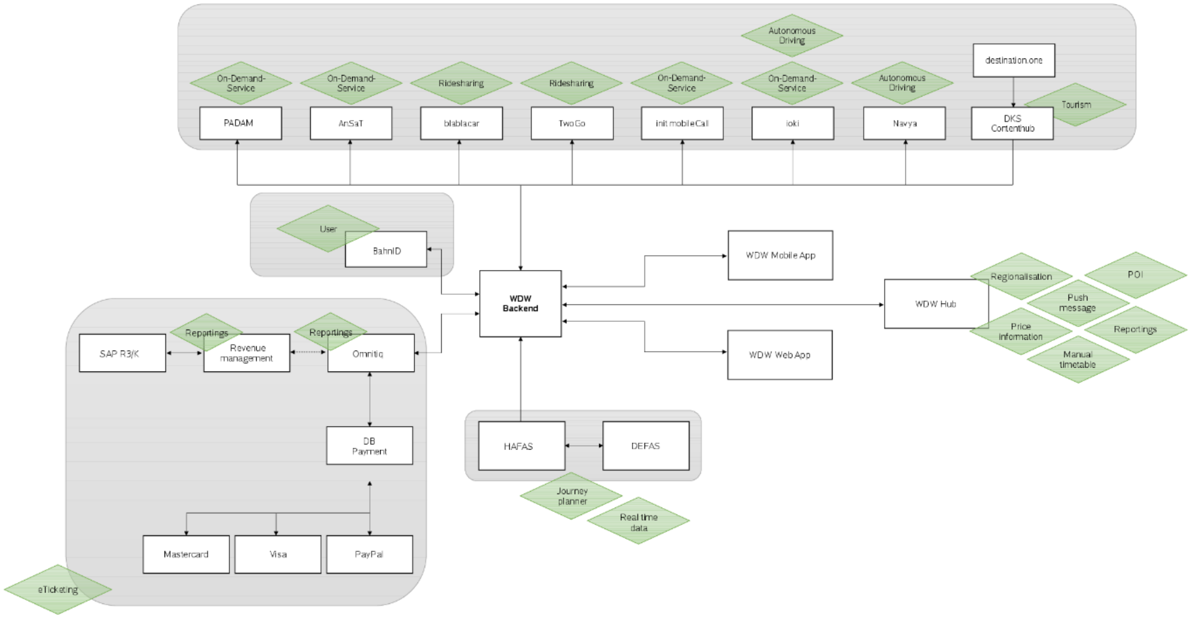


Figure 13 - DB Regio Bus System Architecture On-Demand Service Bad Birnbach with MaaS-App "Wohin Du Willst"

The DB Regio MaaS App "Wohin-Du-Willst" (WDW) was originally launched in 2016 as a MaaS-platform to enable the booking of on-demand transport with a focus on rural areas. The original intention was to create an alternative way of booking shared taxis via an app rather than by telephone, as is traditionally the case. During development, WDW is also always involved in research projects in various areas, such as autonomous driving, as part of DB's "Innovative Transport Concepts" department. As a result, autonomous shuttles have been integrated into the journey booking system as part of the "HEAL" research project and on-demand transportation services in rural areas.

In addition to regular timetable information, ticketing and real-time information via push notifications, the app itself also offers the "Address to address" service, which enables users to travel from one address to another, with the app suggesting optimal routes and means of transport. Users can select any location throughout Germany. Depending on the local transport options available, the WDW app integrates various forms of public transport such as shared taxis, on-call buses, rail connections and private providers such as BlaBlaCar and Twogo.

In the meantime, the app has developed into a frequently used commuter app, which is also often used for school transport. At the latest with the app's feature of being able to purchase the Deutschland Ticket, the business model of WDW not only includes sales to the districts, but increasingly also to the end users, which is why the number of users has increased many times over since 2022.

As described at the beginning, there is no standardised IT system landscape at DB Regio Bus, as the requirements of the passenger transport authorities differ greatly from region to region and the systems must be aligned accordingly. There has also been no digital linking of the different modes of transport to date. Only timetable data and real-time information must be fed into two different data hubs (e.g. HAFAS). This means that various public and private timetable information systems can access it via an API. There are efforts to make further mobility data generally available in data pools such as Mobility Data Space (using Gaya X technology https://mobility-dataspace.eu), but progress is slow (already identified for Ultimo as a potential data source to be connected. One project currently being worked on by DB Regio Bus in NRW is a standardised system for passenger information, ticketing, and maintenance. This is explained in the diagram below.

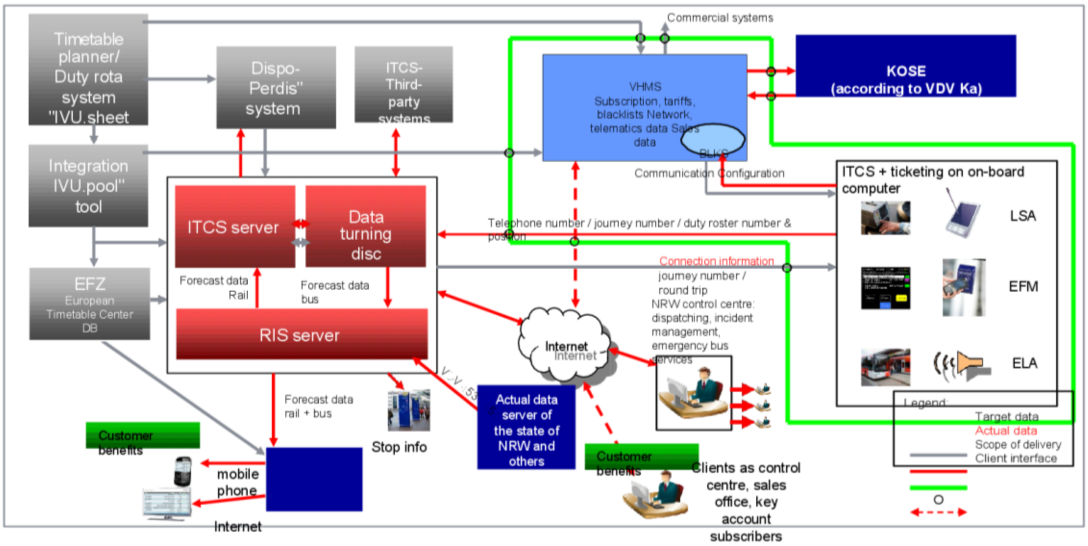


Figure 14 - DB Regio Bus NRW architecture of a state-wide electronic fare management system including inspection technology and integrated sales function.

Another special feature of the German public transport market is the existence and increasing expansion of transport associations. This association is intended to counteract the current jungle of fares offered by the individual transport companies and to improve and strengthen the region's public transport services and make them easier to use. Herford is connected to the VRR (Rhine-Ruhr transport association) in accordance with its location. This also offers customers its own VRR app with timetable information, real-time data and ticketing. However, as a PTA, Stadtverkehr Herford is also a member of the cooperation OWL mobil, an OWL mobil is a cooperation between Minden Herforder Verkehrsgesellschaft mbH (mhv) and the Ostwestfalen-Lippe transport association (VVOWL). Herford has made a conscious decision to use the OWLapp – a joint brand developed by the districts of Minden-Lübbecke, Herford and Gütersloh, as it is easier to have a say in development here. So far, the app only offers on-demand passenger information, real-time data and digital tickets for various networks for the districts of Minden-Lübbecke, Herford and Gütersloh as well as the cities of Detmold and Gütersloh. Although the city of Herford is currently looking into the topic of on-demand transport, no concrete decision or tender has yet been made. DB Regio Bus and the city of Herford have therefore agreed to initially implement the developments of the Ultimo project using DB Regio's own MaaS app "Wohin-Du-Willst" and to gradually develop a MaaS system by the end of 2025. In order to enable the continuation of AV in MaaS beyond the Ultimo project duration, discussions will also be held with the responsible stakeholders in 2024 to integrate the mobility offers and services of Ultimo into the OWLapp.

APIs and data flows

In lack of a holistic IT-Infrastructure at DB Regio and the membership in different Transport Associations of our regional branch, there is no API overview or data flow diagram available on local level. In the operations of the bus service for the city of Herford we use the following not connected services:

- PPBus system (DB Regio platform – own development) replaces Perdis (currently still in parallel operation) for operational control.
- Fleet management by Geotab.
- Passenger (real-time) information: target and actual data via the IVU pool interface to the OWL and VRR network companies in the EVA system.
- Ticketing: DB Regio Bus NRW wide background system ITCS for on-board computer sales and own subscriptions, but various other sales solutions at the different transport associations. (Please see figure 11)
- E-ticketing via OWL Mobil App (under construction - as OWL-wide solution)

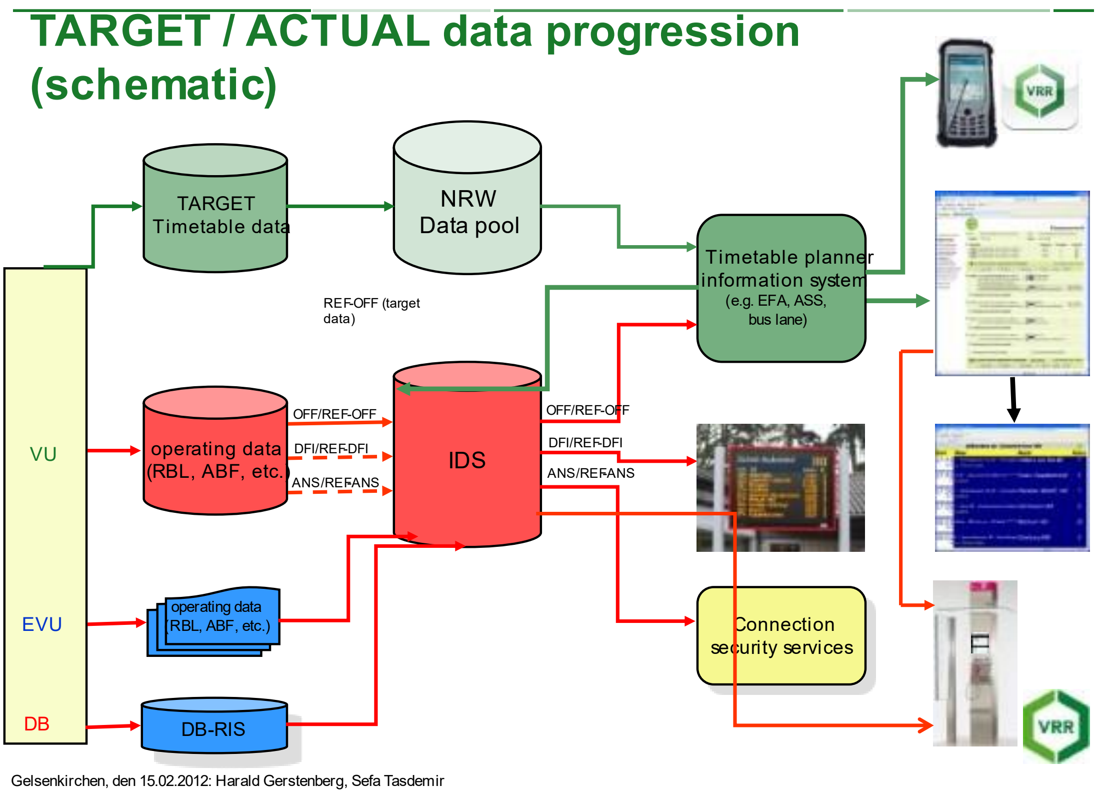


Figure 15 - Data Flow Diagram DB to VRR for real time information by VRR

To summarise, we can say that Herford is a green field in terms of system architecture and linking services, both for operations and for passengers. In terms of IT infrastructure, software applications and data interfaces, we can also use this demo site as a best-practice example for the transformation of a technically outdated but successful bus operation into the age of AV in MaaS and the future of public transport.

Passenger services

If Level 4 vehicles become available in 2025, further routes are to be developed and various forms of service established. The focus is on on-demand runs with mini-buses (8 to 12 passengers) to supplement existing bus services in areas of the city and surrounding areas with currently poor public transport provision. In addition, slightly larger vehicles (GAMA Blue Bus with 20 to 30 passengers) could also be used in level 4 operation in regular services for more frequent services at off-peak times or new lines to improve public transport services in more rural regions of the city of Herford. Other applications such as shuttle services for events or factory transport are also conceivable. At the end of 2025 or beginning of 2026, all automated buses (15 vehicles of different manufacturers and sizes) are to be integrated into a MaaS system that does not yet exist locally and will be initialized by the Ultimo project.

Regarding the technical design and development, please refer to the deliverables D 2.1 / D 4.1 and D 5.1.

Various projects have already focussed on autonomous on-demand transport in conjunction with personal services. The aim of the HEAL project, for example, was to facilitate the booking of vehicles for medical treatment, particularly for the needs of older people. In another project called "Shuttle Modell Region Oberfranken II" (SMO II), the main objective was the operation of driverless shuttles that serve as a complementary and supplementary component to public transport systems. Furthermore, the development of the first highly automated vehicle ready for authorisation was part of the SUE project.

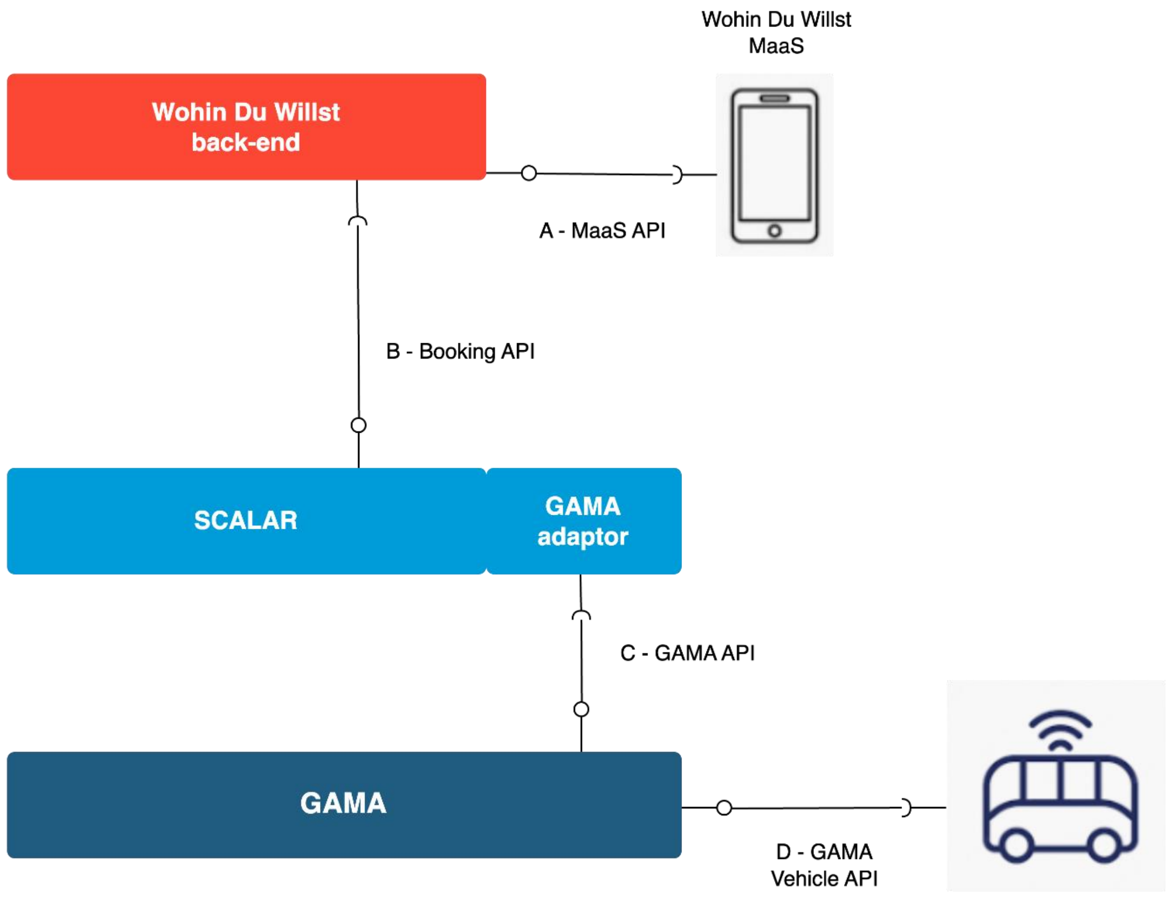
In Herford, we are building on these findings from the previous projects. The basic research of Avenue and the project SMO II in particular are important elements in bringing us closer to real operations with Ultimo. It is important to us that we implement targeted services for vulnerable groups to further strengthen Mobility4all in public transport. We also want to work on infotainment services and the simple linking of different forms of mobility in order to enhance the user experience for all passengers and feeling safe while traveling without a driver anymore.

2.2.2 DB Regio needs and target MaaS service

DB Regio, with its extensive network and commitment to efficient and integrated regional transport solutions, aims to utilise the potential of MaaS to improve the overall mobility experience for its contribution in the ULTIMO Project. This strategic initiative aims to utilise its experience in technology and innovative service models to create a comprehensive MaaS platform that meets the diverse travel needs in the context of D3.7..

The "Starke Schiene” strategy is divided into three categories "Robust", "More powerful" and "More modern", the latter includes the "Digital platforms" component. An example of such a DB digital platform can be found today in the MaaS platform "Wohin du Willst" (WDW).

DB Regio will be using SCALAR orchestration platform for the for Herford on-demand autonomous mobility service. SCALAR will be integrated with its MaaS application WDW to provide the service to the end-user.



The following APIs are in use to support the Autonomous On-demand transport use cases.

A	Wohin Du Willst proprietary API	API used by the MaaS application to query Wohin Du Willst Web Services.
B	SCALAR Booking API	This API is used by the MaaS application to place booking and provide booking status to the Traveler.
C	Gama API	This API is used by the fleet orchestration platform to get telemetry of the AV and send missions and track progress of the missions.
D	Gama Vehicle API	This proprietary API is used by Gama to get telemetry, handle missions and monitor the health of the vehicle.

2.2.3 DB Regio Policies for public transportation

In order to be allowed to transport passengers from A to B in Germany, a license is required. Certain requirements must be met for this, which are regulated by the PBefG. The abbreviation PBefG stands for the Passenger Transport Act. It sets out the regulations that companies must comply with when transporting passengers on buses, trams, light rail vehicles, underground trains and taxis. The Association of German Transport Companies (VDV) summarizes that these requirements must be placed on the person of the operator and are checked for expertise, financial capacity and personal reliability. Persons are entitled to carriage insofar as the duty of carriage exists in accordance with the provisions of the Passenger Transport Act (PBefG) and the legal provisions issued based on this Act. Within the framework of the ULTIMOS project, particular attention must be paid to the special provisions for the individual types of transport and § 21 Duty to operate, § 22 Duty to carry and § 23 Liability for damage to property.

Automated driving

Regarding the legal framework for fully automated and driverless Level 4 operation in public transport in Germany, individual operating licenses for the vehicles were generally obtained through corresponding exemptions by the state governments in accordance with § 21 Abs. 1 StVZO (Road Traffic Licensing Regulations) in conjunction with Section § 70 Abs. 1 StVZO by means of expert opinions from technical testing services. In addition, the operation of individual projects was also seamlessly integrated into the transport companies' services from a transport perspective and a passenger transport license was granted in accordance with § 2 PBefG in conjunction with § 42 PBefG.

The AFGBV (Autonomous Vehicle Approval and Operation Ordinance), which has been in place since 1 July 2022, provides a self-contained legal framework for the approval and operation of autonomous motor vehicles outside of the exemption authorization under the StVZO and the PBefG.

The AFGBV is responsible for:

1. the granting of operating licenses for motor vehicles with autonomous driving functions as well as licenses for automated and autonomous driving functions that can be activated subsequently,

2. the authorization of defined operating areas,

3. the authorization of motor vehicles with autonomous driving functions for road traffic,

4. the market surveillance of motor vehicles with autonomous driving functions with operating licenses granted or to be granted based on this Ordinance, as well as of subsequently activated automated and autonomous driving functions and vehicle parts, and

5. the requirements and obligations for the manufacturer, the owner and the technical supervision of motor vehicles with an autonomous driving function in defined operating areas and of motor vehicles with an automated or autonomous driving function in accordance with Section 1f of the Road Traffic Act.

These authorizations are currently still subject to high personnel and factual requirements (especially for the owner (§13) and technical supervision (§14)). With AFGBV, the use of autonomous vehicles in defined operating areas is possible in principle, but due to the requirements in Section 14, only as test traffic for the time being. This requires extensive communication with the KBA (German Federal Motor Transport Authority).

On Demand Policies

In addition to rigid scheduled services (Section 42 PBefG), there are now two options under licensing law for using on-demand services in regular operations: scheduled on-demand services (Section 44 PBefG) and pooled on-demand services (Section 50 PBefG). What they have in common is that they are on-demand, and several journey requests can be pooled, but they differ in terms of their transport obligations, the size of their area of application and access to public co-financing.

Scheduled demand-response service

The scheduled demand-response service is considered a supplement to traditional scheduled services and, as it is considered public transport within the meaning of Section 8 (1) PBefG, can be (co-)financed by public funds. At the same time, as public transport, it is subject to the obligations of scheduled services, meaning that it must fulfil the requirements regarding accessibility, transport, operating and tariff obligations. This is usually in conflict with the spatial development of the service area and in terms of the waiting times within which the operating obligation must be fulfilled. Both aspects must be organized by the public transport authority.

For vehicles with alternative drive systems, the availability of a suitable charging/refueling infrastructure is an additional dimension. In future, public transport authorities will therefore be required to always take technological requirements into account in addition to transport requirements when defining conceivable areas of use.

Bundled demand-response transport

In contrast to scheduled demand-response transport, bundled demand-response transport is of a purely commercial nature and is not part of local public transport. It cannot be publicly co-financed and is not subject to any transport, operating or fare obligations. In urban and suburban transport, the regulatory requirements result from the mandatory bundling quota to be set by the authorizing authority, the permitted number of vehicles and the minimum charges. Bundled on-demand transport is a private-sector mobility service that is intended to supplement local public transport.

The federal and state governments regularly support public transport projects with funding pots and programs. The programs are usually aimed at different stages of a project, such as planning and piloting, digitalization or operation. These funding programs always support the innovative nature of public transport projects. Accordingly, the funding of these funding calls is also to be understood as start-up funding. “Directive on the funding program for supplementary local transport services to improve mobility in rural areas with demand-oriented forms of public transport and pilot projects for cross-district express bus connections in bus transport” (ErNa) is intended to improve mobility in rural areas, with a particular focus on integrated transport services, i.e. a combination of regular services and demand-led services.

The following conditions for the funding of flexible and On-demand forms of public transport contained in the (ErNa) are important for obtaining funding:

1. funding is generally not possible if the service area has been developed in full or in large parts in the past three years with a project funded under this or a predecessor program

2. the projects must be public transport projects that are or have been approved in accordance with Section 42 of the Passenger Transport Act (PBefG), Section 44 PBefG, where applicable in conjunction with Section 2 (6) PBefG or Section 2 (7) PBefG

3. the projects must be in line with the plans of the public transport authority, such as an existing local transport plan or the existing regular-interval service

4. the individual projects serve to open up rural areas

5. the European legal provisions of Regulation (EC) No. 1370/2007 as well as the municipal and public procurement law requirements must be fulfilled.

Additional requirements apply in the case of start-up financing.

2.3 TPG (PTO) transportation architecture

TPG is a PTO, providing public transportation services in Geneva and close towns. TPG has its own fleet of vehicles but also delegates some of the transport as is the case with DRT and when they are not allowed to like it would be in the case for vehicle doing most of their stops on the French side.

TPG uses vehicles ranging from minibuses for smaller towns to busses, articulated busses and trams. The intention of public transport in Geneva is to provide ways for the population to reach the city center from close buy areas as well as to reach their housing when coming back from work as well as different key buildings in the city or towns such as shops, administrative buildings, etc.

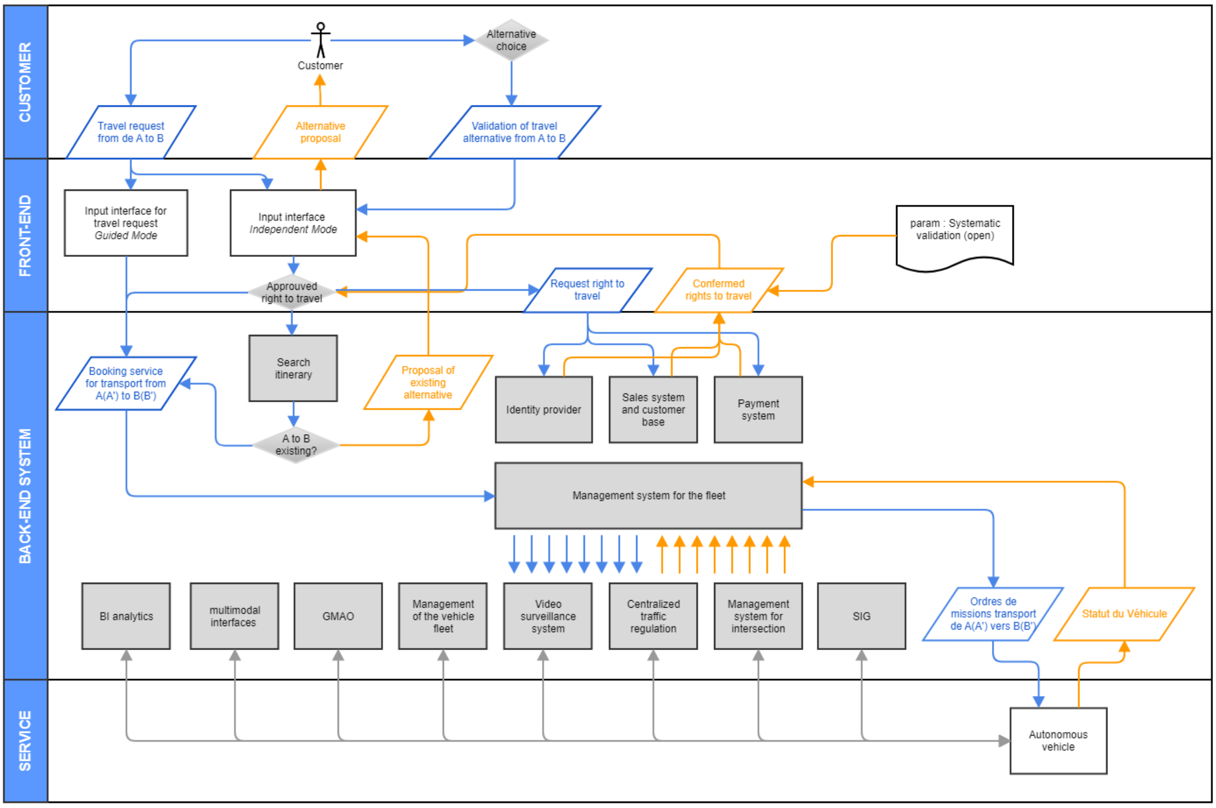
TPG intends to continue working with the previously acquired NAVYA vehicles and is currently working with politics to have some automated vehicles reaching the Swiss country.

As soon as these vehicles hit the ground in Geneva, they will be field tested first in the belle-idée area, then on the operational site where we have our current DRT and when allowed replace the current DRT divers and vehicles.

2.3.1 TPG existing architecture

Today the DRT services are separate from the current fleet operated by TPG. Meaning that the architecture will evolve. DRT should be integrated into the ordinary fleet with the integration of all current public transport offers into a MaaS service.

LaaS will also be its own thing but connected and communicating with the DRT. As a PTO we are not allowed to do logistics, but we can share are vehicles to other companies so that they can do their own logistics.

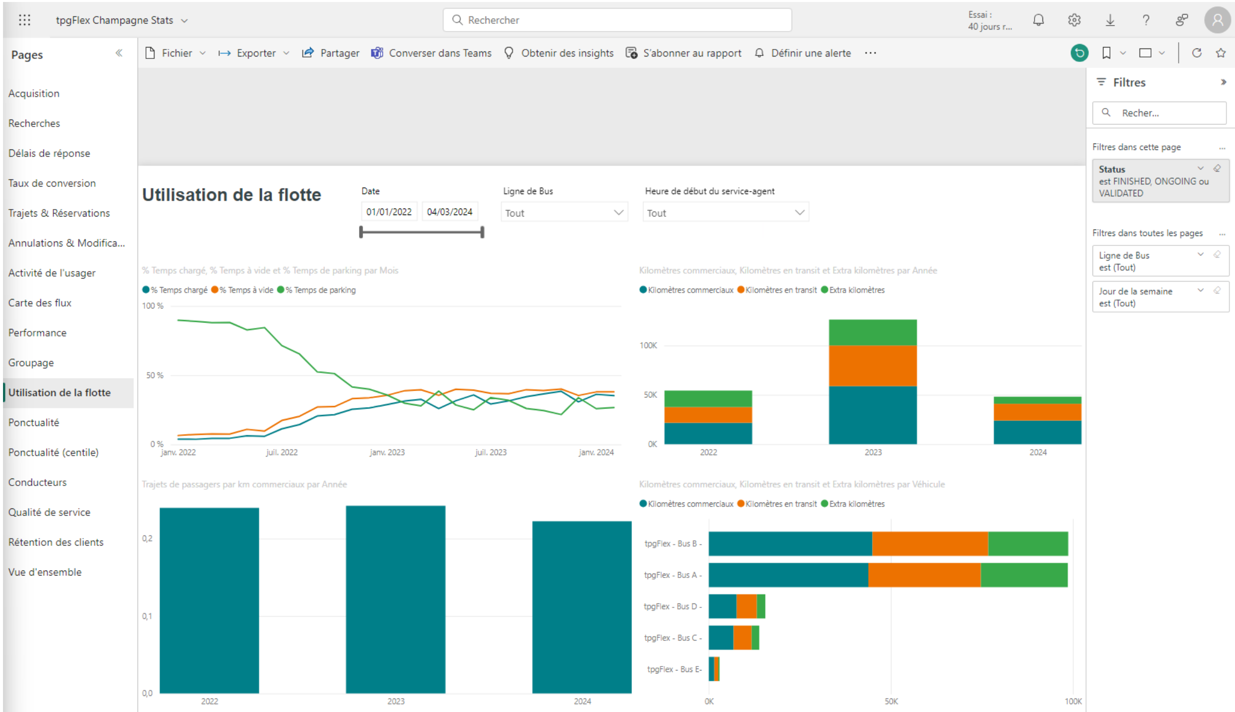


Today we are using the above architecture for TPG fleet. The backend systems remain to this day disconnected from all our DRT systems but will be reconsolidated with the coming of the MaaS that has been work in progress for some time now shown in the frontend part above.

APIs and data flows

Today most of the data TPG has access to for DRT is through their internal power BI solution.

The current data is all the DRT data, in the close future, electrical vehicle data and AV data should also be available from the fleet orchestrator. This data is used to understand user needs so that changes can take place so that most daily passengers benefit from these changes. The changes could be adding a fixed bus line, extending an existing bus line or redirecting an existing line.


tpgFlex Champagne Stats
Rechercher
Fichier
Exporter
Partager
Converser dans Teams
Obtenir des insights
S'abonner au rapport
Définir une alerte
Pages
Acquisition
Recherches
Délais de réponse
Taux de conversion
Trajets & Réservations
Annulations & Modifica...
Activité de l'usager
Carte des flux
Performance
Groupage
Utilisation de la flotte
Ponctualité
Ponctualité (centile)
Conducteurs
Qualité de service
Rétention des clients
Vue d'ensemble
Utilisation de la flotte
Date
01/01/2022
04/03/2024
Ligne de Bus
Tout
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Tout
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Kilomètres commerciaux, Kilomètres en transit et Extra kilomètres par Année
Kilomètres commerciaux
Kilomètres en transit
Extra kilomètres
Trajets de passagers par km commerciaux par Année
Kilomètres commerciaux, Kilomètres en transit et Extra kilomètres par Véhicule
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Filtres
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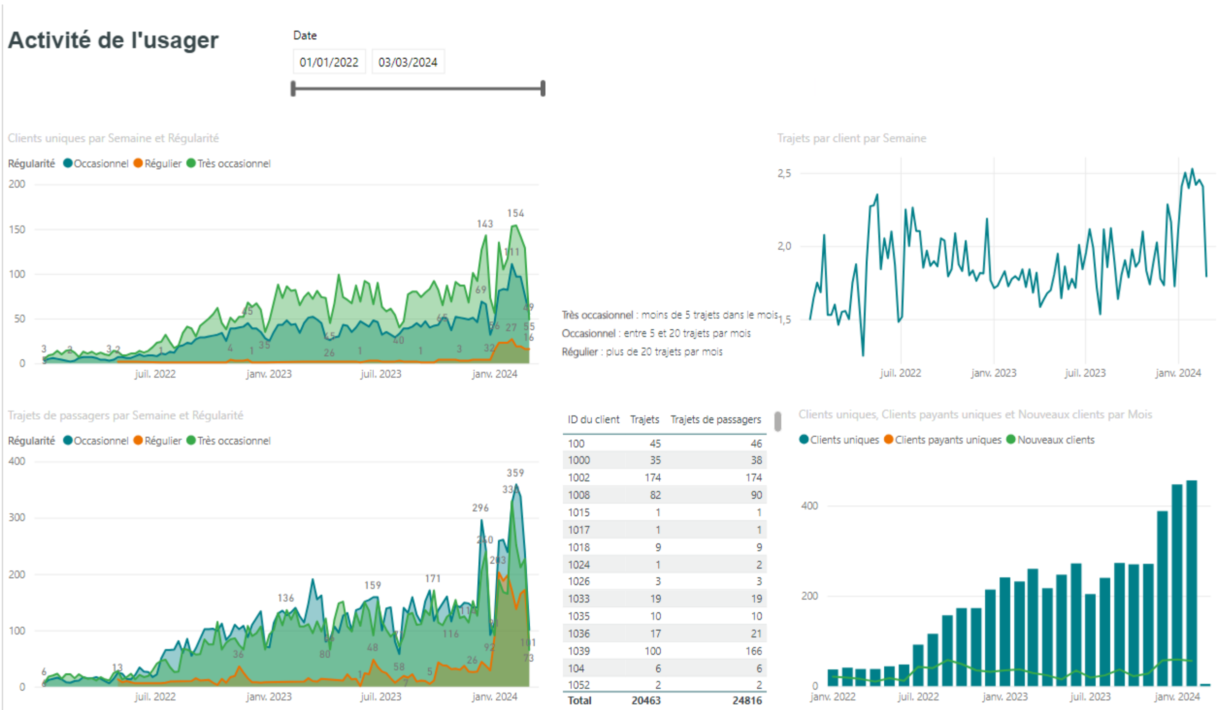
Activité de l'usager
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Clients uniques par Semaine et Régularité
Régularité
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Trajets par client par Semaine
Très occasionnel : moins de 5 trajets dans le mois
Occasionnel : entre 5 et 20 trajets par mois
Régulier : plus de 20 trajets par mois
Trajets de passagers par Semaine et Régularité
ID du client
Trajets
Trajets de passagers
Total
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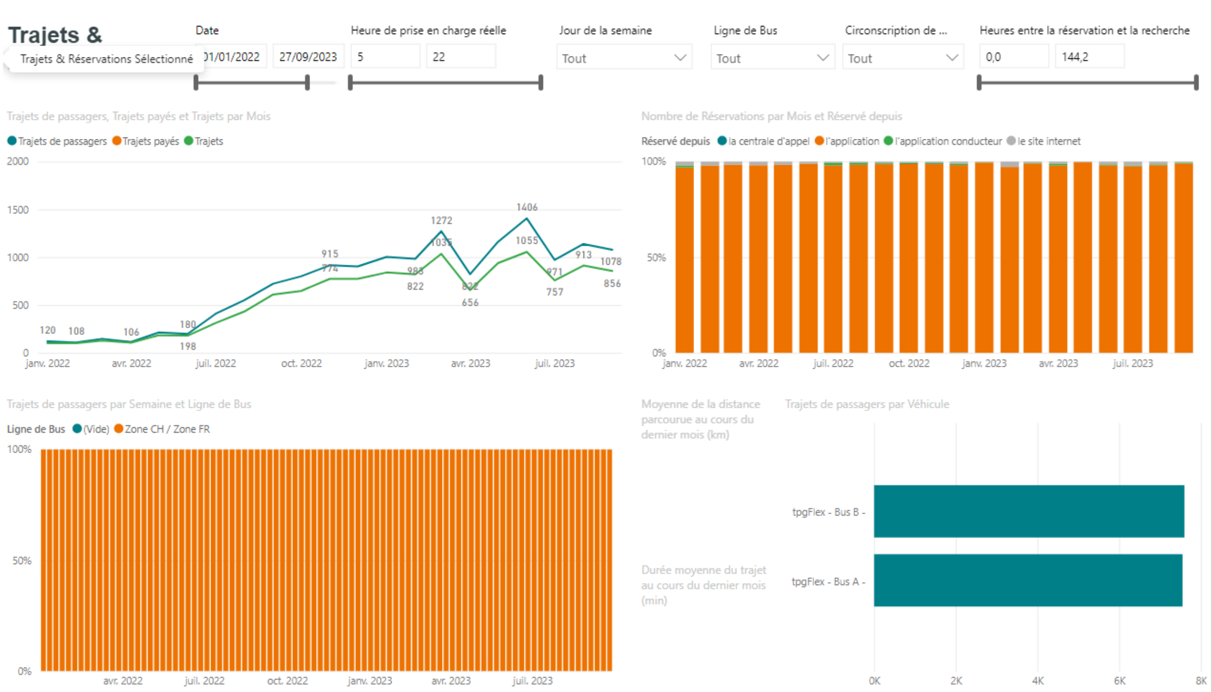
Clients uniques
Clients payants uniques
Nouveaux clients

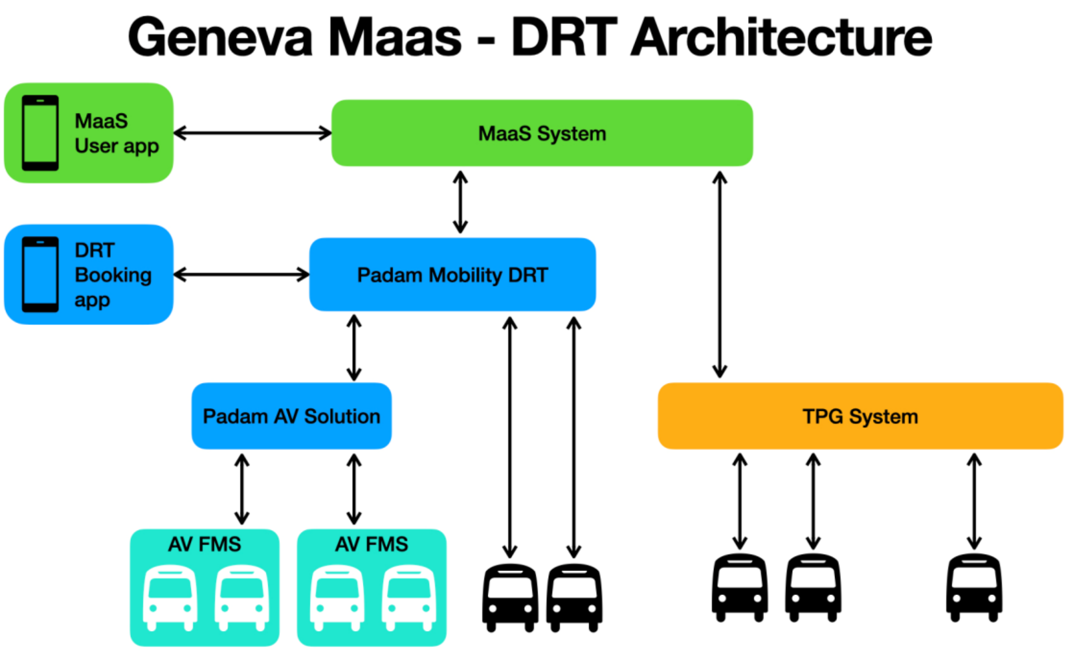


2.3.2 TPG needs and target MaaS/LaaS service

Maas

The goal for TPG is to reach a MaaS service by the end of 2026.

The first target of Maas architecture including DRT and AV DRT can be describe as following:



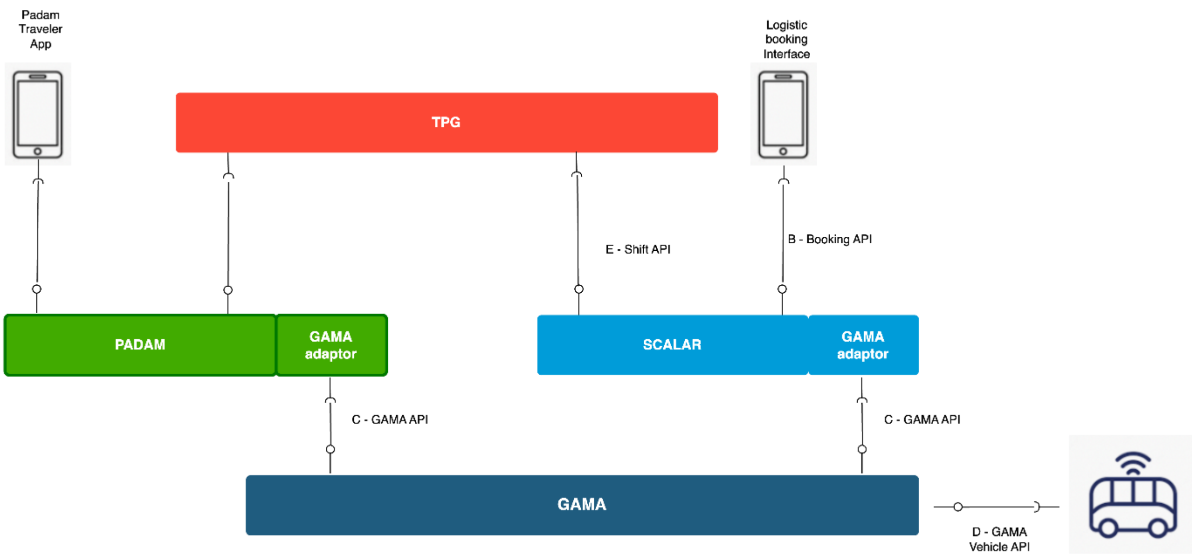
TPG is relying on 2 orchestration platforms. Padam for on-demand People Mobility and SCALAR for Logistics as a Service (LaaS).

LaaS

LaaS use cases will be deployed in the wider area of Geneva in collaboration of TPG, Ovo and ZF. The partners are currently working on the use cases that involve local commercial actors who will be able to use the capacity of AVs in off-peak hours for people transportation. During those hours, the AVs will be available to transfer containerised goods from different Points of Production (PoP) to logistics hubs and/or Points of Sell (PoS) of the local supply chain. The flexibility of the AVs even allows them acting as "floating" hubs where the offloading of the goods can be made in different locations along the route.

Main ULTIMO Actors:

- TPG: Planning of the service, i.e. time windows for people and goods transportation service availability
- ZF: Fleet orchestrator, provider of the FO platform SCALAR, for service planning, booking API and booking interface for goods transport
- Ovo: the logistics service provider, will use SCALAR booking interface to place bookings for its customers, local commerce actors
- Gama: AV providers



The following APIs are in use to support the Logistics as a Service use cases.

B	SCALAR Booking API	This API is used by the logistics booking application to place delivery order and track the order statuses.
C	Gama API	This API is used by the fleet orchestration platform to get telemetry of the AV and send missions and track progress of the missions.
D	Gama Vehicle API	This proprietary API is used by Gama to get telemetry, handle missions and monitor the health of the vehicle.
E	SCALAR Shift API	This API is used by the TPG to define shifts where the AV will be available for Logistics deliveries.

2.3.3 TPG Policies for public transportation

Today TPG wants to extend as much as possible their offer to areas that are not covered by transport. The centre city been well covered today, the focus is now on the on-demand service and autonomous vehicles for the countryside surrounding the city of Geneva. Connecting all areas to train stations, trams, administrative buildings, schools and other key buildings to the entire transport network is vital. The lack of drivers been more important as time goes on, it is important for transport companies to open to new solutions such as automated vehicles making the transportation more affordable and viable in these low population areas.

Rules for DRT for passengers are the same for all the public transport in the Geneva area except for the 3 stops ticket that cannot apply for DRT.

To make all the above possible, self-driving vehicles are of high importance in the DRT service.

For these vehicles to be allowed to work on specific areas the following steps are required:

- Legally allowed to drive in the designated area, authorisation delivered by the road authorities,
- Legally allowed to drive with the homologated vehicles, authorisation delivered by the vehicle authorities,
- Legally allowed to have passengers for public transportation with transport goals and objectives that must be met, authorisation delivered by the public transport authorities,
- Transport service is requested by the local authorities and service is sufficiently used to be maintained,
- Software and data hosted aligned with terms and services followed by TPG internal policies and local GDPR authorities,

From an operational perspective, an on-demand transport service can operate in a variety of ways, depending on the needs of the end-users in the area. Firstly, it's important to specify if the service is point-to-point (with real or virtual stops), door-to-door (usually for individuals with limited mobility), or a hybrid version that combines elements of both modalities. Secondly, it is necessary to choose the reservation mode available to users, which can be either in advance or in real time. Once these points are defined, it is necessary to identify the service model (or algorithm) that best suits the context and objective of the operators to maximize performance results. Some service models observed in the market are:

- Free-floating[12]: Model where users can have access from many-to-many origins and destinations in a specific geographic area. In other words, there are no restrictions on the locations from which journeys can be scheduled inside the operational zone during service hours.
- Fixed destination or origin (also called feeder service)[13]: A model where users have access from many-to-one or one-to-many. Generally, the fixed stop is a connection to a mass transit such as a subway.
- Semi-flexible (also called virtual line)[14]: A model in which some constraints are introduced, such as a route based on a precise itinerary, where the vehicle will visit only the nodes that are requested by users. This means that there is also a specific order of stops.

Experimenting and optimizing the different mods for DRTs is interesting and TPG is experimenting with various mods today to see the benefits of some of these mods.

2.3.4 TPG Policies for on-demand public transportation

On-demand services are expected to attract new passengers to public transport by offering pick-up closer to home and more flexible, passenger-centric services. Improved last-mile services are intended to encourage more long-distance journeys to be made by public transport. To achieve this, passenger information should be provided comprehensively, and booking, including payment, should be made available through digital public transport channels.

On-demand services in Switzerland are not adequately integrated into existing public transport channels. Several separate apps need to be used along the journey. Particularly, stop-based on-demand services cannot be found, booked, or paid for by end customers through traditional public transport customer channels. Some authorities (cantons) demand integration of on-demand services into public transport customer channels for ordering (Umsetzungskonzept On-Demand-Verkehr, SwissPass Alliance, October 2023).

The objective for the future should be end customers to be able to search, book, and pay for on-demand services through traditional public transport channels. The following table summarizes the aspects of the on-demand transport services that need to be taken into

[12] Pettersson, F. (2019). An international review of experiences from on-demand public transport services. Retrieved February 23, 2024, from https://kollektivtrafikk.no/app/uploads/2021/02/on-demand_pt.pdf

[13] idem

[14] Hugo, B. R. (2023, June 28). Comparing the performance of dynamic and semi-flexible Demand-responsive Transport models under varying demand scenarios. https://upcommons.upc.edu/handle/2117/397870

consideration for future regulations, from planning, dimensioning of the service, pricing and ticketing as well as information dissemination to the travellers, considering both the cases of human-driven to provide a custom assistance for PRM and autonomous vehicles. Onboard systems will also be monitoring the passengers during their travel time in the vehicle making sure everything fine and everyone is safe. Such systems will also enable bidirectional communications and ways to assess in real time any situation.

Area	Details
Planning and Dimensioning of the service	Provision of the number of passengers per request by the user, as well as the pickup and dropoff locations per request. Capacity of standing and seated passengers per vehicle typ. Seat reservation should be allowed in case of standing places. Maximum distance to and from pickup and dropoff locations, tailored in the needs of urban and rural areas Deviation between the requested pickup or dropoff time and latest pickup/dropoff time, in order to allow an optimal matching between availability and requests, for urban and rural areas Delays and cancellations from the service provider's side Cancellations or no-shows from the traveler's side Accessibility to traveling with kids Accessibility to customized needs, i.e. travel with luggage/sports equipment, travel with animals etc Accessibility to disabled people and people with impairments (that has not really been covered by the report though)
Pricing and ticketing	Fare calculation of on-demand services, pricing as well as existing subscription schemes in the public transport, eg. Zone-based pricing scheme, day pass, integration with SwissPass etc Payment method and channels, eg. Credit card, only via TA
Pre-journey planning/information dissemination to traveler	Access to information and possibility to book the service Understanding of the service Uniformity of service typology in the industry Integration with public transport Integration of existing PT or MaaS applications

	Regulate alternative non-digital channels
Booking confirmation	In-app confirmation of the booking details including pickup time Vehicle identification ETA to destination
During journey	Live updates / Real-time information Communication between traveler - service provider Emergency and incident management protocols
Post-journey	Feedback Customer service

3 Overall open ULTIMO architecture

Based on the existing architectures and the identified APIs of the partner operators, we have defined a high level, open architecture allowing a modular and configurable architecture

3.1 High level ULTIMO architecture

As mentioned, a common Ultimo architecture that fits all three pilot sites has not been found yet, however for the purpose of progress in the other areas of the project the following high-level architecture has been used as a skeleton for encompassing the topics of work package 3.

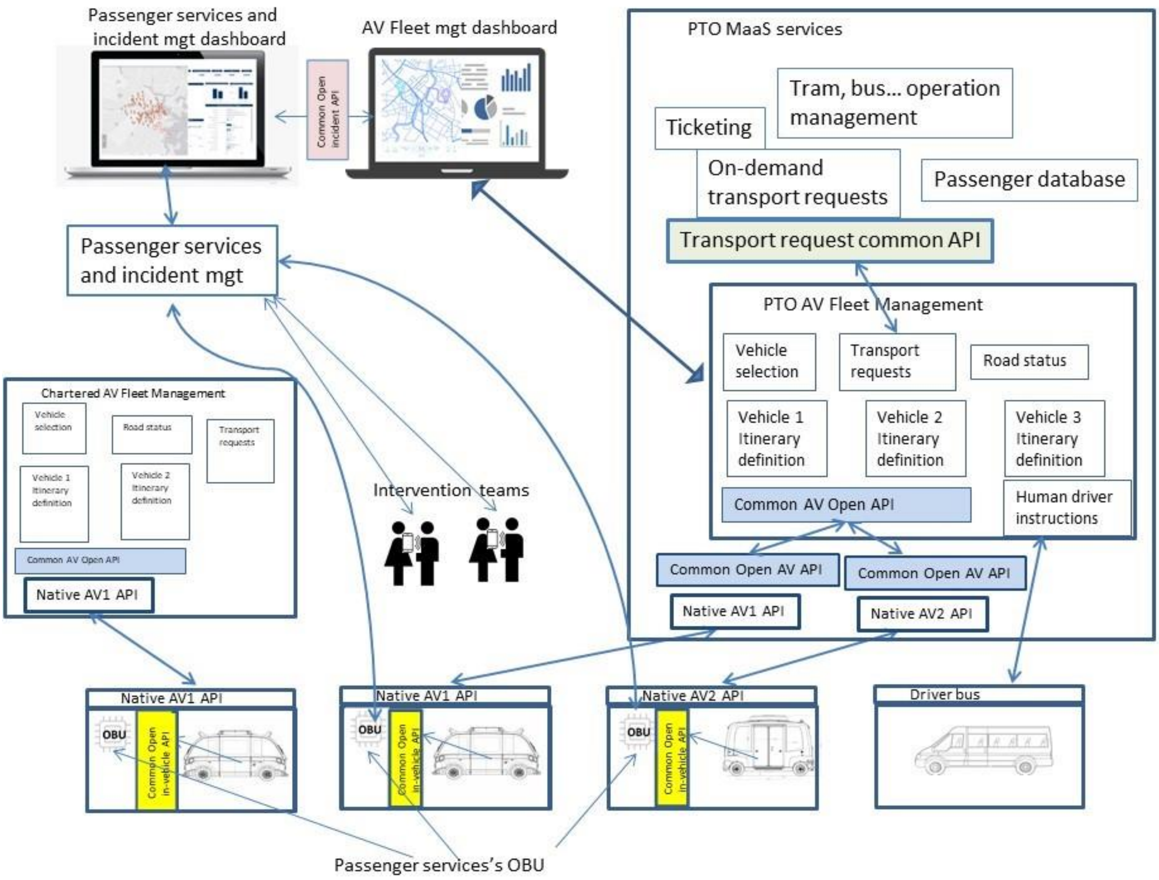


Figure 16 High level ULTIMO architecture

The figure shows the 4 API points that are described in delivery 3.1. Also shown are the onboard units OBU's needed for passenger services in a driverless vehicle. The operational architecture of GAMA's AV, and the generic OBU services are described in the following chapters.

3.1.1 Operational Architecture

High level architecture

The Gama Fleet Management System is an advanced ecosystem designed to support the operation and supervision of autonomous vehicle fleets. It integrates various technologies across public and private cloud interfaces as well as embedded vehicle systems to deliver a comprehensive solution for real-time monitoring, mission management, and data optimization.

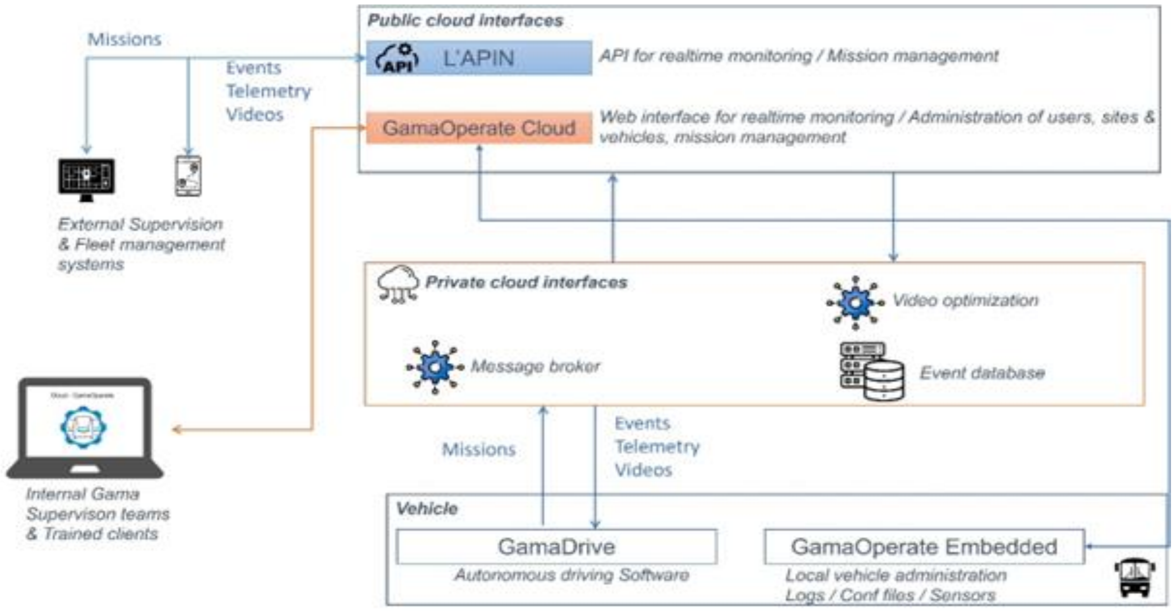


Figure 17: Gama's high-level architecture

System Components

Vehicle Level Components

At the vehicle level, two main systems work in tandem:

- **GamaDrive**: The autonomous driving software that interprets sensor data to navigate and make real-time driving decisions.
- **GamaOperate Embedded**: A localized administration system that manages logs, configuration files, and sensor calibrations to keep the vehicle operating smoothly.

Private Cloud Interfaces

These interfaces are microservices that operate within a secure private cloud environment:

- **Message Broker**: Acts as the communication spine of the system, routing messages between services and ensuring data consistency and reliability.

- **Video Optimization**: Handles the heavy lifting of video data processing, compressing, and formatting video feeds for efficient streaming.
- **Event Database**: A repository for all event-related data, structured for quick retrieval and analysis, aiding in data analysis and historical record-keeping.

Public Cloud interfaces

The public Cloud interfaces is the central hub for real-time data processing and administration. It comprises two main elements:

- **L'APIN API**: An API that facilitates real-time data exchange, allowing external systems and applications to receive live updates and send commands for mission management.
- **GamaOperate** Cloud: A user-friendly portal for administrative tasks such as user management, site configurations, and detailed mission control. It could be managed by Gama's supervision teams or by trained clients.

Data flow and interactions

The data flow begins with mission assignments, which can be executed directly on the vehicle or dispatched to the vehicles via the API or through GamaOperate. As the vehicles carry out their missions, telemetry and video data are streamed back to the cloud. There, the data undergo processing, optimization, and are subsequently stored. The message broker plays a crucial role in maintaining synchronization across all system components, while the event database systematically archives the data, ensuring it is available for future analysis.

3.1.2 Passenger and intervention services architecture

This section outlines the structure of communication networks integral to passenger and intervention services, highlighting the key components involved. It includes a diagram illustrating the interconnections between these components and the nature of the information they share. We delve into the roles of each component and the type of data they exchange, tracing the path of data flow. Typically, vehicles serve as the primary source of data, which various components then utilize to enhance the services they are designed to provide. It's important to mention that details regarding data formats and technical specifications are beyond this document and are covered in separate documentation.

The V2X-OBU plays a crucial role in gathering and supplying data concerning the vehicle and other road users. It is responsible for creating and transmitting information, including the vehicle's speed, location, direction, turn signal status, and other data accessible through V2X technology. This data is then relayed to the Passenger System OBU (PS-OBU), where it undergoes fusion and real-time processing within the vehicle.

The PS-OBU serves as a vital hub for information dissemination throughout the system, leveraging wireless 4G/5G and server/client connections to facilitate data requests from network participants. It sources data from a variety of inputs including direct sensor connections, other wired channels such as the V2X-OBU or the Passenger Information System (when needed), as well as from internal services. In addition, the PS-OBU concurrently manages passenger services developed by CERTH alongside its communications framework. These services can generate data related to specific incidents or alerts, for instance, detecting new passenger arrivals or identifying falls. As a central node for data integration, the PS-OBU compiles and forwards processed vehicle data to the Backoffice via a centralized MQTT broker. Furthermore, it ensures the seamless transmission of multimedia content, including video and audio streams, to and from the vehicle.

Lightweight data (which includes temperature, humidity, GNSS, data from V2X-OBU, etc.) will be transmitted via MQTT with the JSON format, which allows standardization. The syntax of the messages will be designed according to the European Telecommunications Standards Institute (ETSI TS 103 900 V2.1.1, ETSI TS 102 894-2 V2.1.1). Some parameters related to the MQTT transmission, such as update rate, quality of service, synchronization, and timeouts can be set to meet the requirements. There will be a MQTT broker inside each PS-OBU for wired exchange of data with the V2X-OBU, and an additional broker in the back-office to exchange the data with the PS-OBUs wirelessly. The messages arriving at the back office will contain, among others, the identification of the shuttle and the version of such message, to allow easy versioning of JSON messages.

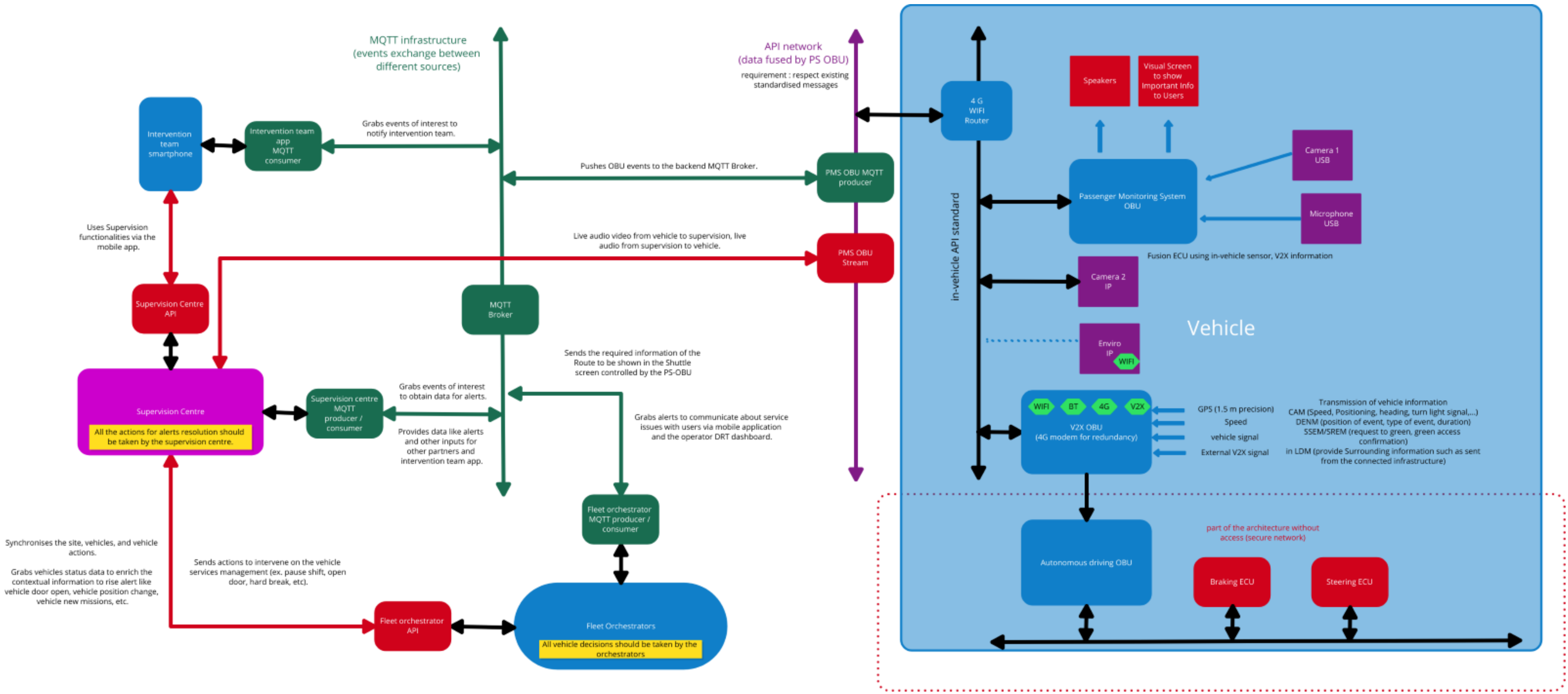


Figure 18: Passenger and intervention services architecture

The MQTT broker stands as the central nervous system of the service architecture, consolidating data from the PS-OBU and other components into a unified hub. This arrangement fosters a producer/consumer model that supports asynchronous communication between various system elements. With established MQTT topics and defined data formats, components can seamlessly integrate as either data providers or receivers, enhancing the system's scalability and flexibility.

The Supervision system capitalizes on this data aggregation to deliver an advanced monitoring and alert management solution for vehicle operations. It classifies events and generates alerts based on specific criteria and contexts, equipping vehicle supervisors with the necessary information to promptly address issues as they arise. The system's design prioritizes alerts to ensure urgent situations receive immediate attention, aiming to bolster both safety and operational efficiency.

Within this ecosystem, the Supervision system is split into two main software entities: the Supervisor Centre and the Intervention Team Application. The Supervisor Centre operates as the operational heart, allowing users to configure the system, monitor vehicle statuses, set alert parameters, and manage responses. It communicates with the Intervention Team Application, which resides on intervention team members' smartphones, through a combination of sockets, MQTT, and REST APIs for a cohesive operational flow.

The Intervention Team Application (ITeam app) complements the Supervision system by providing a real-time platform for managing and resolving alerts. Designed to minimize response times and support effective decision-making, the ITeam app serves as a direct link between the occurrence of an alert and the initiation of a swift, informed response. It receives alerts and instructions from the Supervisor Centre and communicates actions back, facilitating a dynamic and interactive response mechanism aimed at enhancing vehicle safety and efficiency.

To summarise, an example of data flow from the vehicle to the Supervision Center and ITeam app could be as follows:

1) Temperature and humidity sensors record environmental data in the vehicle.
2) The PS-OBU is responsible for collecting data from sensors, producing and enriching it with V2X information coming from the V2X system. For example, add speed, heading and GPS position to the vehicle data set.
3) The PS-OBU packages the data it collects as events and sends them to a centralised MQTT broker by producing data on the specific humidity and temperature MQTT topics.
4) The Supervision Centre consumes the sensors' MQTT topics and depending on the supervisors' policies (e.g., PTO) decides if the current sensor data, in this case, temperature and humidity, are in the desired range.
5) If the sensor data violates the policies the Supervision Centre creates alerts to let the supervisor know that there is an issue. The supervisor can deal with the alert following

a set of predefined actions. For the sake of the example, we assume that the supervisor asks the intervention team to reach the vehicle for inspection because the temperature inside is too high.

6) The Supervision Centre sends a notification to the ITeam application alerting the intervention team (via a cloud notification provider).
7) The intervention team can follow real time updates about the alert, e.g., while reaching the vehicle, thanks to the socket communication from the Supervisor Centre to the ITeam app.
8) Via Rest APIs the intervention team can communicate to the supervisor using the Supervisor Centre what are the actions they have taken to solve the problem.
9) The bidirectional communication can continue until the alerts are resolved by enabling continuous communication between the supervisor and the intervention team.
10) The scenario can be further extended by a communication between the Supervisor Centre emitting alerts to an MQTT broker from which consumers like the Fleet Orchestrator can obtain real-time information about the vehicle status and therefore depending on their policies decide to suspend the operations or reroute the vehicle, or more.

The Fleet Orchestrator is a pivotal addition to the ecosystem, tasked with relaying vital vehicle context and data through MQTT and REST APIs. This functionality allows other system components, notably the Supervision Centre, to automatically adjust their settings based on the vehicle information provided. This centralization of configuration streamlines operations, enabling operators to manage their fleet settings from a singular, impactful location.

Moreover, the Supervision Centre leverages this integration to supervise the Fleet Orchestrator in executing specific vehicle operations, such as halting vehicles, opening doors, or suspending reservations. The Orchestrator employs the MQTT broker to stay abreast of alerts issued by the Supervision Centre, allowing for dynamic adjustments to vehicle scheduling in response to real-time alerts. Concurrently, it contributes data back to the broker, such as anticipated booking volumes per vehicle, facilitating a two-way flow of information. This exchange empowers the PS-OBU to refine its operational algorithms, enhancing service delivery and fleet management efficiency.

3.1.3 Cybersecurity and data privacy policies

Alongside the safety, social and ecological advantages that AVs are promising, cybersecurity and data privacy challenges may hinder their large-scale deployment if not tackled properly. The compromise of any component within the autonomous vehicle (AV) environment could lead to improper driving operations, breaches of sensitive data, and potentially fatal accidents, posing risks to the safety and privacy of passengers or operators.

The potential cyber-attacks on AVs encompass a range of threats, including manipulating perception systems to blind the vehicle's vision, falsifying navigation data to induce a deviation from the intended course, infiltrating communication channels to inject malicious messages, and altering code to impact the vehicle's motion control capabilities [1].

Moreover, any unauthorized access to the AV environment, where a significant amount of directly or indirectly identifiable data is exchanged, poses a potential risk of a data breach. Consequently, the sniffed or illegal data processing that can likely embed sensitive data such as names, phone numbers, travel routes, departure and arrival addresses, can be the source for a variety of privacy attacks, including identity theft, location tracking, and profiling[2].

Despite the deployment of mitigation strategies like cutting edge intrusion detection and advanced monitoring systems, the risk of unknown cyber-attacks within the AV landscape remains high[3]. Considering the growing need to shield the AV ecosystem, well developed policies can support in maintaining a resilient environment, guiding employees on reacting properly in case of a cyber assault and ensuring compliance with the core cybersecurity and data privacy laws and regulations. The cybersecurity and data privacy policies rely on well-defined practices, and procedures that are realistic and viable with regards to the AV evolving technologies, PTOs/PTAs risk governance and data subjects' rights.

In this task a generic issue-specific security policy (ISSP) will be developed, which will provide detailed guidance on the integration of AVs within public transport operators' (PTOs) environments. The methodology of developing policies that are focused on cybersecurity and data privacy in ULTIMO starts from a thorough analyses of existing policies to which each PTO/PTA adhere. Analyses of each site's legislations represent a crucial step since not all sites are under the European Union regulations. At this step we will also perform needs assessment with the purpose to determine legal, regulatory, and industry-specific requirements that the policy must meet, as well as identify potential risks, challenges, or needs that the policy should address. Second, based on extracted knowledge from the state of the art[4] and related scientific publications[5], a first draft of the cybersecurity and data privacy policies will be elicited within the next deliverable iteration (D3.8). It will contain clear, concise statements that define expected behaviours, requirements, and procedures. Such findings will be elevated further by joining them together to the cybersecurity and data privacy requirements that are intended from the ongoing efforts on executing a Threat Analysis and Risk Assessment within T4.4 . Followed by a feasibility study of each policy per stakeholder' site and per PTO/PTA, a decision will be made by each PTO/PTO on the policy adoption that will concern the following pillars:

- Legal compliance
- Access control
- Data processing principles
- Incident response management
- Security training and awareness

The envisioned structure of the cybersecurity and data privacy policy for Avs is the following:

1. Statement of policy
    a. Scope and applicability
    b. Definition of technology addressed
    c. Responsibilities
2. Authorized access and usage of equipment
    a. User access
    b. Fair and responsible use
    c. Protection of privacy
3. Prohibited use of equipment
    a. Disruptive use or misuse
    b. Criminal use
    c. Offensive or harassing materials
    d. Copyrighted, licensed, or other intellectual property
    e. Other restrictions
4. Systems management
    a. Management of stored materials
    b. Employee monitoring
    c. Virus protection
    d. Physical security
    e. Encryption
5. Violations of policy
    a. Procedures for reporting violations
    b. Penalties for violations
6. Policy review and modification
    a. Scheduled review of policy procedures for modification
    b. Legal disclaimers
7. Limitations of liability
    a. Statements of liability
    b. Other disclaimers as needed

[1] https://doi.org/10.3390/jcp3030025

[2] https://doi.org/10.1109/TBDATA.2022.3227336

[3] https://link.springer.com/chapter/10.1007/978-3-031-16815-4_14

[4] **https://doi.org/10.3390/s22020538**

[5]
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3.1.4 Common Platform and ULTIMO DMP

This section focuses on describing the fundamental infrastructure and data management techniques required for supporting the expansive data requirements of the autonomous vehicles. Also, it is emphasized how crucial it is to set up a standard platform that permits smooth integration amongst and interoperability among diverse data sets, enabling a uniform method for data maintenance and utilization. Additionally, it highlights the role of the Data Management Platform (DMP) as a central repository for managing and storing the vast amounts of data generated in order to support the dynamic requirements of autonomous vehicle navigation systems. This overview serves as an initial insight into the strategic planning behind designing a robust data infrastructure.

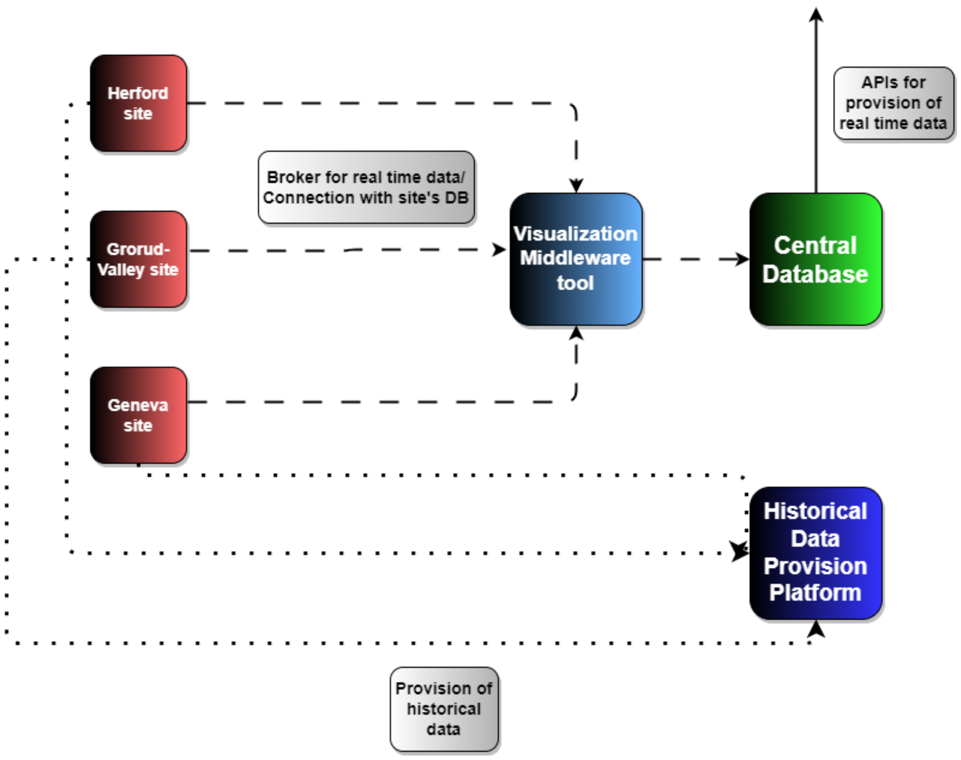

Figure 19: ULTIMO DMP high-level architecture

Expanding on the initial overview, this section delves into establishing a scalable and reliable architecture ensuring the efficient data operation and services development in AV systems. It emphasizes the significance of a common platform that not only facilitates the integration of ULTIMO data but also offers consistency and reliability across operational environments. Furthermore, the importance of the Data Management Platform is highlighted once more, noting its pivotal role in efficiently managing the large amounts of data associated with ULTIMO ecosystem. While a basic insight is being provided, it is mentioned that a more thorough description of DMP's challenges and its operational structure has been detailed in D5.5 - "Big Data Collection Platform and Data Management Portal - First version". This reference strengthens the deliverable's objective of offering a thorough yet approachable entry point into the data management technologies for autonomous vehicles by bridging the gaps between the overall plan and the particular mechanisms in place for data processing.

The key objective is to provide an overview of the basic approach for developing a centralized platform for data integration and maintenance, which is crucial for the smooth functioning of autonomous vehicles. Data from several sources may be conveniently merged and used in various autonomous systems thanks to the Common Platform, which serves as an interface for the integration and dissemination across different systems. The Data Management Platform is introduced as a central component of this ecosystem. Its purpose is to make large amounts of data easier to handle, store, and retrieve so that changes and access are possible.

In summary, the DMP adopts a systematic approach to organize and keep data up-to-date, ensuring not just storage but also accessibility when needed. These important datasets will be stored on the Data Management Platform. In summary, the DMP uses a methodical technique to keep data organized and up to date, making sure they are not only saved but also easily accessible when needed. Furthermore, the DMP uses APIs, which are essentially a set of keys that permit different software to communicate, in order to facilitate easy access to and integrate these data into various applications. These APIs enable the autonomous vehicles to search for specific data and retrieve it in real-time, ensuring that services decisions are based on the most current and comprehensive information available. This high-level overview highlights the initial approach for leveraging the DMP, emphasizing accessibility, efficiency, and integration, vital for supporting the dynamic needs of AVs.

4 Conclusion and next steps

During the explorative phase of analyzing the architecture of the 3 pilot sites, it has become obvious that running on-demand services is done in different ways. This has resulted in a first version that mainly has focused on describing the current architecture and the policies under which the sites operate.

The current TPG site operates totally separate with no integration to other parts of the TPG services. This is a goal for TPG and will be described architecturally in the next version. DB Regio and TPG sites operates on dedicated vehicles that is owned by the sites, however the Norwegian site Ruter# has another approach that uses both dedicated and ad-hoc operated vehicles, but the vehicles are all hired in through operators. This means the architecture will have to deal with direct and indirect control over the AV's in the project. Whether or not this will result in two different architecture approaches will be interesting to explore in the next version of this delivery.

Dissemination of passenger information with no driver in the vehicle will in an on-demand scenario require the vehicle or services like a client app to be able to replace the driver in the vehicle. To this end, the features of a passenger onboard unit have been described in this delivery, but how this unit will fit into the current fleet of AV's and the possible different architectures with direct and indirect control over the AV's will be explored in the next version.

Dealing with cybersecurity and privacy issues will be a topic that due to the nature of on-demand service will become a crucial part. To operate an on-demand service on AV's there is a must heavier need for personal data from bookings and to be able to relay current status to clients, this requires control over data privacy, in a way that is not found in regular line based public transportation. How this will affect the architecture will be part of next version of this delivery.

5 Appendix

Appendix : Ruter#

UITP High level Model

Parts of Ruter's multi-operator model are inspired by a high-level reference model proposed by UITP, see Figure 2.

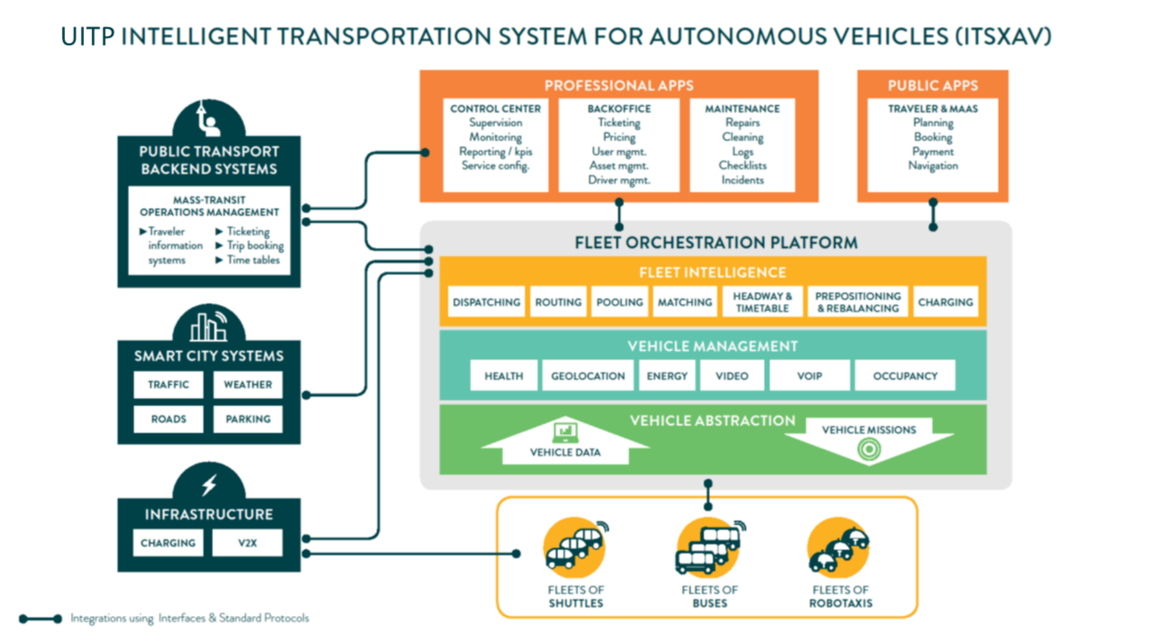

Figure 20: UITP's proposed reference model ITSXAV for operations with autonomous vehicles.

General Considerations to be elaborated

1. Data Management and Integration
    1. Real-Time Data
        1. Latency requirements – orchestrator needs fresh information.
    2. Availability – SLA on data access
    3. Data Exchange formats
    4. Metadata – central repository for metadata
2. Integration with DRT system(s)
    1. API access
    2. Access to real-time data related to individual functions within DRT system
        1. Pooling
        2. Routing
        3. Dispatching
    3. Standardizat ion
        1. Industry standards (SUTI?)

        2. Gap between SUTI and AV operation
3. Integration with existing Public Transport
    1. Standardization
    2. Must have sufficient data access from DRT for seamless integration with existing PT.
4. Scalability
    1. Future Growth
    2. Load Balancing
5. Maintenance and Upgrades
    1. Remote Monitoring
    2. Upgradability
6. Collaboration with External Stakeholders
    1. Public Collaboration?
    2. Open external API's?
7. Data Storage and Retention
    1. Long-Term Storage
    2. Hot and Cold data storage
        1. Availability for real-time analysis
        2. Cost tradeoff
    3. Data storage format - row/column
    4. Indexing
    5. Data Retention Policies
8. Data Quality and Standardization
    1. Data Quality Assurance
    2. Standardized Formats
9. Data Security, Governance, and Privacy
    1. Anonymization and Aggregation
        1. Anonymized hashing towards 3rd party components e.g., user id's in DRT systems.
    2. Access Controls
    3. Regulatory Compliance
    4. Data Privacy
    5. Data Stewardship
    6. Data catalogue – established definitions on data metrics e.g., passenger definition, velocity units etc.
    7. Data lineage / audit trails – traceability to origin
    8. Cybersecurity
    9. System Redundancy
    10. Geographical duplication
        1. Data centers in multiple locations
10. Machine Learning and AI Integration
    1. Data for Model Training
    2. Demand and availability prediction – to avoid locking DRT resources while customer reviews travel options.
    3. Real time data streams

        1. Real-time analytics
        2. Prediction
        3. Optimization
    4. Short Feedback Loops for learning
11. Integration with Analytics Tools
    1. Open Standards
    2. APIs and Interoperability

Ruter - List of Reports, Presentations, and Literature

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