MOBILITY SERVICES ENHANCED BY GALILEO & BLOCKCHAIN

D5.1 Evaluation of demonstrators

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[1] PU = Public | CO = Confidential, only for members of the consortium (including the Commission) | CL = Classified, information as referred to in Commission Decision 2001/844/EC

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Abbreviation

Acronym	Description
DoW	Description of Work
DPIA	Data Protection Impact Assessment pursuant to Article 35 of the GDPR
GA	Grant Agreement
GDPR	General Data Protection Regulation
MaaS	Mobility as a Service
MDM	Mobility Data Marketplace
MOLIERE	MOBILITY SERVICES ENHANCED BY GALILEO & BLOCKCHAIN
WP	Work Package
MDS	Mobility Data Spaces
EDC	Eclipse Dataspace Components
DRT	Demand Responsive Transit
PoMS	Proof of Mobility Service
HAS	High Accuracy Service
GNSS	Global Navigation Satellite Systems

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1. Executive Summary

Molière aims to explore the utilisation of Galileo satellites, data sharing, and blockchain technologies to address critical challenges and achieve new possibilities. This deliverable presents a comprehensive analysis of the purpose, benefits, and potential applications of this innovative approach. By combining the capabilities of Galileo satellites, which provide global navigation and positioning services, with data sharing and blockchain technologies, Molière Project seeks to enhance security, efficiency, and transparency across various sectors. This document delves into the underlying concepts, explores use cases, and outlines the necessary steps for implementing this transformative solution.

The integration of these cutting-edge technologies has the potential to revolutionise important sectors such as mobility and transportation. The deliverable will discuss a few potential applications, emphasising its transformative capabilities and addressing potential challenges during their implementation. This deliverable presents the actions undertaken by the Molière project consortium regarding the demonstrations presented in different use cases in the partner cities.

The demonstration includes five different uses. These use cases are aligned with the project objective that is described in the Use cases section, including the general objectives and the KPIs of the use cases. The use cases are:

- Use Case 1: Micro-incentives and geofencing
- Use Case 2: Mapping status of cycling infrastructure
- Use Case 3: Proof of Mobility Service
- Use Case 4: Decentralised mobility data sharing for flexible transport
- Use Case 5: Bus travel time characterization and prediction using data science

2. About Molière

Urban mobility is becoming an issue of great importance in today's society due to the increasing population movements towards big cities and the exponential growth of cities in developing countries. Today, urban mobility schemes are evolving faster than ever, mainly due to social, economic and technological changes. The traditional choice between walking, taking public transport or buying a car is being extended with a wide range of new flexible mobility services, such as vehicle sharing and ride-hailing.

In this context, a new mobility paradigm is needed - from disconnected to complementing. Promoting more sustainable, safe, affordable, equitable, and accessible mobility is crucial, where micromobility and shared mobility services increasingly complement public transport. The ultimate goal is to reduce dependence on single occupancy private vehicles.

Molière will build the world's best open data commons for mobility services, the “Wikipedia of public transport and new mobility data”, a Mobility Data Marketplace (MDM) underpinned by blockchain technology, raising the profile, visibility, availability, and utility of geo-location data from Galileo, and will test it to fuel and demonstrate a diverse set of concrete, highly relevant mobility scenarios and use cases where geo-location data is key, addressing the needs of cities, public transport authorities, mobility service providers, and end-users.

3. Structure of the deliverable

This document provides a comprehensive overview of the "Molière" project, which aims to explore the integration of Galileo satellites, data sharing, and blockchain technologies to enhance mobility services. The document starts by explaining the main capabilities of the Galileo Satellite system and its relevance for the sustainable mobility sector. It highlights Galileo's accurate navigation, multi-constellation compatibility, support for infrastructure planning and management, and its integration with smart mobility systems, to optimise transportation systems and services.

Furthermore, the document delves into the capabilities and benefits of the Galileo Satellite System in various use cases within the mobility sector. For instance, it discusses the use of geofencing in cities, where accurate geopositioning is crucial to distinguish between nearby areas and avoid triggering automatic changes in device behaviour. Galileo's higher resiliency against multipath errors, a common issue in urban environments, is also emphasised.

It explores the importance of data sharing in the mobility sector, focusing on the challenges and opportunities it presents. Data sharing has numerous benefits, but it also raises privacy and legal concerns, especially concerning the EU's General Data Protection Regulation (GDPR). The document mentions the options of direct access to raw mobility data or competitive access through APIs, each with its implications. Establishing standards for data formatting and exchange can enhance interoperability, but bespoke integrations may also be necessary in certain situations.

The document introduces the concept of data spaces and how they can facilitate smart mobility. Mobility Data Spaces (MDS) in Germany, funded by the German Federal Government, is part of the European cloud initiative Gaia-X. MDS aims to create a catalogue of mobility data, where companies and institutions can monetize or exchange data for innovative mobility solutions. It uses the Eclipse Dataspace Components (EDC) for secure data access and exchange.

The Mobility Data Marketplace (MDM) developed as part of the Molière project is introduced as a decentralised infrastructure owned by those holding its governance token. This decentralisation mitigates risks associated with centralised models, enhancing trust and platform resilience. The MDM serves as the foundation for various use cases, promoting cooperation between stakeholders and providing comprehensive mobility solutions.

The document then describes five different use cases developed as part of the Molière project. Each use case is carefully explained, including its rationale, objectives, and outputs. For instance, Use Case 1 explores micro-incentives and geofencing to encourage sustainable mobility, while Use Case 2 focuses on mapping the safety of cycling infrastructure. Use Case

3 aims to provide a robust mechanism for allocating incentives to promote MDM growth, while Use Case 4 explores decentralised mobility data sharing for flexible transport. Finally, Use Case 5 involves bus travel time characterization and prediction using data science.

Overall, this document showcases the potential of integrating Galileo satellites, data sharing, and blockchain technologies in the mobility sector. It demonstrates how these technologies can enhance security, efficiency, and transparency while promoting sustainable, equitable, and accessible mobility solutions. The project's use cases serve as tangible demonstrations of these transformative capabilities, making a significant contribution to the advancement of mobility services enhanced by Galileo and blockchain.

4. Galileo Satellites: A Foundation for Global Navigation and Positioning

4.1. Overview of Galileo Satellites

The Galileo GNSS constellation is relevant in the sustainable mobility sector due to its accurate navigation, multi-constellation compatibility, support for infrastructure planning and management, integration with Intelligent Transportation Systems, emission monitoring and control, facilitation of mobility services and applications, and assistance in emergency and rescue operations. These capabilities contribute to the optimization, efficiency, and sustainability of transportation systems and services.

Galileo is designed to provide global positioning and navigation services. In the mobility sector, it is of great relevance to increase geoposition accuracy in challenging environments like under dense foliage or dense urban areas, which are in great need of better and sustainable mobility services. Furthermore, its reliability ensures consistent positioning information that improves the experience of the user and allows better detection and correction of errors that would widen the possibility for mobility services.

4.2. Capabilities and benefits of the Galileo Satellite System

The Galileo Satellite System, a cutting-edge Global Navigation Satellite System (GNSS), is transforming navigation in today's fast-paced world, catering to various applications such as micromobility services and car sharing systems. Its capabilities address the challenges of accurate geopositioning in urban environments with towering buildings and dense foliage.

Geofencing, crucial for modern applications, can suffer from poor location accuracy. Galileo's Enhanced GNSS (EGNSS) parameter ensures precise positioning, critical for micromobility and car sharing services. The challenge of urban geopositioning arises due to buildings obstructing direct line-of-sight visibility to satellites. Galileo's higher resiliency against multipath errors significantly improves location accuracy.

In urban areas, traditional GNSS receivers struggle with street-level resolution errors. Galileo reduces measurement errors enhancing precision. Galileo's capability to combat multipath fading is particularly beneficial in urban settings.

With accurate navigation, multi-constellation compatibility, infrastructure support, integration with Intelligent Transportation Systems, emission monitoring, and more, Galileo transforms transportation systems worldwide. It opens new horizons for effortless and reliable navigation, empowering a connected and dynamic future.[2]

The error of the measurements and lack of accuracy of a standard GNSS receiver cannot be ignored at street level resolution. This is a problem in GPS and GLONASS which the European GNSS constellation Galileo aspires to solve by reducing the error component of the measures up to a few centimetres. The source of the error is mostly due to multipath fading of the received GNSS signal. This is especially critical in urban environments as applied to almost any shared mobility services, where the GNSS signal is likely to be received multiple times with different power levels and time delay.

The following table[3] enlists and describe different examples of the usage of Galileo, including the Galileo GNSS parameter:

Table 1. Galileo applications

Use case	Description	Relevant GNSS Parameter
Geofencing in cities	Geofencing refers to the creation of virtual perimeters for real-world geographic areas, or in other words, is the process of determining when a device has entered or left a predetermined geographic boundary. Poor location accuracy can therefore cause significant problems when used for geofencing. If geolocation is not accurate, distinguishing between nearby areas (a street vs a sidewalk, or a park vs a bike path) becomes challenging. This can lead to users receiving incorrect directions, triggering unpredictable, automatic changes in device behavior (for example, misdetection of a low-speed area, where both false positives and false negatives can have fatal consequences). All micromobility services (scooters, bikes, e-bikes, moped sharing) and also car sharing/pooling services should use an accurate geoposition if they want to engage customers and reduce the churn rate. EGNSS can avoid this situation by positioning the vehicle more accurately.	Accuracy, integrity
The challenge of geo-positioning in urban areas	High buildings hamper GPS geopositioning because they obstruct the direct line-of-sight visibility to satellites, and additionally give rise to non-direct line-of-sight signals or multipath bound inaccuracies. Whether a person is on a scooter, a car or just walking, in urban areas where buildings can block signals from navigation satellites, the use of hardware capable of combining inputs from different satellites, i.e., GPS, GLONASS or Galileo is key to improve the accuracy and the availability of the vehicle position and thus the quality of the service. One of the main benefits of Galileo, compared to other GNSS, is that Galileo has higher resiliency against multipath, meaning it will determine location more accurately. Multipath errors are as of today one of the major error sources for conventional GNSS receivers. A multipath error is caused by the reception of signals arriving not only directly from satellites, but also	Accuracy, availability, continuity

[2] From EUSPA: https://www.euspa.europa.eu/european-space/galileo/What-Galileo

[3] From Molière's deliverable: D4.2 - GNSS & Blockchain integration

	reflected from the local objects in the environment. Basically, a multipath error will cause your location to be less accurately determined.[4]	
Better policy outcomes through geopositioning	Accurate geopositioning can help ensure that a micromobility service for example has sufficiently allocated vehicles to underserved neighborhoods or making sure that the provider does not flood the streets with more vehicles than they have licensed. For these types of policies, accurate location data such as from the Galileo program presents a highly reliable signal and an opportunity to drive better usage of the cities' mobility infrastructure	Accuracy, integrity
Accuracy and precision matters for Autonomous vehicles	Autonomous driving is not a distant vision: It will be part of everyday life in some cities in a few years from now. To actually become reality, several technologies will have to reach maturity and be rolled out in concert. Driverless cars promise to open up new mobility options for people with impairments and aging populations, reduce car accidents and even free up the space wasted in parking. There is no way to make all this happen without accurate and reliable geopositioning. So, once again, Galileo plays a key role. Furthermore, the Galileo system (differently from other GNSS) authenticates its satellite signals by incorporating a digital signature to the navigation data that certifies its sources. This allows Galileo users to assess the trustworthiness of the signals, making them more robust against spoofing attacks (disguising a communication from an unknown source as being from a trusted source)[5]	All (Accuracy, integrity, continuity, availability, Robustness to spoofing and jamming and Authentication)
Active Travel	Active mobility or active travel is becoming more and more popular. People are now more than ever non-motorized vehicles like bicycles to move around the city. Knowing where you walk or cycle really matters, especially the first time you arrive in a city is critical and if the location is not good enough the user experience can be damaged. For example, if you are walking on an elevated pedestrian lane, but the location pointer shows you on the ground-level sidewalk, then you would simply receive wrong instructions and lose your way. If it is wanted to improve people's health and at the same time promote sustainable mode of transport, there's a need to provide accuracy to pedestrians and cyclists and Galileo again plays a key role in.	Accuracy

5. The importance of data sharing, important in the mobility sector

"Mobility data" is defined as information about travel that is collected using digitally enabled mobility devices or services. This may include information about trips (i.e., origins, destinations, trip length, trip route, start and end times, etc.) or the vehicles used (i.e., vehicle location, average speed, direction, sudden braking, emissions etc.). Mobility data is typically

[4] Galileo for urban mobility: moving cities ahead with space data. Paper ID 993
[5] Galileo for urban mobility: moving cities ahead with space data. Paper ID 993

recorded as a series of latitude/longitude coordinates and collected at regular intervals by smartphones, on-board computers, or app-based navigation systems.[6]

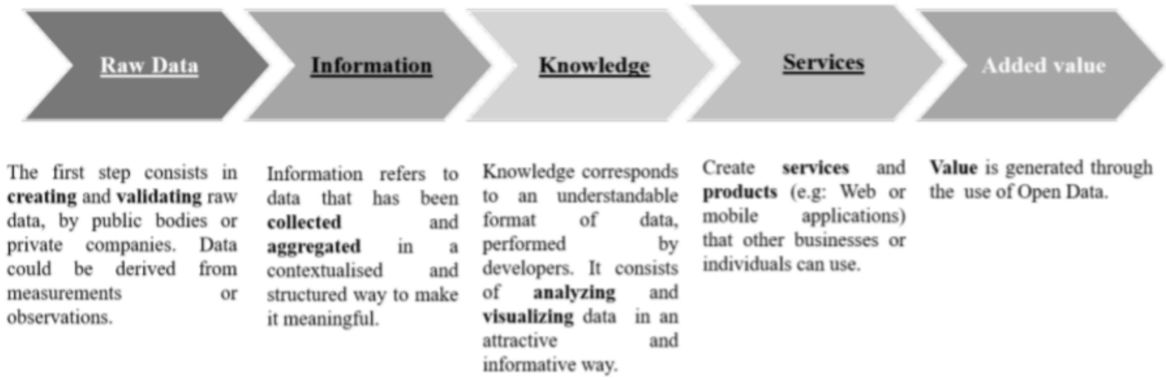

Figure 1. Open data value chain[7]

5.1. Challenges and Opportunities

Data sharing has a number of benefits, but a key question that needs to be considered is whether to pursue direct access to mobility data via data lakes[8] or ensure competitive access through application programming interfaces (APIs). Direct access to raw mobility data holds several implications due to the sensitivity of the information, including protecting privacy and complying with related legal frameworks such as the EU's General Data Protection Regulation (GDPR). On the other hand, APIs are not commonplace, so interoperability remains an issue where legacy systems, such as public transport, must "compete" with new mobility providers.

Establishing standards for formatting and exchanging data can be beneficial due to increased interoperability between producers and consumers, but under some circumstances, more bespoke integrations could make sense as well. Data sharing will also have to comply with the different regulatory and operating requirements of the related modes of transport (i.e., Public Transport vs other mobility services).

On the other hand, mobility data could have a great positive impact for different actors. The figure below provides an overview of the different stakeholders and describes how each group uses mobility data.

[6] NACTO and IMLA Guidelines for Managing Mobility Data | National Association of City Transportation Officials

[7] From MOLIERE - D3.1 - Use Cases Definition and Requirements

[8] Definition of a Data Lake: «A central storage repository that holds big data from many sources in raw, granular format», for more details see: https://www.talend.com/resources/what-is-data-lake/

Figure 2. Mobility Data users and stakeholders[9]

5.2. Data spaces

Doing smart mobility right requires data. Imagine if you could tell how each person on the planet is moving right now. Or, what if you could learn everyone's moving patterns over time, including their preferred types of movement? All of this becomes possible with the aggregation of the right data – data which is already collected and available but is not yet easily accessible in one place.[10] Smart public transport systems, MaaS solutions, and increasing automation all require accurate data to function. Apps that consider users' actual movement in real time will be more relevant and more efficient for the users. Vehicles are the key component of smart mobility, which includes not only cars and buses but also scooters, e-bikes, etc. New business models around cars and mobility increase the need to have accurate data about the vehicle itself as well as drivers and passengers, their location through (E)GNSS, its operation status, and so on. Cities and municipalities, in particular, have an increasing need for understanding mobility and traffic patterns to develop the smart city of tomorrow. The ability to gather relevant data from all different sources can help overcome the challenges related to urbanisation, congestion, traffic planning, and sustainability.

Society has started to acknowledge data as an asset. Data marketplaces provide buyers the opportunity to purchase datasets (or consolidated insights) to enhance their analytics and offer new services to their customers, while sellers are able to monetize their data. Introducing a decentralised European Mobility Data Marketplace will allow this to happen without compromising on data sovereignty.
The benefits of a Mobility Data Marketplace are manifold and will vary according to different stakeholders. Here is a list including some of those benefits:

Benefits for Mobility Operators

- Improved traffic management through traffic data exchange with other transport operators
- Tangible relief due to reduced administrative and organizational effort (e.g., easier and centralized access to required data)

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[9] From MOLIERE - D3.1 - Use Cases Definition and Requirements

[10] From Moprim: https://www.moprim.com/

- Increased transparency and security through established standards
- Wide data distribution in end user devices through easy access for service providers

Benefits for Companies and Research
- Improved business opportunities through easy access to traffic data market
- New research impulses through a wide range of additional and easily available data
- High transparency and security through secure standards
- Sharing reliable information enhances customer satisfaction[11]

5.3. *Mobility Data Space (MDS)*

5.3.1. *Introduction to MDS*

As part of use case 2, Keita Mobility Factory is offering the data obtained as part of Moliere from the LanePatrol solution as part of the MDS catalogue. The Mobility Data Space is funded by the German Federal Government and is part of the European cloud initiative Gaia-X. Its idea is to create a catalogue of mobility data from which companies, organisations and institutions could monetize their data or share and obtain data for innovative mobility solutions.

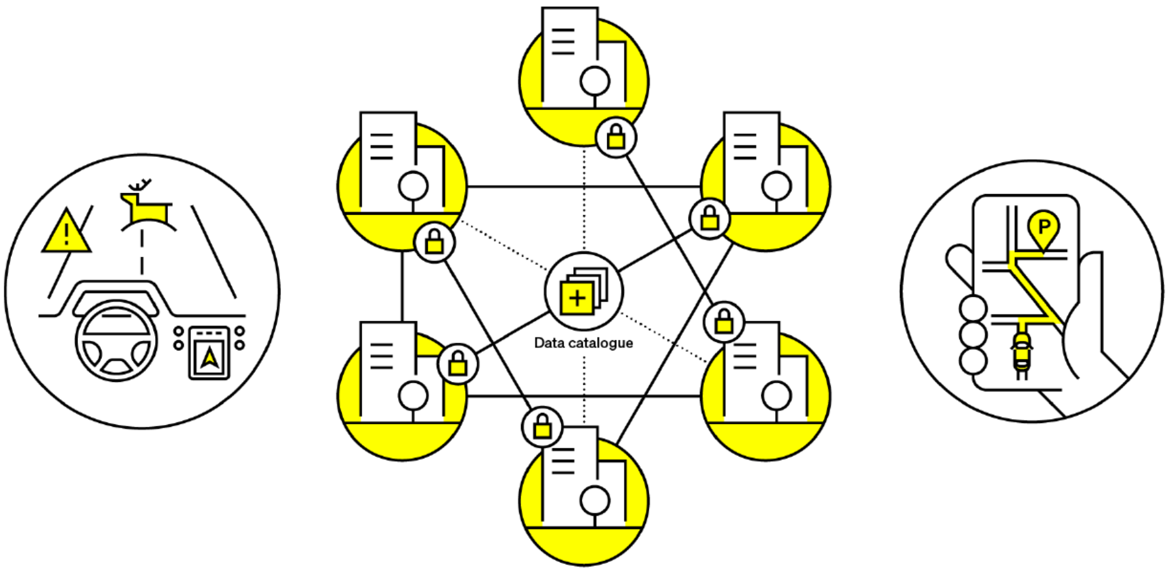


Figure 3. MDS connected catalogue scheme[12]

The Mobility Data Space (MDS) serves as a data marketplace, fostering data exchange among equal partners within the mobility sector. The data provider maintains full ownership of their data and retains the autonomy to decide the scope and participants of data sharing. The primary objective of MDS revolves around establishing a cross-company data economy that facilitates the realisation and advancement of innovative, environmentally sustainable, and user-friendly mobility concepts.

[11] Germany's Mobility Data Space-

[12] From MDS: https://mobility-dataspace.eu/

MDS plays a pivotal role in unifying various entities, including companies, organisations, and institutions, with distinct data-related interests. On one side, it accommodates those seeking to monetize their valuable data assets, while on the other side, it addresses the needs of those requiring data to develop cutting-edge mobility solutions. Additionally, MDS aims to foster a win-win scenario through targeted data exchanges that yield mutual benefits for the involved stakeholders.

In achieving its objectives, MDS lays the foundation for a framework built on trust and cooperation. By promoting openness and transparency in data exchange, it fosters a harmonious ecosystem where data providers and recipients can confidently engage in collaborative endeavours. The overall vision of MDS revolves around leveraging data as a key driver for transformative advancements in the mobility domain, contributing to sustainable and user-centric mobility experiences.[13]

MDS uses the Eclipse Dataspace Components (EDC), a collection of components for participating in data spaces. The EDC Connector is a component that provides secure and reliable access to data and its integration into different systems. The EDC Connector forms the basis for data exchange between MDS members and acts as an intermediary between providers and recipients. The decentralised architecture always ensures data security and data sovereignty.

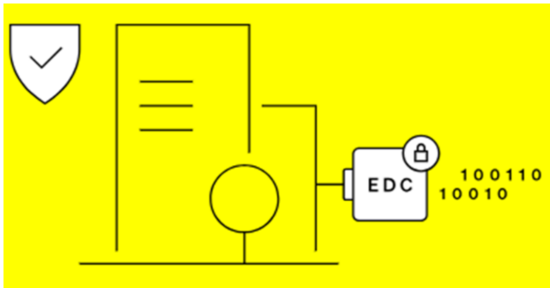


Figure 4. EDC scheme from MDS

5.3.1.1. Connector-as-a-Service (CaaS)

Connector-as-a-Service (CaaS) is a browser-based service provided by MDS partners and available to members on demand. With CaaS, members do not need to install the EDC Connector on their own systems. Instead, they can log in via their browser and access the data provided by MDS. Data security and data sovereignty are guaranteed at all times, and data is still exchanged only between the contractual partners.

[13] Germany's Mobility Data Space-

aaS allows MDS members to bypass the installation of the EDC Connector on their own systems. MDS members can continue to exchange data with other members. It does not matter if only one, both or neither party uses CaaS.

The Connector-as-a-Service (CaaS) is a standardised way to share data between companies. According to MDS, CaaS is a browser-based service provided by MDS partners and available to members on demand. With CaaS, members do not need to install the EDC Connector on their own systems. Instead, they can log in via their browser and access the data provided by MDS. Data security and data sovereignty are guaranteed at all times, and data is still exchanged only between the contractual partners.

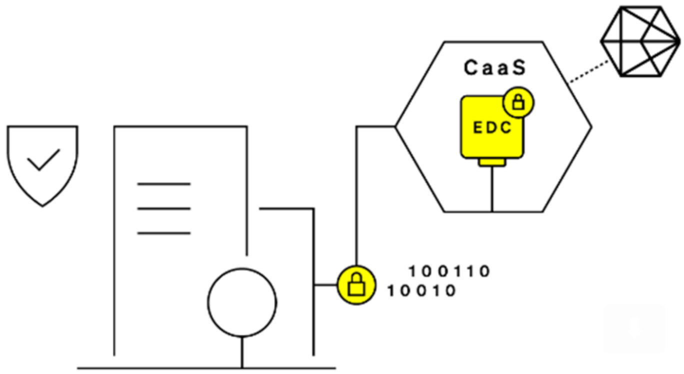


Figure 5. CaaS connection to EDC scheme

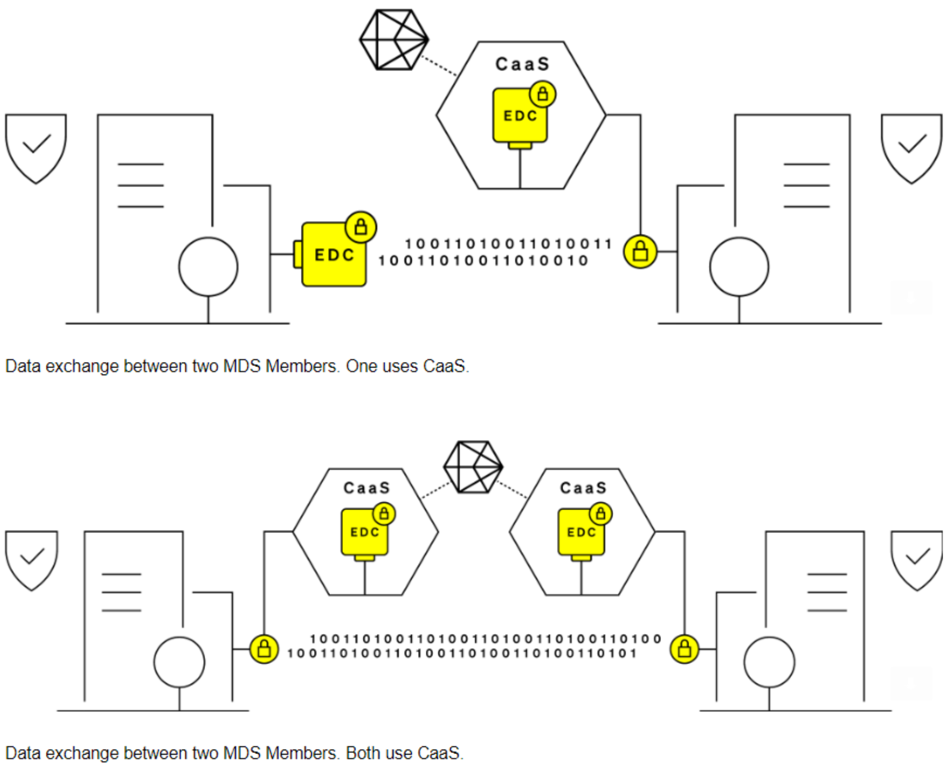


Figure 6. MDS Connector as a Service schemes[14]

[14] From MDS: https://mobility-dataspace.eu/

Keita Mobility Factory data from use case 2 is part of the MDS catalogue under the following characteristics:

Data category: Infrastructure
Description: Level of safety of cycling infrastructure based on the CycleRAP methodology.
Data supplier: Data platform

5.4. Molière's Mobility Data Marketplace (MDM)

5.4.1. Introduction to the MDM

Moliere's Mobility Data Marketplace (MDM) is designed to facilitate an interconnected ecosystem of various mobility services, creating a network that provides comprehensive mobility solutions to citizens. Operating under the principle of "coopetition," the MDM acknowledges that mobility services can be both complementary and competitive. Yet, it seeks to leverage these dynamics to create a more seamless and efficient mobility infrastructure.

The main way in which the MDM facilitates this cooperation is by standardising the communication patterns between all stakeholders, and primarily the Mobility Service Providers and the end-users. The MDM receives information about mobility services, and facilitates their discovery, combination, booking, and their payment for end-users via apps connected to the MDM's backend platform.

The MDM is not just an aggregation platform for mobility services, but also an ambitious project to foster integrated mobility experiences. It strives to enable any mapping application to access comprehensive mobility data for journey planning and, ultimately, evolve these applications into fully integrated mobility solutions. These solutions would enable bookings, crowdsourcing of data points, and provide an integrated experience that is far beyond what traditional mapping applications and data sharing oriented architectures offer.

5.4.2. Technical design

The main novelty of the MDM is that it is decentralised. This means that as an infrastructure it is not under the control of a single organisation or a tightly defined consortium. Instead, the MDM is owned by anyone who holds its governance token. The governance token represents a stake in the platform, and enables decentralised decision making, allowing participants to vote on key decisions, appoint representatives, and distribute voting rights.

While the governance of the MDM relies on public blockchain infrastructure, the exchange of mobility services is carried out in private localised blockchains. This is so that the network can respect the privacy expectations of end-users and providers alike, as well as tailor each deployment to local regulations and particularities.

A token-based voting is used in the governance layer to maintain a registry of node coverage areas. These tokens can also incentivize the development of new platform features and facilitate consensus on strategic changes or upgrades.

Through its decentralised structure, the MDM effectively mitigates platform risks associated with centralised models. It disperses control among holders of the governance token, reducing the dependency on a single authority, thereby enhancing trust, stability, and overall platform resilience.

5.4.3. *Relevance for the use cases*

The MDM serves as the base layer that underpins all the use cases, with varying degrees of integration. In particular, use cases 1 and 3 explore subsidies to nudge stakeholder behaviour. Use case 1 explores micro subsidies as a mechanism to encourage sustainable mobility, whereas use case 3 explores a robust mechanism to allocate incentives to all stakeholders in the MDM to incentivize its growth, especially in early stages of its deployment. These subsidies can be very easily delivered on a blockchain platform as long as they can be tokenized, in an auditable and verifiable fashion. Use case 2 enhances the quality of the data in the MDM by reporting the quality of bike lanes, which could then be used to inform routing choices for end-users (part of future work). Use cases 4 and 5 relate to tracking with precision bus services, and making the data available to consumers.

5.4.4. *Future of the MDM*

In order to fully reach its potential, the MDM needs to grow to a truly massive scale. This will require not only leveraging the token incentives explored in use case 3, the capability to nudge users of use case 1, and the enhancement of its data as explored in the other use cases, but also extending its APIs to support all the main modes of mobility, as well as sponsoring the formation of a minimum viable community of providers and users. This is a massive undertaking that is nonetheless extremely exciting to the authors of this document.

6. Use cases

6.1. Overview

The Molière Project explores the integration of Galileo satellites, data sharing, and blockchain to address challenges and unlock new possibilities. This document presents a comprehensive analysis of its purpose and potential applications. By leveraging these technologies, Molière seeks to enhance security, efficiency, and transparency across sectors. One of its transformative potentials lies in revolutionising mobility and transportation sectors.

It includes information related to five different use cases including its conclusions:

- Use Case 1: Micro-incentives and geofencing
- Use Case 2: Mapping status of cycling infrastructure
- Use Case 3: Proof of Mobility Service
- Use Case 4: Decentralised mobility data sharing for flexible transport
- Use Case 5: Bus travel time characterization and prediction using data science

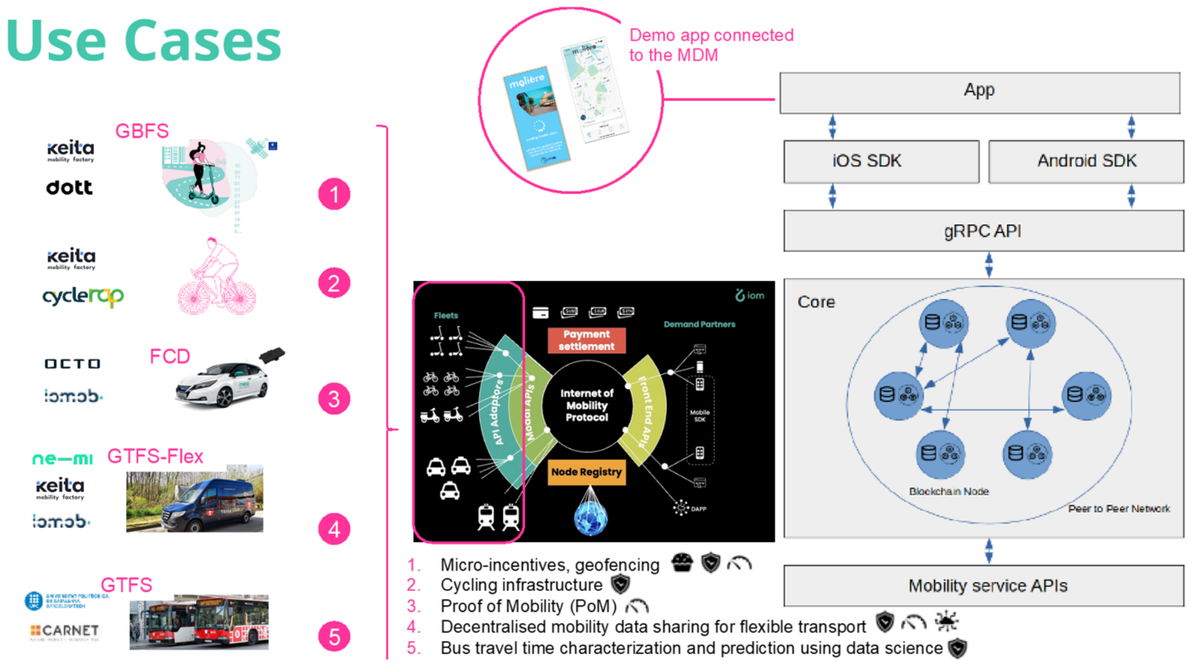


Figure 7. Use cases alignment with Molière[15]

To standardise the details related to the use cases, each of the five of them have been explained in the following structured information:

- Use case Rationale – the problem the solutions is solving
- Use case details – description of the work and needs for the use case
- Use case link to Moilère - Why is it important for Molière and EUSPA (Galileo and Copernicus)
- Use case objectives and outputs
- Use case conclusions

The demonstrations showcased in partner cities showcase the project's progress towards its objectives and KPIs.

6.2. Objectives and KPIs

During the project duration the composition of the consortium has changed with SEAT leaving, being replaced by Dott, Keita and Nemi. Some use cases have been updated to address Molière's goals. The new updated use cases have also updated their different KPIs to measure success. Hence the originally developed KPIs no longer fit and have been replaced by the ones below.

[15] From MDS: https://mobility-dataspace.eu/

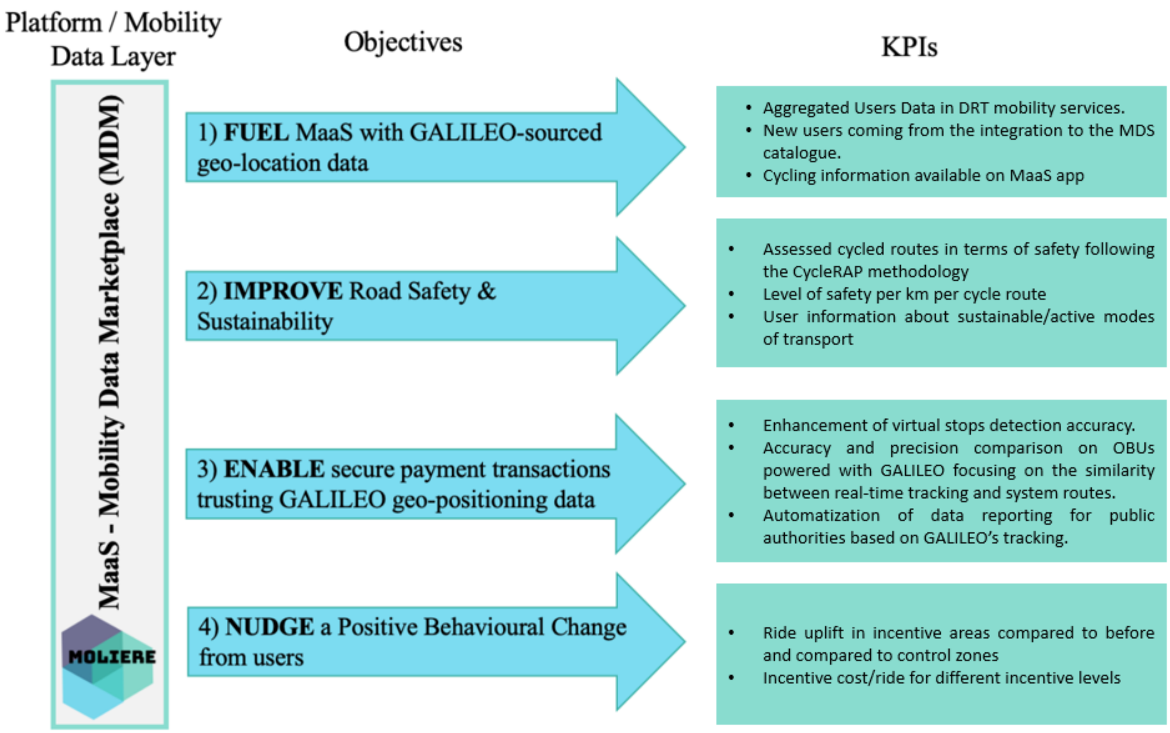


Figure 8. Objectives and updated KPIs Molière

Molière's objectives and KPIs are relevant as they provide measurable goals to assess the impact and effectiveness of the project's innovative approach.

6.2.1. FUEL MaaS with GALILEO-sourced geo-location data

This objective aims to measure the integration of GALILEO-sourced geo-location data into Mobility-as-a-Service (MaaS) solutions. GALILEO is a global navigation satellite system, and by utilising its accurate positioning data in MaaS, the project seeks to enhance the efficiency and reliability of mobility services.

6.2.1.1. Aggregated Users Data in DRT mobility services.

This KPI focuses on aggregating data from users of Demand-Responsive Transport (DRT) mobility services. Analysing this data can provide valuable insights into travel patterns and user behaviour, helping optimise DRT services to better meet user demands.

6.2.1.2. New users coming from the integration to the MDS catalogue.

The MDS (Mobility Data Space) catalogue plays a central role in the project, serving as an open data commons for mobility services. Measuring the influx of new users to the MDS catalogue indicates its growing utility and attractiveness to different stakeholders, fostering collaboration and data sharing.

6.2.1.3. Cycling information available on MaaS app

This KPI aims to enable accessing safety data more easily through the use of a MaaS app. This is intended for end users utilising the app as a decision and navigation system.

6.2.2. IMPROVE road safety & sustainability

This objective aims to assess the project's impact on enhancing road safety and sustainability. By using GALILEO's precise geo-positioning data, the project can identify and evaluate safer cycling routes, promoting active and sustainable transportation options.

6.2.2.1. Assessed cycled routes in terms of safety following the CycleRAP methodology

CycleRAP is a methodology to assess the safety of cycling routes. This KPI indicates the project's commitment to enhancing cycling safety by evaluating and improving cycling infrastructure.

6.2.2.2. Number of kms of safe cycle routes

This KPI quantifies the safety level of each kilometer of cycling routes, with a granularity down to 10m. By doing so, insights are given where areas require safety improvements and prioritise measures to make cycling safer and more attractive.

6.2.2.3. User information about sustainable/active modes of transport

Providing users with information about sustainable and active transportation options encourages positive behavioural changes and reduces dependence on single-occupancy private vehicles, aligning with the project's overarching goals.

6.2.3. ENABLE trusting GALILEO geo-positioning data for mobility services

This objective is intended to understand the project's success in building trust in GALILEO's geo-positioning data for mobility services. Ensuring accurate and reliable data is essential for the successful implementation of innovative mobility solutions.

6.2.3.1. Enhancement on virtual stops detection accuracy.

Virtual stops detection accuracy refers to accurately identifying stops for public transportation services. Improving this accuracy can lead to more efficient and reliable public transport services for users.

6.2.3.2. Accuracy and precision comparison on OBUs powered with GALILEO focusing on similarity between real-time tracking and system routes.

This KPI compares the accuracy and precision of on-board units (OBUs) powered with GALILEO data to track real-time vehicle positions. It evaluates the effectiveness of GALILEO as a navigation tool for mobility services.

6.2.3.3. Automatization on data reporting for public authorities based on GALILEO's tracking.

Automating data reporting for public authorities using GALILEO's tracking data streamlines data collection processes and supports evidence-based decision-making, which is crucial for efficient mobility management.

6.2.4. NUDGE a positive behavioural change from users

This objective is intended to evaluate the project's ability to encourage positive behavioural changes in users through incentives and other means, leading to increased adoption of sustainable mobility options.

6.2.4.1. Ride uplift in incentive areas compared to before and compared to control zones

This KPI measures the increase in ride uptake in areas with implemented incentives, compared to both the pre-implementation period and control zones without incentives. It gauges the effectiveness of incentives in driving behavioural change.

6.2.4.2. Incentive cost / ride for different incentive levels

This KPI calculates the cost per ride for different incentive levels. It helps optimise the incentive strategy by identifying the most cost-effective measures to nudge users towards sustainable mobility choices.

Overall, these KPIs provide a robust framework for evaluating the success of the Molière project and its potential to revolutionise a section of the mobility sector through the integration of Galileo satellites, data sharing, and blockchain technologies. They align with the project's objectives and contribute to addressing critical challenges and achieving new possibilities in mobility services.

6.3. Use case details

6.3.1. Use Case 1: Micro-incentives for Micromobility

6.3.1.1. Use case Rationale

Micromobility has become a widespread phenomena in European cities. It offers a significant modal shift potential when designed properly. According to Dott rider surveys, 69% of Dott riders report they travel less by car/taxi/ridehailing since using Dott. Across different cities, 15-20% rides are directly replacing car trips, as reported by the riders. 33% of rides connect to public transport for intermodal journeys

The mode shift potential is limited by economic constraints. Typically, micromobility operations are unsubsidised, hence the ride fees have to cover the costs of operations. This might not be an affordable option for certain parts of the society to use micromobility. Micro-incentives for targeted use-cases can improve inclusion and accessibility of the service.

In other instances, it might not be possible to offer an economically viable service in certain, more peripheral areas of a city region, leaving those areas without first/last mile mobility options. Micro-subsidies for specific areas can enable an economically viable service in a transparent and efficient manner, and improve accessibility and reliability of publicly available mobility services in these areas.

In the context above, the term "micro-incentives" is defined as individualised discounts per user or per ride, which leads to a cheaper ride fare for the user, covered by the micromobility operator. "Micro-subsidies" are individualised payments from Public Authorities, which compensate mobility operators for loss making rides, e.g. "micro-incentives".

The goal of this use case project is to improve service reliability, accessibility and inclusivity in socio-economically disadvantaged areas, which are also underserved by public transport. It is intended to validate a positive impact of micro-incentives to justify future public (micro-)subsidies supporting these incentives.

6.3.1.2. Use case details

The Brussels capital region was chosen as a use case site as Dott has very well established operations since 2019, operating with 4.500 e-scooters and 1.500 e-bikes across all 19 communes. For the micro-incentives to apply, it was defined 2 geo-spatial criteria, validated by Galileo / GNSS-based geofencing technology.

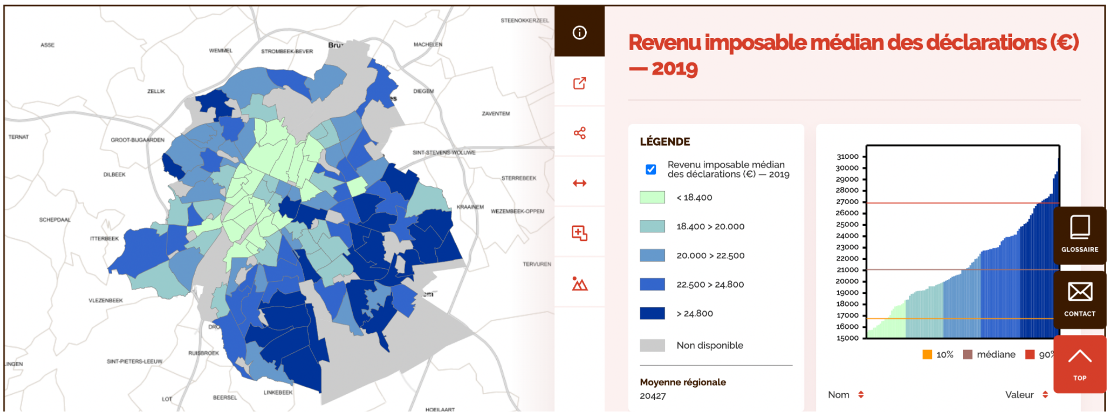


Figure 9. Median taxable income of residents is less than 20k per year[16]

[16] https://monitoringdesquartiers.brussels/Indicator/IndicatorPage/2336?Year=2019&GeoEntity=2

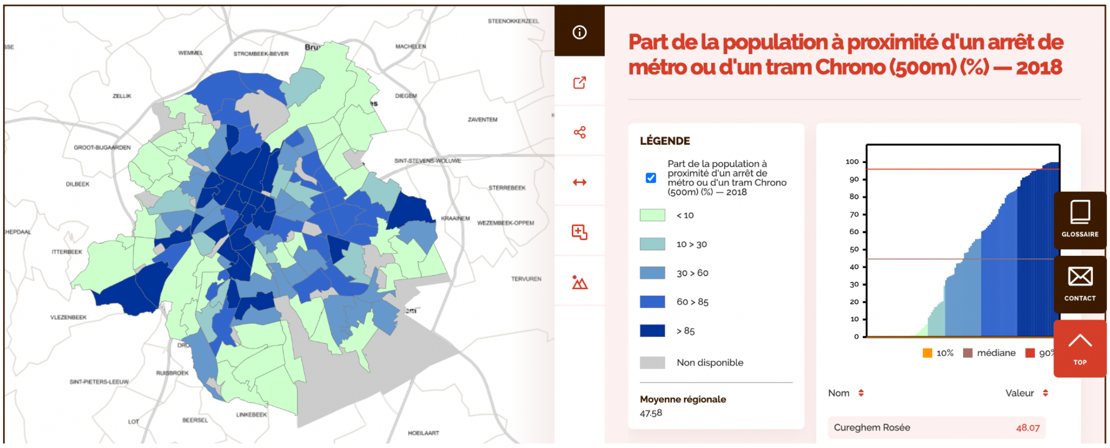


Figure 10. More than half of the residents do not have access to a tram or metro stop within 500 metres of where they live[17]

Overlaying these 2 geo-spatial parameters, a map covering the following zones was obtained: 'Cureghem Vétérinaire', 'Bas Forest', 'Moortebeek - Peterbos', 'Scheut', 'Dailly', 'Chaussée de Haecht', 'Saint-Denis - Neerstalle', 'Cureghem Rosée', 'Helmet'

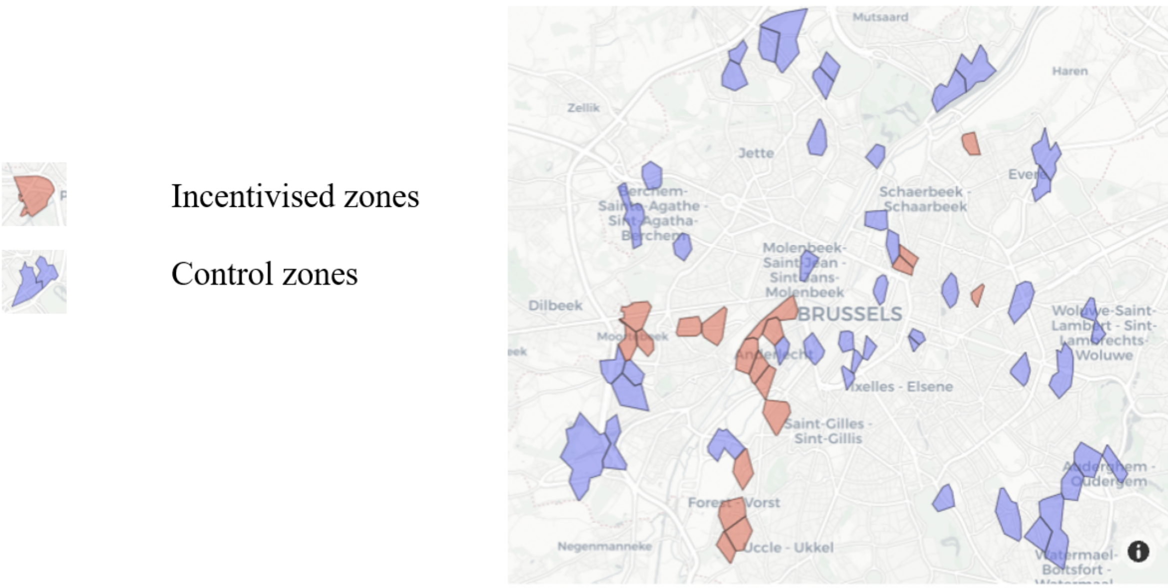


Figure 11. Incentivised and Control zones in Brussels

<u>Hypothesis to validate in the use case</u>
By incentivising rides in these defined zones, the demand can be increased compared to control zones, which triggers more supply of vehicles by the operators and thus a more reliable service.

<u>Methodology</u>

[17] https://monitoringdesquartiers.brussels/Indicator/IndicatorPage/2281?Year=2018&GeoEntity=2

In order to be able to apply micro-incentives based on geo-spatial criteria, Dott has used the Molière budget to develop a micro-incentives engine, for a variety of possible use cases such as user incentivised rebalancing, incentivising rides in low-income or peripheral areas, etc.

The usage of e-scooters and e-bikes was incentivised in the defined zones by a 30%/70% discount, to test the price elasticity of micro-incentives, visualised by a symbol.

- April 24th - June 04th: 30% discount, little user comms (organic growth)
- June 5th - July 15th: 70% discount, strong promotion in-App

Two KPIs were analysed:

- Ride uplift - in incentive areas compared to before and compared to control zones, thus extracting seasonal and climatic influencing factors
  - Cost efficiency - Incentive budget / ride) with different incentive levels

For technical reasons, these incentives only apply to Pay-as-you-Go riders, which account for ca. 35% of all Dott riders in Brussels. Pass holders are excluded from it. The incremental uplift of rides was measured compared to (1) before incentives started, and (2) between incentive zones and control zones without incentives.

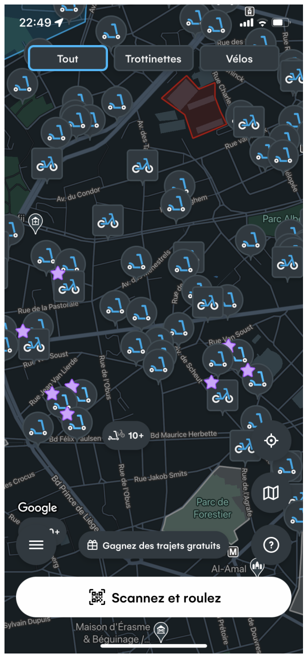


Figure 12. Dott app with information of incentives on e-scooters and e-bikes

<u>Reporting tool for cities</u>

While it is possible to measure the impact of the incentives internally, it was intended to make it transparent to Dott partner cities so that they can justify the socio-economic benefits of and be accountable for future micro-subsidy programs through access to appropriate data.

For this, Dott is making use of “Rideal”, a backend platform which enables public and private organisations to manage, monitor and control all their micro-incentive programs – centralised, transparent, in real-time, and operator-agnostic.

Data is shared between Dott and Rideal through an MDS API. Most notably, Rideal makes use of 2 MDS endpoints - *actual_cost* and *standard_cost* - so that cities or Public Transport Authorities can easily track performance and spendings against defined budgets for their micro-incentive programs.

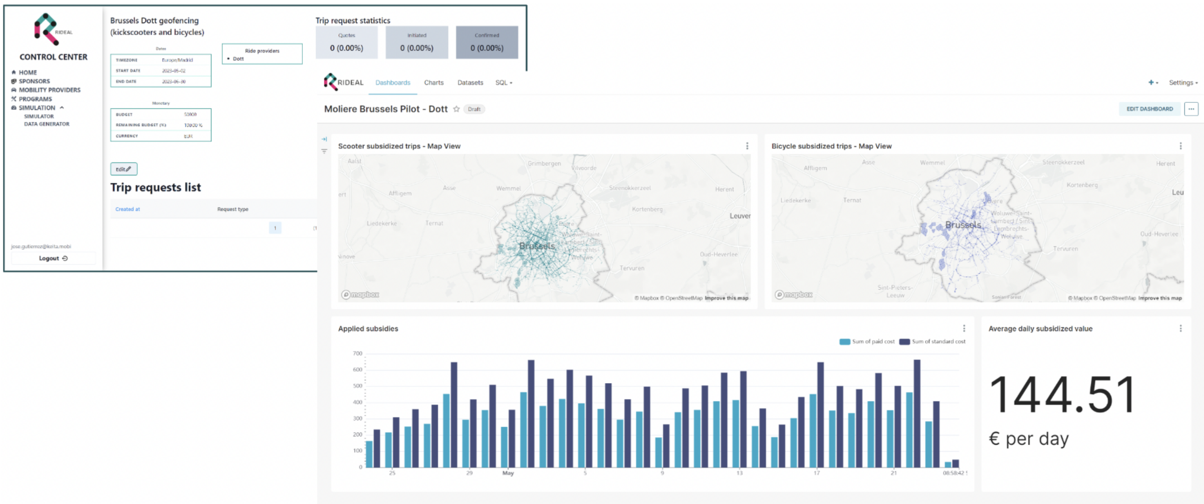


Figure 13. Rideal web app with information from the incentive program in Brussels

6.3.1.3. Use case link to Molière

Dott e-scooter's positioning relies on a GNSS multi-band receiver, which enables efficient geo-fencing technology. While the data transfer of this use-case is not routed via the Molière Mobility Data Marketplace, but instead uses a direct data transfer between Dott and Keita, there are several use cases and benefits of an integrated data transfer in the future.

During the use case, geo-spatial data was solely used. In the future, the concept of micro-subsidies could benefit from exchanging individual rider's socio-demographic data (age, gender, income, etc) to target subsidies even further. This could become relevant towards a MaaS Level 4 development which also entails social goals. As part of the communication and dissemination workstream, Dott aligned with 8 European Cities on appropriate use cases and their technical and legal feasibility.

6.3.1.4. Use case objectives and outputs

The objective of the use case is to prepare a market rollout of micro-subsidies, informed by a concrete case study.

The use case will deliver 3 outputs:

- Concrete insights on the impact of micro-incentives to improve service accessibility in defined zones, including insights on price-elasticity of micro-incentives.
- A proof of concept of a micro-subsidies management platform for cities to allow efficient, data-driven and transparent management of mobility subsidy budgets.

- A sample contract between Authorities managing subsidy budgets and mobility service operators consuming them.

6.3.1.5. Use case conclusions

Executive Summary

- It was possible to validate the hypothesis that incentivized rides do have a statistically significant positive effect on ride uplift in the defined areas.
- With 17.283 incentivized rides, 442 additional rides were generated compared to the expected demand based on the typical rider volume and normalised against the expected demand in Dott's control zones.
- When disaggregating this ride uplift potential of 2.56% into e-scooters and e-bikes, the effect varies, with a bigger ride uplift potential for e-scooters (2.65%) than e-bikes (2.12%).
- These values need to be put into the context of a limit on the maximum possible uplift one can achieve with existing fleets in defined areas without additional supplies of vehicles.
    - Based on the fleet availability and organic ridership volumes in the defined zones during the pilot period, the pilot's maximum possible ride uplift was 28% for e-scooters and 53% for e-bikes.
    - In other words, it was possible to leverage between 7.0% (e-bikes) and 9.5% (e-scooters) of the maximum possible ride uplift in the defined zones through micro-incentives.
- The effect of the discount increase from 30% to 70% is neglectable.
    - On an aggregated level (e-scooters and e-bikes combined) an increase of 2.45% was witnessed which is very similar to the uplift effect of a 30% discount.
    - While for e-bikes, there's no ride uplift at the 30% discount level, there is a quite strong (3.72%) uplift potential for the 70% discount level.
    - For e-scooters the ride uplift potential has reduced when applying the 70% discount (2.18%), compared to the 30% discount level (3.22%).
- At a 30% discount level the average incentive value per ride, or in other words cost for Dott, is 0.96 €. At a 70% discount level the cost would be 2.47 € per ride to achieve a similar ride uplift.

Aggregated results for e-scooters and e-bikes

No benefit of switching from 30% discount level to 70% discount level was observed, on the contrary. The ride uplift has even slightly reduced.

Table 2. Total number of incentivised trips 30% vs 70% e-scooters and e-bikes

Test #	# of rides incentivised	Cumulative budget	# of rides increment	% PAYG ride uplift	Incentive cost / ride
1) 30% discount	7973	7,657€	214	2.68%	€0.96
2) 70% discount	9310	22,973€	228	2.45%	€2.47
total	17283	30,630€	442	2.56%	€1.77

<u>Results for e-scooters</u>

The graph below shows the ride uplift over time for e-scooters. Until April 24th, it shows stable daily variations. When applying the 30% discount, the ride uplift gradually climbs to 214 incremental rides. When applying the 70% discount, the graph climbs further to 376.

Figure 14. Ride uplift e-scooters

Table 3. Total number of incentivised trips 30% vs 70% e-scooters

Test #	# of rides incentivised	Cumulative budget	# of rides increment	% PAYG ride uplift	Incentive cost / ride
1) 30% discount	6638	6,113€	214	3.22%	€0.92

2) 70% discount	7535	17,823€	162	2.18%	€2.37
total	14173	23,936€	376	2.65%	€1.69

Results for e-bikes

The graph below shows the ride uplift over time for e-bikes. An increase within the days before applying the discount was witnessed, which might be explained by a local event, followed by a stable pattern when applying the 30% discount. Only after applying the 70% discount, a significant ride uplift of 66 incremental rides compared to the control zones was observed.

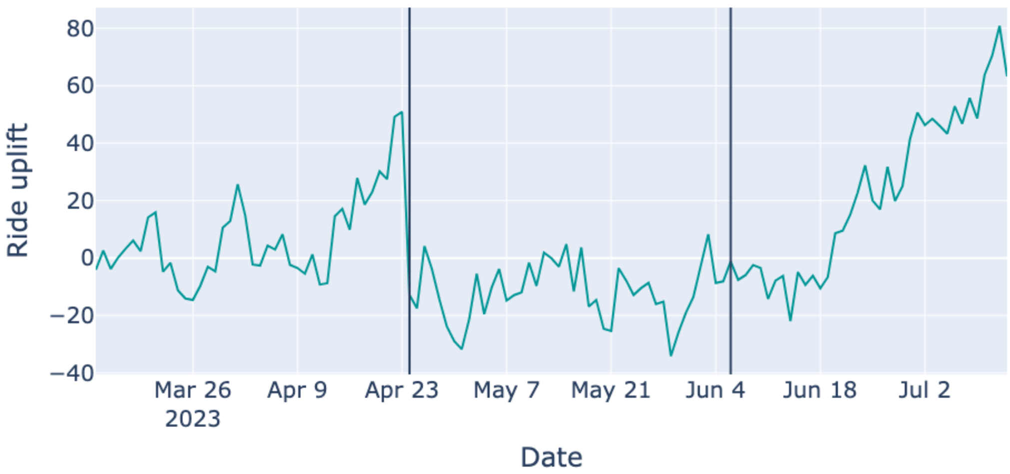


Figure 15. Ride uplift e-bikes

Table 4. Total number of incentivised trips 30% vs 70% e-bikes

Test #	# of rides incentivised	Cumulative budget	# of rides increment	% PAYG ride uplift	Incentive cost / ride
1) 30% discount	1335	1,544€	0	0.00%	€1.16
2) 70% discount	1775	5,150€	66	3.72%	€2.90
total	3110	6,694€	66	2.12%	€2.15

Trip heatmap

Conclusions

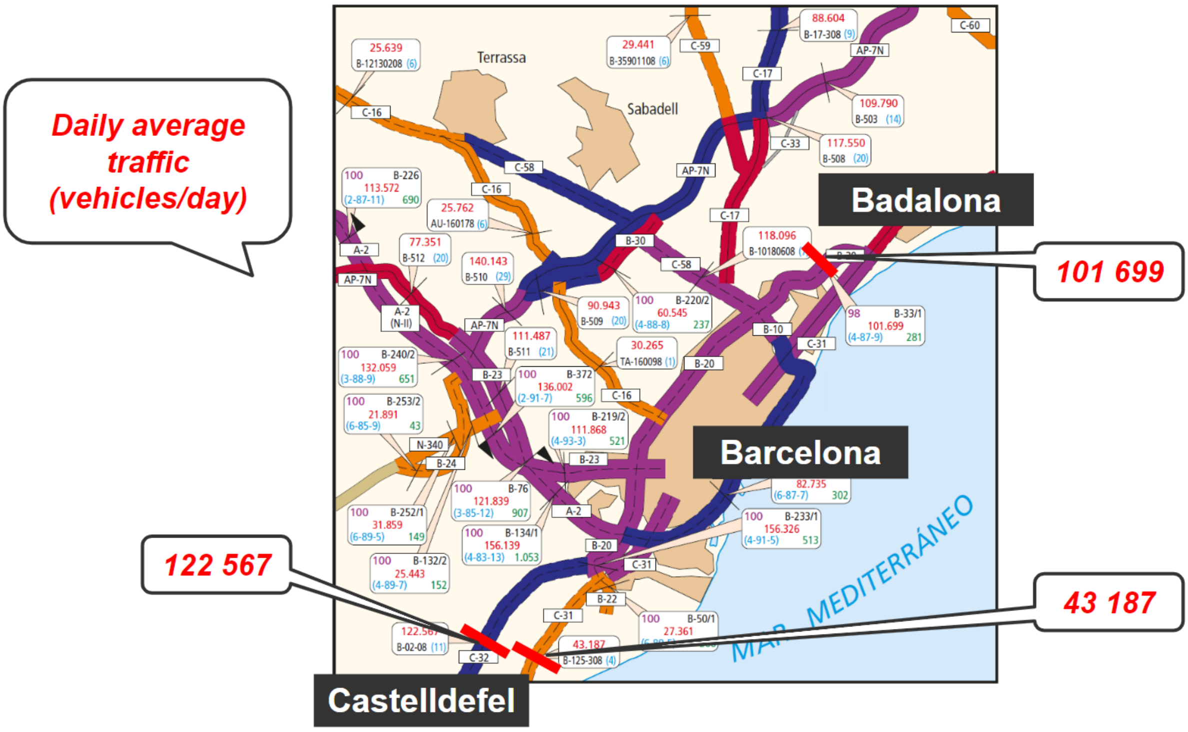
- While the pilot was constrained by some technical limitations, e.g. not being able to address the totality of Dott riders, especially pass holders, who are typically the most engaged and receptive user groups, it was possible to show a positive behavioural impact, with increased usage of micromobility in low-income areas with poor transport connectivity, thanks to micro-incentives.
- It was demonstrated that with a per ride subsidy of less than 1,00 € the ride volume can be boosted in low-income areas with relative transport poverty.
- Throughout the pilot process, some technical gaps to close were identified in order to be able to scale incentives across all user groups. These were beyond the scope of what could have been achieved within Molière.
- While one particular use case for micro-subsidies was analysed, there was engagement with mobility experts from Bristol, Budapest, Dublin, Düsseldorf, London, Milan, Madrid, and Oslo to identify other relevant use cases.
- These use cases will inform potential product roadmaps, data standard adjustments and legal considerations for handling the required data.
- The results and recommendations of this public-private co-creation process can be accessed in the Annex X to this report.

6.3.2. Use Case 2: Mapping status of cycling infrastructure

6.3.2.1. Use case Rationale

Numerous people commute every day to Barcelona from Castelldefels, Badalona, and other places for work and other activities.

There’s a potential to increase the safety and attractiveness when travelling by bicycle from these towns to Barcelona.



Traffic Map 2019, Spanish Ministry of Transport, Mobility and Urban Agenda

Figure 16. Road daily average traffic in Barcelona

6.3.2.2. Use case details – description of the work and needs for the use case

CASTELLDEFELS TO BARCELONA

Castelldefels is home to some FC Barcelona football players, its Olympic canal is used for water sports, and hosts a population of over 60K people.

There are two very different cycling routes from Castelldefels to Barcelona:

- The shortest route (22.5km) goes through three important towns Gavà, Viladecans, and Sant Boi accounting for a sum of over 190K people.
- The other cycling route goes along the seaside for almost half of the 29 km route to then join an industrial district to finally enter Barcelona from the south.

Figure 17. Barcelona - Castelldefels cycle route (obtained from Google Maps)

BADALONA TO BARCELONA

On the other side of the Besós river, Badalona is the third largest city in Catalonia by population with over 217K people and it's approximately 10km away from Barcelona's city centre.

There are two main cycling routes to access Barcelona from Badalona:

One of them goes for around 4km (of the total 10.6km) along the seaside to then pass by industrial districts on both sides of the Besós river.

The other cycling route goes through a more residential area along a 10.4km route that travels more distant from the seaside

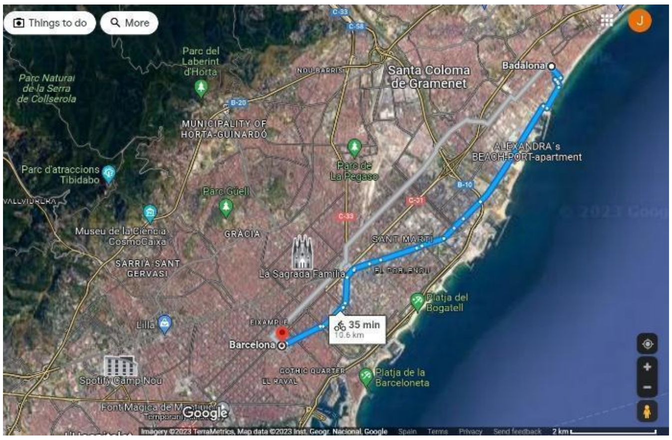


Figure 18. Barcelona - Badalona cycle route (obtained from Google Maps)

6.3.2.3. Use case link to Moilère

The device developed as part of Molière's scope was required to take photos every 10 metres to measure the cycling infrastructure safety according to the CycleRAP methodology. The calculation of this distance was solely based on the positions calculated by the GNSS, thus the precision of multi-constellation GNSS receivers that use Galileo are necessary to avoid errors. With 1 metre horizontal accuracy and 1.5 metres vertical accuracy, it will be possible to start collecting the GNSS calculated altitude of every photo to allow us to compute the inclination of the bicycle lane that will be used to automatically select attributes.

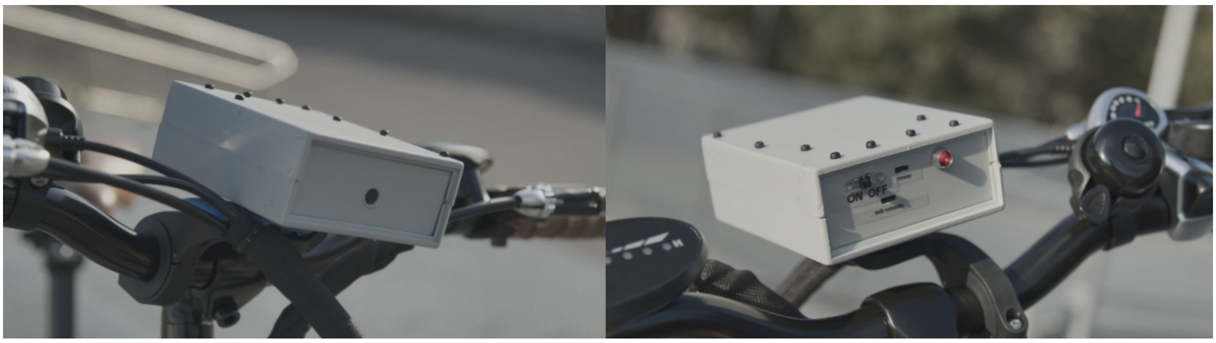


Figure 19. LanePatrol device to collect georeferenced images

6.3.2.4. Use case objectives and outputs

- Using the image-collection device designed by Keita Mobility Factory, georeferenced images will be obtained from both of the routes that connect each of the two cities (Castelldefels and Badalona) to Barcelona.
- With the LanePatrol solution, these images will be coded and analysed following the CycleRAP methodology.
- A report with the analysis, findings and conclusions will be delivered as part of Moliere's output and shared with relevant stakeholders in the public and private sector.
- The scoring from the CycleRAP methodology will be shared in the shape of a colour-coded layer on map services, including LanePatrol, the Mobility Data Space from Germany and Moliere's MaaS app.

6.3.2.5. Use case conclusions

The solution LanePatrol was developed to assess and improve cycling Infrastructure safety, it leverages the CycleRAP methodology, a comprehensive methodology based on an international standard providing a way to objectively measure and benchmark safety. Together with the solution and the methodology, it was possible to obtain a level of safety, a score, for sections of approximately 10 metres through the use of images obtained from a device that collected georeferenced images while mounted on a moving bike. This device contains a GNSS receiver to be able to geolocate the images with enough accuracy, specially in urban areas where it can be more difficult to obtain accurate positioning.

Figure 20. LanePatrol process leveraging CycleRAP

The end goal of the use case was to be able to generate insights about the safety of the cycle routes connecting Barcelona to neighbouring cities of Badalona with a population of around 220k people and Castelldefels, and other towns along the route: Esplugues del Llobregat, Cornella del Llobregat, Sant Boi del LLobregat, Viladecans and Gava summing a tota of around 400k people.

The CycleRAP methodology helps "pinpointing and mapping where bicyclist and light mobility crashes are likely to occur. The model uses data about the features of a road, street or path to evaluate the risk of crashes for bicyclists and light mobility users—irrespective of the type of facility (or whether it is on or off-road) and for all crash types. It can be used anywhere in the world."[18]

The methodology analyses four categories of crash types, always from the point of view of the bicyclists or the light mobility users. Then, it sums up the risk value to give an overall risk value for each section of the route. Nevertheless, the overall qualitative score (defined by the colour) will always be taken from the riskiest score from the four categories.

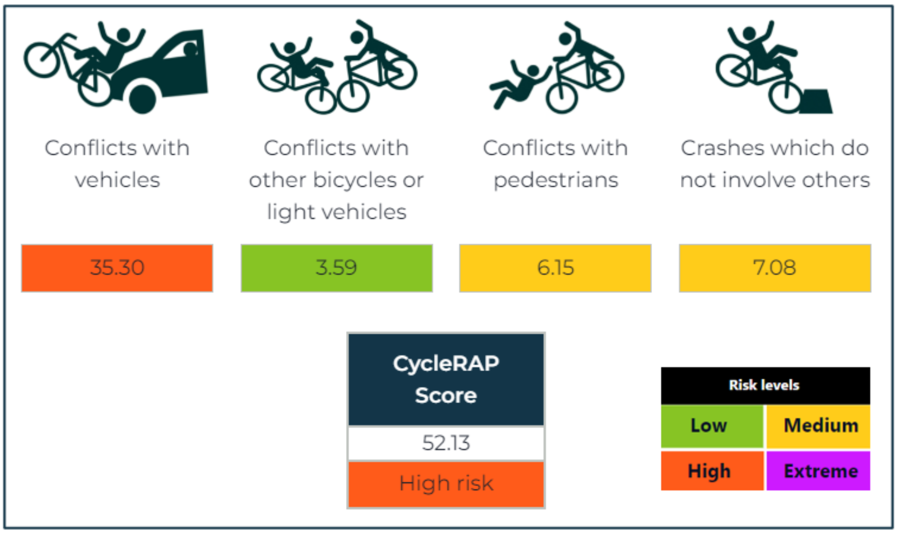


Figure 21. Example of CycleRAP scoring

[18] https://irap.org/cyclerap/

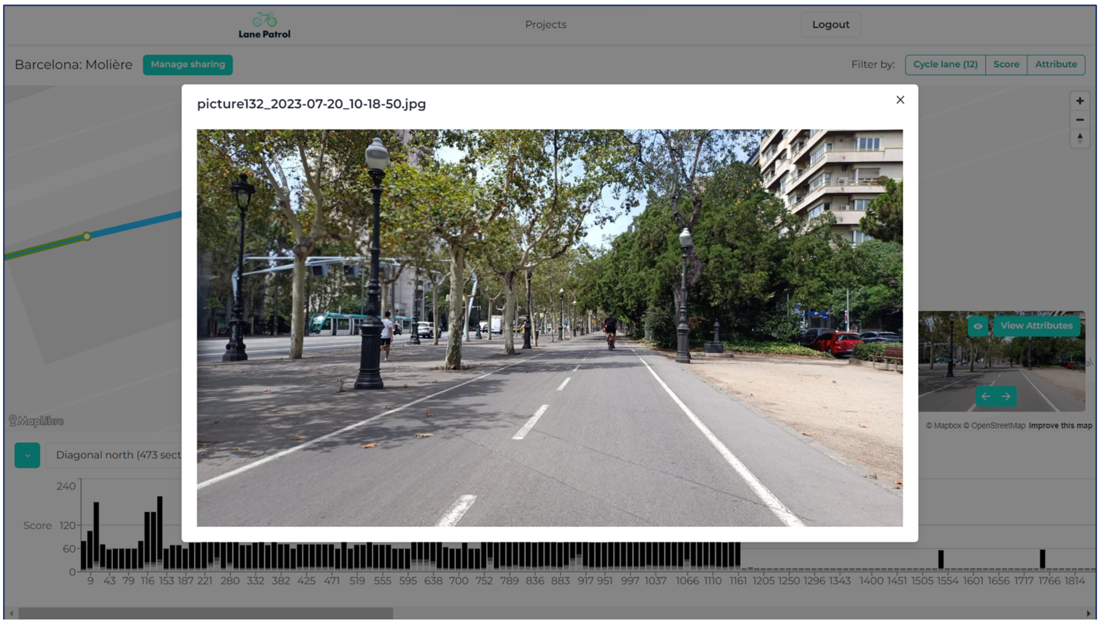


Figure 22. Example of images on LanePatrol

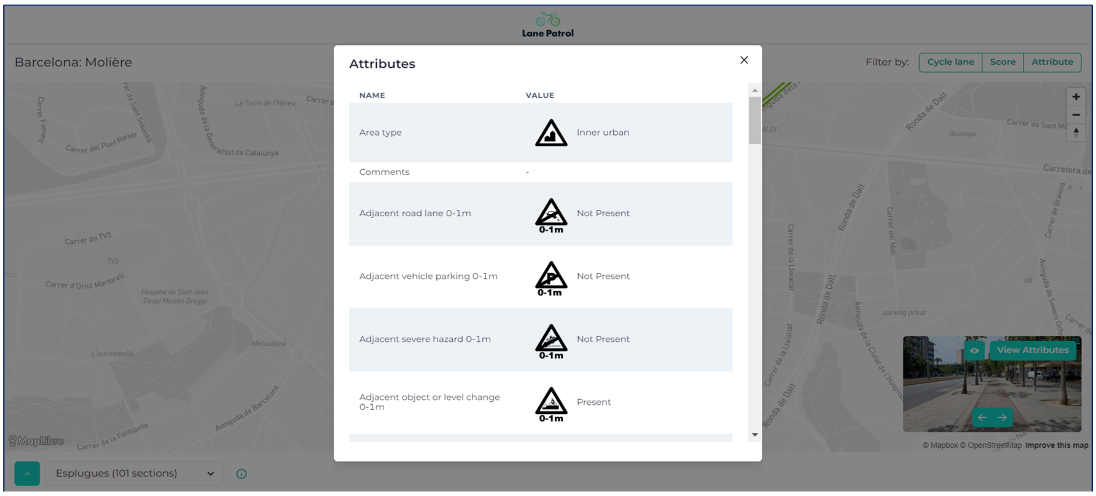


Figure 23. Example of detailed information about the cycling infrastructure

Routes details and conclusions

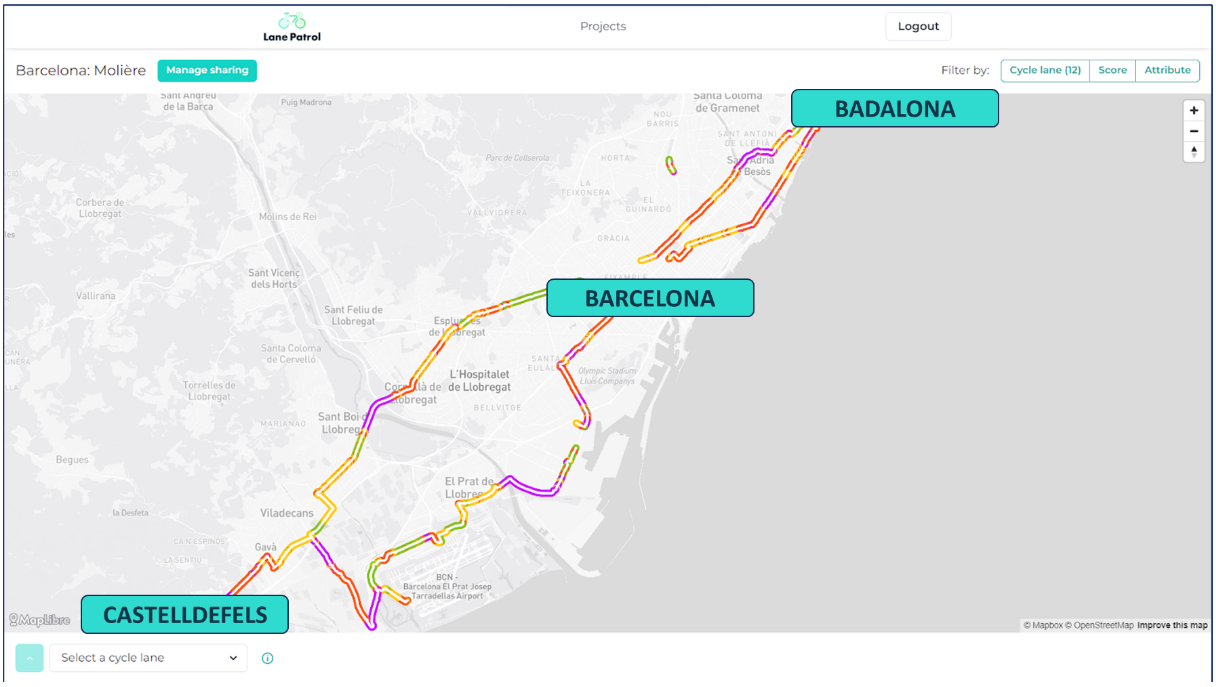


Figure 24. Overview of the level of safety from the analysed routes

- Barcelona - Badalona (via seaside)

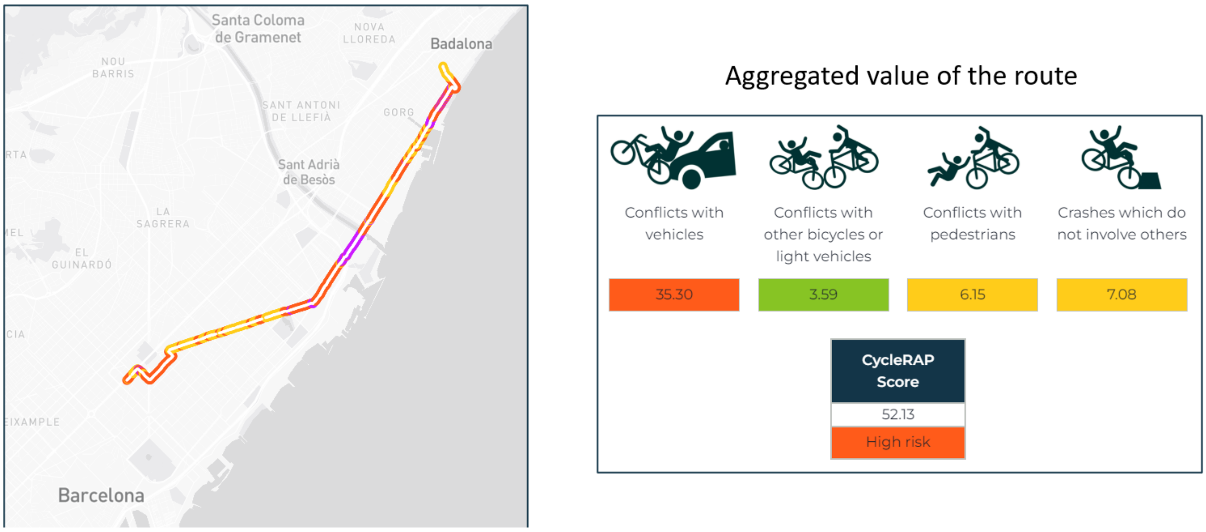


Figure 25. CycleRAP score Barcelona - Badalona (via seaside)

  - The aggregated data shows that despite having Moderated risk (yellow) in several sections of the route for the CycleRAP score (the overall store), the most common risk for this route is High (red).
  - It can be seen that near the crossing of the Besos river, Extreme risks (purple) areas can be found. It can be seen on the 'Barcelona - Badalona (via Rambla Guipuscoa)' that this crossing is also complicated near the river.

- ○ The main conflict is with vehicles, however, moderate risk exists with pedestrians and objects along the route.

- Barcelona - Badalona (via Rambla Guipuscoa)

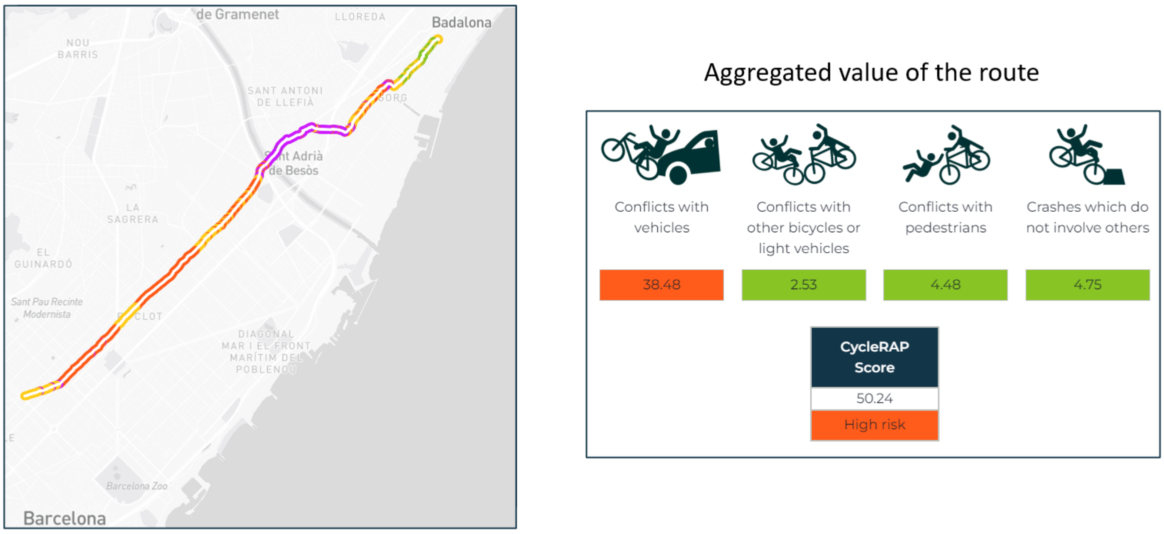


Figure 26. CycleRAP score Barcelona - Badalona (via Rambla Guipuscoa)

- ○ The aggregated data for the CycleRAP score shows a High risk (red)
- ○ Just like on the 'Barcelona - Badalona (via seaside)' route, it can be seen that near the crossing of the Besos river, the route tends to have a Extreme risks (purple).
- ○ The route does not show conflicts with other bicycles, pedestrians and objects as it does show High risk (red) with vehicles.

- Barcelona - Castelldefels (via Sant Boi)
  This route is separated into two parts:

  ➢ Barcelona Centre -Zona Franca

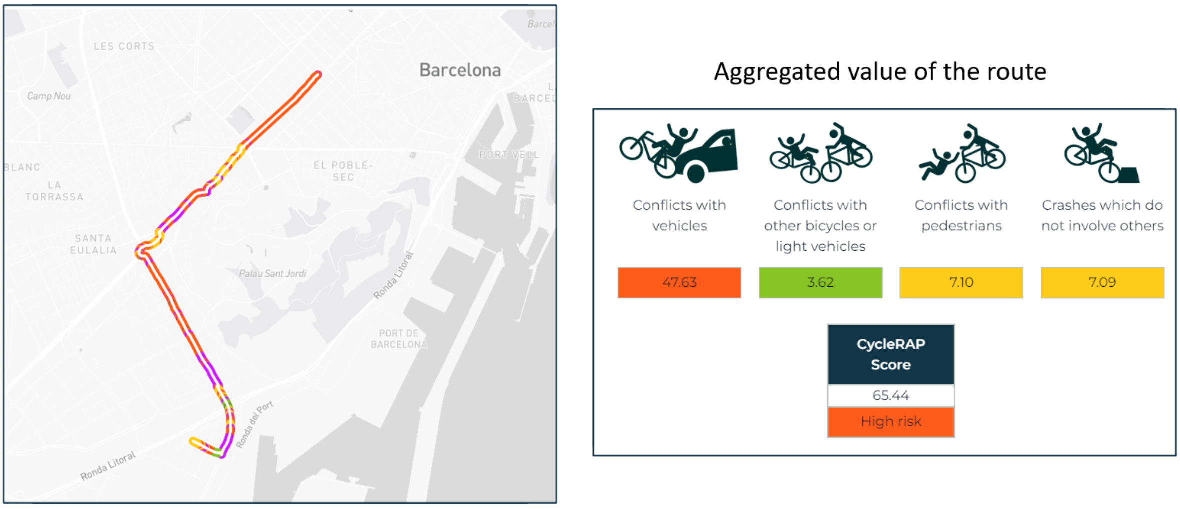


Figure 27. CycleRAP score Barcelona Centre - Zona Franca

- The aggregated data shows that most of the route has a High risk (red) and some sections with Extreme risks (purple). The Extreme sections tend to be intersections.
- The main conflict is with vehicles, however, moderate risk exists with pedestrians and objects along the route.

➢ Zona Franca - Viladecans

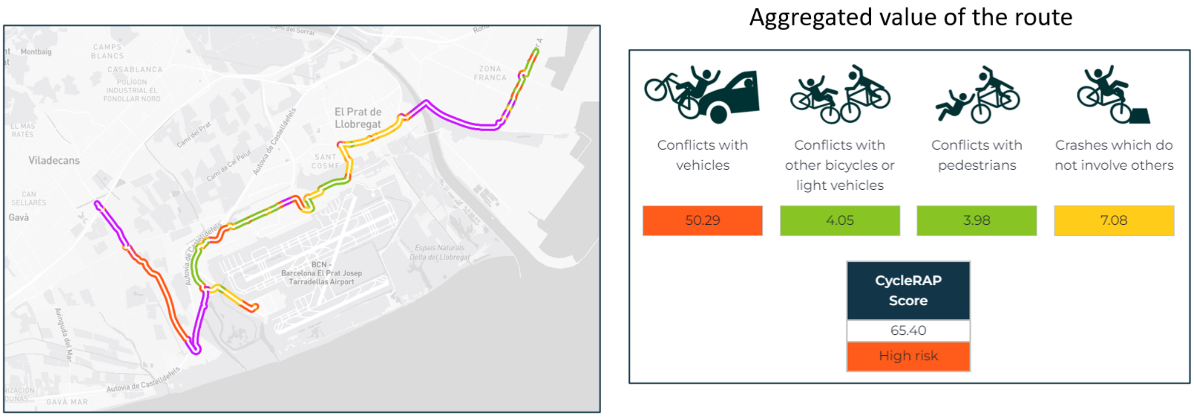


Figure 28. CycleRAP score Zona Franca - Viladecans

- The aggregated data for the CycleRAP score shows that along this route there are different risk levels. It can be seen that Extreme risk (purple) is found near the 'Llobregat' river (similar to what happens in other routes crossing the Besos river) and along the route on the furthest western section.
- It can be seen that there's mainly Low risk (green) in conflicts with bicyclists and pedestrians, however there's Moderate risk (yellow) with objects and High risk (red) with vehicles.

- Barcelona - Castelldefels (via airport)
  This route is separated into six parts:

  ➢ Barcelona Diagonal

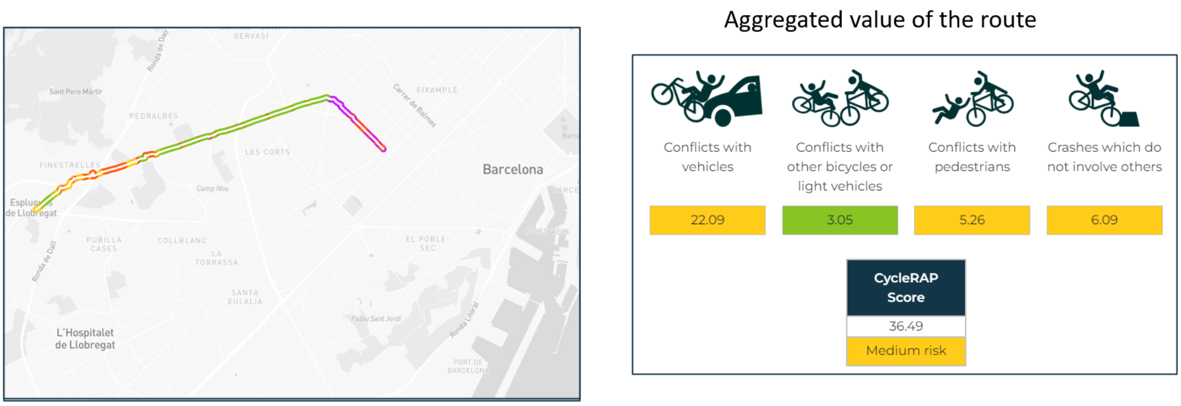


Figure 29. CycleRAP score Barcelona Diagonal

  - This is the safest section from all the routes with large part of it with Low risk (green) and Moderate risk (yellow)
  - Moderate risk (yellow) is the main level for all types except for the conflict with other cyclists which is Low risk (green)

  ➢ Esplugues

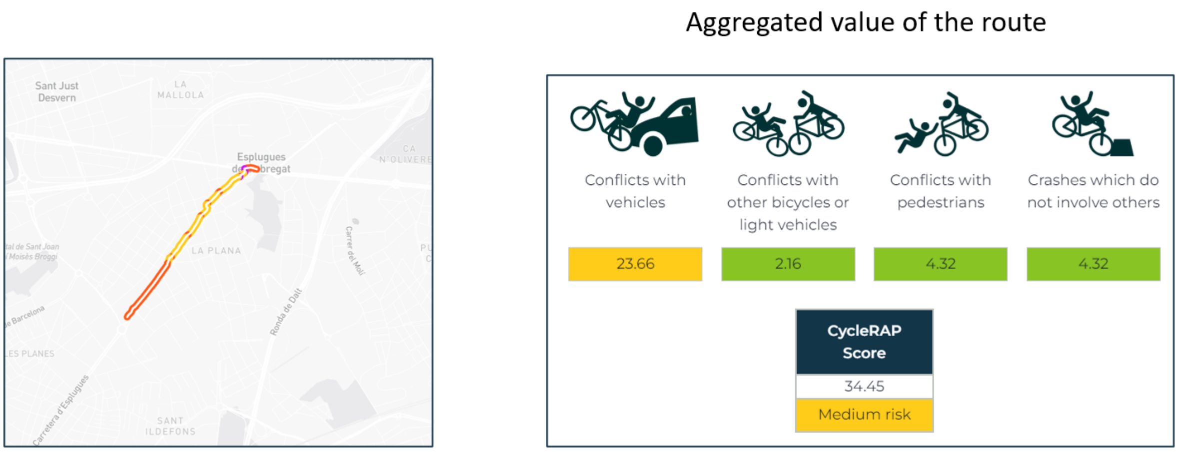


Figure 30. CycleRAP score Esplugues

  - Along the route, it can be seen that the risk is mainly Moderate (yellow) with a big share of High risk (red).
  - The average score for the risk categories is Low (green) except for the conflict with vehicles that is Moderate (yellow).

➢ Cornella

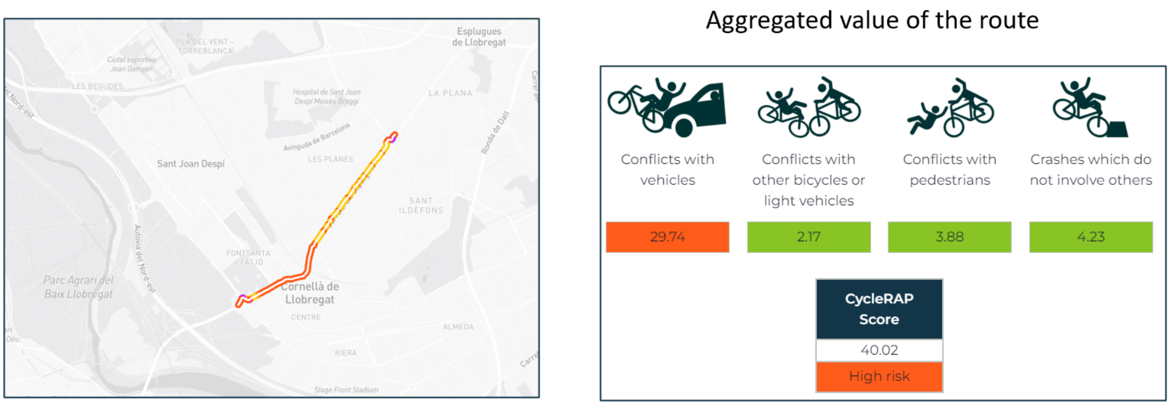


Figure 31. CycleRAP score Cornella

- Along the route, it can be seen that the risk is mainly High risk (red) with a big share of Moderate (yellow).
- The average score for the risk categories is Low (green) except for the conflict with vehicles that is High (red). Mainly when the route is getting closer to the Llobregat river.

➢ Sant Boi

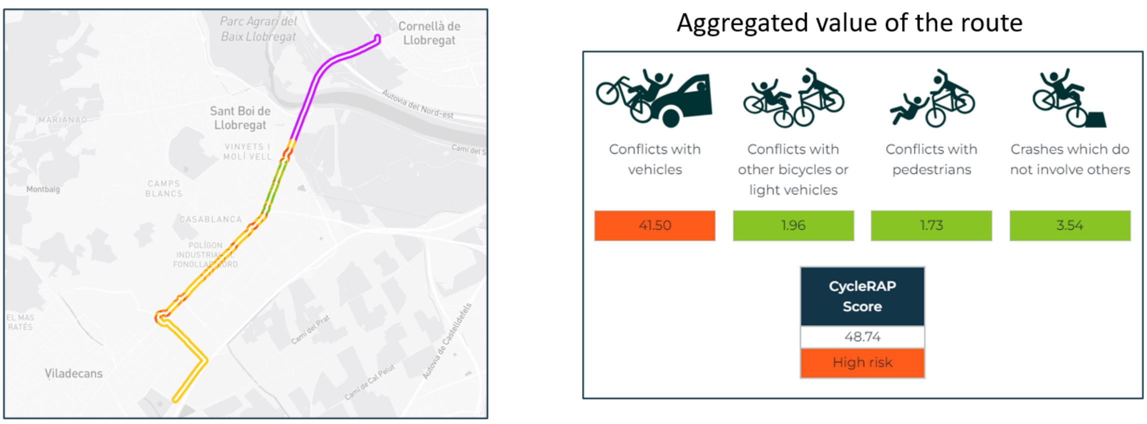


Figure 32. CycleRAP score Sant Boi

- This route has three clear sections, to the east an Extreme risk (purple) from a route involving a section of a freeway; a small Low risk (green) section in the middle and; a Moderate risk (yellow) section, which is the longest to the west.
- The average score for the risk categories is Low (green) except for the conflict with vehicles that is High (red). Mainly when the route is getting closer to the Llobregat river.

➢ Viladecans

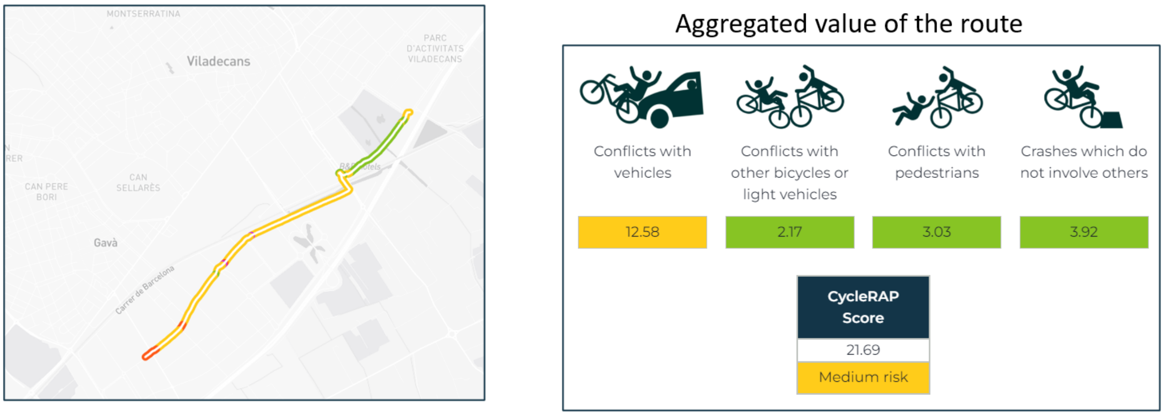


Figure 33. CycleRAP score Viladecans

- Despite this being a mainly industrial area, it has little flow of vehicles thus having a Moderate risk (yellow).
- Conflicts with vehicles are mainly MOderate (yellow) and for the rest of risk categories Low risk (green).

➢ Gava

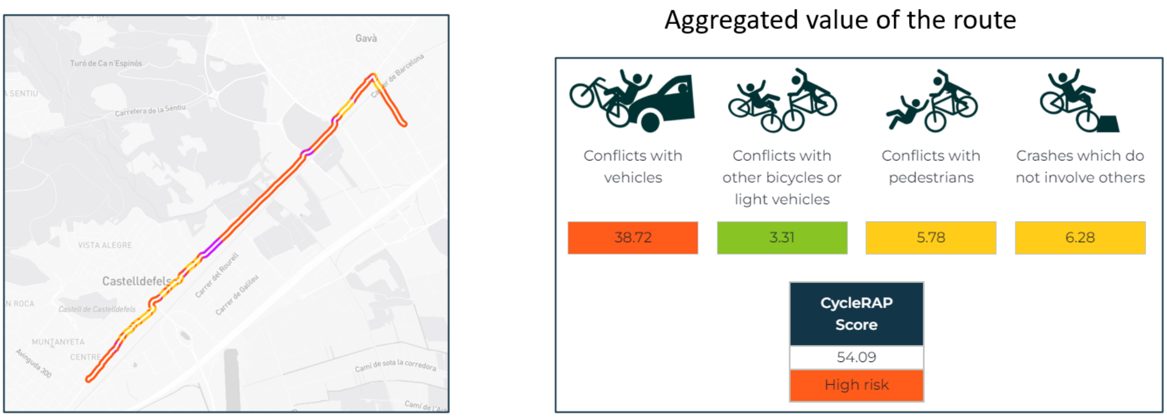


Figure 34. CycleRAP score Gava

- The aggregated data shows that most of the route has a High risk (red) and some sections with Extreme risks (purple). The Extreme sections tend to be intersections.
- The main conflict is with vehicles with High risk (red), however, moderate risk exists with pedestrians and objects along the route. Low risk (green) for conflicts with other cyclists

The LanePatrol solution, along with the CycleRAP methodology, has been successfully utilised to assess and improve cycling infrastructure safety in routes connecting Barcelona to Castelldefels and Bdalona, covering over 75kms.

The CycleRAP methodology has proven effective in objectively measuring and benchmarking safety for bicyclists and light mobility users, regardless of the type of facility or location. It analyses four categories of crash types and aggregates the risk value to provide an overall risk score for each route section, with the overall qualitative score determined by the highest risk score among the four categories.

The insights generated through LanePatrol and CycleRAP have revealed critical safety information about the analysed cycling routes. In the Barcelona to Badalona route via the seaside, while some sections exhibit a moderate risk, the most common risk is high, with extreme risk areas found near the crossing of the Besos river. Similar trends are observed in the Barcelona to Badalona route via Rambla Guipuscoa, indicating the need for focused safety interventions in these areas.

For the Barcelona to Castelldefels route via Sant Boi, there are varying risk levels across different sections. Extreme risks are found near rivers, and conflicts with vehicles are a major concern. The Barcelona to Castelldefels route via the airport stands out as the safest section with low to moderate risk levels, making it an example to learn from for other routes.

The insights gathered from these assessments are valuable for urban planners, city authorities, and policymakers to prioritise safety measures and design more cyclist-friendly infrastructure. By focusing on the identified high-risk areas and implementing appropriate safety measures, it is possible to improve overall road safety for bicyclists and light mobility users.

LanePatrol's use of geolocated images and the CycleRAP methodology in this project demonstrates the potential of technology and data-driven approaches to make urban cycling safer and more appealing for residents and visitors alike. As cities strive to promote sustainable and active modes of transportation, solutions like LanePatrol play a crucial role in building safer, more inclusive, and sustainable urban mobility networks. The success of LanePatrol and CycleRAP in this use case underscores their relevance and potential in addressing critical challenges in urban mobility, paving the way for safer and more accessible transportation systems.

The future of this solution is to continue leveraging Galileo and other remote sensor services, for example EU-DEM v1.0 is a digital surface model (DSM) to automatise part of the CycleRAP assessment on LanePatrol. Furthermore, after a positive validation of the LanePatrol service, there are functionalities in the pipeline such as creating automated maintenance and investment plans for local and regional stakeholders to improve the cycling infrastructure safety from the CycleRAP assessments in LanePatrol.

6.3.3. *Use Case 3: Proof of Mobility Service*

6.3.3.1. Use case Rationale

Moliere's Mobility Data Marketplace (MDM) functions as a mobility aggregation platform, where mobility services can be announced, and they can be discovered, combined, booked and paid for. Moliere's MDM is therefore clearly an instance of a two-sided marketplace, with providers on one side, and end-users on the other.

Kickstarting the network effect of a two-sided marketplace like the MDM poses a challenge, often referred to as the "chicken and egg problem". Both service providers and end-users are interdependent and vital to the platform's operation: without the presence of one, attracting the other is very difficult.

A mechanism to tackle this problem is to incentivize the activity on the platform. Under this approach, either (or both) parties receive a subsidy for their participation in the network.

This approach can become exceedingly capital intensive under traditional architectures such as centralised software-as-a-service platforms. However, note that the MDM has a key difference with such traditional architectures: as a decentralised network, it necessarily features a governance token. This token represents a stake in the ecosystem, granting the holder rights to participate in the decision-making process, which includes the direction of development and deployment of the platform, and more. It inherently has a value determined by the perceived worth and growth potential of the platform.

By leveraging this governance token, the MDM can create an incentive mechanism that subsidises the participation of both parties without becoming capital-intensive like centralised software-as-a-service platforms. The platform can distribute these tokens as a reward to service providers for offering their services and to users for their participation, booking, and payment for services.

However, there is a key difficulty: while governance tokens incentivize participation on the MDM platform, they also expose it to the risk of fraud, as participants may simulate activity to collect rewards. These dishonest actions threaten the platform's integrity, dilute token value, and may shake the trust of genuine stakeholders. Note that the MDM seeks to be decentralised, and therefore without a central authority that allocates incentives according to its whims; instead, the incentive scheme must be transparently set and allocated programmatically.

In conclusion, it's imperative to establish robust detection and prevention measures against fraudulent behaviour. This use case introduces Proof of Mobility Service, an approach that seeks to validate real services were delivered, and thus curtail incentive collection fraud.

6.3.3.2. Use case details

Proof of Mobility Service (PoMS) should conceptually be seen as a series of measures to prevent dishonest players from collecting incentives fraudulently by simulating the delivery of real mobility services. (Despite its name, PoMS does not seek to definitely prove in the strictest sense that a mobility service was delivered, as this is a challenging proposition; instead, it merely tries to make it economically impractical for fraudsters.)

The reference scenario is the MEC Carsharing fleet. MEC allows its users to rent electric cars by the hour and up to days, and has a number of vehicles distributed among 10 car parks in the

Barcelona area. It was assumed a scenario where MEC rents its services through the MDM, and allocation of incentives based on car rentals by end-users, proportional to the distance the cars moved around. The intuitive idea being that the MDM rewards rentals that turn into actual mobility and therefore real value for users.

As explained, the MDM's incentive allocation scheme could lead to fraud. In this scenario, a rogue provider could simulate extra trips without actually their cars moving at all just to collect governance tokens for a profit. The PoMS solution to this problem is to introduce an independent party that reports the movements of the vehicles. The PoMS service then allocates incentives if the two data sources match.

6.3.3.3. Use case link to Molière

With the permission granted by MEC carsharing, Octo Telematics devices were deployed in part of their fleet. The devices that were utilized are Octo EasyPro, which is a compact telematics On Board with an embedded microprocessor, a 6-axes internal integrated accelerometer and gyroscope, Bluetooth Low Energy 4.1 module, GSM module (GPRS 2G Quad-band) with an internal antenna, e-Sim and a Multi-Constellation GNSS receiver.

Figure 35. Octo EasyPro being installed in a vehicle from MEC carsharing

6.3.3.4. Use case objectives and outputs

The objective of the use case is to design, implement and test the PoMS scheme in the MEC car sharing fleet.

The data collected and analysed represents 20 different cars, 902 trips and 112,957 readings. These data were then compared with the bookings reported by MEC. A simple PoMS implementation was then developed as described in the next paragraphs.

The PoMS algorithm builds an estimator of the location of a car by interpolating observations from the onboard Octo device, and treats this dataset as ground truth. Then, it computes the average distance from the data points reported by the provider to the estimated location of the car. Finally, it determines the trip to be valid if the average distance between the points is below a threshold.

In order to test the efficacy of this PoMS mechanism and set the right threshold, additional experimental procedure was conducted as follows.

The dataset the provider sent us included very few points along the trajectory of a car. For this reason, independent readings from the provider from the ground truth were stimulated. Independent readings were first generated by randomly interpolating the locations of consecutive points, and added gaussian noise to introduce an average error of 5m. Note that this is much larger than the expected accuracy of a Galileo-enabled system.

The experiments were grounded in the principle of leave-one-out cross-validation, a common technique in the realm of machine learning and statistical analysis. One trip at a time were systematically removed from this dataset, essentially simulating the scenario of a non-existent or fraudulent trip.

The modified dataset was then processed through the PoMS implementation, and the percentage of trips incorrectly detected either as positive and false negatives was recorded. This test scheme was then repeated with varying thresholds, and the number of false positives, false negatives and total trips was recorded for each candidate threshold. The results are summarised in the figure, which also serves as a basis to pick the threshold parameter.

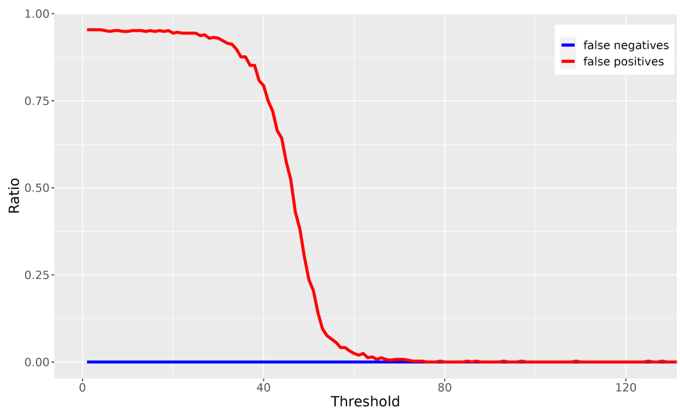


Figure 36. False positives and false positives threshold

As can be expected, excessively small thresholds yield a high number of false positives. Worth noting false positives are not 100% because a small number of trips are very short and their start and finish match perfectly in both datasets. Error rates start diminishing sharply around threshold 40 metres, and disappear almost entirely for thresholds larger than 75. The threshold to 100 was set, In order to leave a safety margin.

The reader may wonder why these errors are so large compared to the typical errors in geopositioning, especially under Galileo. Consider that 1) data must amtch from sensors that are not synchronised, and hence their points are collected at different points in time, 2) a large noise to the readings in this experiment were artificially added, and 3) consecutive points were very naively interpolating , without taking into consideration speed, acceleration and trajectory variations, as well as the plausibility of the interpolated values in a road system. It is believed, however, that increased complexity to improve accuracy is unnecessary at this stage, since car trips will be much longer than this accuracy margin, and so the incentives will remain unaffected in practice.

Note also that the scheme produced no false negatives. This is highly desirable in the scenario. The reason is that a fraudulent participant will attempt to report a large number of inexistent trips, which need to be filtered out. In contrast, it is acceptable to have a small number of false positives (representing real trips that were mislabelled as fraud), since this will have a negligible impact on the aggregate incentives collected by the provider, as long as the error rate is small enough.

6.3.3.5. Use case conclusions

The Proof of Mobility Service (PoMS) was introduced as a robust mechanism to tackle potential fraudulent behaviour in the allocation of incentives in the Mobility Data Marketplace (MDM), thus encouraging genuine participation. PoMS aims to validate the delivery of real services, thereby ensuring that incentives awarded in the form of governance tokens are legitimately earned.

the validation of PoMS was carried out using a carsharing fleet provided by the MEC carsharing fleet in the Barcelona area. Data from Octo Telematics devices installed in the cars were compared with the bookings reported by MEC, developing an implementation that granted incentives based on matching data, and ensuring that the service provided correlated with real value to the end-users. The absence of false negatives in the experiment is highly promising, as it implies that the system is robust to attempts by fraudulent participants to report nonexistent trips, while the minimal error rate of false positives has a negligible impact on the aggregate incentives collected by the provider.

Expanding the implementation of PoMS to other mobility modes remains as future work. This will necessitate a thoughtful consideration of the verification mechanisms on other modes of transportation, given that they will possess unique attributes and challenges. For example, the use of the onboard hardware devices, which served well in the context of carsharing, might not be feasible for lighter and less energy-intensive modes like e-bikes due to their weight and power consumption requirements.

6.3.4. *Use Case 4: Decentralised mobility data sharing for flexible transport*

6.3.4.1. Use case Rationale

Virtual stops detection has become one of the most important challenges. This means that when the bus has actually passed a physical real stop, it is needed to detect it virtually. Unfortunately, this isn’t always the case, sometimes it is possible to miss track.

It’s been seen accurate results with GALILEO as the receiver for the clients' buses OBU’s, since the frequency of the positions sent is higher due to the accuracy of detecting new positions.

The goal is to build a tool for reporting accurate driven km’s to public authorities, a cross-validation between theoretical and actual driven routes and with this, prove with extracted metrics which receiver is best for usage recommendations on new bus services and share the data with the Molière data space.

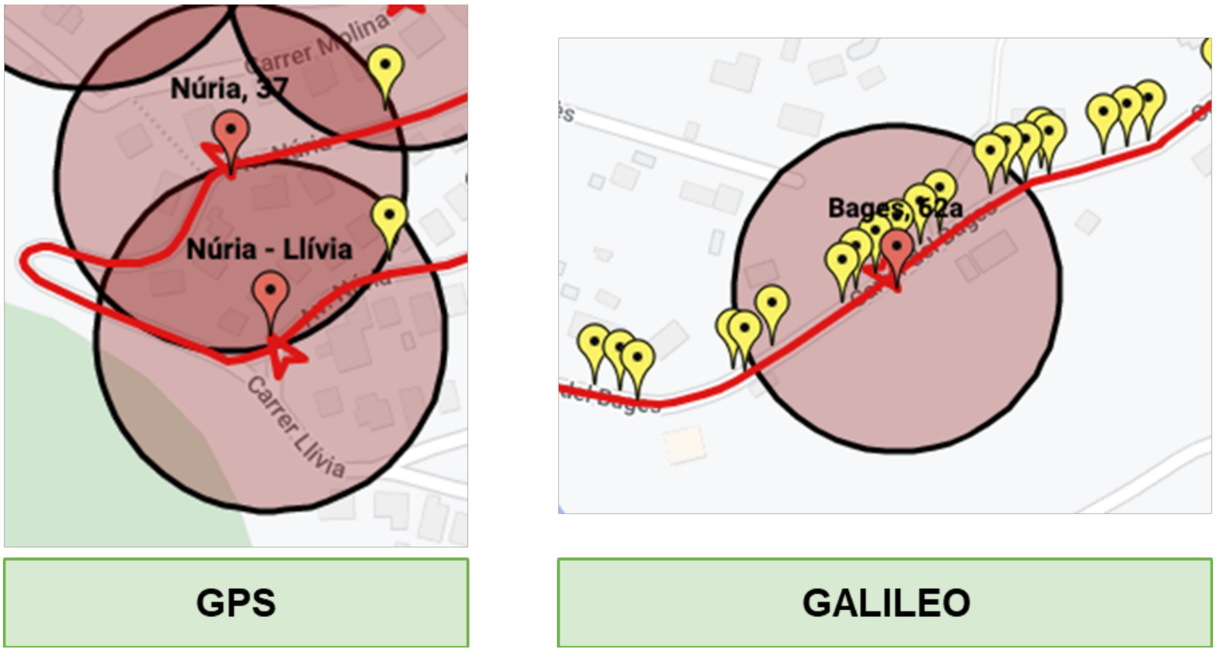


Figure 37. Comparison between GPS and Galileo

6.3.4.2. Use case details

Route Cross-Validation

The theoretical route is defined for a given trip and after the trip has been completed, it is possible to print the driven route. With this, a first visual analysis validation can be done between the theoretical and driven route and check if the route has been done properly.

It is possible to have some exceptions where the client's drivers can decide when to alter the route given certain circumstances such as somebody not getting into the bus, which implies that there is no need to get to the drop off stop.

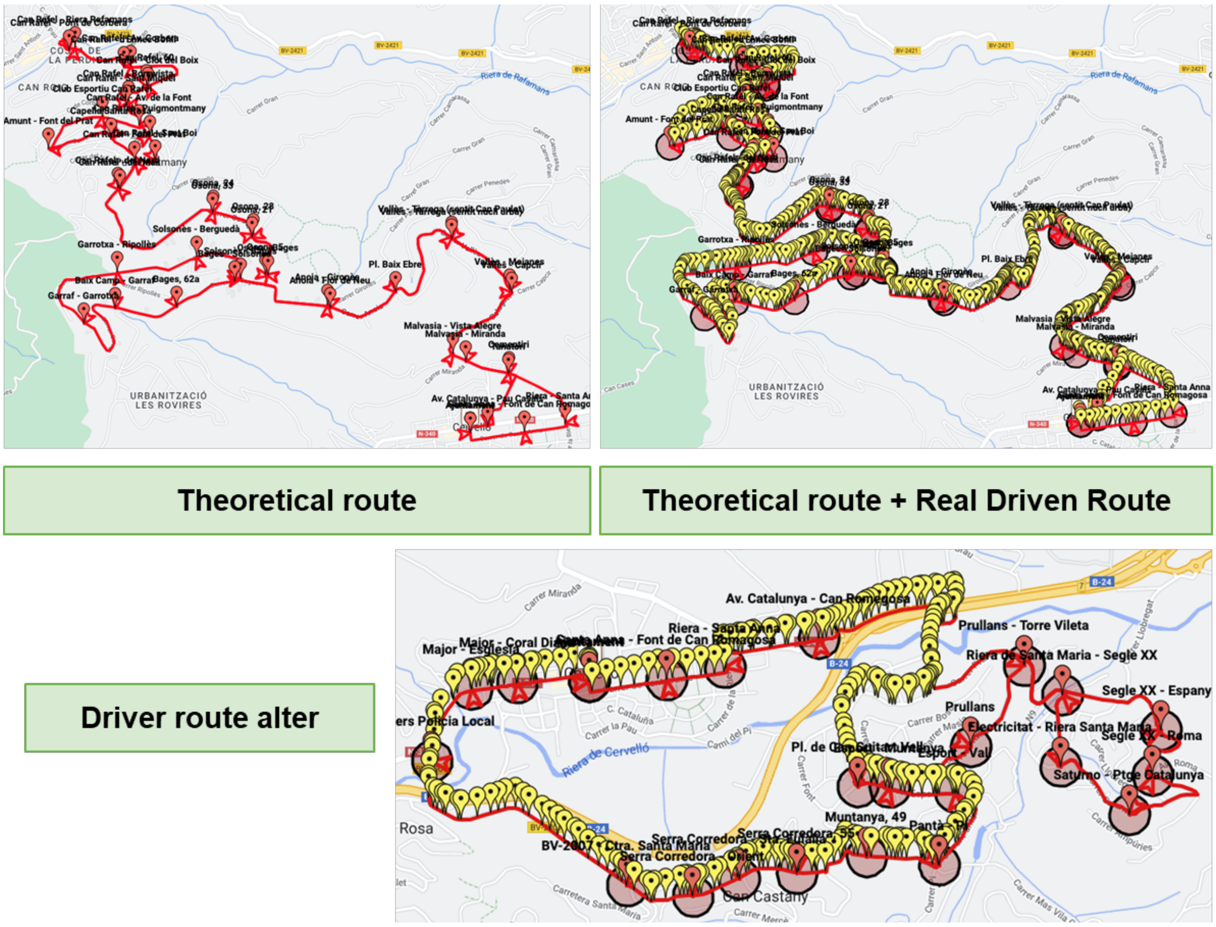


Figure 38. Examples of theoretical and real driven route

Given the previous point, it is needed to extract the accuracy metrics and deviation on how the OBU with GALILEO or other receivers is really affecting the trips.
With this, it will be possible to have an easy comparison between different receivers, which will be able to determine which one is the most optimal and data to be shared with the Molière data space.

6.3.4.3. Use case link to Molière

The clients OBU's send to the platform geolocation data when a new position is detected by the receiver. In case the client chose an OBU with GALILEO, that data will be used to extract metrics and compare accuracies and deviations between different GNSS receivers.
Given the sending frequency of authenticated data of the GALILEO receiver, it's been seen that there are more positions on trips driven by GALILEO's OBU's than with other receivers, which makes it more precise in order to do the cross-validation in the systems.
With the results of this experiment, it will be possible to prove which receivers are the most optimal in this scenario backed-up by the collected data and demonstrate the new features developed during the development of this use case.

6.3.4.4. Use case objectives and outputs

Objectives

- Demonstrate the accuracy between different OBU's with different GNSS receivers.
- Real kilometres reporting to the public authorities with the cross-validation between theoretical and actually driven routes.
- Data sharing with the Molière Data Space.

KPIs

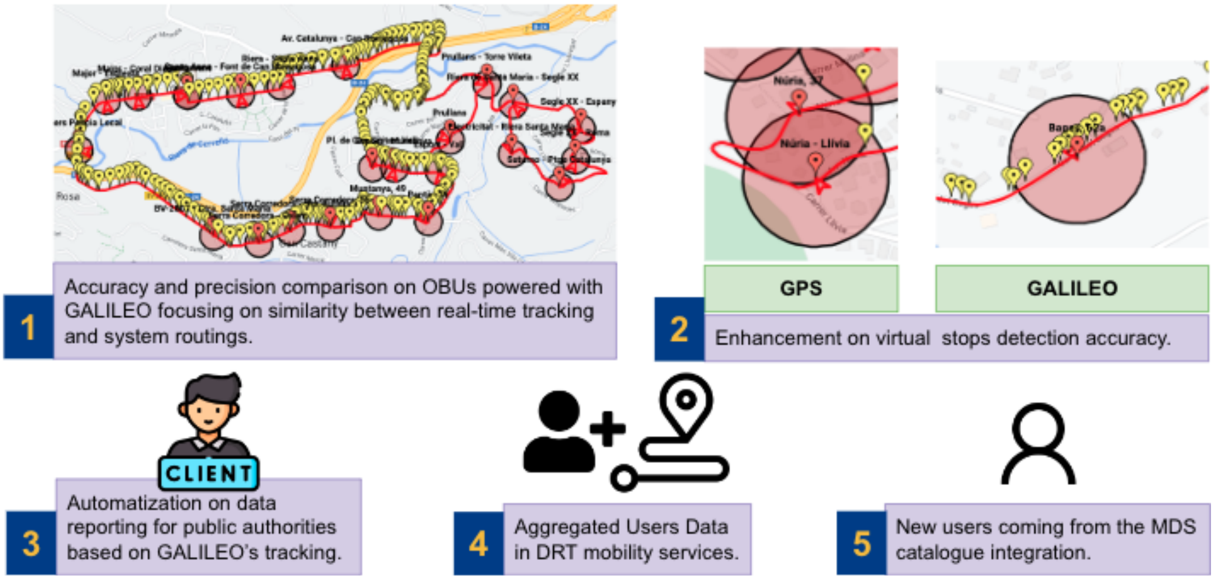


Figure 39. Nemi use case KPIs

Outputs

1. The **accuracy on the detection of virtual stops increased** about **13%** during the development of the improvements while using **GALILEO**.
2. **Temporal** analysis between the **driven** kilometres and the **theoretical** platform kilometres, these are **GALILEO** powered services.

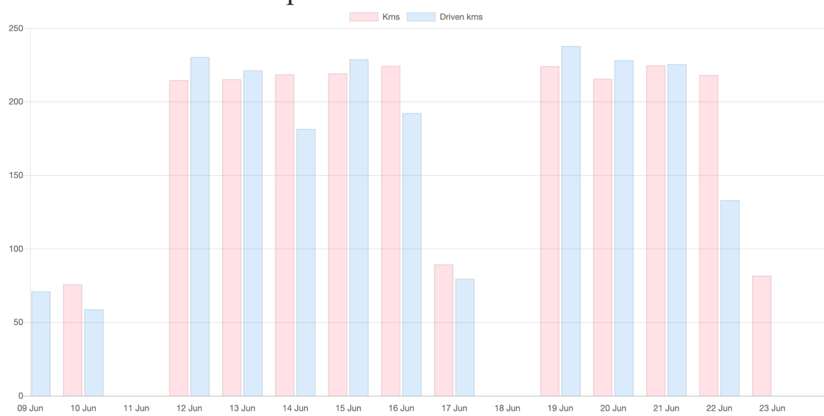


Figure 40. Comparison between theoretical and real driven kms

3. **Temporal** analysis of the **path similarity** and the **proportion between** the **theoretical** platform kilometres and the **actual driven** kilometres, these are GALILEO powered services.

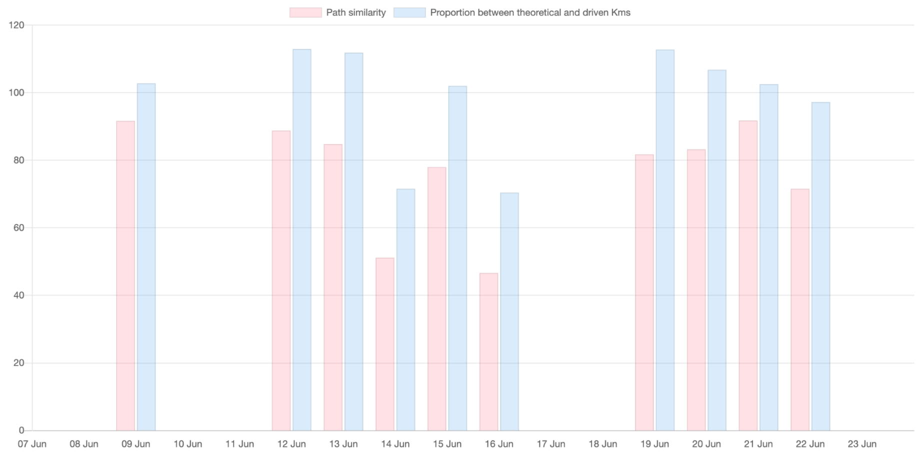


Figure 41. Comparison between path similarity and the proportion between theoretical and the driven kms

4. **Automatic reporting tool** of all the trips of a specific service having both the theoretical kilometres and the actual driven. It can be seen how some trips are almost perfect, but some of them seem to have some segments missing which could've been caused by a lost connection.

40417261	****	2023-06-09T18:15:00....	13.606900000...	14.519928053...
40744354	****	2023-06-12T08:45:00....	15.456600000...	14.855665730...
40744381	****	2023-06-12T07:00:00....	12.5509	13.481380028...
40852492	****	2023-06-13T07:00:00....	12.5509	14.414045860...
40852524	****	2023-06-14T07:00:00....	12.5509	12.262767974...
40852556	****	2023-06-15T07:00:00....	12.5509	13.650184195...
40852588	****	2023-06-16T07:00:00....	10.534899999...	13.875912077...
40900684	****	2023-06-09T16:45:00....	8.33	8.2341099207...
40915487	****	2023-06-13T08:45:00....	13.573700000...	13.655496951...
40915535	****	2023-06-14T08:45:00....	13.5737	5.5904797260...
40915808	****	2023-06-15T08:45:00....	12.0947	12.035140069...
40915839	****	2023-06-16T08:45:00....	13.633799999...	18.7114073812...
40953463	****	2023-06-12T16:45:00....	11.5909	10.825613991...
40953511	****	2023-06-13T18:15:00....	6.4314	11.9971192951...
40953564	****	2023-06-14T16:45:00....	10.246	9.9806976840...
40953613	****	2023-06-15T18:15:00....	13.606900000...	13.2681705921...
40953660	****	2023-06-16T18:15:00....	13.896800000...	10.421043944...
40954223	****	2023-06-14T18:15:00....	9.3707	7.0340178083...
40983535	****	2023-06-12T11:00:00....	14.541300000...	15.965999531...
40996281	****	2023-06-12T12:30:00....	14.839400000...	14.265659739...
40996409	****	2023-06-13T11:00:00....	15.2675	15.8681742051...
40996474	****	2023-06-12T09:30:00....	7.1769999999...	7.0896739984...
41061462	****	2023-06-12T18:15:00....	9.2968000000...	17.560287732...
41062292	****	2023-06-13T09:30:00....	13.928999999...	13.664959858...
41062704	****	2023-06-13T12:30:00....	14.425699999...	13.127492849...
41087037	****	2023-06-13T16:45:00....	7.9912	7.01932194111...
41158823	****	2023-06-14T09:30:00....	14.674600000...	0.0000419695...

Figure 42. Examples of comparison of theoretical and actual driven kilometres

6.3.4.5. Use case conclusions

- the **GALILEO** powered services got an average of **77.45%** similarity between the **real-time tracking and the theoretical routes** on the services. On the other hand, all the **other GNSS** receivers combined got an average of **67.56%** similarity.
  After building the platform to be capable of collecting this data and analysing it, this metric was extracted by comparing the distances between theoretical and driven segments and between stops, giving a higher weight to stops. The Fréchet distance was also used for this calculation.
- Related to the enhancement of the accuracy of the **virtual stops detection**, it was seen an **increase** of **13 %** of the stops detected due to the developments done. This percentage is extracted by comparing the percentage of the stops detected between old trips and the new ones.
- An automatic tool was built for reporting **real driven kilometres** and also the **recurrence** of the different **itineraries** that have been made.
- It wsa possible to keep fueling the Mobility-as-a-Service market with the **GALILEO** based generated data in the platform with the **aggregated user's** data.
- The **integration** to the **catalogue** of the **Mobility Data Space** was easy and successful, it was possible to prove that even being on an early stage the possibilities are infinite, and the contribution is easy. This will open up future possibilities with clients and increase the data shared with it at the same time that the size of the platform is increased.

6.3.5. *Use Case 5: Bus travel time characterization and prediction using data science*

6.3.5.1. Use case Rationale

New paradigms in urban mobility have emerged in the last few years because of a myriad of reasons. At the heart of it lies technology, allowing societies to explore new opportunities and overcome daunting challenges. Different communication systems, often referred to as V2X or vehicle to everything, allow the flow of information between all agents on a transportation network. In addition to that, higher standards of living have led to a set of higher expectations from the demand side of transportation. Mobility patterns nowadays show high degrees of spatial and temporal heterogeneity in a marked contrast with the traditional commuting schemes, adding pressure on the transportation network in the form of congestion and pollution. Pressing issues such as global warming and climate change pose a daunting challenge to humankind. In this regard, transportation, and urban mobility in particular account for a high percentage of the total greenhouse emissions.

Public transportation is not oblivious to these new trends and challenges. Among the many technologies involved in past and current mobility scenarios, satellite data plays an integral role. Traditional navigation systems allowed the monitorization of vehicles and completely changed the way in which drivers interacted with the territory and the transportation network. However, the mobility of the future requires precise navigation systems to ensure the proper performance of vehicles in terms of efficiency, safety, sustainability, and overall quality of the data gathered. Originally used as a tracking tool, georeferenced data fosters precise analysis and extraction of relevant information concerning transportation variables. Therefore, accurate data is not simply a matter of competitiveness but a condition to accomplish new mobility goals. As an example, aggregated pollution models as opposed to micro-models or instantaneous models require averaged speed values which result in broad generalisations and unreliable results. On the other hand, micro models require highly precise data and unfold the possibility of estimating regression models of pollution as a function of predictor variables derived from GNSS data. Thus, not only can one precisely estimate and track pollution values but also determine relationships between geometrical and operational variables of the bus line and pollution values.

Use Case 5, developed by researchers at the Barcelona Innovative Transportation (BIT) research group at the Civil Engineering School in Barcelona in Universitat Politècnica de Catalunya, attempts at discussing qualitatively and quantitatively the potential uses of high accuracy data in bus systems. While large positioning errors have traditionally been accepted when tracking bus systems, the notion of accurate positioning data not being necessary is contested in Use Case 5, with a view to discuss the market opportunities to be exploited by the potentialities of GALILEO High Accuracy Service (HAS) in bus systems and contrast them against other Global Navigation Satellite Systems (GNSS).

In the context of the MOLIERE project, the UPC research team has developed a software tool specifically designed to analyse bus systems only through georeferenced data. This may help transit agencies reduce costs by resorting to GNSS systems to extract information, a more competitive technology compared to other available solutions nowadays.

6.3.5.2. Use case details – description of the work and needs for the use case

Use Case 5 is centred around transit and particularly bus operations in urban environments. More specifically, UPC has developed a software tool for transit operators and practitioners to analyse bus systems from GNSS data. The software has been produced during the MOLIERE project and tested with real data from the H16 bus line was kindly shared by TMB, Barcelona's most important transit operator.

Brief description of the software

Throughout the MOLIERE project, an open-source software initiative to analyse bus systems from GNSS data has been developed and tested. This is intended to be used by transit agencies, municipalities, or practitioners to better manage and plan bus operations. While several transportation open software initiatives have been developed throughout the years, most of them do not provide and incorporate specific knowledge of bus systems. With this contribution, it is aimed to share a bus-oriented tool capable of describing and forecasting relevant variables.

The structure of the software consists in a sequence of Python scripts. Input data is required from the user to initialise the execution of modules. Preprocessing tasks are then executed such as data cleaning or identifying basic operational information regarding the bus system analysed (i.e., route direction, bus stops, cycle number). Once the basic information has been added to the datasets, the user is allowed to retrieve results through the execution of the results.py module. Fitting of statistical models to variables computed earlier is possible by means of the stats.py module, as well as visualisation of results after running the plot.py module.

<u>Data and scenario</u>

The H16 bus line belongs to the family of horizontal bus lines in Barcelona's Orthogonal Express Bus Network. Currently active since November 18th, 2013, the H16 line has a length of 12 km in both directions and partially absorbs the demand on the southernmost area of the city between Zona Franca and Plaça del Fòrum. It is estimated that H16 provides service to approximately 20,000 daily passengers distributed along three main areas: Gran Via, Sant Antoni neighbourhood - Plaça Catalunya and Poblenou. As of July 2021, the H16 line operates entirely with 23 18-metre-long high-capacity electric buses. Two charging stations at both ends of the line provide fast rapid battery charging operations in an average charging time of 5 minutes.

The data used in use case 5 comprise 1 Hz bus observations recorded on the 25th of October 2021. Among the many attributes included in the dataset, timestamp, latitude and longitude coordinates, and bus consumptions indicators allow to extract relevant information and estimate the state of the vehicle. All observations belong to the GNSS constellation other than GALILEO. This allowed us to assess the error in the estimates derived from other satellite constellations other than GALILEO and contrast the results obtained with its expected accuracy. Figure 43 shows the layout of the bus line analysed in Use Case 5 as well as two BEB vehicles at the recharging stations located at both ends of the line.

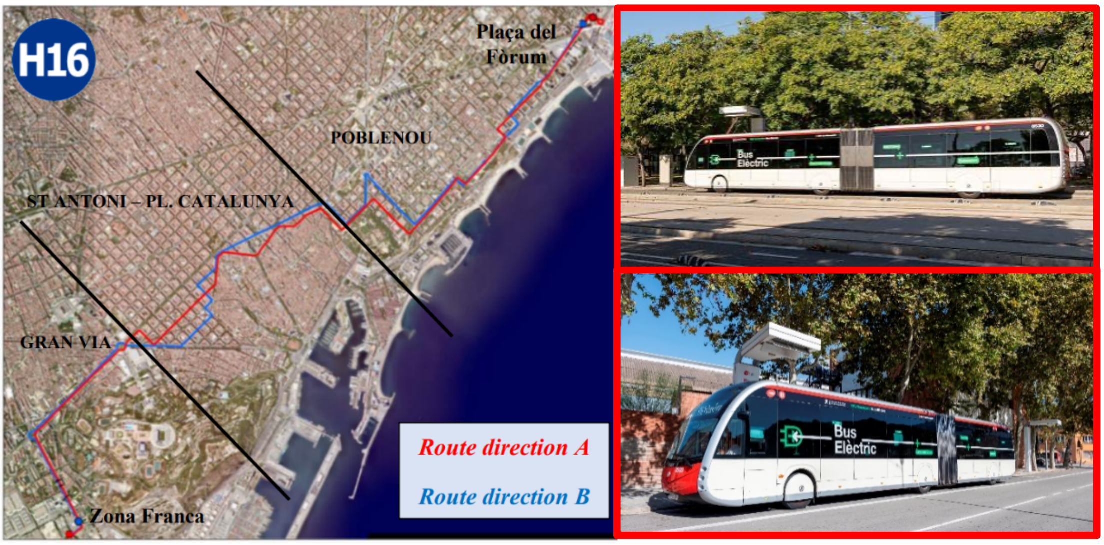


Figure 43. Bus line route map (left) and bus fleet electric vehicles (right

-

The assessment of the error in the data resorts to the estimate of the following variables:

1. Bias in trajectories: Many bus lines have dedicated bus lanes. Rarely do buses abandon bus lanes during their operations, thus confining most of the positioning of the vehicle within the boundaries of the lane. If geometrical information of the bus route is available (e.g., linestring of bus route points) bias or lateral distance of the recorded observations to the bus route line provide an estimate of the accuracy of the satellite system.

2. Random noise in the data: A recurrent modelling decomposition of satellite observations comprises the bias in the trajectory plus a random error term and assumes an additive behaviour between both variables. By removing the bias from the observed coordinates and differencing the distance from the unbiased coordinates to the real position between consecutive data points an estimate of the corruption in the data can be performed.

3. Acceleration: Bus operators set limiting values to accelerations. High acceleration values (both positive and negative) translate into uncomfortable trips and may raise safety issues. Thus, level of service diminishes as well as customer satisfaction. Typical values for acceleration in research literature range between 0.8-1.0 m/s^2. Bus drivers rarely exceed such accelerations. By estimating accelerations through satellite data, acceleration profiles derived from data indicate the extent to which the sensor estimates deviate at least from the actual or physical values.

4. Energy consumption: Through a set of dynamical equations, all forces acting on the vehicle can be modelled, and an estimate of the instantaneous energy consumption estimated.

6.3.5.3. Use case link to Moilère

Use Case 5 revolves around the concept of georeferenced data in bus systems and, more specifically, highly accurate GNSS such as GALILEO gas. The motivation behind Use Case 5 is to discuss the potential market share of GALILEO in bus systems, an industry where traditionally high accuracy data has been deemed unnecessary.

The MOLIERE project is expected to pursue the following 4 high-level objectives:

a. Objective 1: FUEL MaaS with GALILEO-sourced geo-location data.
b. Objective 2: IMPROVE Road Safety & Sustainability.
c. Objective 3: ENABLE secure payment transactions trusting GALILEO.
d. Objective 4: NUDGE a Positive Behavioural Change from user.

The goals and work executed in Use Case 5 comprise objectives 2 and 4 mentioned above. Regarding objective 2, it is believed that the use of GALILEO aligns with the improvement of road safety and sustainability. Accurate positioning systems do not only provide better tracking of the vehicles, but also lend themselves to produce more precise statistical models and causal relationships. By diminishing the error term associated with GNSS, topics of interest such as emissions and energy consumption or emission of pollutants can be deeply analysed after correlating important operational variables extracted from georeferenced data. Relationships between route slope, accelerations or speed may be more confidently estimated essentially due to the lower error values associated with GALILEO. This information is particularly useful for transit operators to optimise and reduce costs related to energy consumption and society in general, since externalities such as emissions and energy consumption will be better managed after confident correlations between such target variables and performance indicators are established. Moreover, traditional operational variables such as dwell time at bus stops do not require probabilistic methods to discriminate between the vehicle operating at a bus stop or not because of better accuracy of the coordinates of the vehicles. Low accuracy translates into ambiguity regarding the status of the vehicle (e.g. is the vehicle at a bus stop serving demand or waiting at an intersection?), thus reducing reliability on the results. In short, high biases and poor accuracy of the observations and kinematic variables do not allow to properly characterise the bus system.

As for objective 4, the use of high accuracy positioning services not only helps transit agencies extract insights from reliable data with a view to manage and plan public transportation operations, but also provides useful information and a reliable service to bus users. In the context of bus operations, research studies cite punctuality as one if not the most valued variable by users. While they do not particularly mind vehicles arriving earlier at nodes, user disutility highly depends on waiting time at the bus stop, especially if the vehicle is delayed. In this regard, providing accurate real time information as opposed to aggregated or historical expected behaviour of transit operations to users enhances user reliability and satisfaction towards the system. By precisely knowing at which point along the route the vehicle is and the time it may take to reach any node users are able to better plan their trips. Good performance of the bus network is expected to attract more demand at the expense of the usage of private vehicles, which aligns with the new paradigm of mobility towards more sustainable systems.

6.3.5.4. Use case objectives and outputs

Objectives

As stated in the previous sections, the primary objective of Use Case 5 is to discuss the potential use of high accuracy navigation systems in bus networks. To achieve it, valuable insights from working with georeferenced data may be drawn and presented to the rather to discuss the subject at hand. Below are listed the set of outputs computed and/or discussed to argue the need for precise georeferenced data in bus operations.

1. Assessment of the quality of the data used in terms of kinematic variables through a comparison of the observed values in the data and the real behaviour of bus vehicles.
2. Distribution of errors in bus coordinates after using GNSS constellation different from GALILEO.
3. Ambiguity of results and information extracted from noisy data when working with georeferenced information.
4. Decomposition of the signal into a bias and an error term to mathematically understand the nature of the signal.
5. The opportunities of GALILEO regarding sustainability and environmental issues.
6. Estimate of the error reduced by GALILEO HAS in terms of bus energy consumption.

KPI's

Use Case 5 aligns with some of the main objectives in terms of several KPI's. The relationship between both concepts is the following:

a. Objective 2: IMPROVE Road Safety & Sustainability
   i. Emissions calculations
   ii. Energy consumption calculations

iii. Assessment of driving behaviour
iv. Identification of black spots along the route
v. Time spent at charging operations

b. Objective 4: NUDGE a Positive Behavioural Change from user.
  i. Precise real-time tracking of the vehicle provided to the user
  ii. Expected arrival times at bus stop
  iii. Status of the vehicle

Summary of outputs

From the datasets introduced above, many relevant variables can be estimated and help us understand the potential differences between low accuracy signals such as the data used and more accurate systems such as GALILEO. In this section, it followed by a summar of the results and insights computed through the implemented software and stress the advantage GALILEO may have against other GNSS in specific fields of urban mobility.

Figure 44 shows the estimated values of the biases in the trajectories (left) and the residual noise on top of it (right). It was noted that the primary source of error corresponds to highly biased trajectories. On average considering the whole fleet of vehicles the tracking of the bias in the trajectories is 0. However, when trajectories are observed individually, inaccuracies arise and provide a very different picture to the actual trajectory of the vehicle. Figure 44 right shows the noise on top of the bias. Values are small, typically around 0.3 metres and show autocorrelation. This implies that the signal behaves regularly between observations, although such signal may be affected by the bias mentioned above.

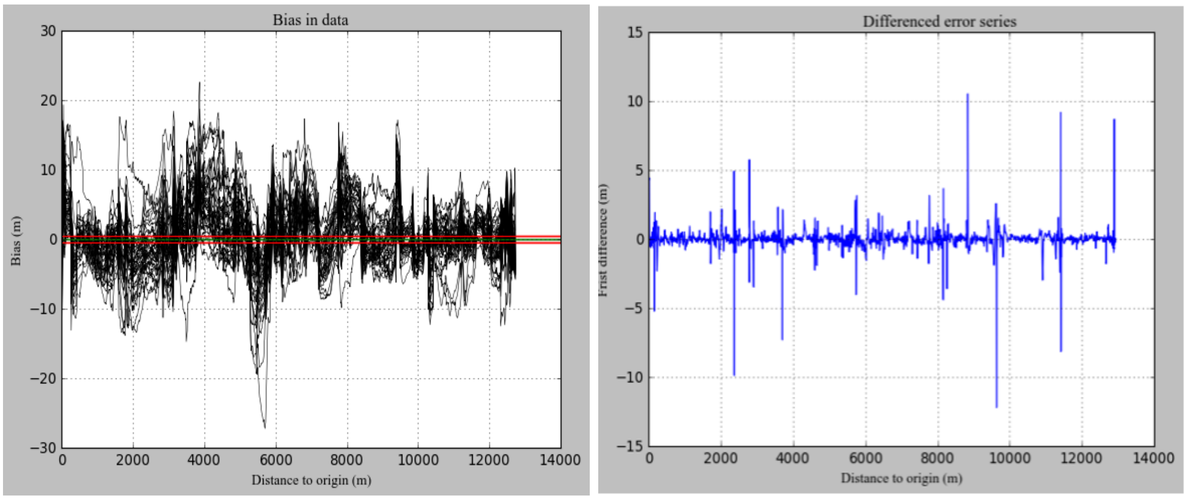


Figure 44. Error distribution of bus

Figure 45 shows the acceleration profile of all trajectories considered in the data. The red lines indicate the acceptable and typical maximum values of acceleration in bus operations, generally estimated to be around 1 m/s^2. Results yielded values exceeding such maximum acceleration values to be in the range of 20% of the observations. It can be seen that the distribution of accelerations appears to be symmetrical around 0 with extreme values exceeding 20 m/s^2 in absolute value. The implications behind the poor estimates of acceleration affect important operational information. Understanding of bus consumption and pollution requires acceleration as one of the main input parameters. As shown in Figure 45, accelerations are very sensitive when estimated from GNSS data. Such sensitivity extends to the results regarding consumption and emission of pollutants. In this regard, the accuracy of GALILEO positively differentiates the constellation from other GNSS when it comes to the use of georeferenced data to tackle environmental issues. In the view, this is one of the main potentialities GALILEO may explode and use to its advantage against other constellations.

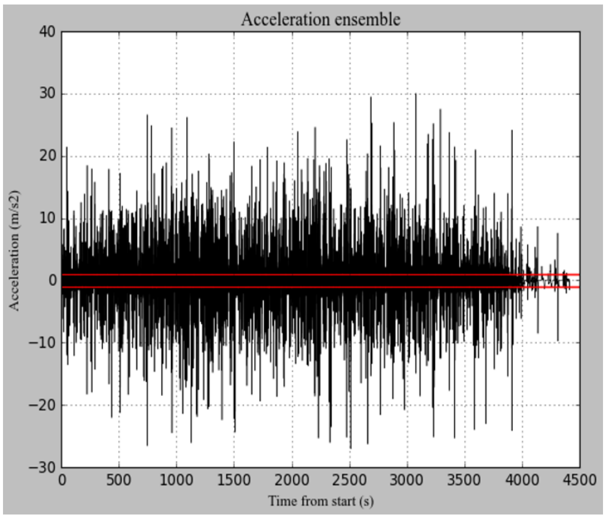


Figure 45. Acceleration profile

Figure 46 shows real data of buses carrying out battery charging operations at the two stations located at the end of the line. The data used does not belong to the GALILEO constellation. This can be readily seen from Figure 46 right. Distribution of errors appears to be symmetrical around an expected value of 0. Errors appear to be uncorrelated regarding X and Y coordinates along the route of the bus. In the dataset, errors between around 5 metres were common to be observed. Such errors are far from the submeter accuracy required in many transportation systems or modes of transportation.

In the case of buses, several problems and technologies may be compromised as a result of the low accuracy of the signal. For instance, automation of transit vehicles is one of the current paradigms in public transportation. Among the myriad of sensors and devices installed in autonomous vehicles, GNSS information is of the essence to help navigate the vehicle. Noisy data does not guarantee safety of passengers inside the vehicle, that is, aggressive driving behavithes may be masked because of unreliable GNSS observations. Moreover, filtering algorithms may be needed to estimate the error in the data. These processes require additional computational cost and energy consumption of the vehicle. With accurate GNSS data, both safety and cost reduction should be enhanced. In addition to that, the implementation of automated solutions in public transportation heavily relies on user perception and acceptance of these technologies.

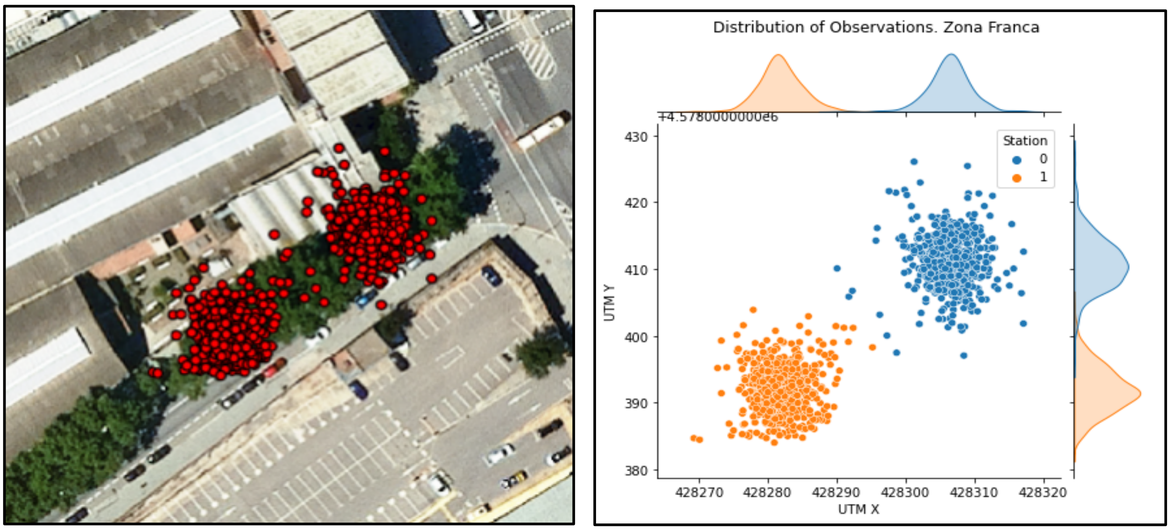


Figure 46. Error distribution of bus coordinates

It is important to note that many of the inconveniences derived from the usage of low accurate GNSS data concern analytical tasks, as opposed to merely tracking vehicles (operational task). Figure 47 schematically depicts an example of a recurrent issues derived from error in bus observations retrieved from a GPS receiver. Assume a bus vehicle is waiting at an intersection somewhere between the traffic signal that regulates the flow of vehicles at the intersection and the bus stop. The vehicle is not alight and/or boarding passengers at the stop. In other words, the real status of the vehicle is motionless and not serving demand. One fundamental problem of GNSS data and bus systems is that of estimating the actual status of the vehicle. Conventional GNSS such as GPS show errors well above the submeter precision GALILEO is expected to offer. In Figure 47, the circle in red represents the distribution of errors produced by a constellation different from GALILEO, whereas the circle in blue represents the error from GALILEO signals. The latter does not lead to ambiguous or wrong interpretations of the state of affairs: the vehicle is not operating at the bus stop but rather waiting at the intersection. However, the error distribution in red leaves room for different interpretations. Both the scenario of the bus at the bus stop or waiting for the green phase at the intersection are possible.

The issue of confidently determining whether the vehicle is at the bus stop or close is not trivial. Useful information can be extracted from georeferenced observations as the one depicted in Figure 47. Probability distributions of dwell time at the bus stop will be empirically derived through accurate GNSS systems. By accurately estimating dwell times at bus stops, demand models can be inferred based only on GNSS data, without resorting to user information and thus guaranteeing data privacy of travellers. Similarly, distinction between different status of the vehicle is likely to be estimated correctly assuming the error of the GNSS system is low. A useful operational application because of working with accurate data concerning the status of the vehicle is the possibility of informing passengers of boarding the vehicle when several buses operate at the same stop (bunching effect). This is important in terms of reducing the total travel time and waiting time at the stop, thus enhancing the level of service and user perception.

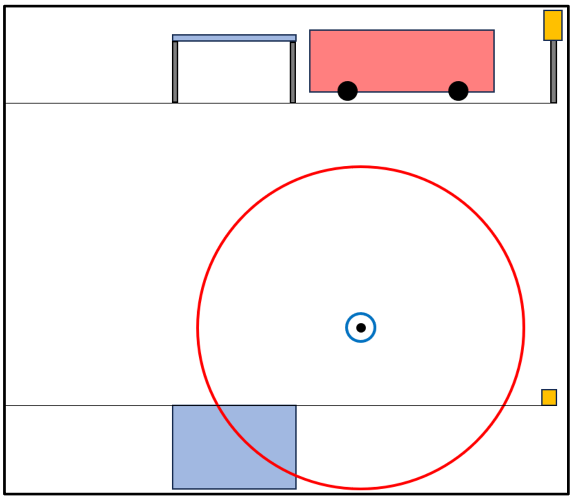


Figure 47. Ambiguity of poor GNSS signals

6.3.5.5. Use case conclusions

The tracking of large vehicles such as buses by means of georeferenced data has not traditionally required high positioning accuracy. However, the notion of accurate observations not being of relevance in controlling bus operations does not stand against today's requirements of data processing and monitorization of specific operational variables. Moreover, transit and mobility users in general demand efficient, instantaneous, and reliable access to information, which adds complexity and a more challenging scenario to transit agencies in attracting and keeping demand.

In the context of the MOLIERE project, UPC has developed a software tool aimed at extracting bus systems related information from GNSS data. The number of relevant insights to be drawn solely based on accurate georeferenced information is vast: total travel times, arrival times at stops, dwell time at bus stops, headway, headway adherence, energy consumption, emission models, among others. Particularly, transit operations account for a high percentage of emissions in urban settlements. In addition to providing efficient and reliable transportation activities and high levels of service, management of energy consumption and pollution plays a role in meeting new standards in public transportation systems. In this regard, it is believed that the use of GALILEO data, as opposed to other GNSS constellations, better aligns with the principles of sustainability since it allows managers and city planners to tackle environmental issues through more accurate data and confident relationships between pollution or energy consumption and operational variables. From accurate GNSS data (e.g., GALILEO HAS), instantaneous micro-models can be computed.

The use of GALILEO may also play a role in the relationship between costs and information. As stated above, important variables and precise tracking of a bus fleet can be accomplished through accurate georeferenced coordinates. A reduction in cost is achievable through GALILEO since highly complex and expensive devices and networks may be partially substituted by a GNSS receiver installed in the vehicles. This is of particular interest to small transit operators whose budget constraints do not allow them to invest on costly support systems and must rely on tracking systems.

Finally, accurate information not only affects transit agencies and city planners (supply side of the system) but also users. Higher standards and more complex mobility patterns regarding spatial and temporal heterogeneity require consumption of information on the part of the user. Bus systems play a huge role in sustainability issues by moving large volumes of passengers from several origins to different destinations. Attraction of demand depends on the reliability and efficiency of the systems. By providing reliable real time information a shift from private vehicles to public transportation takes place. The high accuracy of GALILEO aligns with the expectation users demand from transit agencies and shows potential usage in the bus system market by fulfilling travellers' needs and standards.

7. General conclusions

In summary, the conclusions from the five use cases in the Molière project are as follows:

Use Case 1: Micro-incentives for Micromobility

- Incentivized rides had a statistically significant positive effect on ride uplift in defined areas.
- The micro-incentives resulted in a ride uplift potential of 2.56% for e-scooters and 2.12% for e-bikes.
- The maximum possible ride uplift achieved through micro-incentives was 7.0% (e-bikes) and 9.5% (e-scooters).
- Increasing the discount from 30% to 70% had a negligible effect on ride uplift.
- Micro-incentives were effective in increasing micromobility usage in low-income areas with poor transport connectivity.

Use Case 2: Mapping status of cycling infrastructure

- The LanePatrol solution, along with the CycleRAP methodology, successfully assessed and improved cycling infrastructure safety.
- Critical safety information about cycling routes connecting Barcelona to neighbouring cities was generated.
- The CycleRAP methodology effectively measured and benchmarked safety for bicyclists and light mobility users.
- Insights from the assessments are valuable for urban planners and policymakers to prioritise safety measures.

Use Case 3: Proof of Mobility Service

- The Proof of Mobility Service (PoMS) provided a robust mechanism to tackle potential fraudulent behaviour in allocating incentives.
- PoMS validated the delivery of real services, ensuring legitimately earned incentives.

- The implementation of PoMS demonstrated no false negatives and a minimal error rate of false positives.
- Future work includes expanding PoMS to other mobility modes and verifying mechanisms for different transportation types.

Use Case 4: Decentralised mobility data sharing for flexible transport

- GALILEO-powered services showed an average of 77.45% similarity between real-time tracking and theoretical routes, outperforming other GNSS receivers.
- Accurate georeferenced data from GALILEO had positive implications for sustainability and environmental issues.
- GALILEO's accuracy in georeferenced data positively affected bus energy consumption estimates.

Use Case 5: Bus travel time characterization and prediction using data science

- Accurate georeferenced data from GALILEO enabled more precise statistical models and causal relationships.
- The accuracy of GALILEO positively differentiated it from other GNSS in terms of tracking bus operations and environmental issues.
- GALILEO has potential to reduce costs for transit agencies and improve user reliability and satisfaction.

In conclusion, the Molière project successfully explored the utilisation of Galileo satellites, data sharing, and blockchain technologies to address critical challenges and unlock new possibilities in various sectors. The project demonstrated the transformative capabilities of integrating cutting-edge technologies in mobility and transportation, leading to improved security, efficiency, and transparency. The use cases showcased the practical applications and benefits of these technologies in different real-world scenarios, laying the foundation for potential future product roadmaps and data standard adjustments in the mobility industry.