Deliverable 6.2

Simulation of Emerging Mobility Solutions and Participatory Policy Assessment: Case Studies

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Table of Contents

Figure Index

Table Index

Summary sheet

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Abstract	This document defines a collaborative policy assessment methodology to effectively use the new data, models and tools produced by MOMENTUM in urban mobility planning in order to help local authorities conducting a holistic evaluation of emerging mobility solutions and addressing local concerns
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Organisation	Country	Abbreviation
EMPRESA MUNICIPAL DE TRANSPORTE DE MADRID SA	Spain	EMT
NOMMON SOLUTIONS AND TECHNOLOGIES SL	Spain	NOMMON
DIMOS THESSALONIKIS	Greece	THESS
ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS	Greece	CERTH
STAD LEUVEN	Belgium	LEUVEN
TRANSPORT & MOBILITY LEUVEN NV	Belgium	TML
STADT REGENSBURG	Germany	REGENSBURG
TECHNISCHE UNIVERSITAET MUENCHEN	Germany	TUM
AIMSUN SL	Spain	AIMSUN SL
POLIS – PROMOTION OF OPERATIONAL LINKS WITH INTEGRATED SERVICES, ASSOCIATION INTERNATIONALE	Belgium	POLIS
UNION INTERNATIONALE DES TRANSPORTS PUBLICS	Belgium	UITP
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List of acronyms

CoP	Community of Practice
D	Deliverable
DRT	Demand Responsive Transport (transport on demand)
DST	Decision Support Tool
EDM	Encuesta domiciliaria de movilidad (Household mobility survey in Madrid)
EIT UM	EIT Urban Mobility
ICT	Information and Communications Technology
ITS	Intelligent Transport Systems
KPI	Key Performance Indicator
LEZ	Low Emission Zone
MaaS	Mobility as a Service
OD	Origin-Destination
PT	Public Transport
PTA	Public Transport Authority
PTO	Public Transport Operator
SUMP	Sustainable Urban Mobility Plan
T	Task
WP	Work Package

Executive Summary

MOMENTUM takes a wide perspective that includes all the challenges that European cities are facing due to the transformations in urban mobility and an increasingly uncertain future. This wide approach is complemented by considering four specific case studies. Each case downscales the challenges associated with new mobility options to the local circumstances of a European city, and provides solutions based on the research conducted in the project. The four European cities are **Madrid** (Spain), **Leuven** (Belgium), **Regensburg** (Germany) and **Thessaloniki** (Greece). This approach guarantees the relevance of the project results, given their heterogeneous characteristics in terms of size, morphology, environmental, socioeconomic and cultural factors, mobility issues and policy goals.

The objective of the present document is to **describe the processes and results** derived from the **policy simulation and the participatory policy assessment**, by using the tools and the methodologies developed in the project to evaluate the impact of a set of alternative policy options and innovative mobility solutions in the four participant cities. This deliverable also includes a summary of the main outcomes from all the analysis carried out during the project for the four MOMENTUM cities.

The approach of the policy assessment includes the active participation of local communities of practice (local groups of stakeholders) to discuss on the results of the tools developed by MOMENTUM, from the perspective on how these results have helped or given to the partner cities some information to evaluate possible scenarios as well as to show and discuss them with their communities of practice. In this process, cities have been always accompanied by their correspondent technical partner in order to conduct the experiments, always with the guidance of cities.

The different interactions have been both presential and virtual (online) and have included presentations, debates, roundtables and testing of different tools, by focusing on the specific challenges and use cases of the four cities:

- **Madrid**: the focus of the assessment procedures in Madrid has been put in two shared mobility services, BiciMAD (public bikesharing system) and Muving (private mopedsharing service), and their role as a complement to public transport by addressing the following frame questions: Is shared mobility a substitute for the private car?. To answer this question, we took advantage of the implementation of the Urban Vehicle Access Regulation Area (UVAR) in the central district, where shared mobility services operation is well established, in November 2018 as a natural experiment to analysis private vehicle to shared mobility modal shifts; Is it a viable solution for all?. In this case we focused on income differences between shared mobility suers and the rest of the population; and, is the role of shared mobility a complement to public transport? In this case we analysed the penetration of shared mobility trips in OD pairs with different degree of connections though public transport.

  After the demand analysis for before and after the implementation of the UVAR zone:
  - No evidence was found that public bicycles attracted users of private vehicles to make trips to the centre. This may be due to the, reduced, extension of the service in that moment. Newer analysis are required for the assessing the role of BiciMAD with the current extension.
    The evolution of the demand for one of the motosharing services indicates that it was capable of attracting trips by private vehicle, since the demand in relations between the centre and the rest of the city gained importance, especially with the areas that most use the private vehicle to access the restricted area.

From the income analysis we can conclude that:

- Madrid seems to follow a similar pattern to the observed in the literature in terms of adoption according to income level (higher in higher incomes). However, there are differences between the services analysed: adoption is more related to a higher income in moto-sharing than in bike-sharing.
- The area in which the service is deployed determines part of the income trend. 90% of the service's users live inside of the service area. The average income level in the city centre, where the service is deployed, is relatively high in comparison with the average income of the rest of the population.

Experiments performed to assess the relation between shared mobility and public transport have shown that, while there is some uncertainty with respect to the specific modes, certain shared modes can complement public transport modes in two ways: (1) offering a better alternative in OD pairs where public transport offers bad connections and (2) covering the last mile of public transport services.

The analysis of the penetration of BiciMAD by type of origin-destination connection by public transport suggest that, in some cases, travellers prefer public transport where there is a direct connection and use shared mobility whenever they have to change lines. Concisely, we have observed that BiciMAD users have higher relative penetration in OD pairs where there is no direct metro connection. Interestingly, this pattern is only observed for BiciMAD and metro stations, which points at the following possibilities:

- BiciMAD users seem not to consider the bus system even where there is direct connection. There could be some reluctance to use bus, maybe due to the lack of determined travel times or the ignorance of the lines available at each OD pair.
- Muving users appear to not consider public transport modes when doing their trips. This behaviour could be influenced by the free-floating configuration of the system, which enables door-to-door trips that public transport cannot offer.

The analysis of BiciMAD relation with short distance train "Cercanías" (Madrid regional train) has shown that the BiciMAD service might be providing some last mile service to the Cercanías train mode. The experiment has shown that the observed trips between BiciMAD service bases nearby Cercanías stations and other isolated bases and the observed trips between bases nearby Cercanías stations cannot be explained by their distance, with underestimation in the former case and overestimation in the latter.

As a result, the response to the research question: to what extent shared mobility service can improve public transport accessibility by complementing it? the conclusion is that the role of shared mobility depends on how services are deployed and their conditions. In the experiments, MOMENTUM has observed that a low-cost station-based bike-sharing service (BiciMAD) seems to be more complementary with public transport than a free-float moped-sharing service (Muving).

Overall, the policy assessment procedures in Madrid in cooperation with the community of practice have shown that the tools developed under the framework of MOMENTUM project can become a valuable tool for helping in the mobility planning of shared mobility services. More in particular, MOMENTUM tools bring accuracy and certainty about the deployment of Madrid BikeSharing system, BiciMAD, in new areas of the city helping city planners to better address the location of bike stations according to different parameters and its multimodal potential linked to the public transport network. This conclusion can be also applied to other private shared mobility services.

- **Leuven:** A key objective for the city of Leuven in the MOMENTUM project was the further regional integration of all different transport systems and mobility providers with the future spatial developments, by the development of a new, state-of-the-art, multimodal traffic model, taking into account the impact of shared mobility, and, more specifically analysing three policies in the case study:
  - The implementation of a new mobility plan for districts within the city such as Kessel-Lo and Heverlee.
  - The introduction of 50 so-called 'Mobipunten' (small to medium-scale mobility hubs with car-sharing, bike-sharing or scooter-sharing facilities, parking infrastructure and charging stations.
  - The implementation of Regionet, a new overarching strategic mobility plan at regional level. In particular, the introduction of bus lanes and the implementation of high-quality bike infrastructure, in combination with pricing policies and the implementation of peripheral parking and autonomous shuttle buses will be tested. Regionet will also form the basis for future urban development, such that new developments will be concentrated near public transport hubs.

  The city of Leuven had very little experience with data driven policy making let alone making use of advanced modelling. MOMENTUM has allowed the city to make a lot of progress in this regard. The value of this has been acknowledged by numerous stakeholders, including the city itself, regional transport authorities, shared mobility operators and citizens involved in participatory processes.

  The models and tools developed in MOMENTUM have already proven their value in both the decision-making process as to a certain extent in the planning process, and the CoP wants to build on the output of MOMENTUM to continue this path in the coming years.

  Since shared mobility is still pretty much in its infancy in Leuven (car sharing excepted), the interactions with the Leuven CoP have shown that Leuven needs to invest further in this approach, as the need for planning tools will grow while upscaling the efforts, and the effectivity of the tools will improve as more data becomes available.

- **Regensburg:** The main objective of the Regensburg case study was to include the impact of shared mobility in transport planning and decision-making process, by developing new analytical solutions that could complement and enhance the existing multimodal macroscopic transport model.

  - One goal is to use the models, developed by MOMENTUM, to provide data-based support in the decision-making process to support the implementation of a bicycle sharing system. For this goal, we tested the decision support tools in the Western District. The results were discussed with the traffic planner for local mobility from the transport planning department as also with the prospective operator (SMO) involved in the introduction of the bikesharing system.

  - Another objective is to evaluate the impact of shared mobility on vehicle ownership and air pollution based on local circumstances. This test case, which was investigated with the decision support tool level 3, referred to the already introduced exclusive bus lanes and the pilot operation of the autonomous people mover (APM) in the business park. The results were discussed with the traffic planner for public transport from the transport planning department as also with the operator (SMO) involved in the introduction of the APM system.

  Thanks to MOMENTUM project and the policy assessment activities carried out with the cooperation of the CoP, the city of Regensburg has gained insight into the analysis of user data based on the car-sharing service. This analysis has enabled the creation of models to determine demand, modal shift and vehicle ownership patterns. The tools developed have been suitable for investigating the bikesharing service at Level 1 and Level 2 of the MOMENTUM decision support tool (DST). The results will be used in a prospective initiative to introduce a bikesharing service in Regensburg.

Regarding the already existing exclusive bus lines, was able to calculate the size of the modal shift and determine the amount of air pollution reduced. These results are to be taken into account in the upcoming expansion of the exclusive bus lines. Furthermore, Regensburg has got a first insight into the modelling possibilities of the autonomous people mover, which shows that the system can complement the existing public transport service. The city will take into account the advice to take a more detailed study of the demand side in future pilot projects. Finally, the results related to shared mobility services shows that such services can reduce private car ownership in the city.

- **Thessaloniki**: The overall objective of Thessaloniki case study was to improve the planning and decision-making process for the introduction of resilient sustainable mobility schemes, with main emphasis in adoption of DRT, ridesharing and vehicle sharing mobility solutions (micromobility and bike sharing) towards the deployment of MaaS in the agglomeration. This would serve also to develop techniques which can facilitate proofs of concept of new mobility schemes and to improve and extend the use of innovative data sources (Floating Car Data, point-to-point detections, etc.) in the transport modelling process.
The assessment was done via three specific questions to be addressed: How DRT should be implemented to contribute to sustainable mobility? What is the role of ridesharing in the transport system of the city? And What are the impacts of bikesharing and micromobility in transport planning?.

The results extracted through the MOMENTUM DST were discussed and assessed by the CoP of Thessaloniki giving to the municipality some useful insights on the questions set in the beginning of the project.

The definition of the specific area that could offer the most suitable conditions for the implementation of the new mobility services was among the main priorities of the municipality. This topic was examined through data exploratory analysis in the WP3, and the characteristics of the defined areas results were considered during the design phase.

Therefore, the bike sharing and micromobility schemes are more suitable for urban areas with existing bike lanes network since it is easier to develop additional infrastructure for their operation in these areas. Moreover, such urban areas are characterised by short distance trips including last-mile and for this reason they seem to offer better conditions for the successful development of these services. It is worth mentioned that the number of the suggested stations for the bicycles is quite smaller than the one of the e-scooters due to the lower bicycle demand in the examined area.

Regarding the DRT service, the aim of the municipality was the connection of the urban areas with the peri urban ones. The DRT service will feed some existing public transport stops in the border of the urban area, combining thus this new on demand mode with the currently operating public transport to reach the city center. According to the experiments that were conducted, larger fleets with smaller capacity significantly reduce the trip duration of the passengers while also increasing the demand coverage capability of the services.

Finally, examining the operational parameters of a ride sharing service, it was concluded that such services are more attractive in the beginning when they offer low waiting time to the passengers in the lower possible cost. For this reasons, larger fleets were suggested and as the demand raises the waiting time also increases while the mean occupancy and the trip duration are decreased.

The four cities and their respective communities of practice have agreed on the relevance of the analyses and developments carried out in the framework of the MOMENTUM project and the importance of being able to incorporate all the new mobility services that are appearing in the transport modelling processes to be able to develop better urban policies that allow extracting the full potential and minimising the possible negative impacts.

As an overall conclusion, the four MOMENTUM cities remark that:

- Cooperation is essential, thus the relevance of using a Community of Practice not only to promote more fluent exchange of information and approaches but also to promote a better public-private cooperation.
- It is a challenge to cope with fast and dynamic evolution of new mobility solutions (e-scooters, CAVs...)
- Digitalization puts new fine-grained data sources on the table as an opportunity for disaggregating our models and therefore, sharing data, data collection and data standardization plays a key role.
- Modelling efforts have to deal not only with use but also with adoption and its impacts (e.g. car ownership. Besides the traditional transport modelling approaches, data-driven approaches can also enable insights on travel behaviour of users or target groups for shared mobility options. These insights can support policymaking.
- Cities require flexible tools to be able to deal with evolving services, but also to be aware of different data availability and technical skills contexts. Practical tools, such as the DST developed under the scope of MOMENTUM, help cities improving the decision-making process.
- Still room for improvement regarding simulation and planning of shared mobility solutions: operational costs, externalities (i.e. environmental costs).
- Local context matters. Implementations of mobility services can differ significantly from one city to another, so it is difficult to have one tool that can deal with all possible configurations and uses of these services.

1. Introduction

1.1. Scope and Objectives

The goal of this deliverable is to describe the specific **processes and results** derived from the **policy simulation and the participatory policy assessment** defined by D6.1 by using the tools and the methodology developed in the project to evaluate the impact of a set of alternative policy options and innovative mobility solutions in the cities of Madrid, Thessaloniki, Leuven and Regensburg.

Each of the four cities host a MOMENTUM Test Case, having one of the most remarkable developments in the Decision Support Tool developed under the framework of the project.

The current document describes how each city has defined its CoP, the interactions with it, and the different exercises and results obtained from the application of the aforementioned methodology. This deliverable also includes a summary of the main outcomes from all the analysis carried out in the project

1.2. Structure of the Document

The document includes one chapter per city, including:

1) A description of the local context and the need for change
2) The goals of the city use case
3) Members of the Community of Practice
4) Different assessment procedures carried out in each city
5) Main outcomes
6) Summary of the analysis carried out in the project.
7) Conclusions

1.3. Reference and applicable documents

[I] Grant Agreement No 815069 MOMENTUM – Annex 1 Description of the Action.

[II] MOMENTUM Consortium Agreement, Issue 1, April 2019.

[III] MOMENTUM D3.3 Methodologies and Algorithms for Mobility Data Analysis

[IV] MOMENTUM D4.1 Transport Modelling Approaches for Emerging Mobility Solutions: Supply and Demand Models

[V] MOMENTUM D5.2 Interactive Decision Support Tool

[VI] MOMENTUM D5.3 Implementation of the decision support toolset in the case study cities

[VII] MOMENTUM D6.1 Policy Assessment Methodology

2. Madrid

2.1. Context description and vision statement

2.1.1. Introduction

Madrid is the capital and largest city of Spain (3,2 million inhabitants) and the third most populated Functional Urban area in the European Union, including 7 % of total Spain population at regional level (around 6,7 million inhabitants), playing a key role in the economy of the country (the city accounts 12% of the total GDP of the country, increasing up to 19% at metropolitan level).

The city has a total area of 605.77 km2. It is divided into 21 districts (128 neighbourhoods), and received 10,419,709 travellers in 2019; of these, more than 5.5 million (54.85 %) were international and generated an expenditure more than 10,451 million euros. Its airport is the 1st one in Spain (5th in Europe), with 61.7 million passengers in 2019 (24.1 million in 2021 due to the pandemic) and there are 180 nationalities (12,4% of population has foreign origin).

2.1.2. A brief on current transport

Madrid has a wide public transport network that covers all the region municipalities. In the inner city, the system is based on a Metro system composed of 13 lines and 236 stations and an urban bus network, which has 219 lines and 10,574 bus stops (EMT Madrid operational figures, 2021). The metropolitan area is served by a commuter railway network with 9 lines and 94 stations; and by a metropolitan bus network, which has around 450 lines and more than 8,000 stops. The overall public transport network length is 11,000 km.

Regarding active modes, Madrid cycling network is composed of 349 km of dedicated lanes (Madrid City Council, 2020). Among these lanes, it has to be taken into account that the Green Cycling Belt, a recreational cycle path that connects green areas in the outskirts, has a length of 67 km. A network of *sharrows*, i.e. shared lanes with cars with a 30 km/h speed limit, complements this dedicated network, with a length of 346 km (Madrid City Council, 2020). The central district of the city has many pedestrianised spaces.

Car ownership accounts for 384 vehicles per 1,000 inhabitants in the municipality (OMM, 2017) whereas the ration goes up to 530 vehicles per 1,000 inhabitants at regional level (OMM, 2017)

The total trips per person is 2.4 trips per person per day (municipality, EDM2018, 2020), with an average trip distance of 6 km (municipality, EDM, 2004).

Finally, the modal split in Madrid city (EDM2018) is shown in Table 1:

Table 1. Madrid modal split

Mean of transport	Central district “almendra central”	Periphery
Private vehicle	13%	30%

Public Transport	34%	24%
Walking & cycling	53%	46%

In the last years the offer, and use, of shared modes and ride hailing services has suffered a fast grow in the city. In some cases, this increment has been perceived as something negative from part of the population. The proliferation of shared electric vehicles on the streets in the last years, especially e-scooters, has opened a debate about the use of public space since this is sometimes troublesome for the most vulnerable street users.

Madrid city is also an Urban Node of the TEN-T network, included in two TEN-T corridors both at the core and comprehensive level (Mediterranean and Atlantic).

The pandemic situation has altered the mobility patterns in the city: after a dramatic reduction of mobility needs during the confinement (almost 90% reduction), mobility is fast recovering but with an unequal balance, as private vehicle and shared mobility has practically recovered whereas the public transport use is still behind the pre-pandemic levels.

2.1.3. The need for change

The main priority at the city level is the reduction of air pollution caused by private car traffic. In the recent years, a Low Emissions Zone has been implemented in the central district. This zone operates as an Urban Vehicle Access Regulation area. Within this area, only vehicles from residents, electric or with low or zero emission emissions can drive through the area. Other vehicles making use an off-street parking can also drive. In addition, the bus fleet has been partially renewed and more sharrows have been introduced, to contribute to traffic calming.

The current local government launched in late 2019 the environmental sustainability strategy "Madrid 360", in order to meet EU air quality requirements. This plan intends to intensify the bus fleet renewal, by introducing more electric buses, and reinforces the access restrictions to the central district by forbidding the entrance of the most pollutant vehicles. In parallel, the municipality is promoting new parking facilities and Park&Ride (dissuasive parkings) schemes.

According to municipal surveys, 3 out of 5 main problems of the city are related to mobility, only surpassed by street cleaning: air pollution, traffic congestion and sidewalks quality (Satisfaction survey - Madrid City Council, 2018).

2.1.4. Goals, values, mission and vision statement

The main goal of Madrid case study is to **include shared mobility impacts** in the transport planning and decision-making processes. This will be done through the development of new analytical solutions that will complement and enhance the existing multimodal macroscopic transport model developed by EMT Madrid. The focus of the case study will be on the effects that shared mobility has in the travel demand patterns across the city and on the implications for EMT Madrid as a major public transport operator in the city.

The case study uses three types of city areas to perform the analyses, targeting different questions:

- MOMENTUM Lab 1 - Central district. This area is chosen because is the one where shared mobility operators are present since their arrival to the city, and because is the one where the Low emissions'

UVAR zone was implemented. This allowed us to analyse **to what extent is shared mobility used as a substitute to private car trips**, in relation to the implementation of these policies.

- MOMENTUM Lab 2 - Districts where shared mobility services have been recently implemented. These areas were chosen because they have different demographic and social structures, in terms of age, income, etc. between them and with the Central district. The aim of this lab is to understand **to what extent is shared mobility accessible to all citizens**. The experiments have been conducted city-wide to provide a more comprehensive response to the question and a comparative analysis is performed between the areas where the services is available and where is not.
- MOMENTUM Lab 3 - Districts where shared mobility has not yet been implemented. There are a number of peripheral districts without any shared mobility supply at the moment. It is still unclear if public authorities should promote the implementation of these services as a tool for first and last mile complementarity with public transport services. The research question addressed in this lab is: **To what extent shared mobility services can improve public transport accessibility by complementing it?** The selected area of study is the district of Vallecas.

The analysis performed and to be performed as well as the and the results obtained in these living labs will be presented and discussed with a set of relevant stakeholders, a community of practice, in a series of working sections to extract general conclusions on the presented questions and to evaluate the functionalities developed and used for the analysis.

The criteria for the establishment of the community of practice (CoP) as well as the dynamic for the interactions and discussions for policies and tools are discussed in deliverable D6.1 "Policy Assessment Methodology ". Below we present the list of the members of the CoP as well as the specific interactions with it for the case study of Madrid.

2.2. Madrid Community of Practice and establishment process

The MOMENTUM local stakeholder group, formed both by public and private key players in the field of mobility in Madrid, has reviewed and evaluated the functionalities offered by the developed tools. In addition, those stakeholders which are involved in modelling tasks in the city have been invited to different sessions where the tools will be demonstrated.

The following local stakeholders have been part at the Community of Practice:

- General Directorate for Transport Mobility Planning. AYUNTAMIENTO DE MADRID (Madrid City Council)
- FEDERACIÓN REGIONAL DE ASOCIACIONES VECINALES DE MADRID (Regional Federation of neighbourhoods)
- COORDINADORA VECINAL MADRID CENTRO (Coordination of the Neighbourhood associations of Madrid Central District)
- PEDALIBRE Y CONBICI (Cyclist associations)
- tGIS Research Group (UCM) and the EMT-UCM Chair of Cycling Mobility. Universidad Complutense de Madrid (Madrid Complutense University)
- BiciMAD bikesharing service. EMT (Madrid PTO)
- AAVV Puente de Vallecas (Vallecas Neighbourhood association)
- Transyt (Transport Research Centre from the Polytechnic University of Madrid)
- Observatorio de la Movilidad (Mobility Observatory)
- Acciona Mobility (Mopedsharing provider)
- Cooltra (Mopedsharing provider)

- Zity (Carsharing provider)
- Muving (Mopedsharing provider)
- Wible (Carsharing provider)
- Free2Move (Carsharing provider)
- Spin (e-scooter sharing provider)
- Consorcio Regional de Transportes de Madrid, CRTM (Madrid PTA)
- Asociación de Vehículos Compartidos de España (Spanish Association of Shared Vehicles)
- ASOCIACIÓN A PIE (Pedestrian association)
- AYUNTAMIENTO DE LAS ROZAS (Innovation Agency, municipality in the metropolitan area of Madrid City Council.)

2.3. Assessment procedures

The assessment procedure includes different sessions/interactions as follows

2.3.1. First CoP interaction

2.3.1.1. Date, format and approach

The first meeting was organized in November 23rd, from 11:30 – 14:00, in conjunction with a local workshop "Tools to support the planning and management of new forms of mobility: Madrid as a living Lab". The goal of the workshops was to present the data analysis and model developments of the MOMENTUM project relevant to the case study of Madrid. The event had a hybrid format, both on-site and online (streamed). The physical event took place at the facilities of Impact Hub in Madrid (C/Piamonte 23), and in cooperation with Connected Mobility Hub, according to the approach of mixing presentations and panel debates.

2.3.1.2. Main topic of discussion

The workshop included a panel discussion plus an interactive session in which the tools developed in the framework of the project were presented to gather the opinion of the different attendees (organisations, institutions, associations and companies).

2.3.1.3. Participants

In total there were 40 people attending the on-site event, plus the online ones.

The members of the CoP that participated were:

- Susana Magro. Deputy Director General for Transport Mobility Planning. Directorate of Mobility Planning and Infrastructures. Madrid City Council
- Rodrigo de Esteban Martínez. Acciona
- Javier Bullido Pérez. Pedalibre/Conbici
- David Bartolomé. Director of ShareNow and President of the Spanish Association of Shared Vehicles.
- Laura Delgado. Head of External Relations. Madrid Regional Transport Consortium
- Jorge Nacarino Morales. President of AV Puente de Vallecas
- Carlos Mateo. Director of Mobility Services. EMT Madrid.

- Gustavo Romanillos. Professor and member of the tGIS Research Group (UCM) and the EMT-UCM Chair of Cycling Mobility.
- Nuria Blanco (Las Rozas Innova. Las Rozas Municipality)

From MOMENTUM partners:

- Javier Burrieza. Nommon
- Oliva García Cantú. Nommon
- Inés Peirats. Nommon
- Cristina Valdés Serrano. EMT Madrid
- Sergio Fernández Balaguer. EMT Madrid

2.3.1.4. Description of the action

The workshop was structured in two discussion panels, the first one focused on the use of Shared mobility as a substitute for the private car and a second one focused on the characteristics of the users and the use of shared mobility services. Before each panel a presentation of the analysis performed for the Madrid case study in for these topics were presented. As the aim of the project is to develop new data analysis techniques and transport models, the presentations were of a technical nature, trying to communicate the process and its outcome in a reachable way by the audience. All these analyses are detailed in Section **¡Error! No se encuentra el origen de la referencia.** of this document.

Figure 1 shows an image of the event during one of the round tables.

Figure 1- First Madrid CoP interaction; Local Workshop Nov 23rd, 2021 at Impact Hub

The content of the two round tables were the following:

- Roundtable 1 - Shared mobility as a substitute for the private car

In this presentation the results of the analysis conducted to find out whether the implementation of low emissions UVAR zone in the centre of Madrid at the end of 2018 promoted an increase in demand for two shared mobility services (BiciMAD and Muving) were shown. The panellists and audience debated about how car restrictions have changed the demand for new mobility services, and if those services have absorbed trips to the centre that would have been previously made by car. Some of the results presented suggested that while Muving seemed to have absorbed some of the trips previously made by car BiciMAD seemed to have not play a relevant role in absorbing these trips. One topic of discussion was whether or not this was due to the, in that moment, reduced area of coverage of the service and the potential of the service in attracting car users provided they increase their coverage area.

The conclusions presented can be summarised as

- The drop in traffic recorded by the City Council data had to result in a shift of trips to other modes, as the analysis of overall mobility with mobile data indicates that it could not have been due solely to the centre being less visited after the restrictions: total mobility to the centre did not have a very different variation than for the city as a whole.
- BiciMAD did not particularly increase its trips to the city centre from outside the perimeter of the restricted access area (LEZ), but followed a similar trend to the rest of the city. This could indicate that it did not absorb many private vehicle trips.
- Muving did record a better demand development in city centre-resort relations than in the city as a whole. Moreover, this was especially so in the relations with the districts that used the car the most to go to the city centre in 2018 according to the CRTM survey. This could indicate that it did absorb car trips

The participants agreed that these type of analyses of private car uptake are useful for urban mobility planning, and that MOMENTUM has helped in facilitating the conversation between transport authorities and mobility operators.

- <u>Roundtable 2 - Equity, inclusion and the role of shared mobility as a complement to public transport</u>

This roundtable showed the results of the analysis carried out to extract relevant characteristics of the adopters of new shared mobility services in Madrid (income, by age), as well as to identify whether shared mobility is complementing public transport on some journeys. Both panellists and audience discussed about the fact that users of shared mobility are concentrated in the higher income segments, and whether this is determined by the area of operation, or there are other aspects such as fares that also come into play. Also, the influence of the digital divide and the impact on the current lower level of use amongst certain age categories was discussed as. In line with the results presented, all participants agreed that bike sharing and other shared modes can play an important complementary role to public transport on some journeys.

The conclusions highlighted in the presentation are:

- The comparison between the income distribution of the general population and that of shared mobility users (according to the average income in their areas of residence) shows that shared mobility users tend to be of higher incomes. This is in line with the literature (studies from other cities).
- This may be largely due to the area of operation: more than 90% of users live within the area, and by operating in central areas, the profile of residents is already higher income.
- However, differences between bike and bike sharing are observed when the distributions inside and outside the area of operation are tested separately: in the case of Muving (it should be noted that at the time of the analysis, this company was still operating in Madrid), the service was more successful in higher

income areas both inside and outside the area of operation (so it seems that it is not just because the area of operation has higher income), while in the case of BiciMAD the penetration is more homogeneous in each segment.

- The comparison between the age distribution of public transport and shared mobility users according to the mobility survey shows that shared mobility users tend to be young adults and middle-aged people, with very few elderly people. This is in line with the literature (studies from other cities).
- Analysis of BiciMAD's trip acquisition suggests that the service is most successful in relationships between bases with a Metro connection requiring a transfer (complementing the public transport system on journeys without a direct connection) as well as in relationships between bases next to Cercanías stations and bases at some distance from these (last and first mile in metropolitan journeys). These are indications of complementarity.

2.3.1.5. Main outcomes

The main outcomes from this first CoP interaction were:

- Roundtable 1:
    - In line with the results obtained with the analaysis performed in the project the serives operators agreed that there has been an increase in demand after the implementation of the UVAR area. Some operators have also observed increases in demand as a result of partial closings of streets (e.g. urban refurbishings).
    - There was acknowledge on the relevance and usefulness of having access to service operation data to assess the impact of these services. However, it was agreed that there are still limitations with respect to data accessibility. It was argued that shared mobility services are still new and there have been many concerns on data sharing policies and use, but the sector is evolving towards a more open data sharing policy. For this to happen, some access requirements (identification, motives, etc.) are needed.
    - Service operators shared their perception on cities' government interest on the deployment of these services, in both cities offering already the service and city which do not have it available yet.
    - It was discussed that, while the use of shared modes can introduce new problems (excessive use of pedestrian space for parking) this is and was the case before the irruption of these services.
    - Changes in cities' architectures and facilities may help to improve shared mobility service usage.

- Roundtable 2:
    - Technology is usually a complication for the adoption of these services by older people. In addition, the cost and simplicity of access requires an extra effort.
    - While micro-mobility is very useful, it is very complex to articulate. Public transport must articulate transport and shared modes complement, improve public transport.

2.3.2. Second CoP interaction

2.3.2.1. Date, format and approach

The second interaction took place on February 18th from 11:30 to 14:00 in an online format. The main objective of this session was to discuss the design, aided by the optimal station ñocation tool developed in the project, of different deployment scenarios for the BiciMAD service in a new city's district, Villa de Vallecas. (in the southeast side of the city, out of the first ring road M30). The session was titled "Planning the deployment of BiciMAD in the district of Villa de Vallecas". Figure 2 illustrates the attendants and the presentation of the meeting.

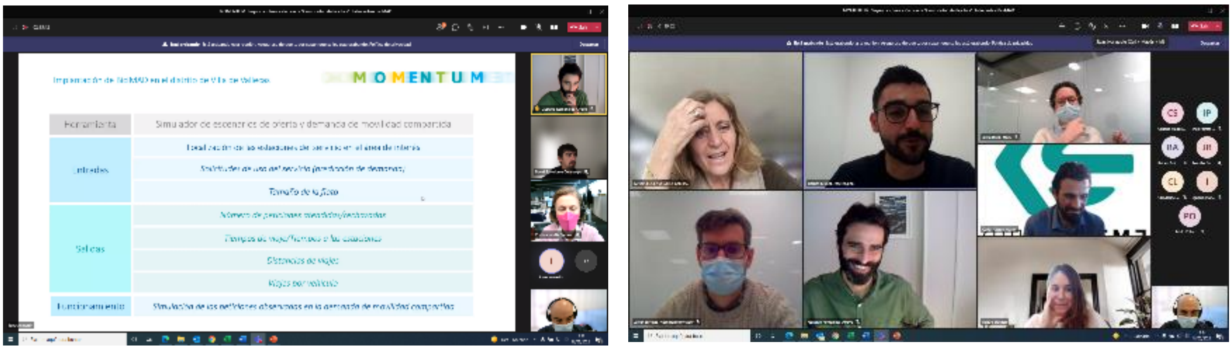

Figure 2- Second Madrid CoP interaction; Online session February 18th

This CoP was divided in two main parts, one dealing with the perceived inclusiveness of the shared mobility services and a second part dealing with the deployment of the BiciMAD service in a new area.

Topics of discussion:

Accessibility of shared mobility services:

Review the contents presented in session 1 of the CoP to continue with the debate on the accessibility of these services. Are shared mobility services an option for all?. Deployment of BiciMAD in villa de Vallecas:

1. Explanation and first session of the Vallecas case study, which demonstrates the use of some MOMENTUM tools for the design and simulation of different deployment scenarios for the BiciMAD shared mobility service in the district of Vallecas. In this first session, the number of service stations and their locations to be deployed was analysed and debated.
2. The possible demand to be used for this experiment was also discussed. Two scenarios were presented: one considering low service penetration (this corresponds to around a 1% of the total trips), for this the estimated demand for the service in the study area was obtained with the demand prediction model developed in the project was put under scrutiny; a high penetration scenario was also discussed which consisted on assuming that the structure of the predicted demand was fixed but the volume augmented to a 9% of penetration.

2.3.2.2. Participants

There were 16 participants:

- Carlos Mateo. Director of Mobility Services. EMT Madrid.
- Gustavo Romanillos. Professor and member of the tGIS Research Group (UCM) and the EMT-UCM Chair of Cycling Mobility.
- Pablo Olalla. AAVV Puente de Vallecas (Vallecas Neighbourhood association)
- María Eugenia López Lambas. Transyt (Transport Research Centre from the Polytechnic University of Madrid)
- Cristina López. Observatorio de la Movilidad (Mobility Observatory)
- Jennifer Rodríguez. Cooltra (Mopedsharing provider)

- José Barrios. Zity (Carsharing provider)
- Raquel Hernán. Wible (Carsharing provider)
- David Bartolomé. Director of ShareNow and President of the Spanish Association of Shared Vehicles

From MOMENTUM partners:

- Oliva García Cantú (Nommon)
- Javier Burrieza (Nommon)
- Ignacio Martín (Nommon)
- Inés Peirats (Nommon)
- Rubén Artime (Nommon)
- Sergio Fernández Balaguer (EMT)
- Cristina Valdés Serrano (EMT)

2.3.2.3. Description of the action

The session started with a revision and discussion of the results of the first CoP interaction, followed by the presentation of the Vallecas case study. The session included the resolution of a live scenario with the inputs agreed among the attendees and the following discussion on the results. The debate was moderated by EMT and Nommon.

During the debate of the conclusions from the first CoP interaction, the attendants were inquired about their opinion on different topics arising from the results, including whether shared mobility modes compete or complement public transport or the inclusiveness of shared modes. Furthermore, there were questions to debate about the objectives and targets of specific policies.

The CoP members were then involved in the design of the station infrastructure to deploy the BiciMAD service in the Villa de Vallecas district. To this aim, the optimal station's location tool of MOMENTUM was used. Section **¡Error! No se encuentra el origen de la referencia.** provides the specific technical details of the case study. The a ttendees were presented with the expected demand estimation from the data-driven demand predictor (See Deliverable D4.1 for more details) and asked to debate about the acceptable walking distance to a station and the range of stations to be installed (upper and lower bounds). Figure 3 shows another illustration of this CoP session during the presentation of the case study.

At the end of the exercise, the attendees were asked for their opinion on the resulting station locations provided by the optima station location tool. In addition, CoP members were asked to give their opinion on the tools and developments generated by the MOMENTUM project.

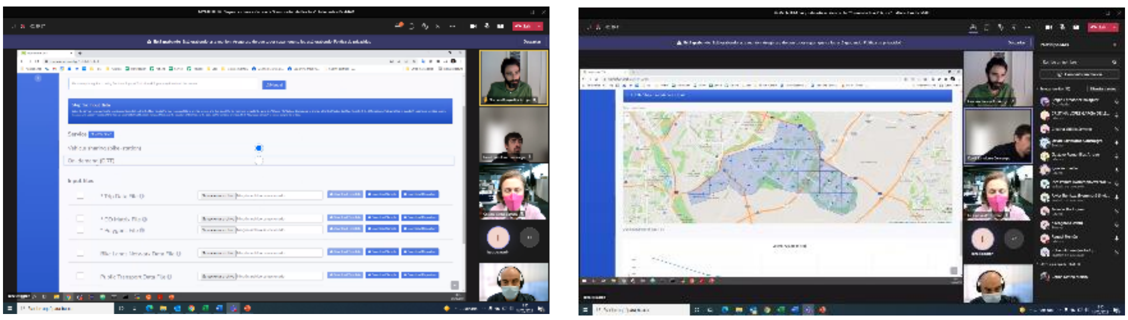

Figure 3- Interactive test of station location module of the decision Support Tool applied to BiciMAD use case in Vallecas

2.3.2.4. Main outcomes

The initial debate of the results presented in the previous CoP promoted further debate and new and interesting insights, such as:

Accessibility of shared mobility services

- The observed low adoption between certain population groups may be related with the perception of security in particular in BiciMAD. This reluctance might be driven by city configuration or service features.
- The low adoption from women groups may be related with the fact that they are not compatible with care activities, more commonly performed by women.
- Intermodality has still a small weight on BiciMAD, but the service promotes them, so they will eventually increase.
- Many attendants pointed that public transport has observed reduced use after COVID-19, while bike-sharing (BiciMAD and others) has a demand over pre-covid levels.
- Most shared mobility operators present indicate that there are unbalances in demand. Vehicle availability is agreed as an important factor. Potential regulations to ensure availability were noted, but not further discussed.
- Recurrent use is necessary to ensure service feasibility. Some operators indicate that providing universal access to shared mobility is difficult. Competence is needed.

Deployment of BiciMAD in villa de Vallecas:

The debate was centred around the two parameters to be adjusted to obtain optimal station's location: walking distance and the number of stations. At the end, it was agreed that no more than 35 stations should be installed, and walking distance should be 300 metres. In addition, the following topics arose:

- While the MOMENTUM tool provides a comprehensive approach to station location, it is usually desirable to have an intermediate compact approach with some stations around a key area and then growing slowly as a stain of ink. Based on this discussion it was decided by the technical partners participating in the case study to consider 3 different scenarios:
    - One considering the full deployment as one (i.e the deployment of the 34 stations suggested by the tool)
    - Two partial deployments considering only the deployment of 20 stations in a first stage. One of them, the compact deployment, considered only 20 stations in the central part of the district. The other, the disperse one, considered only 20 stations in the whole area of the district.
- Different scenarios could be considered, possible reducing the ambition to cover part (and not all) the district in the initial deployment.
- Public transport facilities can satisfy demand better than shared mobility (much more people can travel inside a train compared to all the bikes attached to base). There will be always unsatisfied demand.
- The expansion of BiciMAD may require additional calibration efforts of the tool to include new behaviours and potentialities.
- In addition, the conversation with the stakeholders helped with the definition of a set of rules to adjust the location of the stations.

Conclusions and assessment about the momentum tools and analysis:

Participants agreed that the results provided by MOMENTUM tool are aligned with previous research done by some members of the CoP, specially Transyt group (UPM) and t-gis (UCM). Private shared mobility operators participating in the CoP also agreed in most of the outcomes and conclusions from the perspective of the user profile of these services, market penetration and observed demand, and also the influence of cultural aspects on the user behaviour and willingness to use shared modes.

As a summary, the CoP members agreed that the the station locations optimiser demonstrated provides a better basis for addressing extensions of the public bicycle system, as it provides a better understanding of the areas to be covered based on the expected demand and allows to calibrate different scenarios based on the input parameters.

2.3.3. Third CoP interaction

2.3.3.1. Date, format and approach

The third and last interaction with the Madrid CoP was organized last March 7th, also online, from 11:30 to 13:15. In this case, the session was focused on the Vallecas case study, more precisely on the simulation of a set of scenarios that were derived from the results of the previous session. . This session was titled "Simulation of BiciMAD deployment in Villa de Vallecas". Figure 4 displays a screenshot during the meeting.

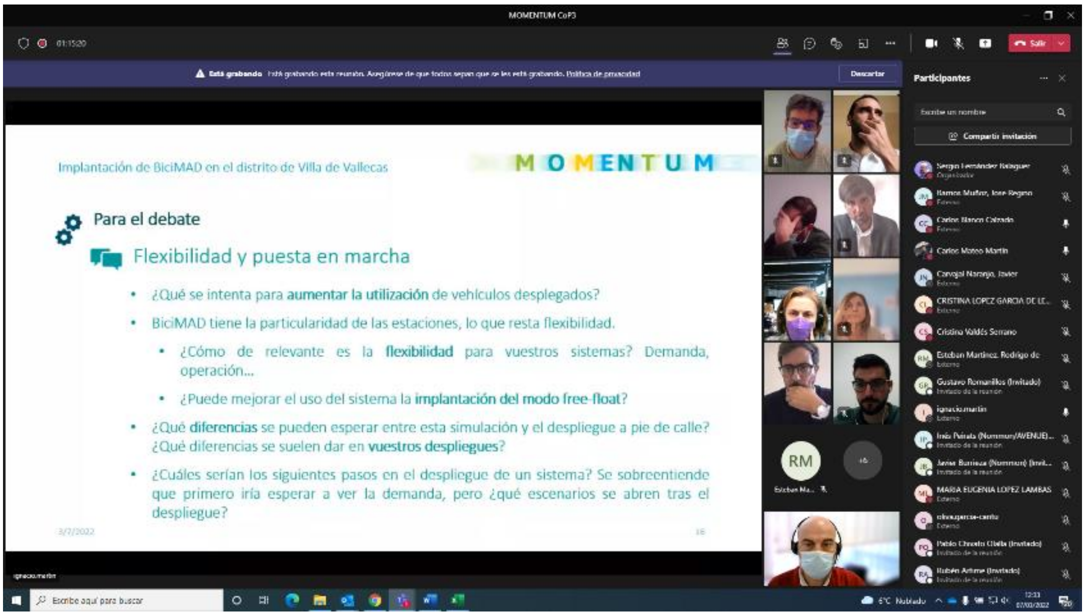

Figure 4- Third Madrid CoP interaction; Online session March 7th

2.3.3.2. Main topic of discussion

The main objective of this last session was to present a later stage of the capabilities of the MOMENTUM toolkit, in this case using as input contributions made by the experts in the previous meeting. The main goal was to discuss the results from simulations and get feedback on the tools and the usefulness of their analysis. The session included the presentation and discussion of operation indicators (demand covered, journey times, etc.) obtained from the simulation of a set of the three different scenarios designed from the outcomes of the previous CoP session. This is the full deployment, the compact partial deployment and the disperse partial deployment.

2.3.3.3. Participants

There were 16 participants:

- Javier Carvajal Naranjo. Head of Mobility Planning Department. Deputy Directorate General for Mobility and Transport Planning. Madrid City Council
- Carlos Mateo. Director of Mobility Services. EMT Madrid.
- Gustavo Romanillos. Professor and member of the tGIS Research Group (UCM) and the EMT-UCM Chair of Cycling Mobility.
- Pablo Olalla. AAVV Puente de Vallecas (Vallecas Neighbourhood association)
- María Eugenia López Lambas. Transyt (Transport Research Centre from the Polytechnic University of Madrid)
- Cristina López. Observatorio de la Movilidad (Mobility Observatory)
- Rodrigo de Esteban. Acciona (Mopedsharing provider)
- José Barrios. Zity (Carsharing provider)
- Carlos Blanco. CEO Wible (Carsharing provider)

From MOMENTUM partners:

- Oliva García Cantú (Nommon)
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- Inés Peirats (Nommon)
- Rubén Artime (Nommon)
- Sergio Fernández Balaguer (EMT)
- Cristina Valdés Serrano (EMT)

2.3.3.4. Description of the action

The session started with a brief presentation of conclusions from the previous session, followed by the presentation of the scenarios to be tested by applying the simulation tools of the MOMENTUM decision support tool (DST) and discussion about the results. The technical details regarding these simulations are summarised in Section **¡Error! No se encuentra el origen de la referencia.** below.

The scenarios and the rules to derive them from the base locations generated in the previous CoP interactions as well as the indicators obtained from each scenario were explained to attendants. Afterwards, resulting indicators were presented and discussed with the members of the CoP.

Attendants were questioned about their expectations for the simulation results and their opinion once they have seen them. Before showing the results, CoP members were inquired about the indicators they use (in case of operators) and their experiences with the deployments of their services.

After the presentation of the results, the debate was first initiated by commenting the most interesting results, including the large amount of rejected requests in some compact scenarios or the impact of the walking distance on demand. Operators were asked about their vision with respect to the BiciMAD service (if it is a competitor or a complementary service, the differences with their modes, etc.) and also about the constraints they found in the different possible settings (free-floating, station-based, etc.).

At the end of the meeting, the utility of these type of tools in the decision-making processes of the stakeholders was debated. CoP members were asked about their processes and whether they would find helpful the use of tools and analyses like the ones provided by MOMENTUM in their processes.

The plausibility and the implications of the different deployments, such as unattended demand, idle vehicles, etc., were discussed.

At the end, there was also a debate about the usefulness of these tools in helping the expansion of services as well as about the indicators available from the simulation, such as the number of requests that have been fulfilled and abandoned (no vehicles), the trip distance for the cycling leg of each trip (route is also available), the number of requests fulfilled per bike, or the cycling time and walking time for each trip.

2.3.3.5. Main outcomes

The main outcomes as derived during the discussion of the 3rd Madrid CoP are summarized in the following points:

- Most operators found the indicators provided by the simulation tools of MOMENTUM useful, even though they identified other interesting ones, including average station occupation or system balancing. Station prioritization indicators would be also very useful.
- Most attendants agreed that their preferred deployment strategy consists of condensed deployments in central zones to expand afterwards.
- Most operators find shared modes distinct to theirs as complementary rather than competitive. There is an overall feeling that more sharing options is better.
- Fleet management is a challenge for many operators. Operators feel they lose a client if they cannot take the service two times.
- Free-floating services are more flexible than station-based ones (BiciMAD). They can perform live experiments easily. This flexibility is also useful for fleet re-locations.
- Debate should be oriented to what variables and what indicators. The results obtained in the case study are helpful to start the debate and iterate until satisfactory results are obtained.
- Cooperation between the mobility related stakeholders is key
- Multimodality is key to enhance the use of shared mobility modes

2.4. Summary of the analyses carried out in the project

This section summarises the technical work developed to answer the relevant policy questions of the Madrid case study discussed in the meetings with the Community of Practise.

1. To what extent is shared mobility used as a substitute of private car trips?
2. To what extent is shared mobility accessible to all citizens?
3. To what extent shared mobility service can improve public transport accessibility by complementing it?

These questions are reported and further discussed in the deliverable D2.2 “Specification of the MOMENTUM test cases”. The methodology followed to address the first two questions is described in detail in the document D3.3 “Methodologies and Algorithms for Mobility Data Analysis”, here just a short summary is presented. The last question is addressed by the first time in this document and is described in detail in this section.

2.4.1. To what extent is shared mobility used as a substitute of private car trips?

This research question aimed at understanding whether private vehicle users would consider switching to shared modes to perform their trips and under what conditions would these changes happen. For that purpose, the analysis was oriented to analyse modal share changes in the event of disruptions affecting to private vehicles.

In this context, the Madrid city provides a natural experiment due to the implantation of an Urban Vehicle Access Regulation Area (UVAR) in the central district in November 2018. This UVAR is placed on a very large area in the centre of the city, where shared mobility services operation is well established.

We conducted a series of data analysis comparing the before and after UVAR travel demand to assess the role of shared mobility services on capturing car trips. The shared mobility service data available for these analyses are BiciMAD, a public bike-sharing system and Muving, a private moto-sharing service.

2.4.1.1. Methodology

To assess the role of share mobility to capture car trips in the UVAR zone we first made a series of analysis to first estimate the car trip dropped and the total demand to the in the UVAR zone, compared with the variations of total demand in the rest of the region, to isolate the impact of the UVAR zone from other effects. And then measure the shared mobility demand variation in the UVAR zone before and after the UVAR. The methodology followed comprises four main steps:

1. Evaluation of the variation of private vehicle traffic from/to the UVAR zone before and after the UVAR zone implementation obtained from traffic counts.
2. Assessing the relation between private vehicle trips variation and total trips demand variation to/from the UVAR zone.
    a. Extraction of trip demand variation for a period before and after the implementation of the UVAR, obtained from mobile phone data with the proprietary algorithms of Nommon and available for the MOMENTUM project, for:
        i. trips within Madrid region
        ii. trips with origin and destination outside the UVAR zone
        iii. trips with origin or destination within the UVAR zone
        iv. trips with origin and destination within the UVAR zone
    b. Comparison of the trip variation to/from the UVAR zone and the trip variation for the Madrid region.
3. Assessment of the impact the restrictions implementation on the trip demand to UVAR zone of private vehicle users.
    a. Identification of origin locations with a higher share of private vehicle trips to the UVAR zone before the implementation of the restrictions. (From the household travel survey)
    b. Measurement of the variation of the number of trips (for a period before and after the restrictions) to the UVAR zone for those locations with a higher share of private vehicle trips before the restrictions.
4. Assessment of the role share mobility services to attend travel demand to/from the UVAR area.
    a. Evaluation of the variation of the shared mobility trips, obtained with service data for:

i. trips within Madrid region
ii. trips with origin and destination outside the UVAR zone
iii. trips with origin or destination within the UVAR zone
iv. trips with origin and destination within the UVAR zone

2.4.1.2. Results

Variation of private vehicle trips to/from the UVAR zone.

- Indicators derived from traffic count data shows that entry/exit variation rates in the UVAR zone decreased by almost 20% between 2018 and 2019

Overall demand variation

- Demand variation in this period (2019 vs 2018) of time for the different zones was:
    - -5% for trips within Madrid region
    - -5% trips with origin and destination outside the UVAR zone
    - -4% trips with origin or destination within the UVAR zone
    - -6.4% trips with origin and destination within the UVAR zone

Effect on private cars

- Comparing OD pairs between the UVAR zone and the rest of the city showed some relation between private vehicle modal share and overall mobility variation. Using linear regression, this relation was quantified in 0.11 for the peak value in June 2019.

The role of shared mobility

- Variation of BiciMAD trip volumes (2019 vs 2018[1]) for:
    - trips within Madrid region 7.7%
    - trips outside the UVAR zone +15.2%
    - trips with origin or destination within the UVAR zone 7.3%
    - trips with origin and destination within the UVAR zone -6.9%
- Variation of Muving trip volumes (2019 vs 2018[1]) for:
    - trips within Madrid region -41.5%
    - trips outside the UVAR zone -44.5%
    - trips with origin or destination within the UVAR zone -34.2%
    - trips with origin and

[1] Variation is adjusted according to the growth of the offer in the different zones

2.4.1.3. Conclusions

From the results obtained with the previous experiments, we can conclude that, while there is no clear evidence that there has been a modal shift from private vehicles to shared modes upon the implementation of the Madrid central district UVAR, the following has been observed:

- The implementation of the UVAR zone 'Madrid Central' caused a reduction in city centre through traffic, but also in connection traffic.
- The number of trips observed in connection trips (to/from the UVAR zone) decreased more than the number of trips in the region. Nonetheless, this effect was transitory and cannot be observed in the yearly analysis.
- The comparison between relative mobility variation in connected trips and private vehicle modal share shows small relationship between both variables at OD pair level. This relation becomes positively related when analysed by periods of the day, suggesting that most reduction in traffic demand switched to alternative modes rather than being dissuaded from the city centre.
- BiciMAD operation data shows that most relations between connected trip variation and private vehicle share can be explained by the increase in supply that happened during the period of study.
- Muving demand data shows different fluctuations through time. Despite, the relation between connected trip variations and private vehicle share becomes noticeable when including weekday information. This indicates that Muving could have received some modal shift from private vehicle.

2.4.2. To what extent is shared mobility accessible to all citizens?

The experiments developed in response to this research question aimed at performing an analysis of the basic socio-demographic characteristics of shared mobility users (age, public transport usage, income) and compared to the entire population. This way, it was possible to identify those socio-demographic and economic factors characterising users that do not use or cannot access to shared mobility services. In this section we will focus on the discussion of the income profiling of shared mobility users. Details on the analysis of age, gender and public transport usage can be found at D3.3 "Methodologies and Algorithms for Mobility Data Analysis" as well as more details on the case reported here.

Some authors have highlighted that shared mobility users are typically high-income individuals. In addition, data sources such as the 2018 regional household mobility survey indicated that shared mobility users that work and have a high education are significantly overrepresented with respect to the rest of the population in the region. These insights further point to high-income users.

In this experiment we analysed the differences or similarities of BiciMAD and Muving user to extract further conclusions than that showed in the survey.

2.4.2.1. Shared mobility users' income profiling

Some authors have highlighted that shared mobility users are typically high-income individuals. In addition, data sources such as the 2018 regional household mobility survey indicated that shared mobility users that work and have a high education are significantly overrepresented with respect to the rest of the population in the region. These insights further point to high-income users. In this experiment we analysed the differences or similarities of BiciMAD and Muving user to extract further conclusions than that showed in the survey.

2.4.2.1.1. Methodology

This experiment consisted of comparing the income of the service's users and that of the rest of the population. To perform this comparison income level was assigned to shared mobility users based on their place of residence (at a postal code level), provided by the service data operator.

Three different scenarios were defined with respect to the service area have been defined:

(i) all service users
(ii) service users living inside the service area, it is worth mentioning that for both services around 90% of the user live inside this area
(iii) service users living outside the service area.

For each of these scenarios, two analyses were performed:

1. Comparison of the income distribution of service users with the income distribution of the population. This way, it is possible to understand the which segments of the population (in terms of income) do not use shared modes.
2. The correlation between the user penetration in a zip code area and the average income in that area is computed for the all the zip code areas within each of the three scenarios

2.4.2.1.2. Results

Figure 5 presents three boxplots representing the income distribution of BiciMAD, Muving and the population. Each of the graphs represents the three scenarios, all users, users living inside the area of influence of the service and users living outside the geofence.

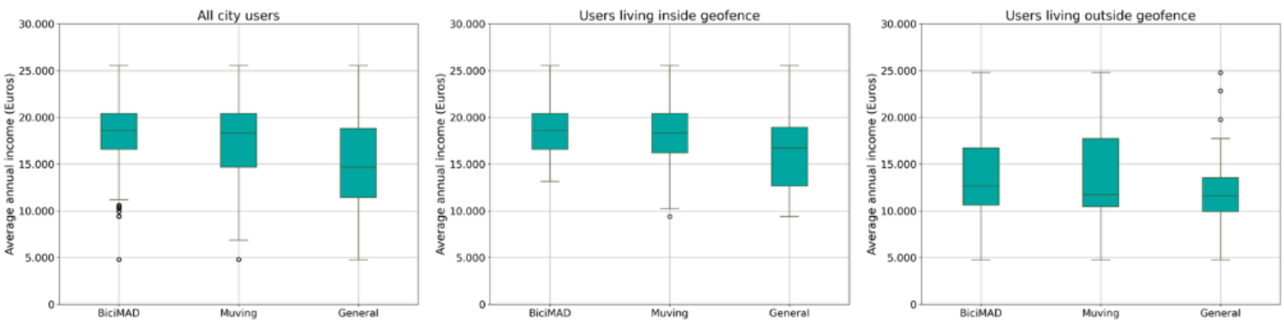

Figure 5. Income distribution comparison for BiciMAD, Muving and the entire population. The scenarios are: service users (left), users living inside geofence (centre) and users living outside geofence (right).

The figure shows that the income distribution of service's users presents small differences with respect to the population. The difference between BiciMAD and the general population is 20% higher for users in the entire city scenario as compared to a 2% decrease (service users) inside the geofence and a 3% increase outside the geofence. Regarding Muving, the difference between users and the general population income distribution is 17% for the entire city, 9% inside the geofence and 14.6% outside the geofence, being Muving user income distribution the highest in all cases.

Regarding the population reached by each service, we can measure the percentage of people with the highest income reached by each service. BiciMAD users are within 30% at the city level, 62% inside the geofence and 36% outside the geofence. Similarly, Muving users are within 35% at the city level, 41% inside the geofence and 25% outside the geofence.

Figure 6 provides the correlation plot for both BiciMAD and Muving services in each of the scenarios defined for the experiment.

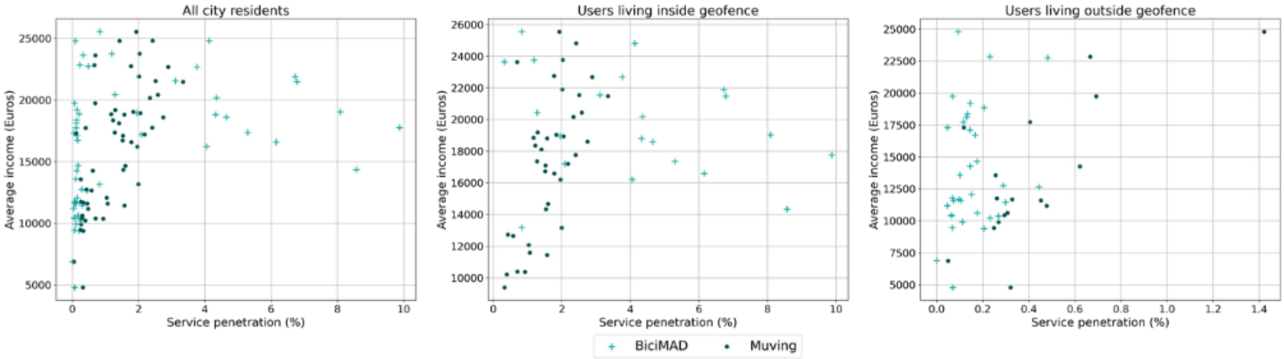

Figure 6. Correlation plots of BiciMAD and Muving service penetration vs income. The cases are: service users (left), users living inside the geofence (centre) and users living outside the geofence (right).

Figure 6 clearly illustrates the differences between BiciMAD and Muving income-penetration relation. BiciMAD scatter plots show no clear trend, indicating that service penetration and average user income are not strongly correlated. Indeed, correlation values are weak, concisely of 0.389 at the city level, -0.323 inside the geofence and 0.242 outside the geofence.

In contrast the scatter plots for Muving follow a linear trend, suggesting than the larger the income the larger the penetration (and vice-versa). In this case, the correlation values are significantly high, of 0.637 at the city level, 0.515 inside the geofence and 0.742 outside the geofence.

These results suggest that Muving service seems to attract higher income individuals than BiciMAD. It is worth noting that the BiciMAD service was the first shared mobility service deployed in the city of Madrid and is well integrated with the public transport system (many stations are nearby public transport stations, there are discounts to public transport users, etc).

2.4.2.2. Conclusions

In light with the results presented we can conclude that:

- Madrid has followed a pattern similar to that observed in the literature in terms of adoption according to income level (higher in higher incomes). However, there are differences between the services analysed: adoption is more related to a higher income in moto-sharing than in bike-sharing.
- The area in which the service is deployed determines part of the income trend. The average income level in the city centre is high is relatively high in comparison with the average income than the rest of the population.

2.4.3. To what extent shared mobility service can improve public transport accessibility by complementing it?

The third and last research question tackles the relationship between public transport and shared mobility services. Shared modes could be conceived to favour multi-modality in combination with public transport: public transport modes covering the longest distance legs of trips while shared modes covering the "last mile" of trips (connection between public transport station and origin/destination of trips), playing a complementary. On the other side, for short distances these modes present a fair overhead cost and are convenient to perform a door-to-door trip when inside the service area. As a result, some shared modes might be competing with public transport modes rather than complementing them.

To test whether shared mobility competes with or complements public transport we have performed two experiments:

1. Analysis of the daily penetration of BiciMAD by type of origin-destination connection by public transport.
2. Comparison of BiciMAD with inter-modality short distance train "Cercanías".

2.4.3.1. Analysis of shared mobility penetration on OD pairs by public transport connection

Shared modes operate between any two points within a geographical area or geofence whereas public transport provides connection between discrete predefined points (stations). These may be directly linked, if they belong to the same line, or indirectly linked, i.e requiring making a transfer, which increased the travel time cost. Furthermore, some areas might not have enough demand to support a public transport line. In this light, shared modes could be an alternative for OD pairs badly or disconnected by conventional public transport and, therefore, complement the existing public transport network.

The aim of this experiment is to understand the role of BiciMAD depending on the type of Public transport connection of each OD pair. To this end three different types of connections were defined:

- Direct connection: in these pairs, both origin and destination zones have a station for the same line of the public transport mode under study.
- Indirect connection: in these pairs, both origin and destination have stations for the public transport mode under study, but they belong to different lines.
- Disconnected: in this case, at least one of the zones has no station for the public transport mode under study.

And the following hypotheses were made:

- High penetration on directly connected pairs implies competence
- High penetration on indirectly connected pairs implies complementarity

The modes considered were the underground (metro) and the urban bus system (EMT). The shared mobility services under study were BiciMAD (public bike-sharing) and Muving (private moped-sharing)

2.4.3.1.1. Methodology

The methodology followed for this experiment comprises 3 main steps:

1. Extraction of shared mobility OD matrices. This were obtained from the operation data of each specific service using the standard vehicles diaries defined in the MOMENTUM project and described in D3.3 "Methodologies and Algorithms for Mobility Data Analysis".
2. Classification of pairs, using data from the public transport lines shapefile available at the regional government open data portal.
    a. Assignment of stations to zones. To derive metro/bus connections, each metro entrance/bus station is associated to a unit of a given zoning scheme (in this case a 1,000-metre side squared grid).
    b. Classification of each pair accordingly with the definition. For each OD pair, the public transport lines passing through each station are compared to determine the connection type of these OD pairs.
3. Calculation of service penetration per type of connection. Penetration for each OD pair was obtained as the ration between the service demand in the given pair divided be the total demand, obtained from mobile phone data and available in the project, in the same pair.

2.4.3.1.2. Results

2.4.3.1.2.1. BiciMAD - Metro

Figure 7 depicts the median of the OD pair penetration for connected OD pairs (directly and indirectly), disconnected OD pairs and all OD pairs.

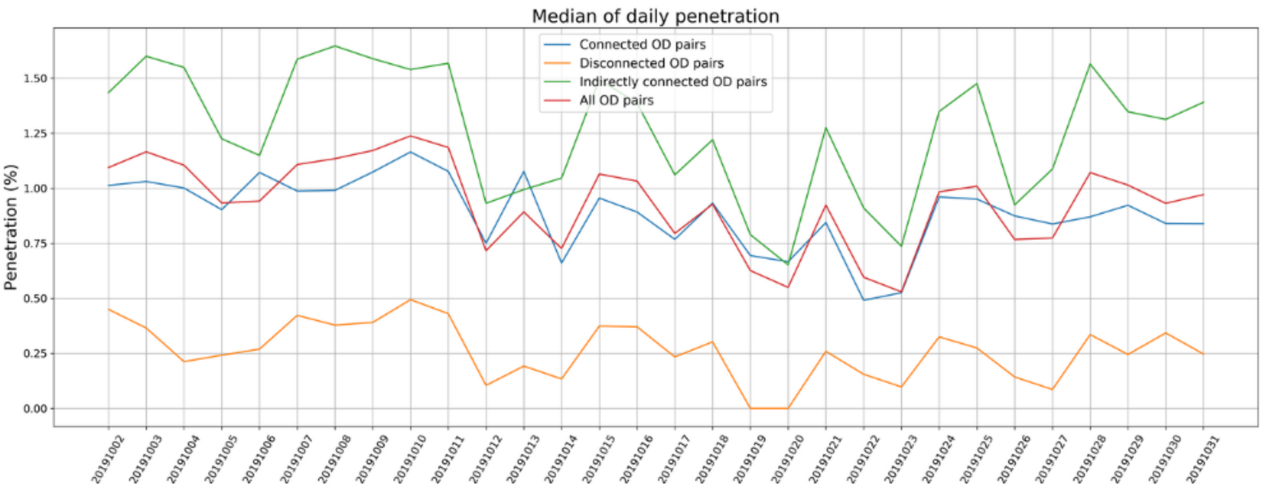

Figure 7. Mean daily penetration of BiciMAD service for metro-connected (blue), disconnected (orange), indirectly connected (green) and all OD pairs (red).

Figure 7 shows that BiciMAD trips have higher penetration on OD pairs that are indirectly connected (green). On the contrary, the penetration of directly connected OD pairs (blue) is below the penetration of all the pairs, suggesting that BiciMAD users could be using public transport whenever the complexity of the trip is low and using the service otherwise.

Figure 8 depicts the daily service penetration as the quotient between the total trips in shared mobility and the total trips in general mobility by connected, disconnected and all OD pairs.

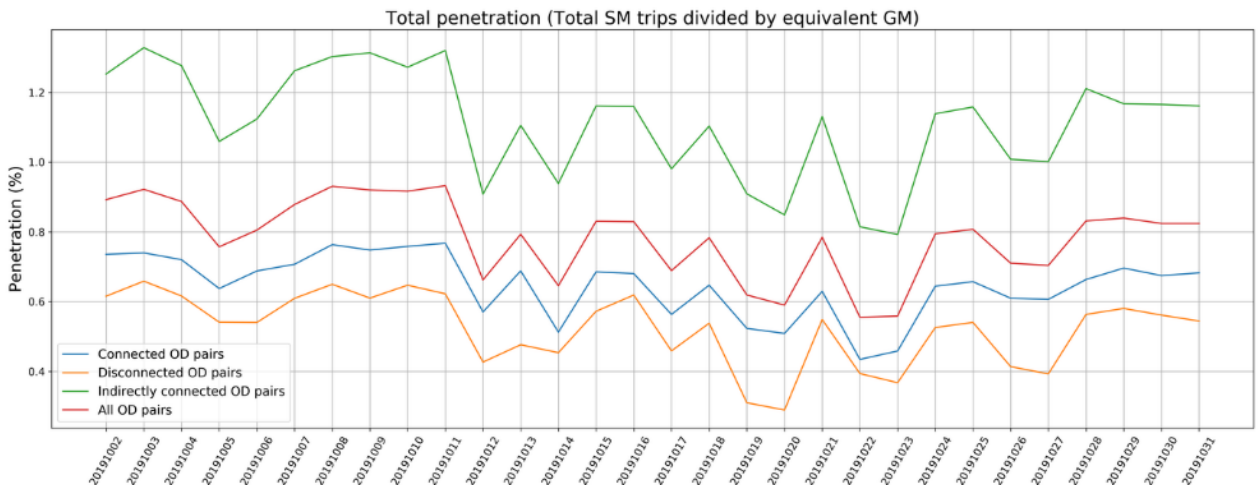

Figure 8. Total daily penetration of BiciMAD service for metro-connected (blue), disconnected (orange), indirectly connected (green) and all OD pairs (red).

Figure 8 does show that the actual penetration of all OD pairs is in the range 0.9-0.5%, which is consistent with the actual estimated overall penetration of BiciMAD of 0.8%. As in the OD pair-based case, the highest penetration corresponds to the indirectly connected OD pairs group.

2.4.3.1.2.2. BiciMAD - Bus

Figure 9 depicts the median daily penetration in the groups and Figure 10 plots the overall penetration in the entire area of influence of the service.

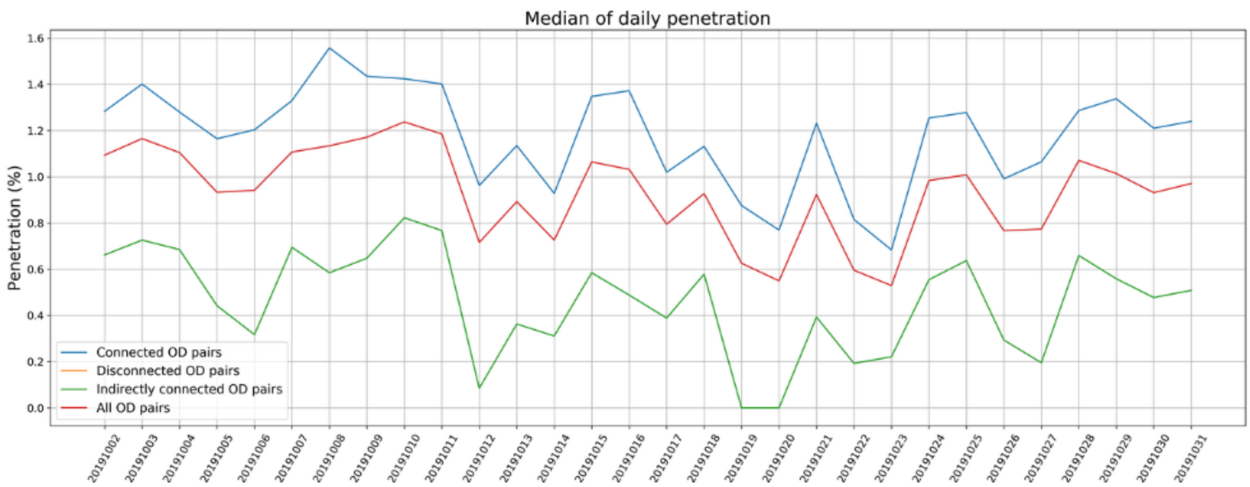

Figure 9. Median daily penetration of BiciMAD service for bus-connected (blue), disconnected (orange), indirectly connected (green) and all OD pairs (red).

In contrast to the metro case, Figure 9 shows that the penetration is higher in those OD pairs directly connected by bus with respect to all OD pairs while indirectly connected OD pairs are well below. Disconnected OD pairs do not appear due to the much larger granularity and scope of the bus network, which facilitates that no OD pair within the service is not (at least indirectly) connected.

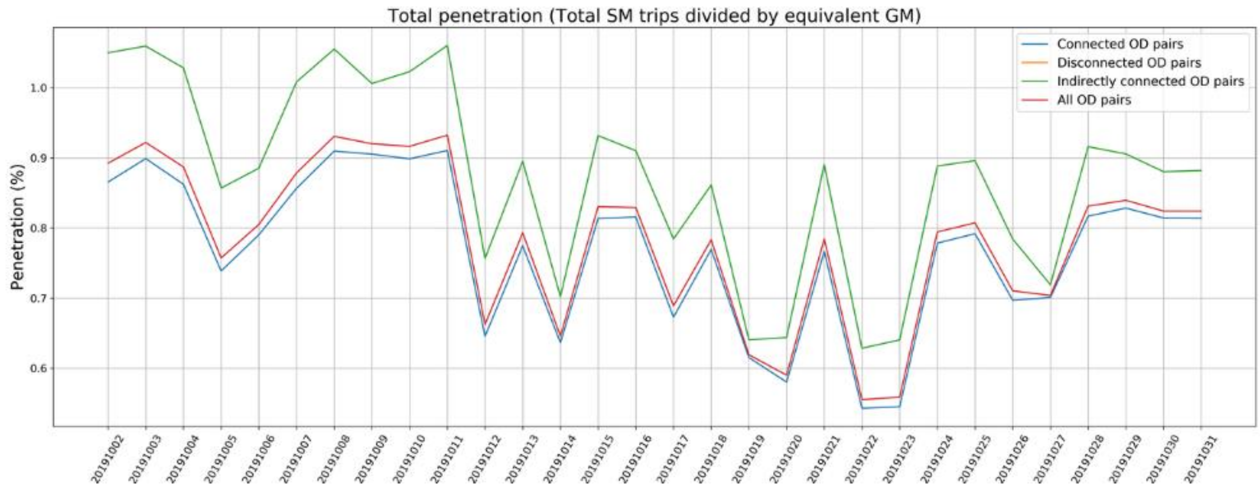

Figure 10. Total daily penetration of BiciMAD service for bus-connected (blue), disconnected (orange), indirectly connected (green) and all OD pairs.

Figure 10 suggests that BiciMAD service demand is larger for those OD pairs that are indirectly connected by bus, even though the effect here is not predominant and, at the OD pair level, the demand is clearly higher for connected OD pairs.

2.4.3.1.2.3. Muving - metro

In the case of Muving, the service penetration is much lower than BiciMAD's. As a result, the daily median is 0 and the value of the total penetration is significantly smaller, so daily accuracy was measured instead. Figure 11 depicts the average daily penetration of the service for connected (direct and indirect), disconnected and all OD pairs and Figure 12 shows the total penetration.

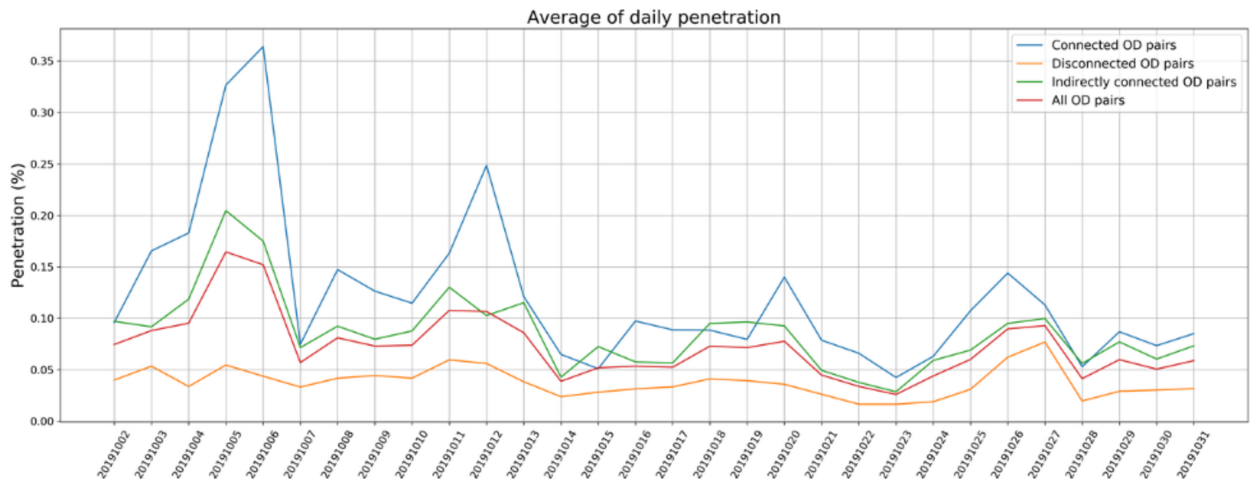

Figure 11. Average daily penetration of Muving service for metro-connected (blue), disconnected (orange), indirectly connected (green) and all OD pairs (red).

Muving service trips seem to be very different from BiciMAD's. In this case, the highest penetration value is for directly connected OD pairs, even though indirectly connected are above the baseline case (all OD pairs) too.

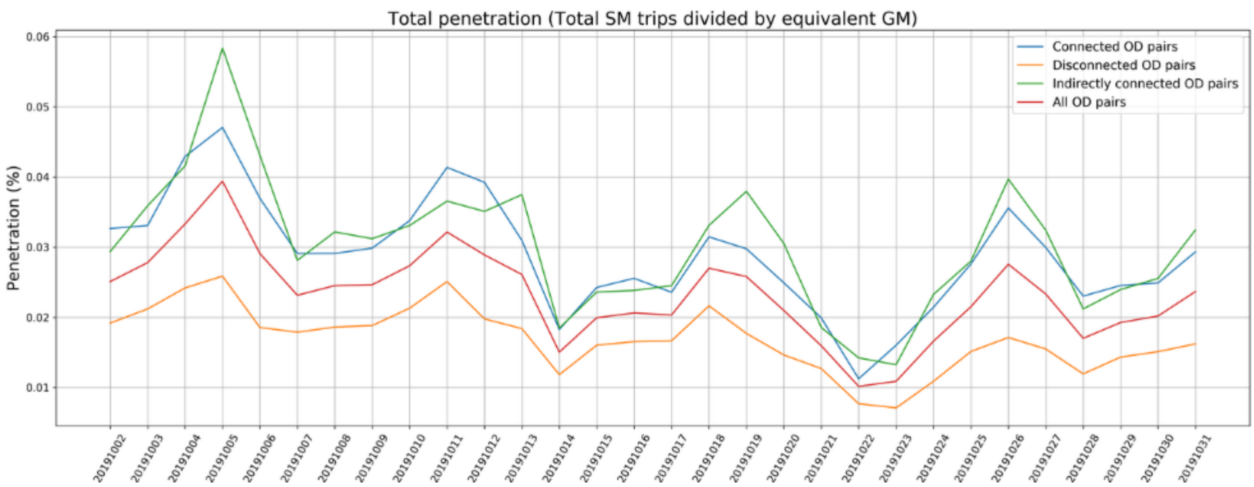

Figure 12. Total daily penetration for Muving service for metro- connected (blue), disconnected (orange), indirectly connected (green) and all OD pairs (red).

Figure 12 shows a similar trend, but in this case, the penetrations of directly and indirectly connected OD pairs is very similar. This suggests that Muving users tend to use the service regardless of the metro options available.

2.4.3.1.2.4. Muving - bus

Figure 13 depicts the average daily penetration of the service for connected (direct and indirect), disconnected and all OD pairs and Figure 14 shows the total penetration.

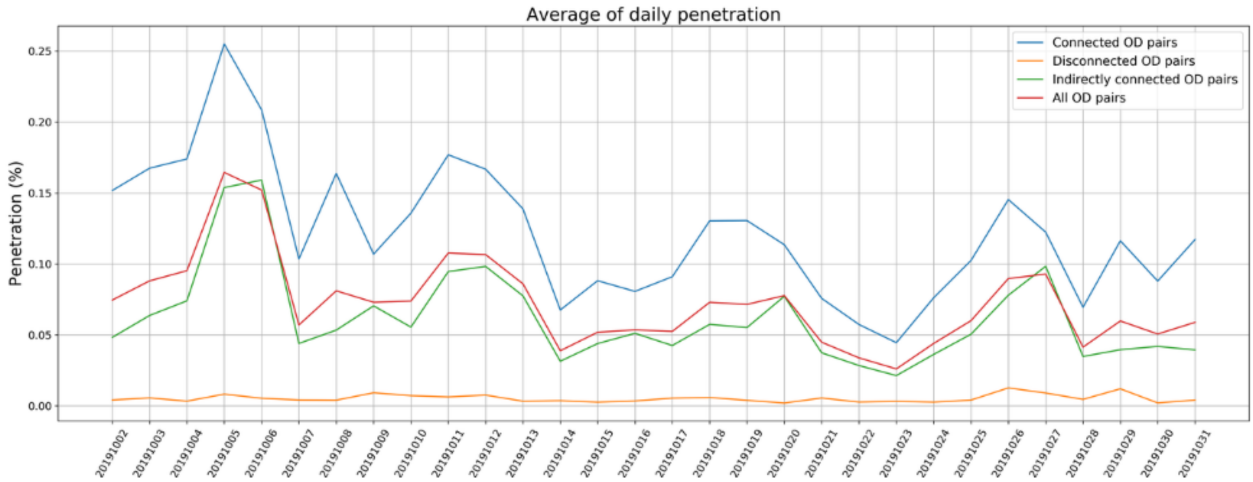

Figure 13. Average daily penetration of Muving service for bus-connected (blue), disconnected (orange), indirectly connected (green) and all OD pairs (red).

Figure 13 shows the same trend as the metro case. The penetration of the service in both directly and indirectly connected OD pairs is above and near the baseline respectively, which points to service users choosing the service over public transport regardless of the bus lines available.

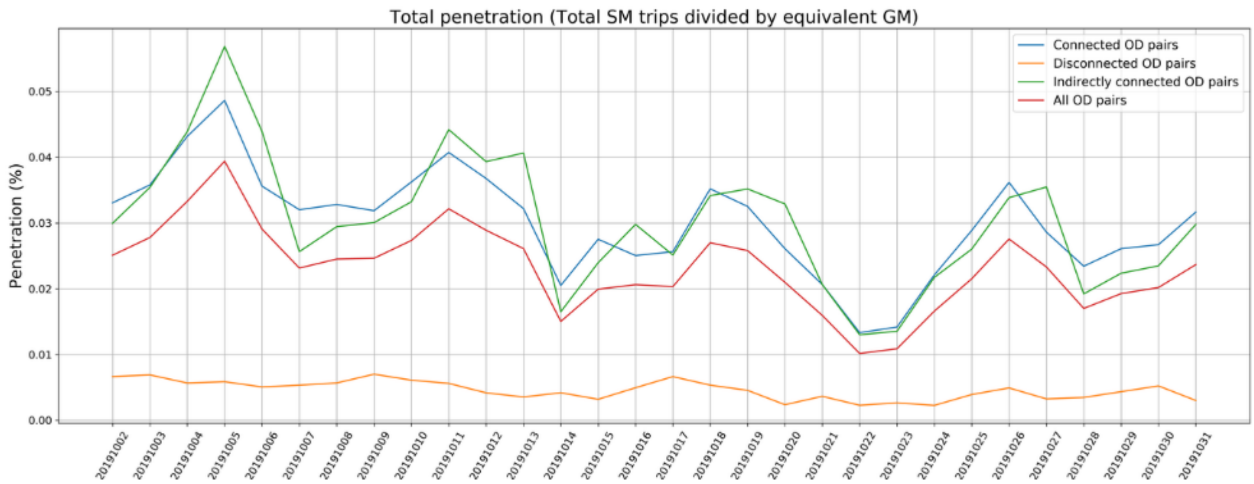

Figure 14. Total daily penetration of Muving service for bus-connected (blue), disconnected (orange), indirectly connected (green) and all OD pairs (red).

Figure 14 shows again how the penetration of Muving in both directly and indirectly connected OD pairs is above the general case (all OD pairs). All these observations sustain the hypotheses that Muving users seem not to consider the available public transport modes for their trips.

2.4.3.2. BiciMAD base analysis according to their demand

One of the main advantages of shared mobility services from the urban planner viewpoint is that they can complement the existing public transport network. For that purpose, shared modes should be used to cover the first and last miles of the trips (that is, from trip origin to the origin public transport station and from the destination public transport station to the trip destination). In certain locations where the distance to the nearest public station is large, this last mile is very important to improve public transport accessibility.

In this light, this experiment tries to assess how well shared mobility covers such distances by comparing the trips performed in the BiciMAD service according to their location with respect to the nearest long-range public transport station in the Madrid train system (Cercanías). Cercanías is a train system that connects some locations within Madrid city with other cities in the metropolitan area and the region. The granularity of stations within Madrid city is very low (roughly 9 stations against 190 BiciMAD bases). This poses a good opportunity to assess whether shared mobility trips are used to connect bases associated to Cercanías stations with other bases far from them.

For this assessment we have made use of a gravity model and have categorised BiciMAD bases into three types:

- **Linked bases.** Those BiciMAD bases that are right at the door or very close to a Cercanías station. BiciMAD bases that are separated less than 100 metres to the reference point of a Cercanías station are considered linked bases. In addition, bases at the gates of large stations (Nuevos Ministerios, Atocha or Principe Pio) have been assigned to the stations in spite of being separated more than 100 metres from the station reference point.
- **Nearby stations.** Those BiciMAD bases that are located between 100 and 500 metres from the Cercanías station reference point are considered nearby stations. While these bases are not directly associated to a train station, they are near enough to not be considered independent.
- **Standalone stations.** BiciMAD bases that are further than 500 metres from any Cercanías station are considered standalone stations.

The goal of the experiment is to obtain the ratio between gravity model predictions (expected demand as a result of the observed distance) and the actual observations in the system (observed demand) to evaluate the relation between observed trips (what actually happens in the station) and predicted trips (that the distance between stations suggests it should happen). The model is based solely on distances and the number of trips at each bicycle station. Hence, we assume that, if there are last/first mile uses, i.e there is complementarity between train and share modes, the model should underestimate the relationships between the “associated” bases and the “isolated” bases, since “more trips than their fair share” are observed.

2.4.3.2.1. Methodology

- Classification of BiciMAD bases. Figure 11 illustrates the locations of BiciMAD bases (coloured according to their assignment) and Cercanías stations.
- Computation of BiciMAD OD matrices for all stations, computed for each day of October 2019.
- Adjustment of the Gravity model. This model follows the equation below:

$$V_{OD} = \frac{V_O x V_D}{d^n} \alpha$$

Where alpha and n are free parameters to be optimised using available data. Such optimisation was performed using the non-linear least squares method as defined by the function *fit curve* from Python library *Scipy*. This way, we adjust the gravity model to the trip data registers per day, origin and destination stations according to the station marginals. The target variable of this model is the expected demand between each pair of BiciMAD bases.

2.4.3.2.2. Methodology

Station classification:

Using the established criteria, the resulting of BiciMAD bases per category is:

- 11 linked bases (more than one base may be linked to a Cercanías station)
- 45 nearby bases
- 128 standalone bases.

Figure 15 shows the location of the different bases and their typology, as well as the location of the Cercanías stations.

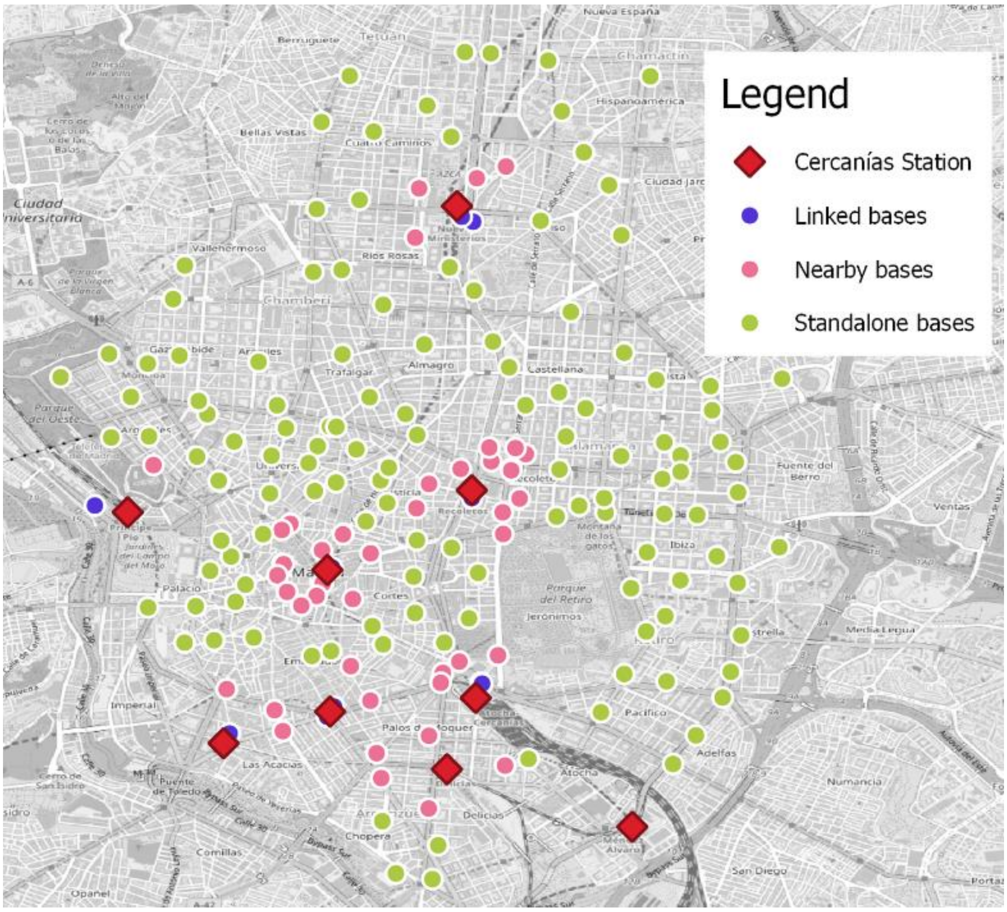

Figure 15. Cercanías stations and BiciMAD bases coloured by their category.

Gravity model

Table 2 displays the obtained volumes from the observation (BiciMAD) and the estimation (gravity model) and the ratio of observations divided by estimations. **The estimated coefficients are 9.75x10^-5 for the multiplying parameter alpha and 0.308 for the power of the distance (n).**

The table shows that the cases linked-linked and linked-nearby had less observed trips than expected while the linked-standalone, nearby-nearby, nearby-standalone and standalone-standalone cases are above estimations. From these, it is worth noting than standalone-standalone is the one with the highest ratio followed by linked-standalone.

The high ratio for the linked-standalone category suggests that BiciMAD trips between these stations are observing larger volumes than they should (according to their distance), which combined with the opposite observation in the case of linked-nearby and nearby-nearby stations supports that BiciMAD could be being used as a last mile service.

Table 2. Comparison of the gravity model results with observed trips in BiciMAD

Combination	Observed trips	Estimated trips	Ratio (o/e)	Number of observations
linked-linked	1,215	1,378.83	0.881	3,410
linked-nearby	10,659	10,831.13	0.984	32,054
linked-standalone	33,212	31,042.71	1.069	85,932
nearby-nearby	19,199	18,745.99	1.024	67,022
nearby-standalone	111,341	106,548.84	1.044	367,164
standalone-standalone	177,112	164,670.67	1.075	488,250

It is worth noting that these results could be biased due to the use of observed BiciMAD trips to calibrate the gravity model. To alleviate this problem, the model has been re-calibrated using trip observations from OD pairs where the combination is not a linked and standalone base combination (linked-standalone). **¡Error! No se encuentra el origen de la referencia.** provides the trips estimated by the model and the observed/estimated (o/e) ratio for all OD pairs including those in the linked-standalone category. In this case, **the estimated parameter values are 9.67x10^-5 for alpha value and 0.304 for the power of the distance (n).**

The table shows a subtle increase in the observed/estimated trips ratio for all cases. This implies that the model is estimating less trips overall possibly due to the lack of higher volume of linked-standalone trips. In any case, the increase is more or less constant and the same patterns as in Table 2 can be observed.

Table 3. Comparison of gravity model results trained without OD pairs connecting linked and standalone stations.

Combination	Observed trips	Estimated trips	Ratio (o/e)	Number of observations
linked-linked	1,215	1,369.54	0.887	3,410
linked-nearby	10,659	10,757.65	0.991	32,054
linked-standalone	33,212	30,868.48	1.075	85,932
nearby-nearby	19,199	18,610.6	1.032	67,022
nearby-standalone	111,341	105,974.83	1.051	367,164
standalone-standalone	177,112	163,773.64	1.081	488,250

2.4.3.3. Conclusions

The BiciMAD operation data suggest a greater uptake of trips in those origin-destination relationships with less direct metro connection.

BiciMAD operation data suggest that there are intermodal uses with the Cercanías network for first and last mile journeys.

2.4.4. Case study - Implementation of BiciMAD system in Villa de Vallecas district

Previous experiments have shown that some shared mobility services seem to be complementing the Madrid public transport system in two different ways: (1) providing faster and more direct alternatives when public transport does not offer a good (direct) connection and (2) providing some last mile service to public transport modes with lower granularity in the urban area (Cercanías).

However, the system has approximately 290 stations deployed in the central districts of the city, with no coverage in most areas of the city. To cover the central area, the service accounts for only 2,700 bicycles. As a result, the potential gains to complement the public transport system offered by BiciMAD are limited by the available infrastructure in the centre of the city.

BiciMAD has the short/medium term goal of expanding into all the districts of the city. These deployments conform very costly tasks, as the city area is very large and there are budgetary limitations, so each new deployment must be carefully designed in order to optimise operations and reduce operational costs.

For this purpose, the MOMENTUM toolset offers some applications that can help in the design and evaluation of the expansion of the BiciMAD service to the entire city. This case study was conceived to demonstrate the potential of the toolset on the design and evaluation of different deployment scenarios for one peripheral district of the city: Villa de Vallecas.

2.4.4.1. Methodology

The main goal of the Villa de Vallecas case study consists of designing a set of deployment scenarios for the service in the Villa de Vallecas district that can be afterwards simulated to assess the performance of each scenario. As discussed before, the MOMENTUM toolset can provide tools for demand prediction (described in detail in D4.1 "New Transport Modelling Approaches", infrastructure placement and scenario simulation described in D5.2 "Interactive decision support tool". The expected workflow of the case study is presented in Figure 12.

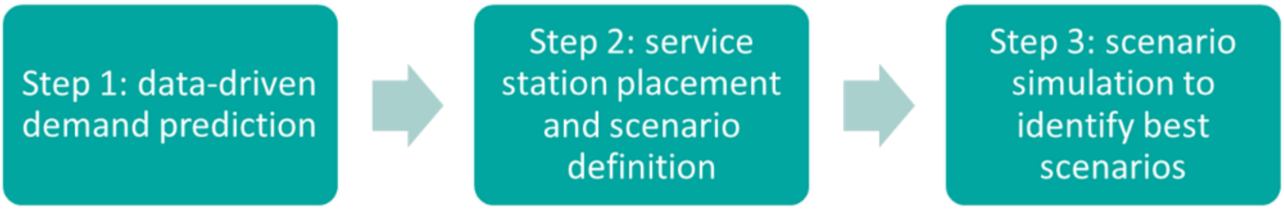

Figure 16. Workflow of the proposed case study developments.

The figure shows three clearly defined steps:

1. Demand prediction:

The initial step consists on the prediction of the demand expected for the BiciMAD service in the Villa de Vallecas district. For that purpose, the data-driven demand prediction model trained for the city of Madrid as part of the project toolset has been used. This model takes as input general mobility trips per OD pair, weather observations (temperature, rain, wind, etc) and land use at origin and destination (home, offices, leisure, etc) to predict the trips expected in the BiciMAD service.

For the current exercise the demand was predicted for a typical working day, using the average of three general mobility OD matrices for the working days of the period 15, 16 and 17 October 2019 obtained from mobile phone data and available for the project.

The land used characteristics obtained from Catastro (building inventory office) of Spanish government and weather data for the Spanish Weather agency (AEMET). Details of the calibration of the model can be found at deliverable D4.1 "New transport modelling approaches".

2. Estimation of stations optimal location:

With the predictions available, the service station optimal placement provided developed in the project and embedded in the MOMENTUM Decision Support Tool (DST) was used to obtain the optimal locations of the bases according to service demand. These locations were used to define a set of alternative deployment scenarios to be compared. In addition to the expected demand (predicted OD shared mobility matrix) the station location tool takes as inputs the parameters of total number of bases to be deployed and acceptable walking distance should be given.

The values to consider for these variables were discussed with relevant stake holders in the working sections described other sections of these document (See **¡Error! No se encuentra el origen de la referencia.**).

3. Extraction of operation indicators:

Finally, operational indicators were obtained using the fleet management module integrated with the Aimsun Ride software, developed and integrated in the project and described in D5.2 "Interactive Decision Support Tool" to determine the best scenarios for deployment.

This simulation takes as inputs:

- Shared mobility demand prediction
- Location of the BiciMAD stations
- Fleet size
- Road network in the area of study

And the outputs are the following indicators:

- Number of satisfied trips
- Number of Non-satisfied trips
- Average trip distance
- Time in vehicle
- Trips per vehicle
- Use time of vehicles
- Number of vehicles without trips
- Percentage of vehicles without trips

The simulator was calibrated with the network and the travel times obtained with the Visum model of EMT Madrid. Details on the calibration of the different models are given in D5.3 Implementation of the decision support toolset in the case study cities

2.4.4.2. Definition of the case study

The district of Vallecas is located at the Southeast of Madrid and has a surface of 51.4 Km2 and around 100K inhabitants. It has 6 metro stops and 2 commuter trains, and at the moment there is not a shared mobility services available in the zone.

The district is not near the area where the BiciMAD service is deployed and it was decided to simulate the deployment as a standalone deployment, i.e. to consider demand only between origin destination pairs inside the district. For this experiment different scenarios in terms of demand and level of deployment where considered.

2.4.4.2.1. Demand scenarios

Two different demand scenarios were considered. The low demand penetration which corresponds to the predicted demand with the current penetration rate, 1.5%, of share mobility. This number accounts for a total demand of 2300 daily trips for the areas of study. And one of high penetration assuming that the structure of the OD demand and the overall demand is unchanged but that the penetration rate increases to 6% which accounts for 9000 trips for the area of study. This percentage was selected based on the consultation with experts performed at the beginning of the project on the expected future penetration of shared mobility services and reported in D2.1 “New Mobility Options and Urban Mobility: Challenges and Opportunities for Transport Planning and Modelling”. To obtain the high penetration scenario the OD shared mobility matrix was multiplied by 4. This numbers were presented and contrasted with the CoP.

2.4.4.2.2. Deployment scenarios

After de second interaction with the relevant stakeholders of the CoP were a life demo and calculation of base location was performed using the Level 2 of the MOMENTUM DST, it was decided to consider a number between 30-40 base stations for the whole area of study and a maximum walking distance of 300 m. It was also decided to consider three different scenarios:

1. One where the full deployment is performed at once

And two more where the deployment was made in a fist stage with a smaller number of stations. For this case two scenarios were considered:

2. A compact one, where 20 bases would be deployed in the central area of the district
3. A disperse one, where a selection of 20 bases would be deployed in the whole district.

The location of the stations for the first scenario were calculated with the MOMENTUM DST. These locations were taken as a base for the other two scenarios. For the compact location scenario, the bases initially located by the tool in the centre of the district were kept and those in the periphery of the district centre were moved to the centre until the number of bases of inside the centre reached 20. For the last scenario the less relevant and peripheral bases have been iteratively removed until the 20 most important bases are left.

Finally, some fine tuning was made manually adjusting the initial position of the station with the following criteria:

- Bases located in parks or pedestrian areas were moved to adjacent streets.
- Avenues and main streets were given priority over the rest.
- When possible, locate stations in crossroads and roundabouts.
- The density of system base was kept homogeneous.
    - Compact deployment: approximation of peripheral bases.
- There must be at least one base around train and metro stations.
- Base movement to activity zones (shops, clinics, etc.)

The combination of these control variables has generated 11 different scenarios that were used to simulate their operation and obtain performance indicators of the simulated system. These results were presented to the CoP members in the third meeting.

2.4.4.2.3. Fleet size

The number of bikes that can fit in each base is 28, for this experiment we have considered, based on the average observed in the existing stations, an occupancy level of 50%, i.e an average of 14 bicycles per station. In some cases, a larger base capacity assumption has been taken to increase the number of available vehicles.

2.4.4.3. Results

2.4.4.3.1. Optimal station location

For the restriction of 30-40 maximum number of stations and a walking distance of 300m, the optimal number and location of stations resulted in 34 stations distributed as shown on Figure 17.

Figure 18 shows the final location of the station after they have adjusted according the criteria previously discussed.

Figure 17. BiciMAD base location distribution in Villa de Vallecas district. A total of 34 stations were proposed by the tool

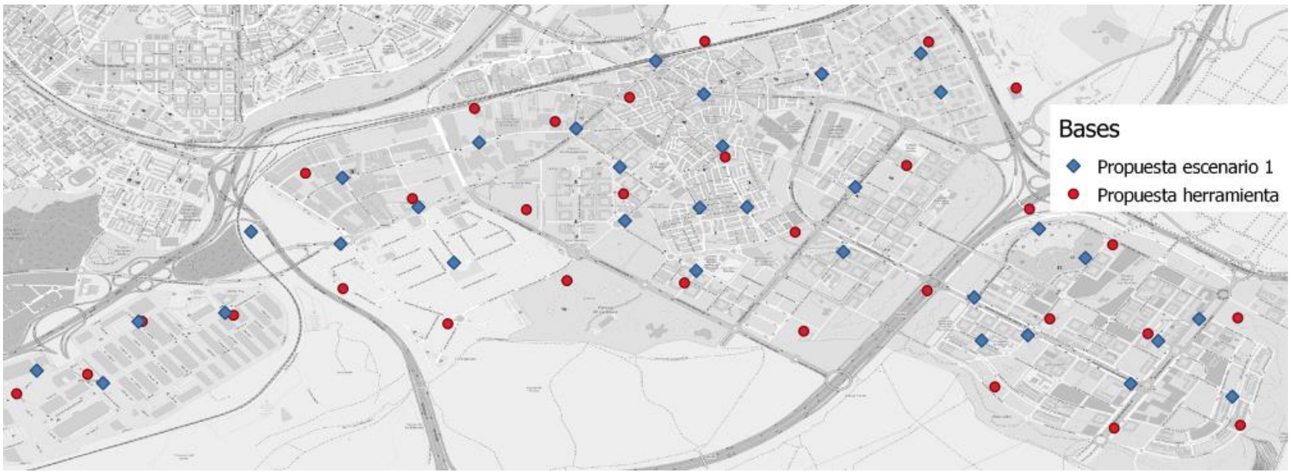

Figure 18. Base proposal for full deployment. Red dots are the base locations obtained from the optimiser while blue diamonds are the final base locations

Figure 19. Base proposal for concentrated partial deployment. Red dots are the base locations obtained from Level 2 of the DST while blue diamonds are the final base locations

The compact partial deployment considering only 20 bases deployed in the central neighbourhood of the district is shown in Figure 19.

The disperse partial deployment is displayed in Figure 20.

Figure 20. Base proposal for non-concentrated partial deployment. Red dots are the base locations obtained from Level 2 of the DST while blue diamonds are the final base locations

2.4.4.3.2. Simulation

Seven different scenarios were simulated with the Fleet management + Aimsun Ride software simulator:

1. Full deployment with low penetration and 476 vehicles
2. Full deployment with high penetration and 476 vehicles

3. Full deployment with high penetration and 762 vehicles
4. Compact scenario with low penetration and 280 vehicles
5. Compact scenario with high penetration and 280 vehicles
6. Disperse scenario with low penetration and 280 vehicles
7. Disperse scenario with high penetration and 280 vehicles

Table 4 summarises the operational indicators obtained for each of the scenarios.

Table 4. Summary of the resulting indicators for each simulated scenario

Scenario ID	**S1**			**S2**		**S3**	
Scenario ID	**S1.1**	**S1.2**	**S1.3**	**S2.1**	**S2.2**	**S3.1**	**S3.2**
Deployment	**Full deployment**			**Concentrated partial deployment**		**Non-concentrated partial deployment**	
Number of stations	**34**			**20**		**20**	
Number of bikes	**476**	**476**	**762**	**280**		**280**	
Penetration	**low**	**high**	**low**	**low**	**high**	**low**	**high**
Satisfied trips	1,024	1,917	5,435	90	544	404	2,469
Non-satisfied trips	912	9,820	6,277	46	319	226	1,558
% non-satisfied trips	47.1	83.6	53.6	33.8	37	35.8	38.7
Average trip distance	2.7	2.7	2.6	1.6	1.6	2.3	2.3
Time in vehicle	39.8	38	39.7	36.5	35.8	38.2	37.5
Trips per vehicle	2.7	5.4	7.4	0.28	2	1.5	9.5
Use time of vehicles	1	1.7	2.9	0	0.48	0.5	3.3
Number of vehicles without trips	82	74	97	*181*	*48*	*40*	*30*
Percentage of vehicles without trips	17.2	15.5	12.7	64.6	17.1	14.3	10.7

The most relevant observations in this table are the following:

- The simulations show different performance of each of the proposed scenarios. For instance, S2 results show that the system would have very low occupation of vehicles as a result of the reduced demand estimated in the concentrated area. Similarly, S1 and S3, which cover more comparable areas, show very different performances.
- Regarding the S1 and S3 scenarios, they have indicators that illustrate different contrasts in terms of performance: S1.1 scenario yields better statistics, except for the number of idle vehicles, whereas S3.2 scenario outperforms S1.2 scenario in all terms. Clearly, S3 scenarios are better in terms of reducing the amount of idle vehicles.
- It can be observed that, regardless of the level of demand any system may have (number of trips), there is always an amount of trips that cannot be satisfied by the system. This is ratified by scenarios S2.1 and S2.2, which leave unsatisfied trips with a level of demand that is absorbed by the same infrastructure (i.e. S3.1 and S3.2).

2.4.5. Required data sources - Lessons learnt

After the execution of the Madrid case study, relevant findings regarding the collection, management and use of data sources are summarised below:

- The fusion of heterogeneous data sources (e.g. mobile phone data records, shared mobility operation data) can provide much richer information in the mobility domain.
- Despite new data sources, traditional data sources such as traffic counts or household mobility surveys are useful to complement new data sources with the information they lack (e.g. trip mode, detailed socio-demographic profiles, etc)
- The rapid evolution of shared mobility systems, with constant changes in supply, make difficult to interpret the demand data they collect. A closer monitorisation of shared mobility services would allow to better quantify the relation between supply (number of docks, number of vehicles, etc.) and demand.
- While shared mobility operation data is a good source to characterise shared mobility service use, they are very limited to provide rich information of users' profile. The fusion of these kind of data sources with socio-demographic and other characteristic sources could help in the characterisation of user adoption.
- Indeed, no single data source is capable of providing the whole picture for any analysis. Most experiments have required the use of more than one data source. Furthermore, experiments based on individual data sources provided partial results that required the complement of further experiments involving other data sources.
- The collection, organisation, pre-processing and analysis of relevant data sources is a time-consuming task that requires a significant effort prior to the start of any data-driven analysis.

2.5. Conclusions

In Vallecas Lab, experiments have shown that, while there is some uncertainty with respect to the specific modes, certain shared modes can complement public transport modes in two ways: (1) offering a better alternative in OD pairs where public transport offers bad connections and (2) covering the last mile of public transport services.

The evidence the analysis of the penetration of BiciMAD by type of origin-destination connection by public transport supports that, in some cases, travellers prefer public transport where there is a direct connection and use shared mobility whenever they have to change lines. Concisely, we have observed that BiciMAD users have higher relative penetration in OD pairs where there is no direct metro connection. Interestingly, this pattern is only observed for BiciMAD and metro stations, which points at the following possibilities:

- BiciMAD users seem not to consider the bus system even where there is direct connection. There could be some reluctance to use bus, maybe due to the lack of determined travel times or the ignorance of the lines available at each OD pair.
- Muving users appear to not consider public transport modes when doing their trips. This behaviour could be influenced by the free-floating configuration of the system, which enables door-to-door trips that public transport cannot offer.

The analysis of BiciMAD relation with short distance train "Cercanías" has shown that the BiciMAD service might be providing some last mile service to the Cercanías train mode. The experiment has shown that the observed trips between BiciMAD service bases nearby Cercanías stations and other isolated bases and the observed trips between bases nearby Cercanías stations cannot be explained by their distance, with underestimation in the former case and overestimation in the latter.

As a result, the response to the research question: *to what extent shared mobility service can improve public transport accessibility by complementing it?* we consider that the role of shared mobility depends on how services are deployed and their conditions. In the experiments, we have observed that a low-cost station-based bike-sharing service (BiciMAD) seems to be more complementary with public transport than a free-float moped-sharing service (Muving).

Overall, the policy assessment procedures in Madrid have shown that the tools developed under the framework of MOMENTUM project can become a valuable tool for helping in the mobility planning of shared mobility services. More in particular, MOMENTUM tools bring accuracy and certainty about the deployment of Madrid BikeSharing system, BiciMAD, in new areas of the city helping city planners to better address the location of bike stations according to different parameters and its multimodal potential linked to the public transport network.
This conclusion can be also applied to other private shared mobility services.

3. Leuven

3.1. Context description and vision statement

3.1.1. Introduction

Leuven is a city with about 100,000 inhabitants and the location of the oldest university of North-West Europe. The university, labelled the most innovative in Europe by Reuters (2019), brings a lot of dynamism and activity to the city, with more than 55,000 students and a lot of spin-off companies in technology and research. The city can be characterized as a suburban area in the influence sphere of metropolitan Brussels, but also as an urban centre with – mainly thanks to the role of the university- a strong growth in employment and a growing attractiveness to the surrounding area.

The historic heart of Leuven attracts many visitors (600.000 overnight stays per year), drawn to the medieval streets and the iconic town hall, dating from the 15th century. The main economic area however is research and technology which accounts for 75% of jobs in Leuven (Statbel, 2016), mainly in electronics, digital technology, healthcare, and biotechnology. Traditional industry disappeared in the last few decades, resulting in only 7.5% of the total employment being in the industrial sector, compared to 92% in services (Statbel, 2016). One important exception is InBev, the largest beer-brewing company in the world which has its origins and headquarters in Leuven, dominating the north-east of the city.

3.1.2. A brief on current transport

First and foremost, Leuven is a cycling city. An overwhelming majority of students use cycling as their main mode of transport, resulting in large number of cyclists throughout the city and a high demand for infrastructure. There are over 30,000 bicycle parking spaces, numerous “cycling streets” where cyclists have the right of way and kilometres of bike lanes (providing various levels of separation from motorised traffic). Aimed mainly at commuters, there are “cycling highways” connecting Leuven to Brussels, to smaller cities in the region and to the Leuven outskirts.

Leuven has Belgium's 6th busiest train station, with an average of 33,932 boardings per week day (2018, NMBS). It connects Leuven with all major Belgian cities, including Brussels, Antwerp, Ghent, and Liege, with the Leuven hinterland, and also directly with the international airport of Brussels. Local public transport is almost exclusively covered by the public bus company De Lijn. They have a bus fleet of 105 vehicles – 6 of which are full electric (Dec. 2019) – which cover 6.6 million vehicle kilometres per year (2019, De Lijn). Public transport use has grown spectacularly since the 1990s, but in recent years there has been stagnation, as lines and buses are completely saturated.

Of course, the car remains an important mode of transport, especially in the outer districts which are still organized in a very car-centric way. Figure 21. Modal share of commute trips of citizens of Leuven, City Monitor 2014-2020.shows however that the car is losing ground, and has actually been overtaken by the bike as the mostly used mode of transportation for citizens of Leuven for their commute to work or school. However, much of the traffic in Leuven is of course generated by people from outside of Leuven, and they still prefer the car by a wide margin.

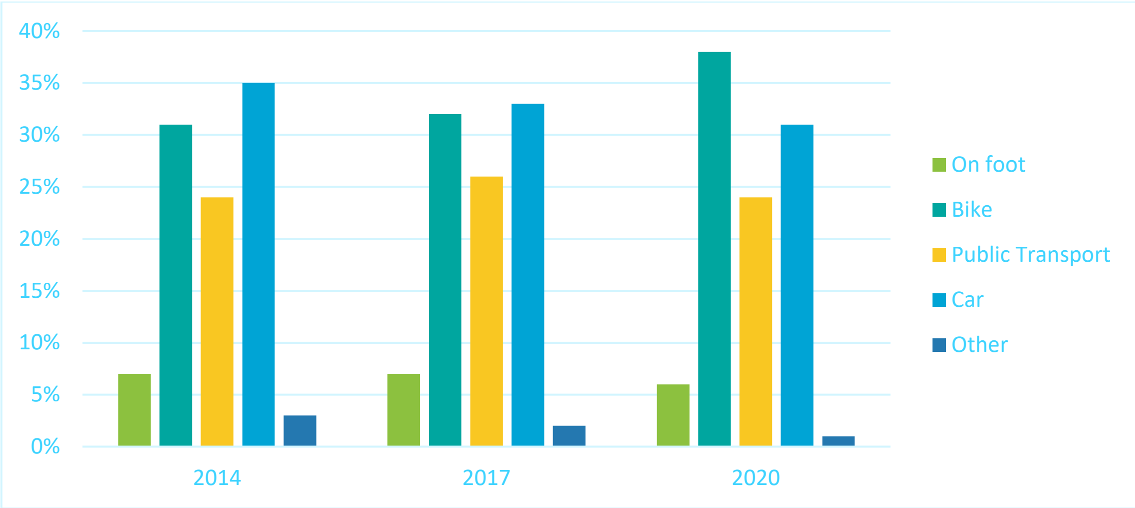

Figure 21. Modal share of commute trips of citizens of Leuven, City Monitor 2014-2020.

Shared mobility services are expanding. Right now, there are several shared mobility options in Leuven. By far the most successful and important service is round-trip carsharing. Figure 22. Number of shared car users (2005-2020) and available cars (2013-2020) in Leuven. Shows the increase in users and available cars in the past 15 years.

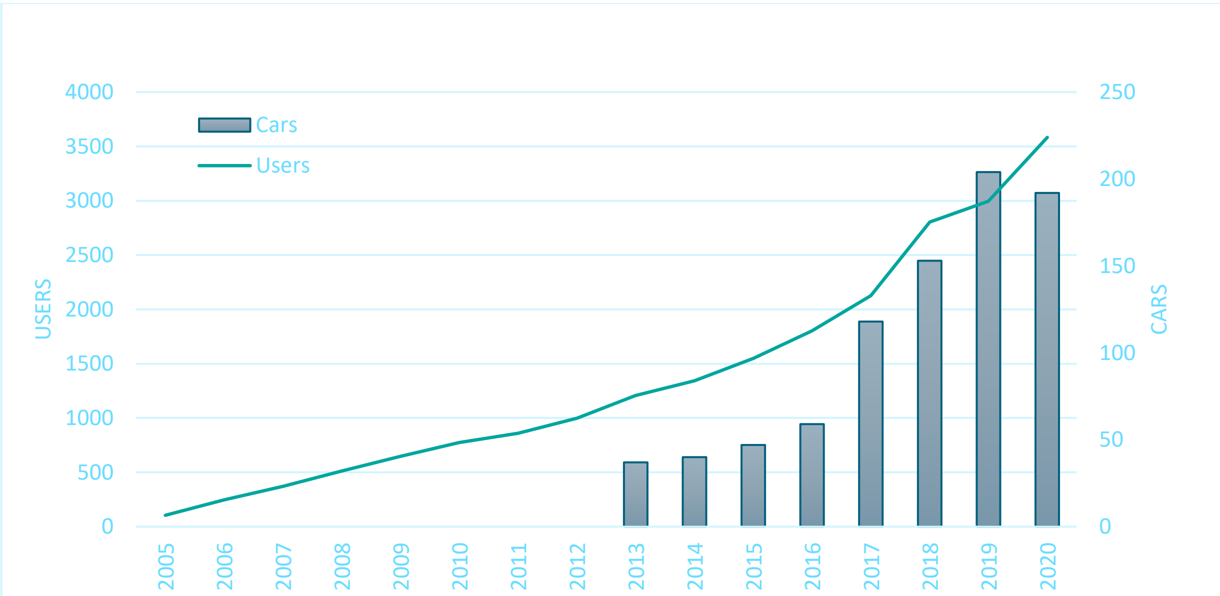

Figure 22. Number of shared car users (2005-2020) and available cars (2013-2020) in Leuven.

Bike sharing has had limited success. The national train company operates a sharing system with only one station at the main train station in Leuven, which serves 2.000 to 3.000 people a year, which translates in about 20.000 to 25.000 rides per year. This service successfully reaches a specific audience, namely irregular visitors of Leuven who combine interregional train with a shared bike. The city has been trying to expand on this system, trying to reach local residents or people who might combine local public transport with shared mobility options. The strategy is to cluster both public transport and shared mobility services at local mobility hubs (see Figure 23: mobility hubs will cluster the public and shared mobility services at strategic locations in Leuven.

Figure 23: mobility hubs will cluster the public and shared mobility services at strategic locations in Leuven.

Although the rollout was delayed because of Covid19 related logistical issues, during 2020 and 2021, e-bikes and e-cargobikes became available at these mobility hubs. Figure 24: Number of active users per month of new shared mobility services offered at mobility hubs in Leuven. shows the uptake of these services, which has been hampered by the lock-downs and other covid measures.

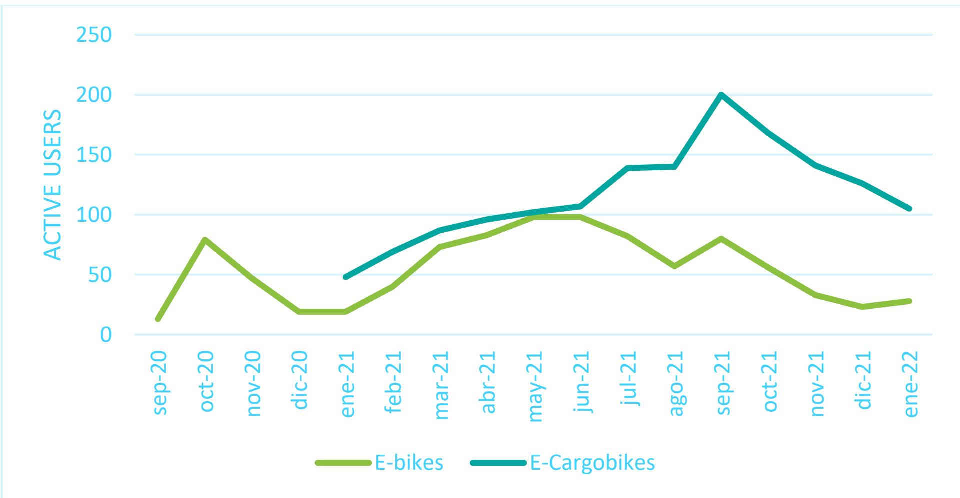

Figure 24: Number of active users per month of new shared mobility services offered at mobility hubs in Leuven.

3.1.3. The need for change

Given the growth of the city in the past two decades, traffic volumes have gone up considerably. As residential, commercial and business-related function are typically quite mixed in the city, the liveability in certain districts has been under pressure and congestion has been a real issue at certain key roads. Moreover, the local government together with local stakeholders from businesses, academia and the general public have put forward really ambitious climate neutrality goals within the framework of "Leuven2030", an organization that has the goal of bundling the strengths of all these stakeholders for transforming the city towards climate-neutrality.

3.1.4. Goals, values, mission and vision statement

Leuven's policy priorities include the reduction of congestion, energy consumption and emissions, and the improvement of accessibility to and from the city centre, the systematic incorporation of new mobility services and the integration of public transport with surrounding communities. The key goal in terms of urban mobility, is a modal shift from personal car use to public, shared and active modes. Figure 25: Trend breaking scenario of the modal share in the Leuven region. shows the trend change that is deemed necessary to realize the ambitions of the city.

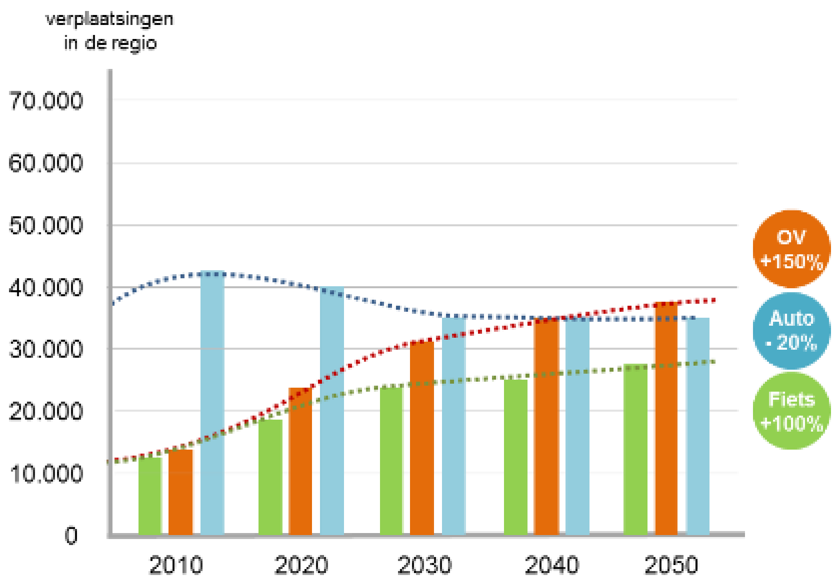

Figure 25: Trend breaking scenario of the modal share in the Leuven region.

Leuven has implemented a circulation plan in the city centre, restricting traffic flows to fixed loops that are not connected to each other but lead back to the outer ringway, and giving pedestrians and cyclists a more prominent place. At the end of 2020, the process of drafting a new mobility plan for the entire city was started, including the implementation of similar circulation plans in the outer districts too.

Another important project is the further expansion of shared mobility services, clustered at mobility hubs. These are locations throughout the city where shared mobility services and public transport services will be clustered. The first hubs were put in place in early 2020, and the coming years shared mobility services will be developed and expanded around them.

On the long-term, Leuven is also rethinking its public transport system and regional cycling connections, with a focus on a high-level regional public transport network called Regionet, which forms the basis for future urban developments in the whole region.

A key objective for the city of Leuven in the MOMENTUM project was the further regional integration of all different transport systems and mobility providers with the future spatial developments. Within this context it is crucial to have clear insights on future travel behavior and future evolution in modal shifts and transport trips for the different travel modes. To this end, one of the main objectives of Leuven case study was the development of a new, state-of-the-art, multimodal traffic model, which also takes into account the impact of shared mobility.

This multi-modal traffic model will be used to study the impact of planned policies. There are three specific policies that will be analyzed in the case study:

1. The implementation of a **new mobility plan** for districts within the city such as Kessel-Lo and Heverlee.
2. The introduction of 50 so-called '**Mobipunten'**, i.e. small to medium-scale mobility hubs with car-sharing, bike-sharing or scooter-sharing facilities, parking infrastructure and charging stations.
3. The implementation of **Regionet**, a new overarching strategic mobility plan (http://regionetleuven.be/). In particular, the introduction of bus lanes and the implementation of high-quality bike infrastructure, in combination with pricing policies and the implementation of peripheral parking and autonomous shuttle buses will be tested. Regionet will also form the basis for future urban development, such that new developments will be concentrated near public transport hubs.

3.2. Community of Practice and establishment process

At the end of 2020, the process of developing a new SUMP for the city of Leuven was started. For this large project, several stakeholder groups as well as consultation structures were put in place. Since redrafting the mobility plan coincided with the MOMENTUM project and given that the city had the ambition to deploy the models and tools developed within MOMENTUM in this SUMP process, it was decided to make use of these existing structures as much as possible for forming a Community of Practice for the MOMENTUM project.

The Community of Practice consisted out of the main stakeholders involved in shaping mobility policy in Leuven, shown in Table 5: Community of Practice Leuven

Table 5: Community of Practice Leuven

Organization
Mayor of Leuven (Mr. M. Ridouani)
Deputy Mayor of Mobility (Mr. D. Dessers)
Deputy Mayor of Public Works (Mr. D. Vansina)

City Council
City Department of Mobility
City Department of Urban Planning
City Department of Public Works
City Department of Enforcement
Police Leuven
Accessibility Council
Consultancy firm Mobility Plan
Agentschap Wegen en Verkeer
Consultancy firm AWV
De Lijn (Public Transport operator)
eHubs Project
Leuven2030
Regionet Project

3.3. Assessment procedures

The assessment procedure includes different sessions/interactions as follows

3.3.1. First CoP interaction

3.3.1.1. Date, format and approach

The first formal meeting took place on the 18th of October 2021 from 13:00 to 15:00, as part of the meetings of the SUMP guidance committee. It was a hybrid meeting with most people joining physically, at the Leuven city administration building. Some informal meetings with certain CoP members preceded this meeting, where more technical topics were discussed with mobility experts. The audience of the formal CoP meeting was largely non-technical, and the focus was entirely on the contributions the model results could make in the decision-making process.

3.3.1.2. Main topic of discussion

The topic of this session were preliminary drafts of the mobility plans, and how simulation results can help shape policy and planning.

3.3.1.3. Participants

Participants were:

- Mr. D. Dessers (Deputy Mayor for Mobility)
- Mr. D. Vansina (Deputy Mayor for Public Works)
- Mrs. E. Nevelsteen (Mobility Department)
- Mrs. S. Claeys (Mobility Department)
- Mr. T Asperges (Mobility Department)
- Mr. E. Nomes (Mobility Department)
- Mr. K. Stuyven (external consulting)
- Mrs. V. Charlier (Director of Spatial Development)
- Mrs. I. Devriendt (Director of Society)
- Mrs. V. Philippaerts (Director Public Domain)

3.3.1.4. Description of the action

The project and main model were introduced. Since many stakeholders do not have much if any experience with interpreting model results, much attention was given to the way results should be interpreted, to what the main caveats are with a simulation approach in general and to the reliability of the data sources used to calibrate the traffic model. Then, results were shown of the first analyses made on local circulation scenarios (see 3.4.1). Plans for the tools that were still being developed at the time, including level 2 of the DST and the full integration of shared mobility in the level 3 model, were introduced.

3.3.1.5. Main outcomes

The main model was regarded as very promising for the further development of the mobility plans. Potential ways of using the tools were discussed. In particular, it was discussed whether model results could be used to present mobility plans to citizens in the participatory process.

Some proposed measures were evaluated with the model results. The model results showed the feasibility of these measures and pointed to some potential side effects that were initially overlooked. As the political process of redrafting the SUMP is still ongoing at the moment of writing this deliverable, the actual measures cannot be described in detail.

3.3.2. Second CoP interaction

3.3.2.1. Date, format and approach

The second formal meeting took place on the 3rd of February 2022 from 13:00 to 15:00, again as part of the meetings of the SUMP guidance committee. It was a digital meeting with many participants, focused on decision making and the larger picture of the Leuven mobility plan. It was preceded and followed by many more informal meetings, presenting the MOMENTUM results in more detail to experts in the city administration, to be used in the actual planning process, and to stakeholders who were not reached through the main meetings.

3.3.2.2. Main topic of discussion

A comprehensive mobility plan for the district of Kessel-Lo was presented, supported by several analyses based on MOMENTUM tools and models.

3.3.2.3. Participants

Participants were:

- Mr. M. Ridouani (Mayor)
- Mr. D. Dessers (Deputy Mayor for Mobility)
- Mr. D. Vansina (Deputy Mayor for Public Works)
- Mr. T. Van Oppens (Deputy Mayor for Data, IT)
- Mrs. D. Vandevoort (Deputy Mayor)
- Mr. C. Devlies (Deputy Mayor)
- Mr. J. Geleyns (Deputy Mayor)
- Mrs. L. Wadera (Deputy Mayor)
- Mrs. E. Nevelsteen (Mobility Department)
- Mr. E. Nomes (Mobility Department)
- Mr. J. de Visser (Mobility Department)
- Mrs. J. Gregoir (Mobility Department)
- Mr. K. Stuyven (External consulting)
- Mrs. F. Declerck (External consulting)
- Mr. W. Ronse (External consulting)
- Mrs. V. Philippaerts (Public Works Department)
- Mrs. M. Scheers (Enforcement Department)
- Mr. G. Baro (Local outreaching Department)
- Mr. K. Wouters (Police Leuven)
- Mrs. V. Wuyts (Police Leuven)
- Mr. G. Antonissen (Communication Department)
- Mrs. Stroeykens (Communication Department)
- Mrs. L. Peeters (Deputy Director City Administration)

3.3.2.4. Description of the action

Several scenarios were presented that were simulated with the MOMENTUM models. These scenarios covered both short-term as well as long-term goals and consisted of sets of measures to reduce motorized traffic in residential areas and create more space for active and shared modes.

Each measure was discussed in detail with the model results as a main input. Limitations and interpretation issues of traffic modelling were discussed at length.

3.3.2.5. Main outcomes

The main outcomes were:

- The city of Leuven had very little experience with data driven policy making let alone making use of advanced modelling. This project has allowed us to make a lot of progress in this regard. The value of this has been acknowledged by numerous stakeholders.
- A general conclusion of the numerous interactions is that tools like the ones developed in MOMENTUM should be evaluated on two levels:
    - Does the tool help in building the argumentation for certain measures that can help in the political process?
    - Does the tool show something new, surprising or insightful that can help guide the planning process?
- The bar for the latter is higher than the bar for the former. The consensus of the stakeholder group is that the DST level 1 and 2 are not really suited yet to play a role in the planning process, as they are not accurate enough or not suited enough to the specific Leuven context. However, they can be used in the political process and they definitely can be the building blocks for even more capable tools in the future.
- The level 3 tool, i.e. the full traffic model with integration of shared mobility, even though its scope was perhaps a bit smaller than originally envisioned, did prove its value even in a planning context.

3.4. Summary of the analyses carried out in the project

3.4.1. Circulation measures

To increase the liveability of residential areas around Leuven and to create more space for active and shared modes, several hyper local circulation measures were simulated. Thanks to the technical improvements made to the way traffic is distributed by the model locally, it was possible to properly analyse potential effects, even in streets with relatively low traffic density.

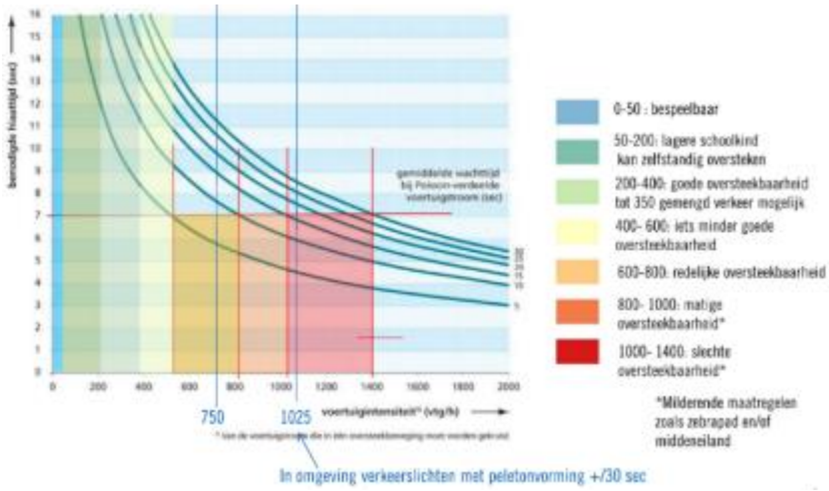

Figure 26: liveability index created to interpret simulation results.

Moreover, to make these simulation results interpretable by mobility experts and policy makers, a lot of attention was given to the way results should be presented as clearly and unambiguous as possible. A liveability index was created and mapped to the model outcomes (see Figure 26: liveability index created to interpret simulation results.). The resulting simulation tool was used for many different scenarios, of which Figure 27: Simulation results of a local circulation measure. is an example.

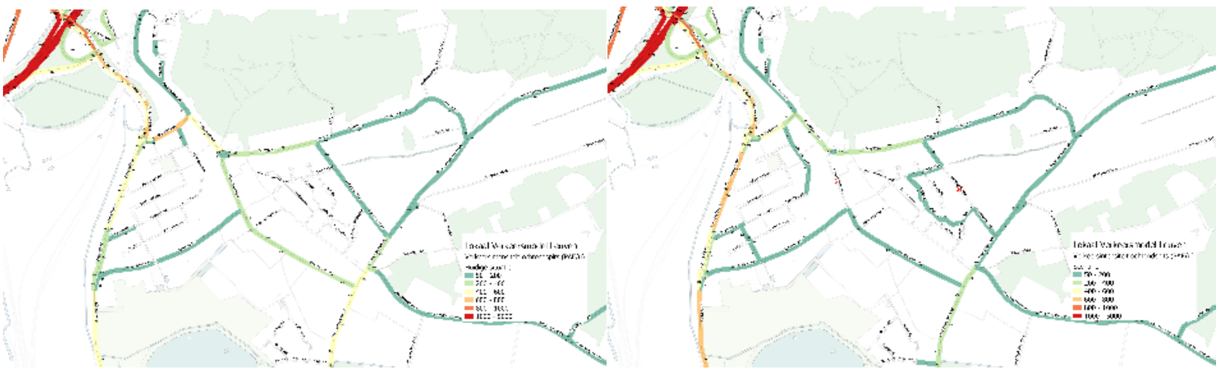

Figure 27: Simulation results of a local circulation measure.

Results show how blocking ongoing traffic in a small, local street (Wilselsesteenweg), have positive effects on the surrounding streets, shifting traffic to the designated regional roads, and even partly to the nearby motorway. Reducing traffic here in this way, allows for using a different road profile and assigning more public space to the implementation of a mobility hub.

3.4.2. Park&Ride analysis

To keep motorized traffic outside of the city centre, Leuven wants to realize extra peripheral parking lots with shared mobility services. To estimate the potential of different locations and the optimal set of locations given certain levels of demand, the level 2 tool of the DST was used. Figure 28: Simulated optimal Park & Ride stations in two scenarios. shows the optimal set of Park&Rides given two levels of demand, minimizing the trip distance of both driving and cycling, access inequalities, the number of stations and the differences in terms of capacity between stations, and maximizing the area coverage.

This analysis was used as a first scenario exploration towards rolling out such a system in the future. More precise estimations could help in the further planning process, but require more detailed data on shared mobility use. As some of the current mobility hubs in Leuven are linked to existing peripheral parking lots, gathering data and knowledge here will allow us to make finer grained analyses in the future.

Figure 28: Simulated optimal Park & Ride stations in two scenarios.

3.4.3. Promotion of carsharing

Several measures to promote carsharing were simulated. These policies include a doubling in available carsharing vehicles and the implementation of new traffic light control schemes that promote alternative modes of transport and that limit the inflow of privately-owned vehicles into the network. The effects of these measures were analysed in terms of car-traffic on the network, changes in car-ownership and air quality (measured in terms of traffic-induced emissions).

The simulation of these measures uses a multitude of the developed tools. The disaggregate car-ownership model is used to propagate the increased carsharing supply into an adapted car-ownership for the synthetic population. The disaggregate mode-choice model links the population's car-ownership with their mode choices. Another important input for the disaggregate mode choice model are the travel times, which are influenced by the new traffic light control schemes. Next to mode shifts, some people might decide not to make any trips anymore. This is accounted for using the induced demand model. both the disaggregate mode choice model and induced demand model require travel times, which are calculated by assigning the aggregated od matrices onto the city's network using the innovative assignment methods for urban environments (D4.1). The assignment results are further used in the emissions model to probe the city's air quality.

The assignment of the car traffic on the Leuven network and the corresponding link-specific CO2 emissions are shown in Figure 29 and Figure 30.

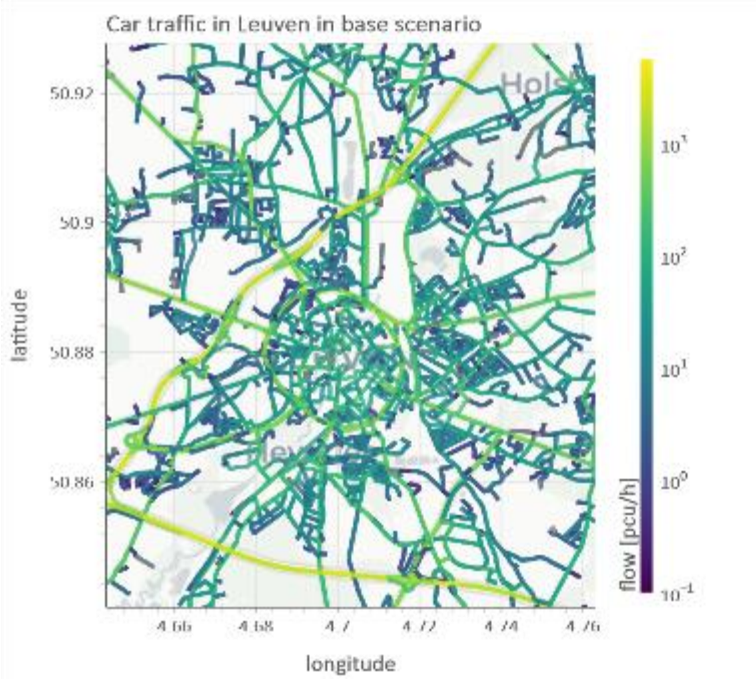

Figure 29 Car traffic assignment between 7am and 8am on the Leuven network, without policies to promote alternative modes of transport.

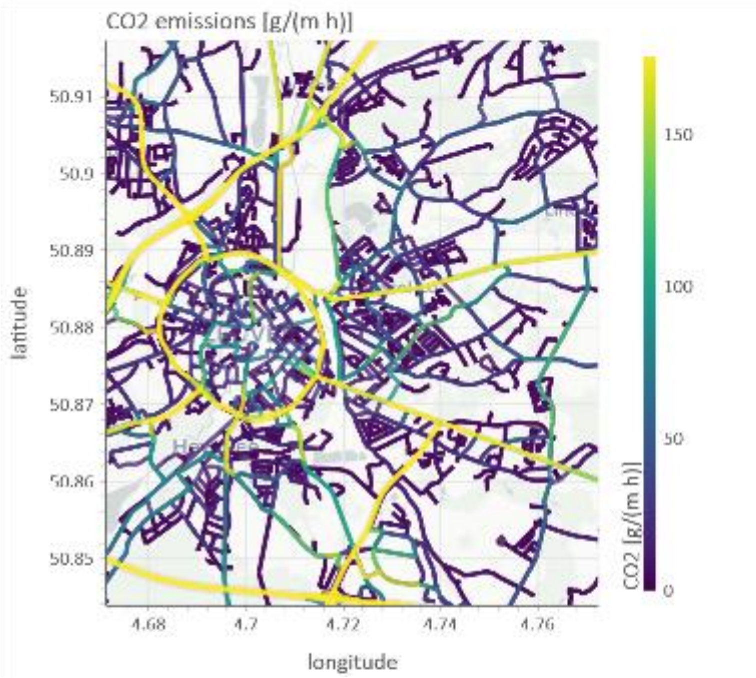

Figure 30 CO2 emissions due to car traffic (Figure 29) on the Leuven network between 7am and 8am. The values are normalized with respect to link length to make results on different links comparable.

The effect of the policies for promoting alternative modes of transport on the car-ownership is shown in Figure 31. Mostly households with multiple cars turn out to reduce their car-ownership. The car-ownership dissected by some of the socio-economic characteristics are shown in Figure 32 and Figure 33. The simulations indicate that the policies reduce the car traffic intensities on the Leuven network (Figure 34).

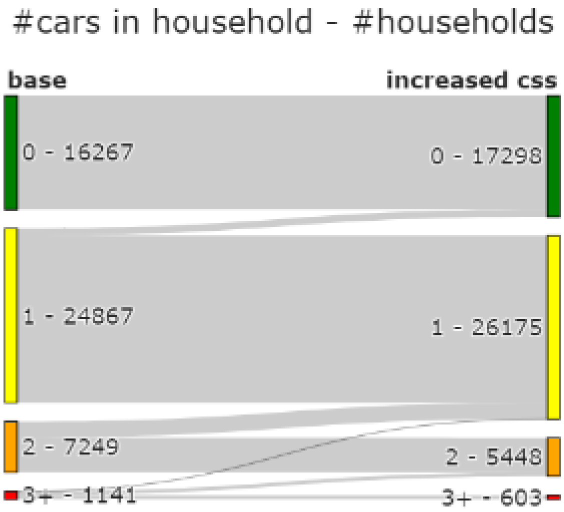

Figure 31 Evolution of car-ownership when introducing carsharing-promoting policies. The left- and right-hand side show the situation before and after the introduction of policies to promote carsharing. The numbers indicate the number of cars in a household and the number of households with this number of cars.

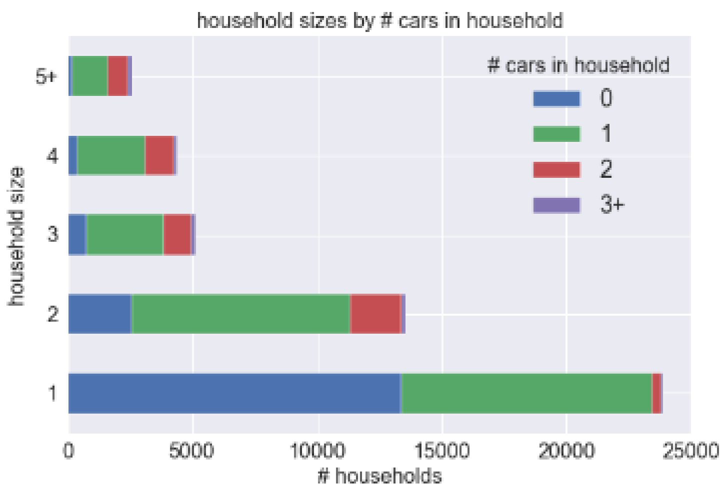

Figure 32 Number of cars in households, grouped by household size.

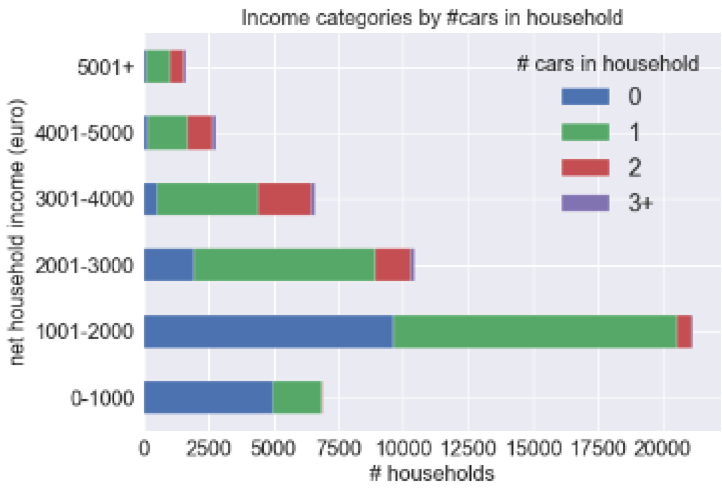

Figure 33 Number of cars in households, grouped by net disposable monthly household income.

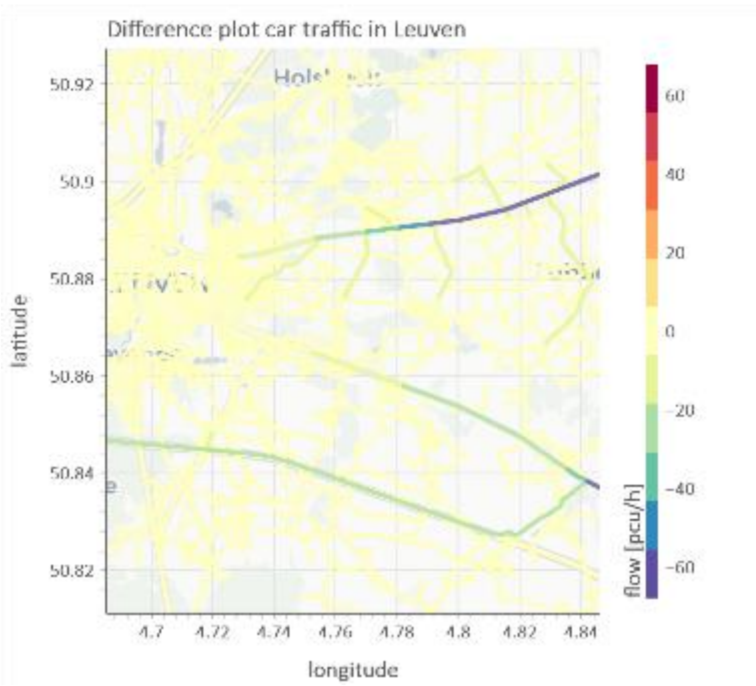

Figure 34 Difference plot for the car traffic between 7am and 8am after introduction of policies for the promotion of alternative modes of transport. The traffic volumes in the alternative scenario were lower than in the base scenario. The main visible effect is due to the travel time increase on the eastern entrance roads that results from the new traffic light control schemes.

Finally, the total emissions over the Leuven network for several pollutants for a modelling hour between 7am and 8am are shown to be reduced in Table 6.

Table 6 Car traffic-induced emissions during one modelling hour on the entire Leuven network, compared before and after introducing measures to promote alternative modes of transport.

Pollutant	Base	Alternative	Reduction
CO_2 (ton/h)	131.13	130.36	0.77

CO (g/h)	241.43	240.01	1.42
NOX (g/h)	76.62	76.17	0.45
PM (mg/h)	3.644	3.623	0.021
VOC (mg/h)	15.222	15.133	0.089

3.4.4. Adding a missing bike link

The city centre of Leuven and the district of Kessel-Lo were for a long time not well connected for bike traffic. Cyclists had to make a rather long detour when travelling between the two city parts. In 2019, the two parts of the city were connect by a new bicycle road, now commonly known as “fietsspiraal”, hinting on the spiral shape of the bike path.

An ex-post analysis was performed to investigate the effects of the introduction of the “fietsspiraal”. For doing so, the disaggregate mode choice model and the innovative assignment methods for urban environments (D4.1) were employed.

Figure 35, Figure 36 and Figure 37 show the bike assignments on the Leuven network before and after the introduction of the “fietsspiraal”. It is clear that a lot of the bike traffic between Kessel-Lo (east) and Leuven (West) gets diverted along the “fietsspiraal” once it is introduced. The bike traffic on the northern and southern connections are reduced. These roads have become less attractive to cyclists, as the travel times are longer and the roads are characterized by busy motorized traffic.

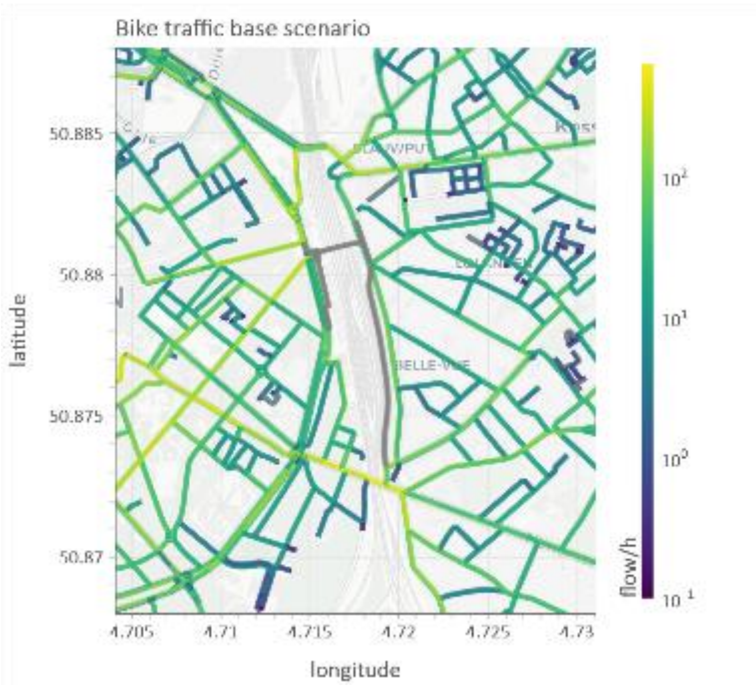

Figure 35 Bike traffic assignment on the Leuven network between 8am and 9am, when the “fietsspiraal” (mainly grey part connecting east and west) is not open to bike traffic.

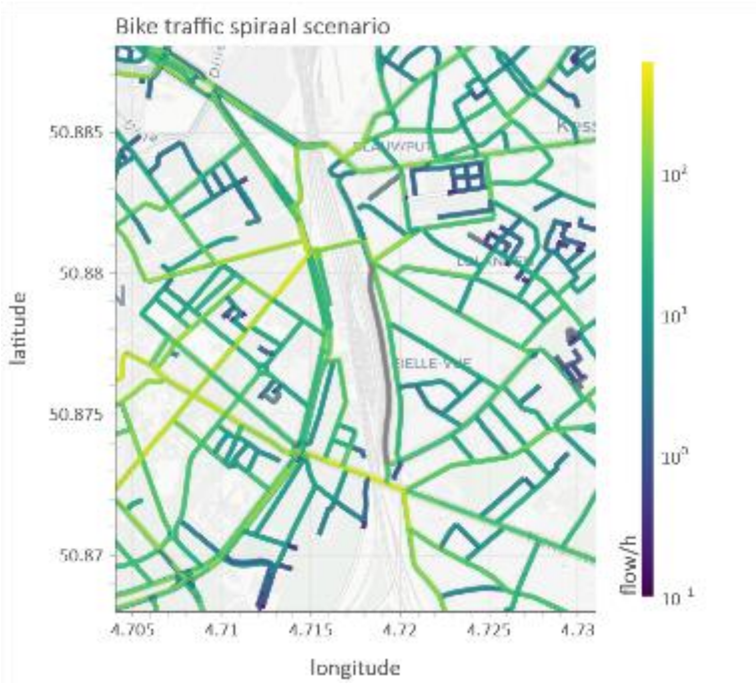

Figure 36 Bike traffic assignment on the Leuven network between 8am and 9am, when the "fietsspiraal" is open to bike traffic.

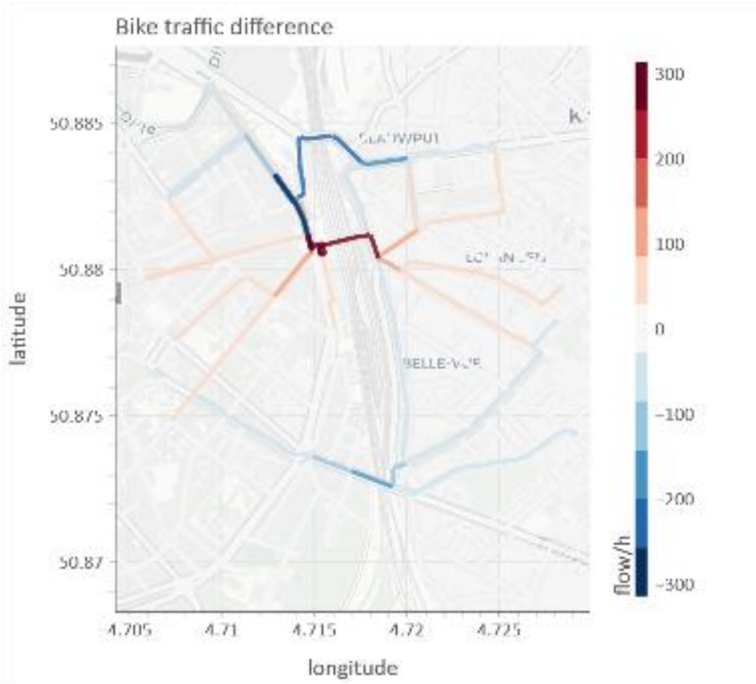

Figure 37 Difference plot of bike traffic on the Leuven network before and after the "fietsspiraal" has opened.

Using the disaggregate mode choice model, the effects of the "fietsspiraal" on the car traffic can be assessed. It turns out (Figure 38) that there is a general slight reduction in car traffic. Due to the faster connection between Leuven and Kessel-Lo, some people decided to change their car for an alternative mode of transport.

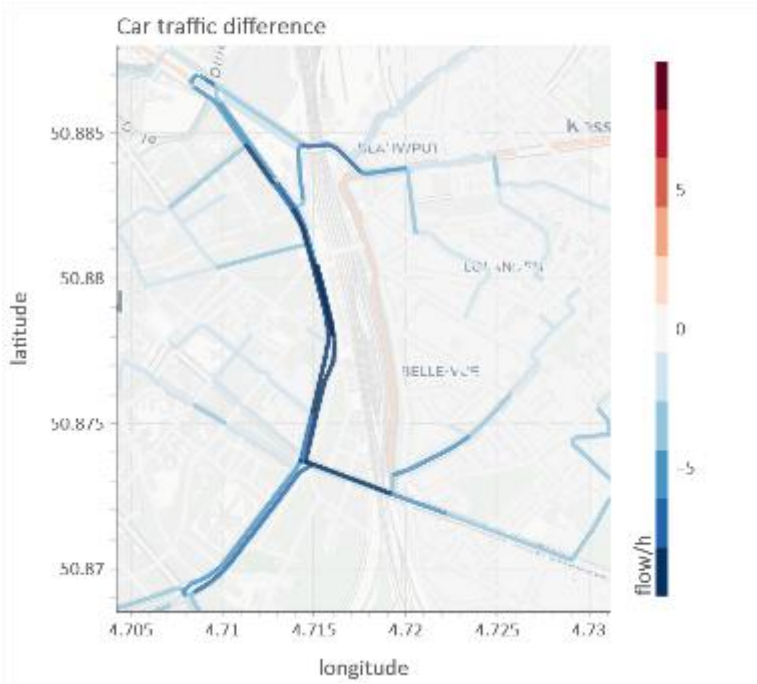

Figure 38 Difference in car traffic on the Leuven network between 8am and 9am after introduction of the "fietsspiraal".

3.5. Conclusions

The city of Leuven had very little experience with data driven policy making let alone making use of advanced modelling. MOMENTUM has allowed the city to make a lot of progress in this regard. The value of this has been acknowledged by numerous stakeholders, including the city itself, regional transport authorities, shared mobility operators and citizens involved in participatory processes.

The models and tools developed in MOMENTUM have already proven their value in both the decision making process as to a certain extent in the planning process, and the CoP wants to build on the output of MOMENTUM to continue this path in the coming years.

Since shared mobility is still pretty much in its infancy in Leuven (car sharing excepted), the CoP is convinced that Leuven needs to invest further in this approach, as the need for planning tools will grow while upscaling the efforts, and the effectivity of the tools will improve as more data becomes available.

4. Regensburg

4.1. Context description and vision statement

4.1.1. Introduction

The city of Regensburg, with 168,000 inhabitants, is the fourth largest city in Bavaria and the centre of eastern Bavaria. It is more than 2,000 years old and is located at the northernmost point of the Danube, about an hour's drive from Munich and Nuremberg.

The historically and culturally significant city is not only a UNESCO World Heritage Site and an international tourist destination (Regensburg includes the largest medieval old town north of the Alps with almost 1,500 listed buildings), it has also developed in the last decades to become one of the major economic centres in Germany and a prosperous commercial and industrial centre (since 2000 Regensburg ranges among the top 15 German business locations).

The city has a total area of 80.7 km2, with 18 districts, and receives 660,000 visitors per year. Regensburg is also known for its universities with 32,000 students and is home to many nationalities (16.6% of the population has foreign origins).

4.1.2. A brief on current transport

Regensburg is connected to the rail network in the direction of Munich, Nuremberg, Vienna and other German cities with long-haul high-speed trains. The international airport Munich can be directly reached with a local train once an hour. There is also a network of local trains which connects the rural dominated hinterland of Regensburg with the city in 30 minutes cycle on working days. Regensburg is located at the crossing of two highways in north-south (A93 Hof – Munich) and east-west (A3 Nuerenberg-Passau) direction.

Public transport is operated by SMO (city lines) with its own bus fleet of 131 vehicles (of which 12 are fully electric; January 2022) and by GfN (regional lines) with contracted bus companies. The city lines include 600 bus stops and 5.5 million vehicle kilometres per year (2019, RVV). In order to grant an integrated fare for the city and surrounding municipalities as well as for railways and buses, there is a transport organisation (Regensburger Verkehrsverbund).

The total road network of the city is approximately 414 km. Accompanying cycle paths have been built mainly on the main roads. In the old town with an area of 1.1 km², an area of approx. 0.2 km² is designated as a pedestrian zone. This pedestrian zone is open to cyclists. Around the old town there is a green belt exclusively for pedestrians and cyclists with a length of around 3 km. Regensburg began converting roads for car traffic into cycle paths in 2019 and is encouraging cycling by adding more cycle paths step by step.

Car ownership is 759 vehicles per 1,000 inhabitants (statistical year book, 2019).

The total number of trips per person is 3.5 trips per person per day (SrV2018), with an average trip distance of 5.6 km.

Finally, the modal split in the city of Regensburg (SrV2018) is as follows:

- Private car: 41%

- Public transport: 11%

- Walking and cycling: 48%

The penetration of shared electric vehicles on the roads is at a low level. A carsharing system (Earl) has been active in Regensburg since 2016 and was expanded from 5 to 20 vehicles in 2021. Since 2018 the carsharing system cooperates with the system for the rural district (Kerl) with 14 vehicles. In 2020, two providers of e-scooters (Zeus and Bird) are active with 300 vehicles, mainly in the city centre. In addition, an autonomous shuttle (Emilia) has been tested in a 1.3 km circuit in the commercial park since 2021. The introduction of the long-planned bikesharing system with 600 shared bicycles was acutally postponed for an undefined time due to a lack of finance in 2021.

Regardless of shared mobility, Regensburg is pushing ahead with the electrification of its own bus fleet (target of 30% of vehicles in 2027) and the expansion of the charging infrastructure. Regensburg had around 185 charging stations per 100,000 inhabitants in 2021 and is still increasing the number continually. Since 2016, Regensburg has subsidised the purchase of electric vehicles, cargo pedelecs and e-scooters by citizens in 2,600 cases with 25% of the net costs. The number of people using cargo pedelecs in Regensburg is remarkably high.

Regensburg is also an urban node of the Rhine-Danube TEN-T network due to its inland port an important cargo transhipment point.

4.1.3. The need for change

The city of Regensburg faces the challenge of managing the increasing traffic volume, caused by the economic prosperity, in a sustainable way. This is done through the support of cycling and public transport, the introduction of higher-quality public transport, the tram, traffic calming measures and the electrification of traffic.

Air pollution has also become an important issue in recent years, so that Regensburg has introduced an environmental zone for the city centre in 2015. In addition, the maximum speed of certain roads will be limited to 30 km/h in order to reduce noise. The reduction of emissions from traffic is a major issue in Regensburg

4.1.4. Goals, values, mission and vision statement

The main objective of the Regensburg case study is to include the impact of shared mobility in transport planning and decision making process. This will be done by developing new analytical solutions that will complement and enhance the existing multimodal macroscopic transport model developed by Regensburg.

One goal is to use the models, developed by MOMENTUM, to provide data-based support in the decision-making process to support the implementation of a bicycle sharing system. For this goal, we tested the decision support tools in the Western District. The results were discussed with the traffic planner for local mobility from the transport planning department as also with the prospective operator (SMO) involved in the introduction of the bikesharing system.

Another objective is to evaluate the impact of shared mobility on vehicle ownership and air pollution based on local circumstances. This test case, which was investigated with the decision support tool level 3, referred to the already introduced exclusive bus lanes and the pilot operation of the autonomous people mover (APM) in the commercial park. The results were discussed with the traffic planner for public transport from the transport planning department as also with the operator (SMO) involved in the introduction of the APM system.

The mission of the Regensburg CoP, formed by traffic planer of the municipality and the operator of public transport and emerging mobility (SMO/REWAG), will be to review and evaluate the functionalities offered by the WP 5 developed tools. These stakeholders which are involved in introducing emerging transport solutions in the city will be invited to workshops where the tools will be demonstrated.

4.2. Community of Practice and establishment process

In Regensburg, the community of practice consists of various representatives of the city administration and representatives of das stadtwerk.mobilität (SMO) and the Regensburg Energy Provider (REWAG). In Regensburg, there are no other people involved in macroscopic transport modelling apart from the person responsible for the Municipal Transport Model, who is part of the MOMENTUM Project. The persons of the community of practice are responsible for the introduction of emerging mobility solutions, or are responsible for pilot projects currently in progress. In a first meeting on 13th July 2021, it was discussed whether the community of practice could be extended to other organisations. Considering that services such as BS and APM are not yet established, this did not seemed to be appropriate.

- City of Regensburg, Transport Planning Department:
  - Hr. Wiesinger Christian (head of Transport Planning Department)
  - Hr. Tonndorf Aaron (deputy head of Transport Planning Department)
  - Hr. Rohls Hendrik (PT)
  - Hr. Heil Christian (Modeler)
- City of Regensburg, Urban Planning Department:
  - Hr. Großmüller Thomas (mobility coordinater for active mode, BS)
- das stadtwerk.mobilität (SMO):
  - Hr. Kalteis Heribert (deputy operations manager)
  - Hr. Krakowitzer Marco/Hr. Barth Christian (APM)
  - Hr. Heitzer Florian (marketing and business development, BS)
  - Hr. Schönbrunner Kai (eMobility, CS)
- Regensburg Energy Provider (REWAG):
  - Hr. Sulzenbacher Stefan (innovative business models, CS)

4.3. Assessment procedures

The assessment procedure includes different sessions/interactions as follows.

4.3.1. Interactions with the CoP

Several interactions with the CoP were carried out with different objectives. On the one hand, appointments were often made bilaterally to test the tools, but there were also more extensive appointments to present the tools and to discuss how these tools can support the introduction of new mobility solutions.

In addition, the dissemination workshops, such as the 3rd Transport Congress in Regensburg and the Peer-to-Peer Workshop were always topics within the CoP. The individual actions are illustrated in the following figure.

Figure 39. CoP Interactions Regensburg, timetable

The following table lists the participants of the individual meetings including their function (BS=bikesharing, CS=carsharing, APM=autonomous people mover, PT = public transport), whether the meeting took place physically or online and the main topics of the meeting. Some of the CoP members were represented at the 3rd Transport Congress in Regensburg and the Peer-to-Peer Workshop.

Table 7. CoP Interactions Regensburg, members

Participant/Date	May 12th 2021	July 13th 2021	September 30th 2021	November 30th 2021	December 6th 2021	March 9th 2022
Physical/**O**nline	O	P	O	O	O	O
Main topics	Test DST Level 1	Test DST Level 1	3rd Transport Congress Regensburg	Peer-to-Peer Workshop Regensburg	Test DST Level 1 + 2	Results DST Level 1-3
Wiesinger Christian		X	approx. 100 registered guests from administration, business, universities and transport companies	approx. 25 guests		X
Tonndorf Aaron						X
Großmüller Thomas (BS)		X			X	X
Rohls Hendrik (PT)						X
Christian Heil	X	X			X	X
Kalteis Heribert		X				
Krakowitzer Marco (APM)	X	X				
Barth Christian (APM)						X
Heitzer Florian (BS)	X	X			X	
Schönbrunner Kai (CS)	X					X
Sulzenbacher Stefan (CS)	X	X				
Santhanakrishnan Narayanan (TUM)		X (O)				X
Constantinos (Costas) Antoniou (TUM)						X

4.3.1.1. Description of the action

The first interaction with the CoP took place on **May 2021**. The input values for DST Level 1 for the bikesharing and carsharing service were discussed. For carsharing, the operator information could be provided and adapted to the input requirements. For the bikesharing it was more difficult, as no operator data was available for Regensburg. Prices from a tender of the bikesharing service were available here, which could be adapted to the input requirement. The tests carried out with these input values and their results were discussed.

It was recognised that the waiting times calculated by the tool are not relevant in practice, as in Regensburg the carsharing vehicles are pre-booked via app. Overall, it was ascertained that the tool with the Mode "vehicle sharing (bike station)" is not suitable for investigating the specific type of car sharing service in Regensburg. In Regensburg, car sharing is used for special trips (e.g. to the furniture store) and not to drive from A to B. The individual vehicles must be returned to the same station where they were picked up. After consultation with CERTH/TUM, the tests for the car sharing service were terminated.

For the bikesharing test carried out, there were different questions about the number of stations and the number of docks per station. The tests served to identify the functionality of the tool. The indication from CERTH that the tools are still going through further calibration steps and changes led us to wait for a further version of the tool.

In **July 2021**, a physical meeting was organized at the stadtwerk.mobilität building in Regensburg. In this extended group of participants, leaders of the city administration and the SMO were invited. The aim of the meeting was to explain MOMENTUM and its organisation, timing and the city's objectives within the MOMENTUM project. The results of the evaluation of the car sharing data and the DST Level 1 were presented (Figure 40). The participants received information in the form of the MOMENTUM homepage, the link to the publications and to the Decision Support Toolset. At this event, Santhanakrishnan Narayanan (TUM) introduced himself as the technical partner of the city of Regensburg and explained the task of TUM.

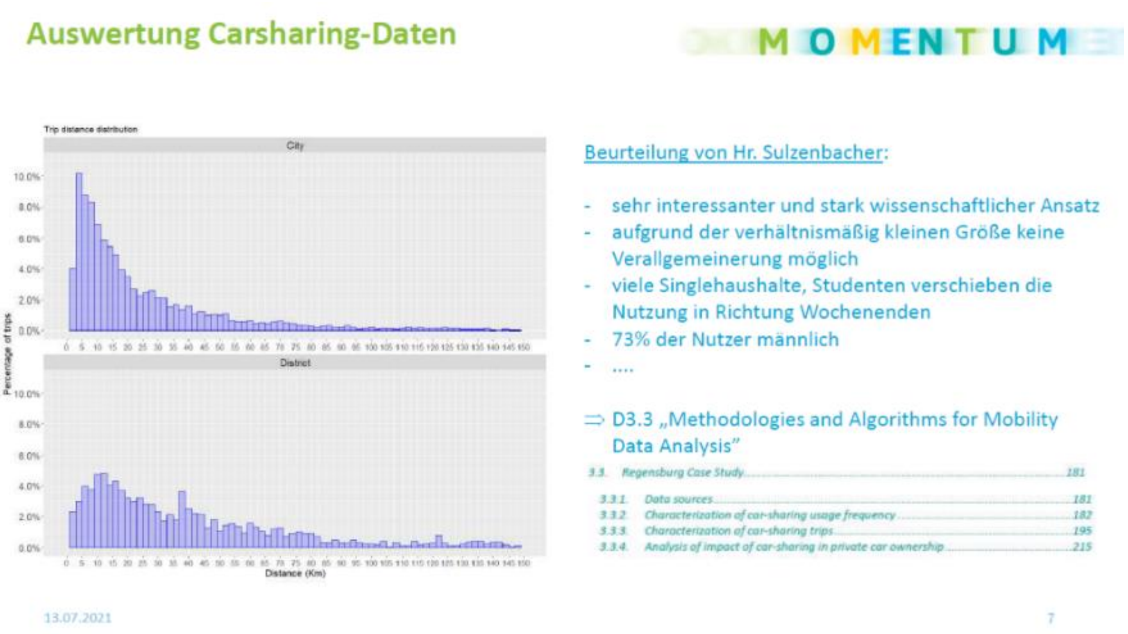

Figure 40. CoP Interaction Regensburg, 13th July Analysis Car Sharing Data

One of the tasks of the meeting was to discuss the possibility of expanding the participants of the CoP to include, for example, user organisations such as the ADFC (German bicycle organisation) or VCD

(Verkehrsclub Deutschland). Considering that services such as BS and APM are not yet established, this did not seem to be appropriate. It has been decided to proceed with the CoP members present.

At the event "**3rd Regensburg Transport Congress**", held on **30th September 2021** and attracting around 100 guests from politics, business, the university sector and transport companies, various hot topics in the field of mobility were addressed.

Figure 41. CoP Interaction Regensburg, 30th September 2021

The mayor of the city of Regensburg and the cluster manager of R-Tech GmbH, who was responsible for organising the event, supported the event, welcomed the participants and introduced them to the topic of mobility. The agenda covered the following topics:

- Mobility in Regensburg: Yesterday - Today - Tomorrow.
- Mobility Management Municipality of Regensburg - What moves a municipality?
- Cable car - urban transport of the future
- RECIPROCITY: Accelerating replication for smarter and cleaner mobility
- MOMENTUM: Modelling Emerging Transport Solutions for Urban Mobility

The mobility of yesterday was described by planning in the 60-80s with the car-friendly city. The tram, which ran in Regensburg from 1903 to 1964, was displaced by car traffic. From the 1980s onwards, the city of short distances was propagated with the promotion of walking, cycling and bus transport. Today the following problems are:

- Congested road and highway network
- only three Danube bridges (the Danube divides the city)
- Noise and emissions
- few separate spaces for public transport

The mobility management of the administration of Regensburg, which includes all routes of the approximately 4000 staff members, is being investigated by the research project MobiRE as a SmartCity component, which is funded by the Federal Ministry of the Interior. The aim of the project is to manage mobility in a more resource-efficient and sustainable way, without compromising the quality of service. After a contribution to promote a cable car solution for Regensburg, the research project "Reciprocity" was presented. Reciprocity focuses the networking of European cities using best practice examples. Regensburg contributes the following best practice examples:

- Electric city bus “EMIL”
- Autonomous people mover “EMILIA”
- E-car sharing concept “EARL”

For the presentation on the Momentum project, the following slide was used to explain what a strategic macroscopic transport model means and what it is used for.

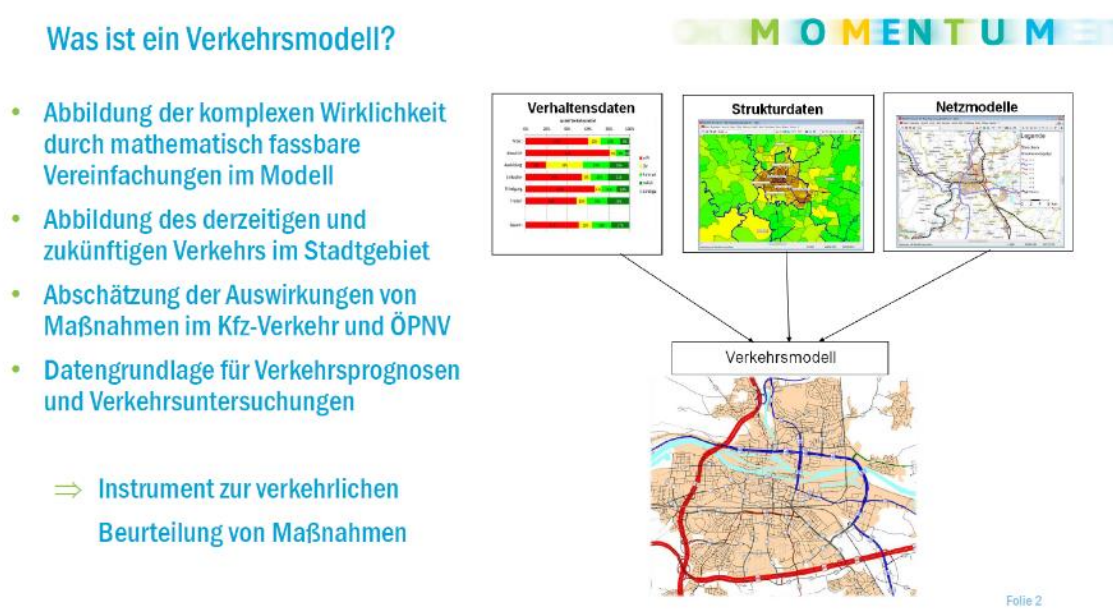

Figure 42. CoP Interaction Regensburg, 30 th September 2021, macroscopic transport model

The scope ranged from the mobility options of the city of Regensburg (Figure 43) to the Decision Support Tools and an example for Regensburg was presented by analysing the charts (Figure 44).

Figure 43. CoP Interaction Regensburg, 30 th September 2021, shared mobility services

Figure 44. CoP Interaction Regensburg, 30 th September 2021, charts

The MOMENTUM project was presented in a two-hour event at the Peer-to-Peer Workshop on 30 November 2021 with around 25 guests consisting of members of the MOMENTUM CoP and members of the RECIPROCITY project.

The agenda covered the following topics:

- RECIPROCITY (welcome, introduction)
- Smart Mobility Regensburg

- State of research on emerging mobility solutions
- Modelling shared mobility services
- Live-Demo DST Level 1/2
- Questions/Answers

Figure 45. Peer-to-Peer Workshop Regensburg, 30 th November 2021, arena picture

The workshop was moderated by Michael Strobel, project manager of R-Tech GmbH, who also presented RECIPROCITY. Florian Heitzer, Stadtwerk Regensburg.Mobilität GmbH, gave an insight into the Smart Mobility strategy of the city of Regensburg. Prof. Constantinos Antoniou from TU Munich provided an overview of the emerging mobility solutions and an introduction to the intermediate modelling approach and its innovation. Besides these, he elucidated the common and uncommon variables influencing the mode choice for different shared mobility services, based on a disaggregate mode choice model. Following his presentation, Santhanakrishnan Narayanan (TUM) explained the intermediate modelling approach in detail, along with a brief on the individual steps newly added in the approach. Furthermore, Santhanakrishnan stressed the need for a new framework to estimate demand for small-scale car-sharing systems, like the one in the city of Regensburg, and presented a multi-method framework, consisting of multinomial logit, linear regression and dirichlet regression models. Josep Maria Grau presented the Decision Support Tool Level 1 and 2 specifically for the planned bike sharing system in Regensburg.

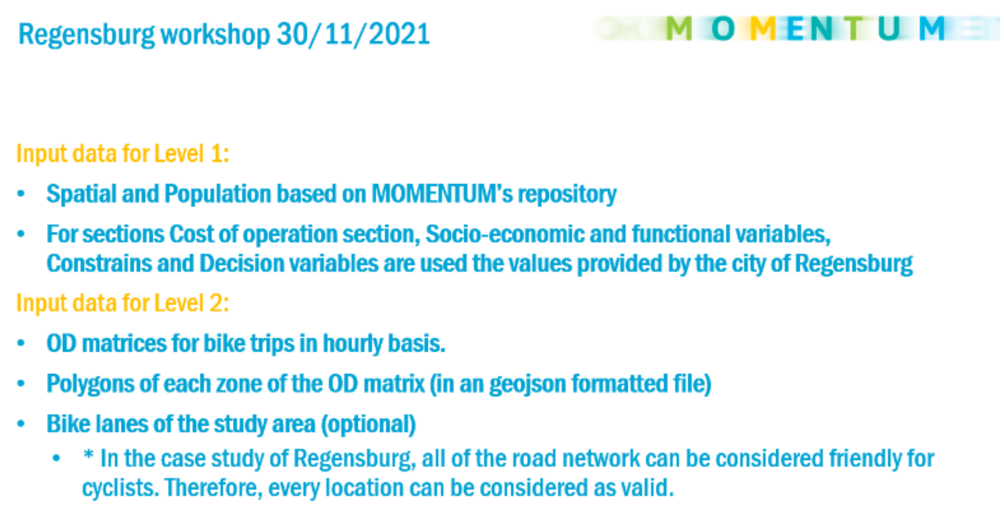

Figure 46. Peer-to-Peer Workshop Regensburg, 30 th November 2021, input data

In **December 2021**, the Decision Support Tool Level 1 and 2 was tested again in a virtual meeting within the CoP Regensburg. In this DST-Version, all calibrations performed since May 2021 have been completed and a representative result for a specific bikesharing use case was expected. The Western District in Regensburg was selected as the use case, a relatively large and populous urban district in which the traffic cells of the traffic model correspond very well with the official district boundaries. The test implementation started with Level 1 and moved on to Level 2. The input data regarding the operator costs were still based on the parameters determined in May 2021. In level 2 a synthetic cycle network was generated to determine the location of the stations depending on the distance to the cycle paths. The bus stops were also digitally prepared in order to take them into account when determining the location of the stations. The visualised results were discussed with the members of the CoP.

Results Level 1:

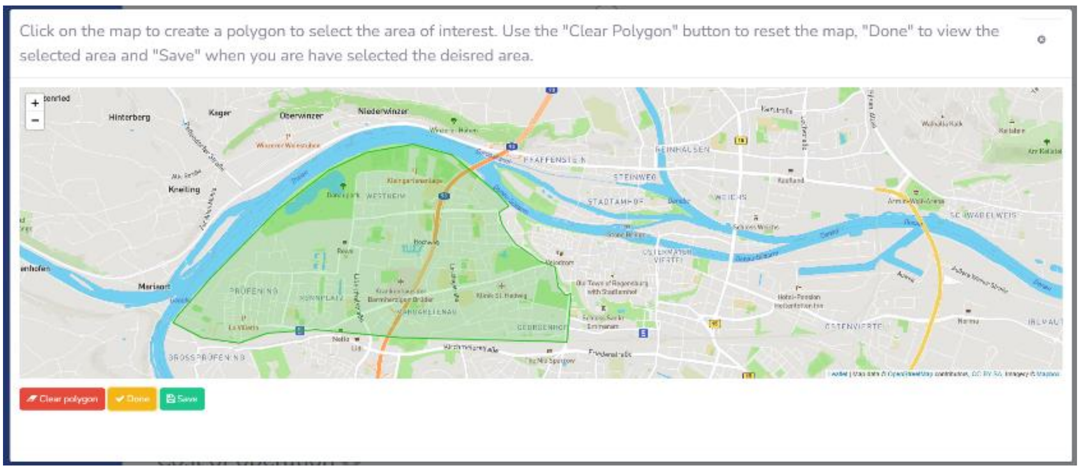

Figure 47. CoP Interaction Regensburg, 6 th December 2021, Western District

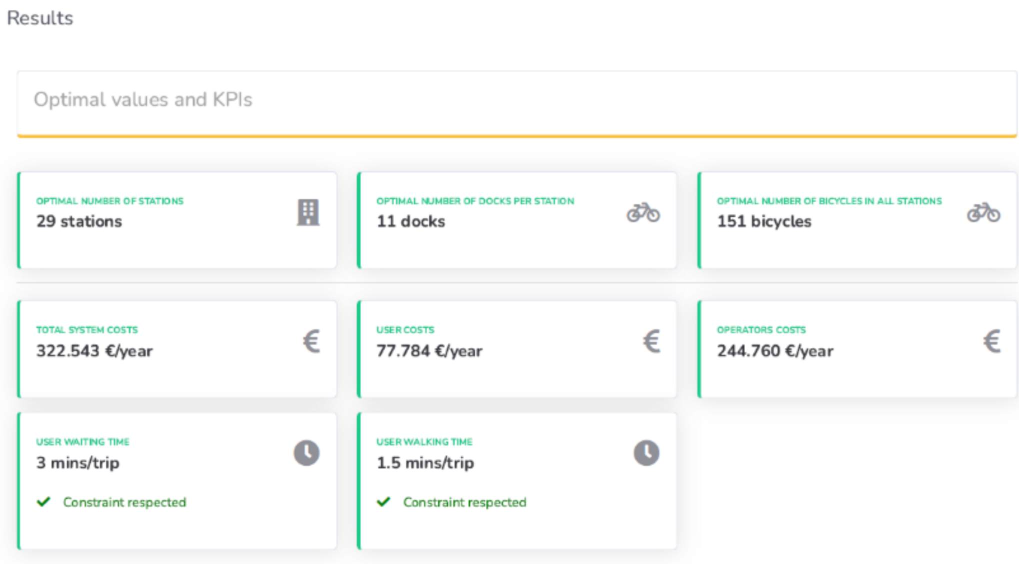

Figure 48. CoP Interaction Regensburg, 6 th December 2021, optimal values and KPIs

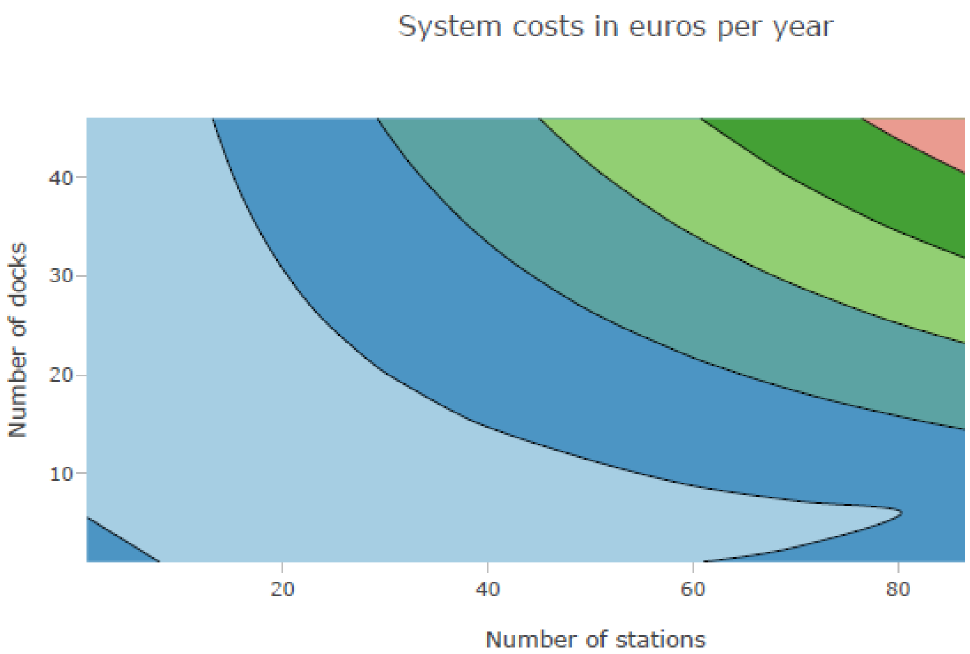

Figure 49. CoP Interaction Regensburg, 6 th December 2021, charts

Level 1 generates a representative result depending on the previously entered demand. The presentation of the charts allows interpretations to change the number of stations or docks. In this regard, this tool can support the decision-making process.

By entering the operating costs, changes in the total cost of the project can be easily monitored and also support the decision-making process. Overall, the members of the CoP considered the tool helpful.

Results Level 2:

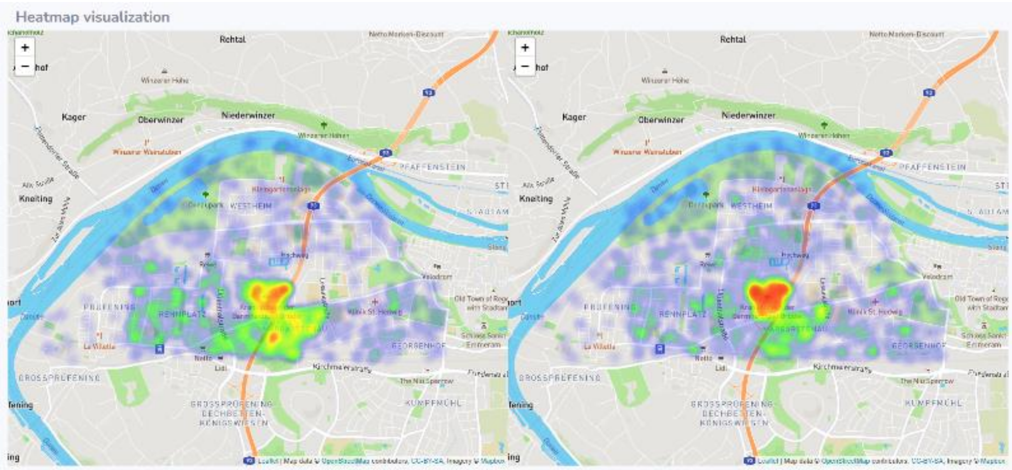

Figure 50. CoP Interaction Regensburg, 6 th December 2021, heatmap

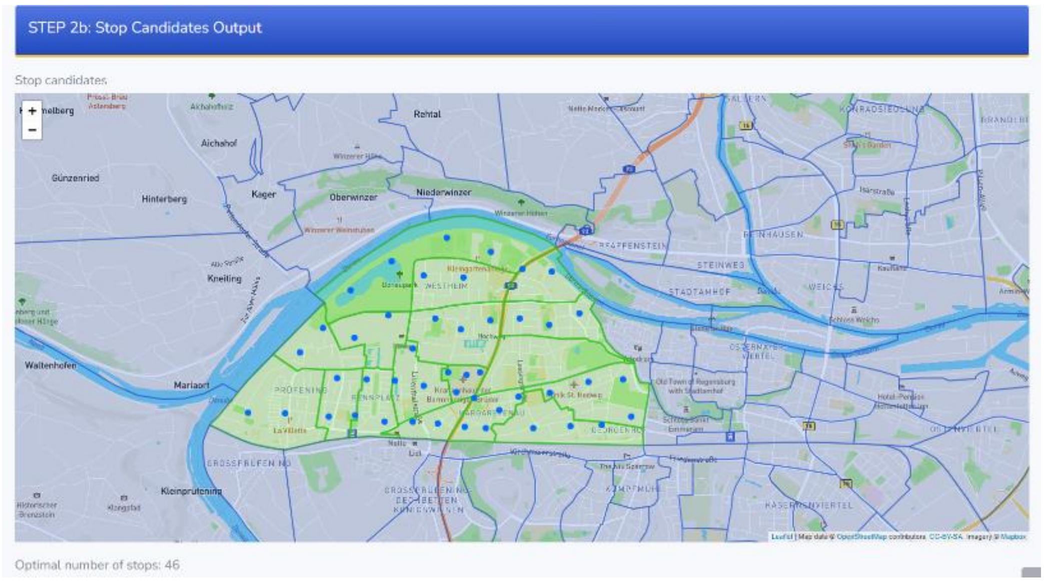

Figure 51. CoP Interaction Regensburg, 6 th December 2021, stations

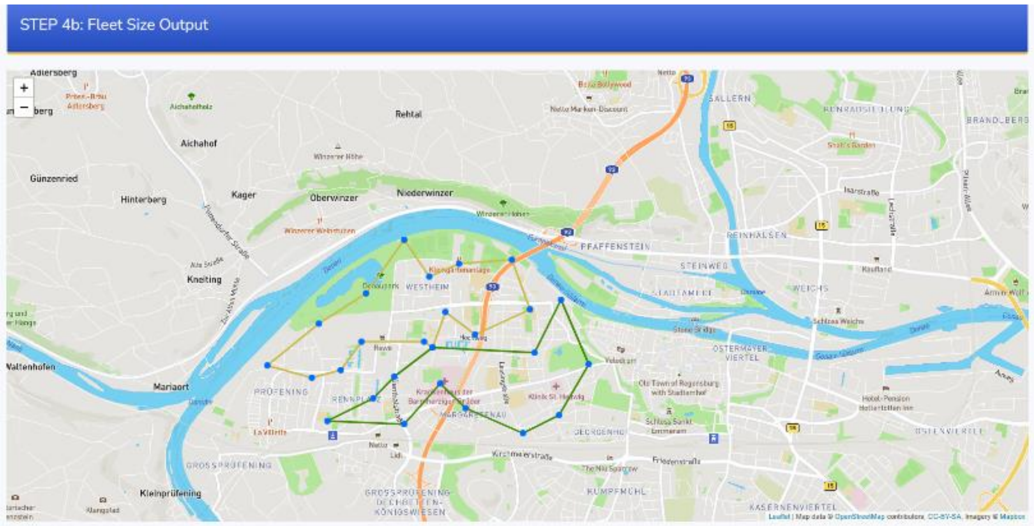

Figure 52. CoP Interaction Regensburg, 6 th December 2021, redistribution

Level 2 is convincing with the location of the stations. However, the feasibility of realisation due to limited space or other restrictions must be examined in a separate step. The location of the station depends mainly on the availability of space. However, it is useful to determine the location of the stations using the model-based analysis as a first step. The analysis of the redistribution is not the main focus of an implementation for Regensburg, but is certainly of interest for a future operator.

Unfortunately, it is not possible to analyse bikesharing data for Regensburg due to its lack of existence.

In **March 2022**, the results of DST Level 3 for the Regensburg use case were presented by TUM. The focus was on the evaluation of the policies that have already been introduced. In Regensburg, exclusive bus lines have been introduced for a while in order to speed up public transport and make it more comfortable. For this purpose, one lane of a multi-lane road was removed from the car traffic and made that lane free for the bus transport. In addition, the buses have priority at traffic signals to accelerate.

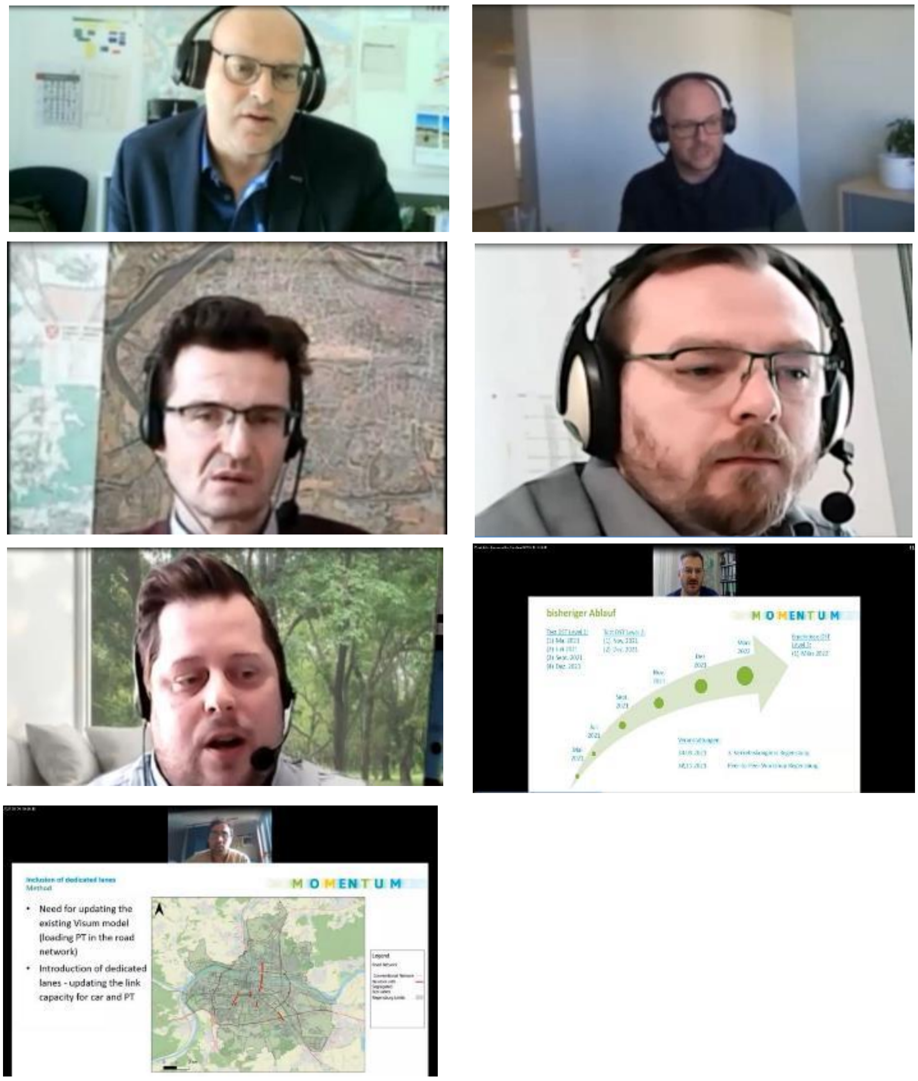

Figure 53. CoP Interaction Regensburg, 9 th March 2022, members

The results in terms of modal split and emissions demonstrate how much these exclusive bus routes affect modal split and emissions. With regard to the autonomous people mover (APM), the investigation focused on the extent to which it complements public transport. The investigation based on the actual test route indicates that the number of journeys is increased by the APM and that it indeed complements public transport.

Due to the small size of the pilot project, no significant impact on the modal split or the emission of air pollution could be determined here; the influence is simply too small.

The People Mover was investigated as transport system for the first and last mile. It was discussed that the people mover should not only be studied from the supply side, but how people would respond to it. It is not yet simple to assess the impact of the APM when it is scaled up as a service for the urban area.

Overall, the tools from Momentum are potentially useful for the implementation or expansion of emerging mobility services.

4.4. Summary of the analyses carried out in the project

The analysis within the case study on Regensburg focused on the implementation of dedicated bus lanes, Autonomous People Mover (APM) and shared mobility services. The methodology followed is described in detail in D5.3. As mentioned in the deliverable, the existing Regensburg Visum model follows a timetable based approach for PT assignment. Therefore, a base scenario model was created, by loading the PT buses into the actual network. In the following sections, the impacts of dedicated bus lanes, APM and shared mobility services are discussed. Since multiple implementations are involved in the case study, an incremental approach is followed, i.e., initially, the dedicated bus lanes are implemented over the base scenario and is called the bus lane scenario. Over this bus lane scenario, APM is implemented, which is call the bus lane + APM scenario. Finally, the shared mobility services are implemented over this bus lane + APM scenario.

4.4.1. Analysis of Segregated Bus Lane Implementation

To analyse the impact of segregated bus lanes in Regensburg, three different KPIs are considered: the mode split, the emissions and the service efficiency of the bus lines. Table 9 depicts the results of the modal split. As it can be observed in the table, the modal share for public transport increased by 1.58 percentage points. Moreover, the private car share is diminished by 1.25 percentage points, which indicates that the increase in quality of the public transport in the city and the restriction of the capacity of the private car network has a positive impact in encouraging the use of public transport and disincentivizing directly the private car trips.

Table 8. Modal split for the base scenario and bus lane scenario

Mode	Base Scenario (%)	Bus Lane Scenario (%)	Variation
Car	52.63	51.38	-1.25
PuT	08.96	10.54	+1.58
Car Passenger	06.61	06.25	-0.36
Bike	15.37	15.37	0
Walk	16.42	16.46	+0.04

The second assessment of the bus lane implementation is their environmental impacts. Since the base scenario model in Visum is forecasted for the year 2030, the emission model is based on fleet composition and emissions factor for the year 2030 in Germany. To calculate the emissions using the model, the link speeds and volumes are extracted from the Visum framework. Since different modes are simulated in the Regensburg Visum model, each mode with their own speed from the traffic assignment, there is a necessity to calculate an average speed in each link. In this case, the weighted mean was calculated based on the Passenger Car Equivalent (PCE) units of each mode [it is assumed that both buses and trucks have a PCE of 2 (Pajecki et al., 2019)]. The results of the 24-hour emissions are depicted in Table 10. Based on the results shown in the table, it is evident that the introduction of the bus lanes causes a significant decrease in transport-related emissions, varying from 3% to 6%. This reduction in emissions can be attributed to the decrease in traffic volumes in the city. In particular, a network section that significantly illustrates this effect is the Nordgaustraße. In Figure 36, it can be seen that the Nordgaustraße segment has traffic reductions of up to 6000 vehicles per day. This reduction of vehicle traffic correlates to a reduction in congestion of the network. In order to evaluate the congestion, one of the most common measures is the Volume/Capacity ratio, which compares the expected service volume with the capacity of a road segment. Based on on this measure, the average Vol/Cap ratio in the Nordgaussstraße has reduced by 5.8%, thanks to the introduction of segregated bus lanes. The reduction of the vehicle traffic in the network combined with the reduction in network congestion support the reduction of the traffic emissions in the city.

Table 9. Emissions for the base scenario and the bus lane scenario

Pollutants	Base Scenario	Bus Lane Scenario	Variation %
CO_2 (ton)	584.88	552.78	-5.49
CO (kg)	703.05	656.31	-6.65
NO_X (kg)	354.863	343.339	-3.25
PM (kg)	8.982	8.476	-5.63
VOC (kg)	26.719	25.020	-6.36

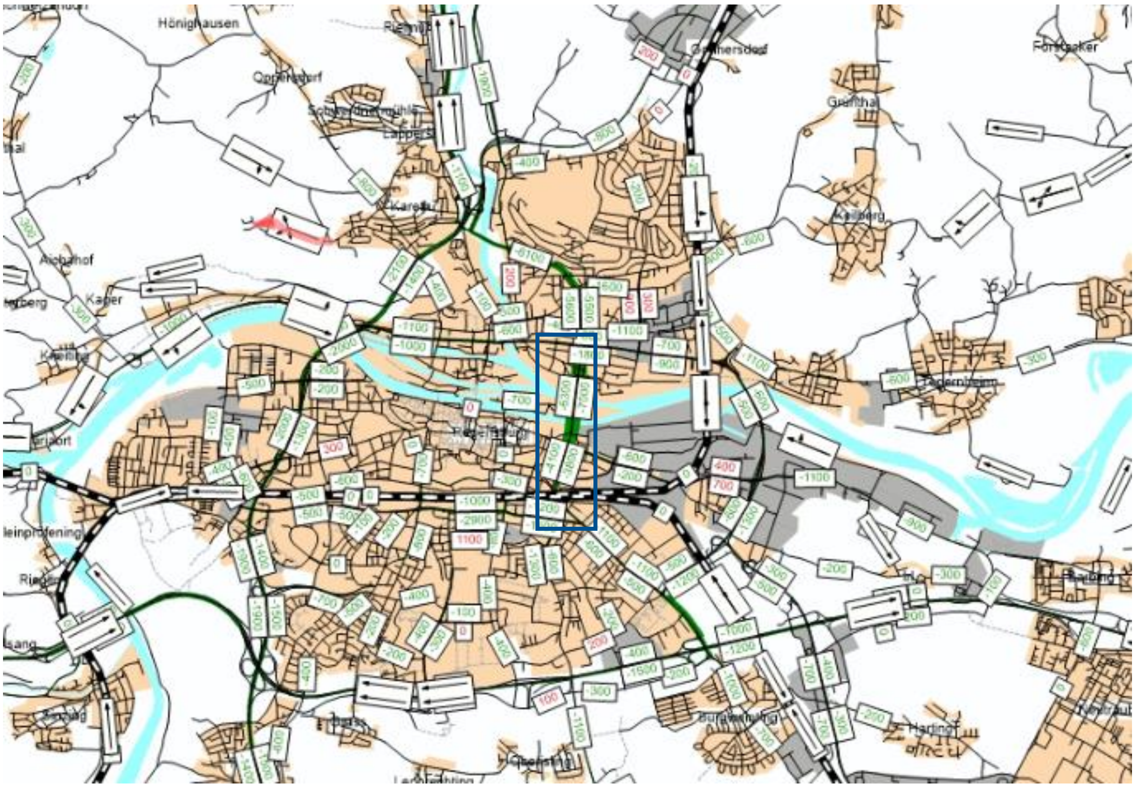

Figure 54. Regensburg change in PCE Volumes in Links. Green: decrease of PCE; Red Increase of PCE; Blue box: Nordgaustraße.

The final assessment of the bus lane implementation is the impact on average service efficiency. This measure is the average time associated with a public transport vehicle trip to travel through the planned route, considering both the total travel time between planned stops and the dwelling times at the stops. The benefits of implementing dedicated bus lanes in Regensburg will amount to a reduction of 8.6%, as compared to the original average service time for the bus lines in Regensburg.

In summary, the segregated bus lane implementation in Regensburg result in positive impacts. Evidence of that is the increased modal share for public transport, which is closely related to the decrease of private car trips in the city. Moreover, the segregated infrastructure promotes a more efficient bus line in the city, by decreasing the average service time, and thus, increases the overall quality of the public transport of the city. Finally, the other prominent advantage of the segregated bus lanes is the decrease in traffic-related emissions in the city, which range between 3% - 6% according to the different pollutants.

4.4.2. Analysis of APM Implementation

The evaluation of an APM service, which is implemented within a single traffic zone, requires a microscopic modelling approach. Nevertheless, as described in D5.3, a methodology was devised to explicitly include APM as a PT mode in the Regensburg Visum model. As indicated in the deliverable, this approach is a trial method. The actual implementation show that the use of this approach necessitates an undue change in the connector system in the pertinent travel zone. Hence, a more simplified approach is considered, especially taking into account the fact that the APM service focuses only on the first and last mile for PT trips.

In transport models, the first and last mile are usually reflected through the use of zone connectors. Thus, the effect of the APM could be evaluated in regard to how it will improve the connector time for the first-last mile of PT trips in Regensburg. In general, the connector travel time is defined based on the walking speed . It is expected that the introduction of APM will result in an improvement in the connector travel time, since the APM line is planned for an average operational speed of 15 km/h, while the average walking speed is 4 km/h. Nevertheless, another factor that will influence the travel time, when using the APM, is the average waiting time of the mover line ($\overline{W}$). Thus, the connector travel time is calculated based on the following equation (*Modified connector time*).

$$T_{connector} = \frac{Connector\ length}{Speed_{walking}} + \left(\frac{Connector\ length}{Speed_{APM}} + \overline{W}\right)$$

The unknown parameter in the above equation is the average waiting time. Amin-Naseri & Baradaran (2014) describe that the theoretical average waiting time for a scheduled service is half of the headway. However, other exiting literature indicate that the resulting waiting times based on this equation is an overestimation, compared to the actual value for similar services with headways of 10 minutes (Nygaard & Tørset, 2016). This statement is also supported by Amin-Naseri & Baradaran (2014), who conclude in their literature review that the theoretical average time is overestimated by a factor of 14.43%, when compared to the actual values. Considering these things, the average waiting time for APM is calculated based on the following equation (*Average waiting times for scheduled services*) from O'Flaherty & Mancan (1970), which show a value of 3 min 11 seconds.

$$\overline{W} = 1.79 + 0.14\ h$$

Based on the simplified implementation of the APM model described above, the impact of APM is evaluated based on the modal split. The first metric is to analyse the mode share changes at the level of Regensburg city. No significant change is found, which is expected as the APM lines serves only the first and last mile within a single traffic zone. The impact on mode choice due to the APM in Regensburg is insignificant since it only increases the public transport (PuT) ridership in 44 trips when compared with the bus lane prediction. However, when we take a look at the influence on the traffic zone '2038' (the zone in which the APM is located; following table; it is possible to grasp an understanding of the potential of the APM at a local level. The impact of the mover line is significant at creating more PT trips within, from and to the zone, since the APM diminishes the average PT travel time, thereby making the zone more attractive. Thus, the APM line indeed complements public transport.

Table 10. Influence on the traffic zone '2038'

Zone 2308	**Car**	**PuT**	**Car Passenger**	**Bike**	**Walk**
Bus Lane scenario					
Origin Trips	17214	816	812	1214	970
Destination Trips	16212	818	813	1214	966
Internal Trips	2708	16	26	68	141

Bus Lane + APM scenario					
Origin Trips	17214	855	814	1217	973
Destination Trips	16211	857	816	1217	969
Internal Trips	2708	17	26	68	142

4.4.3. Analysis of bike-sharing system

As described in D5.3, a base synthetic population is generated directly from Regensburg Visum model (Bus lane + APM scenario model). The base synthetic population is then enriched using random forest models. The estimated random forest models have a precision of around 82%, guaranteeing that the model is suitable for population enrichment. Followed by this step, the disaggregate mode choice model is run to calculate the demand for the bike-sharing service. It is assumed that the minimum age for the bike sharing service is 16 years and the alternative specific constant of the mode choice model is calibrated to an expected demand of 0.2% (based on the internal estimations by Regensburg city). Fishman (2016) conducted a review on bike sharing services and found out that the bike share schemes across the world attract between 0.3 trips per bike per day and 7 trips per bike per day. The expected demand of 0.2% translates to roughly 2.06 trips per bike per day. This value is reasonable, when compared to the values found for similar cities. Although the calibration for the expected demand of 0.2% will result in a high negative alternative specific constant for bike-sharing, there are combinations of attributes that result in positive utility (e.g., males with vocational or university degree, possessing PT pass, belonging to age group 20 to 44 and travelling up to 5km). Regarding the number of requests served per vehicle per day, the average value is around two. When analyzing the distances, an average trip distance value of 3km is found. Most of the trips have length less than 5km, with few trips going beyond that value, reaching a maximum of around 9km.

4.4.1. Analysis of car-sharing system

The roundtrip station-based car sharing system in Regensburg is currently being operated as a small-scale service. The estimation of demand for this service requires an external approach. As described in D4.1, a multi-method approach has been developed in MOMENTUM for the demand estimation, the results of application of which is described in this section. The model was applied for a weekday (Friday) in the month of March. The results show that the system serves 18 trips, with an average of 1.8 trips per vehicle per day. The number of trips per car-sharing station is shown in Table 11.

Table 11. Demand per station for the car sharing system in Regensburg

Station Name	Number of trips
Burgweinting	1
Candis	2
Dachauplatz	3
Königswiesen Süd	2
Landratsamt	2
Petersweg	3
Stadtamhof	3
TechBase	2

4.4.2. Impact of the shared mobility services on car-ownership

To ascertain the impact of the shared mobility services on private car-ownership, a disaggregate car-ownership model from Narayanan & Antoniou (2022)[2] is utilised. Initially, an aggregate car-ownership model described in D4.1 was planned to be used, as a disaggregate model was not available. However, Narayanan & Antoniou (2022), later, extended the disaggregate car-ownership model developed for Leuven (described in D4.1) to a global model, based on the data from three cities (Regensburg, Madrid and Leuven). Taking advantage of this later development, the impact of the shared mobility service on private car-ownership is evaluated using this global model.

The results are shown in Table 12. It should be noted that the car-sharing service in Regensburg is currently operated in a small scale with a special business model, as explained in D4.1. Furthermore, the expected demand for the bike-sharing service is also low (around 0.2% modal split). Hence, it is natural that a major reduction in car-ownership will not occur. Nevertheless, as shown in the table, the introduction of shared mobility services has the potential to reduce the private car-ownership, with 0.76% reduction in single car ownership to no car and around 1% shifting from multiple cars to a single car.

[2] Narayanan, S., & Antoniou, C. (2022). A multilevel analysis on what is common (and not) across the cities, when it comes to private car-ownership: Modelling, behavioural and policy insights. *Manuscript in preparation*

Table 12. Private car ownership in Regensburg

Without shared mobility / With Shared mobility	0	1	2
0	15.67%	0.76%	0.00%
1	0.00%	55.28%	0.99%
2	0.00%	0.00%	27.30%

4.5. Conclusions

In conclusion, it can be noted that the city of Regensburg has gained insight into the analysis of user data based on the car-sharing service. This analysis enabled the creation of models to determine demand, modal shift and vehicle ownership patterns. The tools developed were suitable for investigating the bikesharing service at Level 1 and Level 2. The results will be used in a prospective initiative to introduce a bikesharing service in Regensburg. With regard to the already existing exclusive bus lines, we were able to calculate the size of the modal shift and determine the amount of air pollution reduced. These results are to be taken into account in the upcoming expansion of the exclusive bus lines. Furthermore, we have got a first insight into the modelling possibilities of the autonomous people mover, which shows that the system can complement the existing public transport service. We will take into account the advice to take a more detailed study of the demand side in future pilot projects. Finally, the results related to shared mobility services show that such services can reduce private car ownership in the city.

5. Thessaloniki

5.1. Context description and vision statement

5.1.1. Introduction

Thessaloniki is located on the Thermaic Gulf in Northern Greece and currently accommodating more than 1,000,000 citizens in its metropolitan area it is the second largest city in Greece. According to Kallikratis program[3]the municipality of Thessaloniki consists of the historical centre and the municipal unit of Triandria and based on the latest census (ELSTAT, 2011), hosts a population of 325,182 inhabitants in a total area of about 19 km2, representing about 3% of total Greece population.

The Thessaloniki Urban Area is the contiguous densely built-up urban area around the municipality of Thessaloniki (Figure 1). It consists of the municipalities of Thessaloniki, Kalamaria, Neapoli-Sykies, Pavlos Melas, Kordelio-Evosmos, Ampelokipoi-Menemeni and a part of the municipality of Pylaia-Chortiatis. The Thessaloniki Metropolitan Area includes the aforementioned Thessaloniki urban area and the sum of the suburbs and exurbs (the rest of the municipality of Pylaia-Chortiatis and municipalities of Delta, Thermaikos, Thermi and Oraiokastro) that surround the densely built-up urban area while Thessaloniki's Regional Unit further includes the Municipalities of Lagada, Volvi and Halkidona.

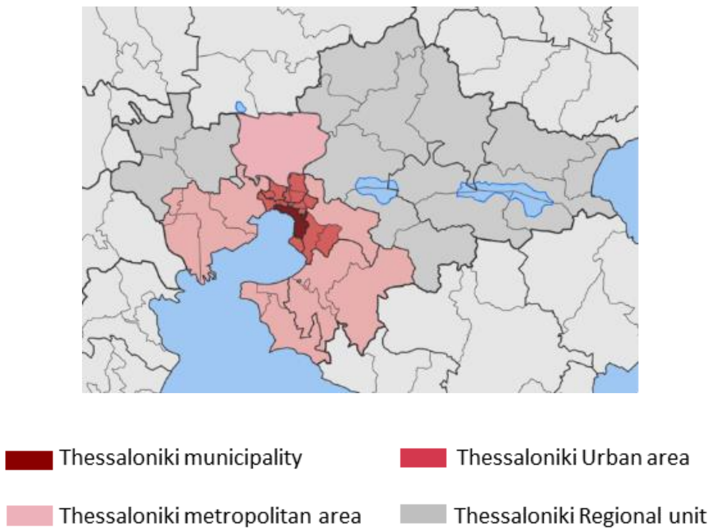

Figure 55. Thessaloniki's administrative division

[3] The Greek Law 3852/2010, which reformed Greece's administrative division in 2011 and redefined the boundaries of local administrative units is known as Kallikratis program.

The geographical location of Thessaloniki places the city among the most important social, financial, and commercial centres in the national and greater Balkan region. The region of Central Macedonia accounts about 14% of the total GDP of the country. Furthermore, due to the maturity of the mobility eco-system in Thessaloniki a transportation hub is developed within the city's limits.

5.1.2. A brief on current transport

The largest part of the Regional Unit of Thessaloniki is covered by the public transport, combining inner city and some suburban bus connections. Currently, 79 inner city bus lines operate, which ran 28.7M service vehicle kms in 2018[4], instead of the scheduled 38.8M service vehicle kms (source: TheTA strategic plan). The number of vehicles is about 622 and the number of stops in the whole area is around 3,500 (OASTH, 2019). However, it should be noted that the aged fleet and the inability to invest during the transition from the private to the nationalized operator resulted in a significant reduction in public transport supply. For those living in the outskirts there is limited possibility to reach the city centre without using the private car, especially at night, because public transportation does not operate after midnight. Six suburban bus line also operate within the Regional Unit of Thessaloniki.

Regarding active modes, although the climate and the landscape of Thessaloniki favours the bicycle use, cycling levels are very low in the city (Nikiforiadis & Basbas, 2019) since there is no connected cycling network in the city. The bicycle lanes network currently operating in Thessaloniki has a total length of 11.73 km and does not provide sufficient accessibility to bicycle users. The bicycle is currently used for leisure activities mainly across the city's waterfront where there are adequate cycling Infrastructure.

The average number of total trips is 2.6 trips per person per day (2017, Thessaloniki's SUMP), with an average trip distance of 3.5 km (2017, Thessaloniki's SUMP).

The majority of trips is conducted with private cars (44%) while 27% is conducted with public transport and 14% with non-motorized modes of transport (11% walking and 3% cycling). Trips by taxi hold the 4%, while trips with motorcycle are estimated to 11% (metropolitan area, 2018, Thessaloniki's SUMP).

Trips having at least one end (origin or destination) within the Municipality of Thessaloniki are distributed almost equally to public transport (32%) and private cars (36%), walking and cycling hold the 14% and 3% respectively and others the 15% (11% motorcycle and 4% taxis) (municipality, 2018, Thessaloniki's SUMP).

5.1.3. The need for change

The municipality of Thessaloniki is aiming to improve the quality of citizens' life and transform the city into a more sustainable place to live and has developed the Sustainable Urban Mobility Plan (SUMP) in collaboration with the Hellenic Institute of Transport (HIT). The SUMP has been developed during 2018- early 2021, in full alignment with

[4] The numbers refer to operational data of bus lines during 2018 as the most representative ones as 2019 Transport Authority of Thessaloniki S.A. was under administrative transformations that influenced its operation and since 2020 and on due to the pandemia, the available data can't be considered reliable.

the framework of instructions, terms, and procedure and the other details for the preparation of the National SUMP Law 4599/2019 and Law 4784/2021.

Future interventions of Thessaloniki's SUMP were proposed for two-time horizons, 2025 and 2030. The most important interventions for the road space re-distribution included the:

- Emblematic intervention in Egnatia Avenue, including the provision of bicycle and public transport lanes
- exclusion of part of the Tsimiski Rd to conventional private vehicles
- redistribution of public space (to pedestrians and cyclists) on main roads of the Municipality
- integrated traffic management interventions around the University Campus and Thessaloniki's International Fair areas
- Low Traffic Zones
- Parking policies and creation of Park & Ride areas
- Promotion of electromobility and electric car sharing mobility (i.e. bicycle sharing/ rental systems proposed at metro stations along the Egnatia Avenue)
- creation of new bicycle network of around 35 km until 2030
- interventions for urban logistics (including the development of the city's Sustainable Urban Logistics Plan - SULP)

On the other hand, the re-design of the public bus network was proposed as a main intervention for the public transport (PuT) system, in view of the new era of the multimodal PuT system (introduction of new public transport modes: metro, suburban railway, maritime transport). Furthermore, metro network is estimated to be operable by the beginning of 2023.

It is expected that the implementation of the SUMP's interventions during the following years will contribute to the creation of a sustainable and resilient transport system offering more suitable conditions for the integration of new mobility solutions such as the shared schemes examined in MOMENTUM.

5.1.4. Goals, values, mission and vision statement

The overall objective of Thessaloniki case study is to improve the planning and decision-making process for the introduction of resilient sustainable mobility schemes, with main emphasis in adoption of DRT, ridesharing and vehicle sharing (micromobility, bike and electric car) mobility solutions towards MaaS in the agglomeration. This will serve also to develop techniques which can facilitate proofs of concept of new mobility schemes and the to improve and extend the use of innovative data sources (Floating Car Data, point-to-point detections, social media, etc.) in the transport modelling process.

The specific questions to be addressed are the following:

- **How DRT should be implemented to contribute to sustainable mobility?** DRT systems are expected to play a role in the surrounding of the agglomeration, where the population density is low. It can be based on flexible bus lanes or on a ride-sharing service where taxis will feed the perimetral bus stations, so this choice will be explored under this question. The application of MOMENTUM tools to the case study will provide insights on the number of vehicles needed, the most appropriate service characteristics (frequency, capacity, etc.) and the pricing strategies for such a service. In addition, the techniques for an efficient clustering of users in the case of ridesharing-based DRT will be explored.
- **What is the role of ridesharing in the transport system of the city?** Ridesharing has been already implemented in the framework of the GALILEO4MOBILITY project in 2019, providing taxi-sharing services to people living in suburban and peri-urban areas (1 of each) towards the city center and back home. The tools developed during MOMENTUM will evaluate this service and possible extensions in the following

terms: How should the ride-sharing service be designed? How many people per vehicle? What areas should be served? What periods of the day? For what kind of trip purposes?

- **What are the impacts of bikesharing and micromobility in transport planning?** Vehicle-sharing schemes will perform better between the city center and the suburban and peri-urban areas for electric cars, while for bike sharing and micromobility it may work better if limited to the city center and the suburban areas only. The focus will be on its relation to cycling infrastructure, by exploring the potential contributory factors for the bike lanes network planning. In addition, the evaluation of current and planned bikesharing schemes will be done through MOMENTUM tools: fleet size, bikesharing model (dock or dockless), distribution and rebalancing operations.

The Community of Practice established in Thessaloniki played an important role in the progress of the procedure. The collection of the feedback of all the participants is a core element since the tool will address the needs not only of the municipality of Thessaloniki that will be the main user but also of the stakeholder group from the mobility ecosystem.

5.2. Community of Practice and establishment process

The Community of Practice in Thessaloniki consists of diverse mobility related stakeholders including transport operators, technology providers as well as public authorities and municipalities, as mentioned below:

- Municipality of Thessaloniki
- Major Development Agency Thessaloniki-MDAT S.A.
- Secretariat of the School of Cycling Coaches
- Municipality of Kordelio - Evosmos
- Municipality of Pylaias - Chortati)
- Municipality of Pavlou Mela
- TheTa (Transport authority of Thessaloniki)
- Thessaloniki Urban Transport Authority
- RISE scooters (shared mobility operator e-scooters)
- BRAINBOX (technology provider)
- THESSBIKE (shared bikes operator)
- Aristotle University of Thessaloniki
- LEVER consulting
- Department of Sustainable Mobility and Networks-Municipality of Thessaloniki
- Taxiway (taxi association)
- Pedestrian Association of Thessaloniki

The CoP of Thessaloniki had the opportunity to interact in two sessions-workshops in which the MOMENTUM tool was demonstrated. The diversity of the community's members paved the way of investigating different perspectives of a wide range of mobility needs of the local ecosystem. Through discussion, the CoP assessed the tool and its usability towards the achievement of an effective policy mix of the examined mobility solutions that will respond to the community needs ensuring the sustainability and resilience of the city's transport system.

5.3. Assessment procedures

The assessment procedure includes different sessions/interactions as follows

5.3.1. First CoP interaction

5.3.1.1. Date, format and approach

The 1st CoP interaction took place virtually on the 1st of July 2021 and has the form of an ideation and co-design workshop. During this first interaction, it is highlighted that since the traditional models and decision support systems for the urban mobility planning seems insufficient to respond to the emerging mobility trends, there is an imperative need for the implementation of new collaborative schemes within the cities.

5.3.1.2. Main topic of discussion

The aim of the online workshop was to present for first time the Decision Support Tool-DST for urban mobility services developed within the MOMENTUM project to the authorities and the mobility stakeholders of Thessaloniki in order to receive feedback about its functionalities. The participants were asked not to hesitate to comment on the complexity of the tool, if the results are presented in a comprehensible way and if there are more topics that they wanted to investigate.

5.3.1.3. Participants

The participants were:

- **Municipality of Thessaloniki (from different municipality departments):** Dimitrios Mitrou, Dimitra Kartsakli, Georgios Papastergios, Stavroula Lazaridou, Chrisa Zournatzidou
- **CERTH-HIT:** Georgia Ayfantopoulou, Jose Maria Salanova Grau, Maria Konstantinidou, Evripidis Magkos, Zisis Maleas
- **Municipality of Pylaias-Chortati**: Georgios Giannakos
- **Municipality of Pavlou Mela:** Nikos Ioannidis
- **OASTH:** Simos Papadopoulos
- **TheTA:** Sam Salem, Michail Karampasis
- **THESSBIKE:** Apostolos Symeonidis,
- **RISE:** Konstantinos Kountouridis

5.3.1.4. Description of the action

CERTH representatives explained that the tool will support the municipalities in the decision making for the mobility issues related to the new transport modes such as the on-demand systems including DRT and ride sharing and the shared mobility such as bike sharing, e-scooters sharing, car sharing or moto sharing. The main topics related to the DST as they were included in the presentation were summarised in the following points:

- The tool is multilevel giving the opportunity to all cities to use it depending on the level of the model they have, detailed or not. Thus, the tool is adjusted to each data type and range.

- The proposed multilevel decision support tool presented in this report consists of 5 levels. Three levels create the technical core of the decision support tool, investigating the effectiveness of different urban mobility proposed schemes to the examined areas. Each of these levels has a different level of depth of investigation.
    - level 1: City has no transport model of the city or any mobility dataset
    - level 2: City has no transport model of the city, but a comprehensive mobility data set
    - level 3: City has a detailed transport model of the city with highly granular mobility data

- Thus, a comprehensive analysis is implemented depending on various and specific transport data. The monitoring schedule will be implemented at the end of the last level applied in the decision support tool.
- The city's strategy is a preliminary level of the multilevel decision tool aiming to decide what data will be included in the model, what geospatial and existing infrastructure information will be taken into account, what types of transportation modes can be tested and what are the areas of the municipality that are more suitable for their implementation. SUMPs are a good base to be used in the city's strategy level.

Before the demo of the DST a discussion related to the questions that can be answered through the tool was taken place among the participants. The questions were summarized as followed:

- ✓ What questions would the stakeholders like to answer from the tool?
- ✓ What is really necessary and why; what should be prioritised and why.
- ✓ If the presentation of the DST results is understandable?
- ✓ If the KPIs set are appropriate?

The demo of the level 1 of the tool followed though the presentation of various examples such as a bike sharing system, an on demand (taxi-ride-sharing service), a vehicle sharing (scooter-floating) service and an on demand (DRT) service. The data and the constraints related to the area where the different solutions will be implemented were inserted in the tool. After the end of the presentation of level 1, a brief demo of level 2 for the DRT service was presented since it wasn't fully completed at that time. The results provided the optimal values of the related KPIs, and the graphs presented motivated the discussion between the companies and the public authorities facilitating the future negotiations between the operators that are mainly interested in the cost and the authorities that are mainly interested in the users' satisfaction

5.3.1.5. Main outcomes

The results extracted from the examination of the mobility services through the level 1 of the tool provided the optimal values of the related KPIs, and the graphs presented motivated the discussion between the companies and the public authorities facilitating the future negotiations between the operators that are mainly interested in the cost and the authorities that are mainly interested in the users' satisfaction.

The representatives of the other municipalities expressed their interest for the use of the tool.

5.3.2. Second CoP interaction

5.3.2.1. Date, format and approach

The second CoP interaction took place on the 23rd of November at the City council hall in a hybrid mode taking advantage of the local workshop.

Figure 56. 2nd CoP interaction at the Thessaloniki City Council

5.3.2.2. Main topic of discussion

The workshop started with the welcome speech of the mayor of Thessaloniki who highlighted the importance of the participation of the mobility related stakeholders in the planning processes. The efforts of the research community as well as of the transport operators are concentrated on the preparation of the cities to face a set of challenges derived for example from the climate change and the COVID pandemic.

Towards this direction the representatives of CERTH/HIT mentioned the goal of MOMENTUM is to develop a set of new data analysis methods, transport models and planning support tools to capture the impact of these new transport options on the urban mobility ecosystem, in order to support cities in the task of designing the right policy mix to exploit the full potential of these emerging mobility solutions. The SUMP of Thessaloniki in which CERTH/HIT provided technical support has already taken into account the different mobility challenges.

5.3.2.3. Participants

The participants that attended physically or virtually the workshop were the following:

- **Municipality of Thessaloniki (from different municipality departments)**: Zervas Konstantinos (mayor of Thessaloniki), Dimitrios Mitrou, Dimitra Kartsakli, Georgios Papastergios, Chrisa Zournatzidou, Tsikoti, Eleni Verani, Voula Tzoumaka, Maritsa Dimitra, Kontos Vasilis, Moraites Christos, Akylas Vasilis, Paliouras Dionysios, Antoniou Penelope, Charistes Christantonis, Mpalntoumis Ilias, Tsara Chrysoula-Christine, Kelesidis Apostolos, Arampatzi Anna

- **CERTH-HIT**: Georgia Ayfantopoulou (Research Director CERTH-HIT), Jose Maria Salanova Grau, Maria Konstantinidou, Evripidis Magkos, Zisis Maleas, Andreas Nikiforiadis, Maria Stefanidou, Panagiotis Tzenos, Thanasis Tolikas, Nikos Militsis
- **Major Development Agency Thessaloniki-MDAT S.A.**: Panagiotidis Lazaros, Tsakiridou Irene, Tsakiropoulou Anthi
- **Secretariat of the School of Cycling Coaches**
- **Municipality of Kordelio-Evosmos**: Vizoviti
- **TheTa** (public transport authority) Sam Salem, Michail Karampasis
- **Thessaloniki Urban Transport Authority**: Simos Papadopoulos, Christos Chatzigeorgiou
- **RISE scooters**: Konstantinos Kountouridis
- **Aristotle University of Thessaloniki**: Choutolidou Athena
- **LEVER consulting**: Katadigkas Rafael
- **TV100**: Rodakoglou George
- **Department of Sustainable Mobility and Networks-Municipality of Thessaloniki**: Lazaridou Stavroula
- **Media Suites:** Tzialla Elisavet
- **Taxiway**: Stavridis Theodoros
- **Brainbox**: Saritsamidis Asterios
- **Pedestrian Association of Thessaloniki**: Aggelidis Giannis

5.3.2.4. Description of the action

After an introduction to the MOMENTUM project, its objectives and its contribution to the acceleration of the decision-making process for the municipalities in mobility issues related to the new transport schemes, the KPIs derived from the tool in each of the three levels were presented. Then a live demonstration of the DST was showcased for two of the four mobility services (DRT service and bike sharing).

In this workshop, the main focus was on the results of level 2. For the DRT service, the trajectories file was inserted in the tool representing the required input variable of the demand. The results of level 2 gave the best scenario for the number and location of the bus stops. Duration and stop histogram as well as chart vehicles-demand coverage were also provided to the operators to help them in the more accurate cost estimation

Similarly, level 2 for the bike sharing service visualized in the map the location of the station candidates based on constraints such as maximum walking distance and number of stations inserted by the operator. The operators had the ability to insert in the tool more constraints such as distance form bike lanes and distance from bus stops and explore which of the stop candidates are more suitable for facility location in order their needs to be satisfied. In the final step, taking into account the dynamic nature of a bike sharing system, the tool provided vehicles' rebalancing routes to the operators. Finally, the level 3 which runs offline was presented giving some valuable insights for the simulation results of the examined mobility solutions.

The main points discussed among the participants were the following:

- ✓ How much the operation of a mobility solution such as a bike sharing system would cost not only for the transport operator but also for the user and the municipality.
- ✓ In a municipality that has lack of public space the efficient exploitation of part of the available public space should be included in the total ''cost''.

- ✓ It should exist a common understanding what cost includes for each stakeholder.

The next slot was dedicated to Thessaloniki's SUMP. The objectives as well as the main interventions suggested in the plan for the time horizon of 2025 and 2030 were presented. The municipality representatives mentioned that the SUMP is a milestone and for now on, it will be the guide for any future intervention in terms of urban planning in Thessaloniki.

In the final slot, the CliMoBCity 2050, a European funded project of INTERREG, that the Municipality of Thessaloniki in cooperation with CERTH/HIT and LEVER company participates in, was also presented. The pack of measures focused on the sustainable mobility and the reduction of CO2 of mobility as they were defined in the CliMoBCity 2050 were further explained. The meeting ended with the discussion on how these measures could give additional value in the SUMP and the conclusion that the MOMENTUM Decision Support Tool could benefit the successful implementation of the mobility related policies that are linked to all the interventions and measures mentioned during the workshop.

5.3.2.5. Main outcomes

The main outcomes as they derived during the discussion of the CoP of Thessaloniki in the second interaction are summarized in the following points:

- ✓ Not only the **cooperation between the mobility related stakeholder** but also the **awareness and the empowerment of the transport system users** are important for achieving multimodality.
- ✓ The creation of **an info mobility kiosk** to inform the citizens about the emerging mobility solutions giving them in parallel the opportunity to be part of the decision-making process is suggested.
- ✓ It is important for the cities to plan **a robust transport system for the existing modes** before the new emerging solutions appear and in this way the integration of the system would be easier.
- ✓ The **complementarity of the traditional and the new transport modelling methods** is needed.
- ✓ **SUMPs** are valuable sources for the suggestion of new mobility solutions
- ✓ The need of **reconstruction**, the **quality improvement** of the public transport, the **equity** in the use of the PT are high priority issues for the multilevel transport planning performed by the DSTs.
- ✓ Compensatory benefit could be asked by the municipality for providing the public space.
- ✓ Common understanding on the **cost for each stakeholder**; the cost is not only monetary, for example in the tool we have the emissions which are an indication of externalities.

5.4. Summary of the analyses carried out in the project

5.4.1. Bikesharing

The area that bike-sharing service will be located is in the municipality of Thessaloniki. This service willing to cover the demand for bike trips within the city in a dock-based form. Considering the mode choice models, data of taxi trips, and scooter trip data available for this area the average demand estimated to 80 trips per hour in the most popular time frames of the day. Given that the system is capable to serve this demand scenario it would be also able to adopt relatively moderate variations on the demand. The number of docks in each station also consider a possible increment of the demand as well as, a slack that allows users to find available parking space in each station. The Level-1 of DST used in order to examine the range in which the size and number of stations should be lie on, so that the search time eliminated to accelerate the more precise searching that take place in Level-2. For the Level-1, socioeconomic and operational costs data used based on abstract approximation according to assumptions on how such systems normally works and internal data (CERTH) from prior experience. The results of Figure 57 shows in the light blue area the acceptable region of stations and docks, that the optimal solution still holds. The actual proposal of level-1 contains 24 stations with 18 bikes each. These results produced based on the assumption that the demand is homogenous across the area, while also focus on the fairness of the solution for both passengers and the operator.

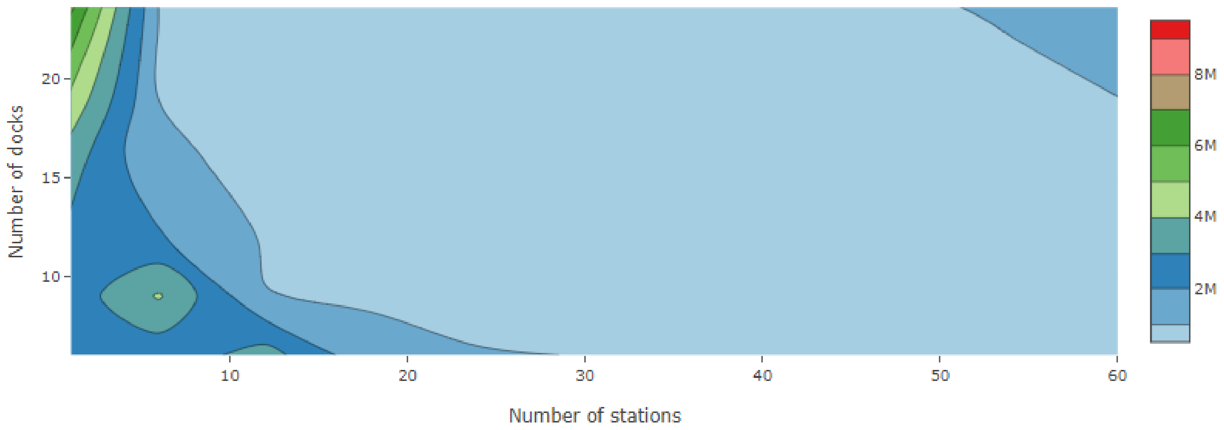

Figure 57. Level-1 System cost (includes costs of both users and the operator) in euros over different parameters of number of stations and dock size for bike sharing service

The level-2 steps beyond the uniform distribution and geometric areas assumption with the use of data that reflect the spatial distribution of the demand. For the case of both micro mobility (scooter sharing) and bike sharing a dataset of real trips leveraged produced by operations of the according services in the area of Thessaloniki. An example of this distribution depicted in Figure 58.

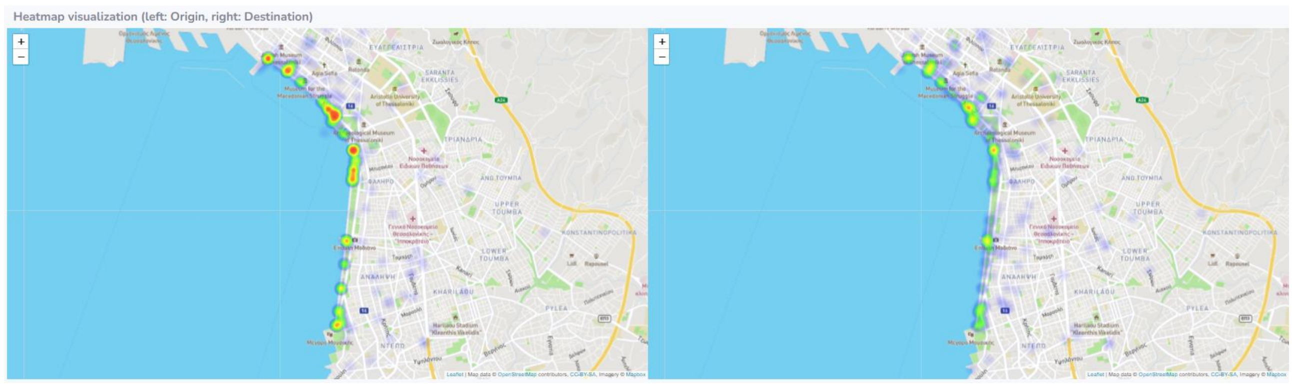

Figure 58. Level-2 HeatMap visualization of the demand

The available bike network of Thessaloniki also inserted in the related field of the tool. According to this distribution the set of station 130 candidates generated (Figure 59).

Figure 59. Level-2: Station Candidates according to DST

The next step is the use of the facility location module to define the final set of stations and the according number of docks each one should have. The final set of stops minimizes the walking distance from both the origin and the destination of each request. Moreover, the station that finally chosen are the closer to the bike lanes network. Small adjustments of the final setup established through manual allocation. The final bike sharing network illustrated in Figure 60. The capacity and the inventory of each station defined also adjusted with an offline heuristic developed especially for the purposes of level-2 and station size estimation.

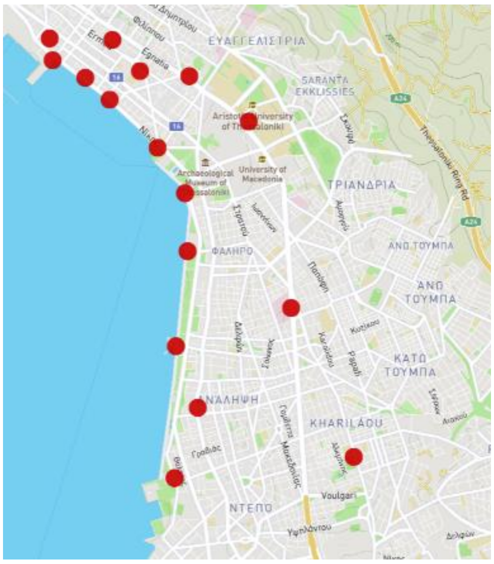

Figure 60. Bike sharing Network

The calculation of the size of each station considers the arrival/departure rates of each station. Based on those rates a queueing system simulation performed to adjust the number of docks and the inventory in each station. To examine the best strategy of setting the size a series of experiments conducted. The experiments s1 and s2 consider uniform inventory and capacity in each station equal to 10 bike/20 docks and 15 bike/30 docks respectively. The number of docks in each station defined to be double the size of the bikes to ensure a fluid operational performance. The s3 series considers that the size and inventory should related to the queueing properties of each station. So, stations with arrival rate higher than departure offer more available space while the opposite requires higher inventories and strict capacity.

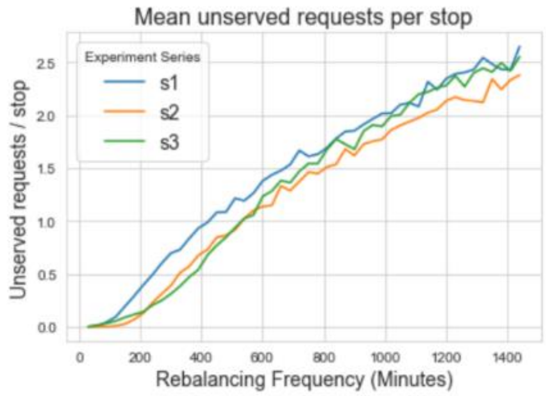

Figure 61a. Mean unserved requests per stop

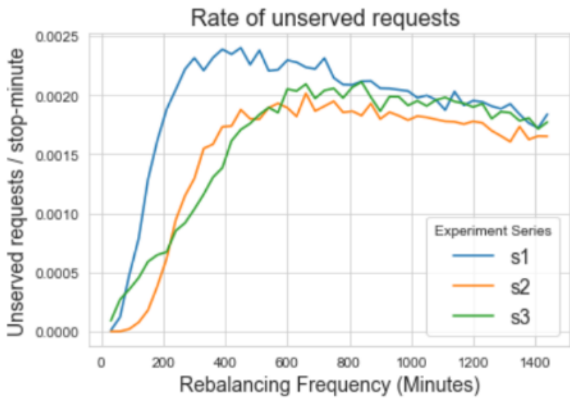

Figure 61b. Rate of unserved requests

The strategy 3 (s3) and 2 (s2) seems to perform relatively the same. However, s2 requires fewer investments in bikes and docks with nearly the same performance. Based on the 61a, b the rebalancing operation can take place every 12 hours (720 minutes) at most. To achieve this only one vehicle needed. The vehicle should group the stations into two partitions and serve the separately. This operation simulated with the use of AIMSUN ride toolset in the Level -3.

The Level-3 examines in more detail a series of service level KPIs via a series of simulation experiments that embed both the transit and the operational nature of the system. For the case of Thessaloniki, the low penetration scenario is followed in Figure 62. The existing Visum transportation model was used as the basis, along with the related demand (OD matrices) and the netwrork. Thus, demand for shared mobility services is obtained from the synthetic population module in order to generated disaggregate trips so that can be used as input to the disaggregate mode choice model. In order to enrich the synthetic population model, features such as trip destination and distance was included too. A random sampling method was users from the OD matrices from the existing transportation model. In the figure below, you can see the main input diagram for modelling and simulation of shared mobility services in the Thessaloniki.

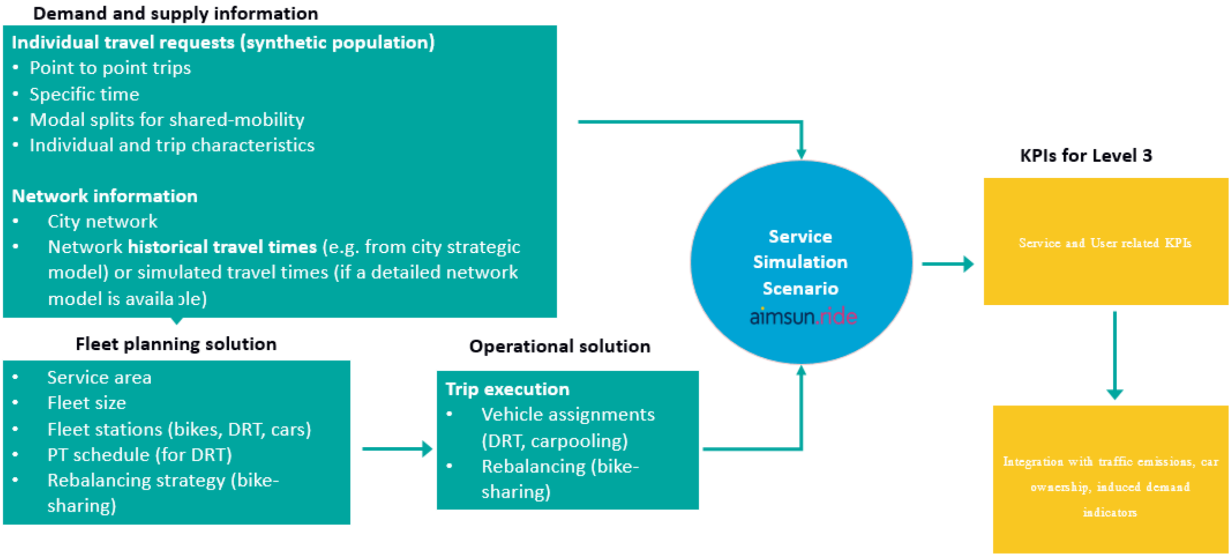

Figure 62. Thessaloniki's low penetration scenario

Following, the estimated disaggregate demand for the shared systems along with data and information related to the request characteristics, service and network supply are fed into the fleet management model, to optimize the trip plan solutions and simulate the operations to serve the demand for the shared services. More information about the synthetic population and the method of model choice model followed, we refer reader to the Deliverable 5.3 "Implementation of the MOMENTUM Decision Support Toolset in Madrid, Thessaloniki, Leuven and Regensburg".

In Thessaloniki, the services examined included the Demand Responsive Trasport (DRT) and the bike sharing system. ased on the questions of the city in previous workpackages, all kpis produced are facilitated from the online DST. It is important to be mentioned that Network's Performance Indicators such as Congestion, Traffic flow, delays, travel times and queue lengths can not be depict on the online tool. Once SP and the mode choice model are executed, user can feed the transprotation model and produce those KPIs.

For the bike sharing system in thessaloniki, the number of reuquests for the service was 75. In the image below you can see the locations of the requests.In the Table 13, are presented the KPIs from the implementation of bike sharing system in the area examined in Thessaloniki.

Table 13. Aimsun Ride Level-3 Bike sharing KPIs

KPIs	Values
Requests served	100%
Number of requests completed	75
Average Total Trip (minutes)	16.7
Max Total Travel Trip (minutes)	27.3

Min Total Travel Trip (minutes)	8.1
Average “bike” travel time (minutes)	9.5
Max “bike” travel time (minutes)	20.5
Min “bike” travel time (minutes)	3.2
Average Walking Time (minutes)	7.2
Max Walking Time (minutes)	12.3
Min Walking Time (minutes)	2.2
Average travelled distance (km)	4.5
Max travelled distance (km)	8.5
Min travelled distance (km)	2.5

In the Figure 63 below, an example illustrated where the user can see the visualized routes of the requests served. Green persons descibe the origin of the request while the red ones the destination points. In the analysis the walking distance is presented too. Finally, detailed information are presented in the table below for each rerquest.

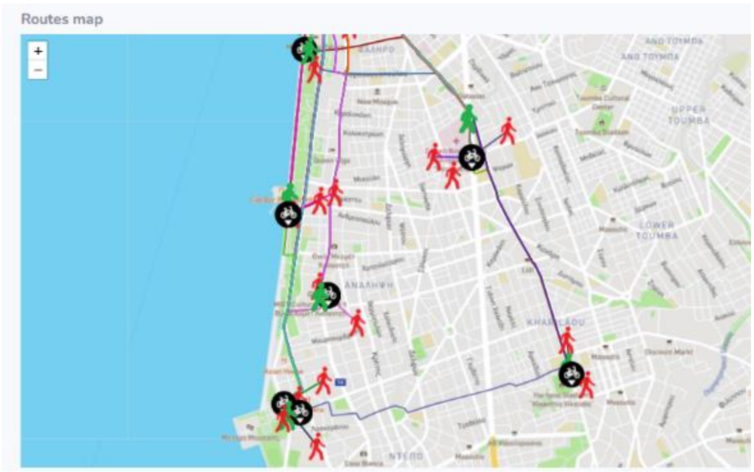

Figure 63. Level-3 bike sharing trips example

5.4.2. Micromobility

The same process applies in levels 1 and 2 for the dock-based scooter sharing service. Based on the socioeconomic and operational characteristics of scooter sharing services the optimal range (light blue surface Figure 64) for the number of stations and docks to each station.

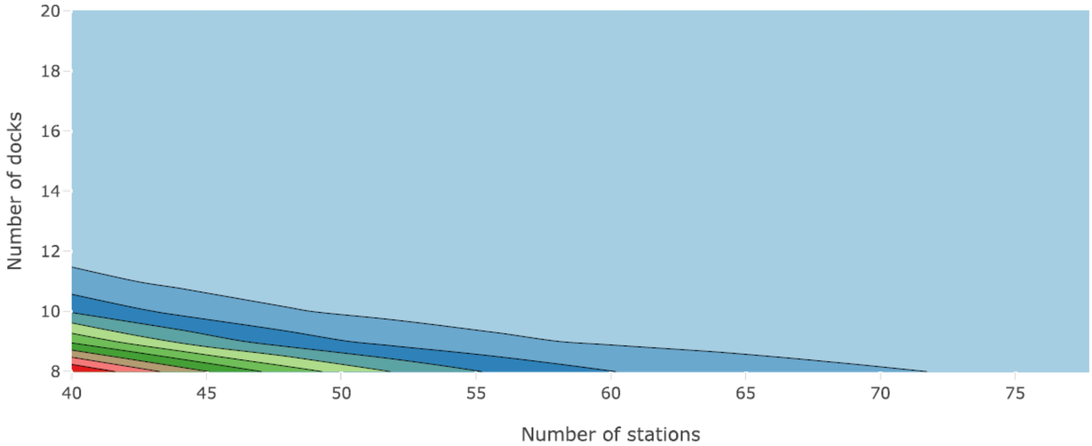

Figure 64. Level-1: System cost (includes costs of both users and the operator) in euros over different parameters of number of stations and dock size for scooter sharing service

With the use of the same approach, as in the bike sharing service, the scooter sharing locations and dock size are defined. Firstly, the spatial distribution of real scooter trips is inserted to the tool to extract the spatial distribution of the demand. According to the cluster algorithms and the goal of 300 meters of mean walking to reach a station, the set of station candidates involves 180 locations. The facility location algorithm is used to extract the optimal subset that covers the demand and defines the docks in each station. The solution takes into account the bike lanes network, the density and reachability requirements and the coverage of the demand goals. Moreover, the solution tries to establish a network that equally servers all the users as is minimizes the standard deviation of the mean walking distance across all the trips. The capacity, inventory and location of the final hubs also minimizes the rebalancing needs of the system. To do so, the queueing features extracted for each station candidate. The ratio between arrival and departure rate used as the basic variable to extract the optimal inventory and capacity of each station. In addition, this setting forces the users to choose pickup and delivery points that fit their trips while also drives the system to be more balanced and stable.

The aim of scooter sharing is to provide locations for the shift of operational model from free-float to dock-based. The final configuration of scooter sharing network contains 748 docks across 67 stations with a maximum of 500 scooters in total. The final network is presented in Figure 65. The rebalancing fleet was not in the objectives of the micro mobility test case so that the simulation also was not conducted.

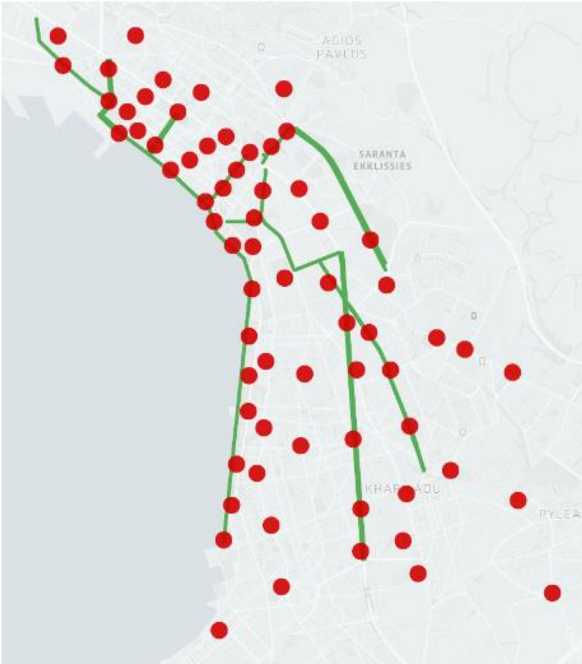

Figure 65. Scooter sharing network

5.4.3. DRT

The DRT system that examined in this test case considers fixed stations that passengers join and leave the service but flexible routes for each trip. The Level-1 considers the factors of frequency and fleet size that service should have. In fact, it estimates the optimal combination between the large, flexible, frequent, and expensive fleet to a small fleet with low service levels and significant waiting and travel times. Given the demand from 60 to 160 trips/hour the estimated fleet size is 8-18 vehicles. However, this estimate aims to serve all the demand. Alternatively, in the level-2 the city examined the situation to serve a portion of the demand to save big investments in fleet size and make the implementation of the service intractable. Moreover, a fleet size between 20-40 seats may also achieve to reduce the size of fleet while in parallel serving larger part of the demand.

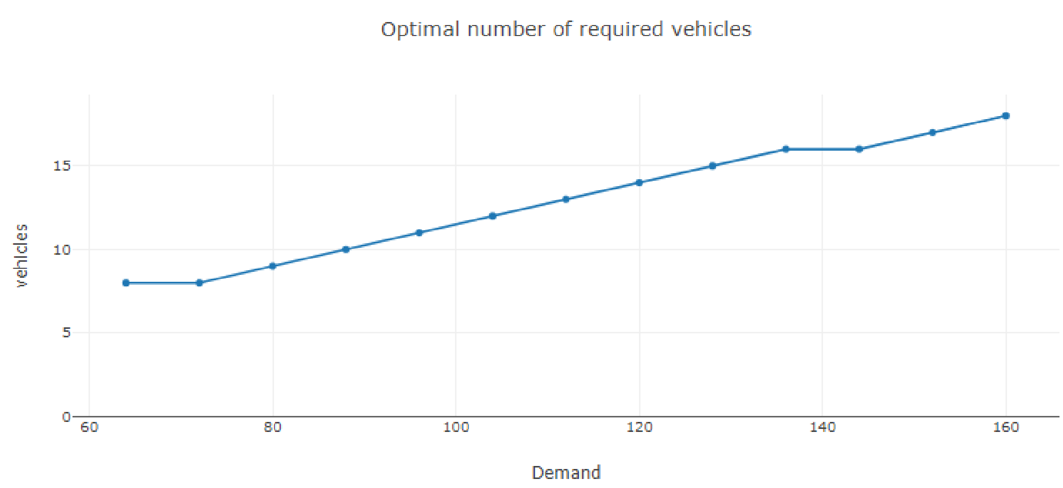

Figure 66. Sensitivity analysis of DRT fleet size over demand scenarios

In level 2 car floating data were used to extract the spatial demand patterns in the areas of Thermi, Panorama and Pylaia. Four steps were executed:

- Data preprocessing and formatting for feeding the tool
- Extraction of stations candidates
- Extraction of the stations' final location
- Fleet size and capacity definition through simulation experiments

The red spots in Figure 67 represent the system's stations as they were extracted in step 3 via the Mixed Integer Programming (MIP) Facility Location Problem considering also the preexisting stops of the public transport network. The selection of the final locations considers not only the demand distribution but also the trade off between the walking distance to reach the stop and the increasing operator's cost for setting a large number of stations. The number of stops is 18, depot included. The average walking distance is 200 meters for a user to reach a stop. The average distance from one stop to the closet is about 1.2 km.

Based on the results about the location of the final stops, the Transport Authority of Thessaloniki S.A. (TheTA) is currently pilot testing a DRT line within the framework of MultiDEPART project, funded by the EIT UM.

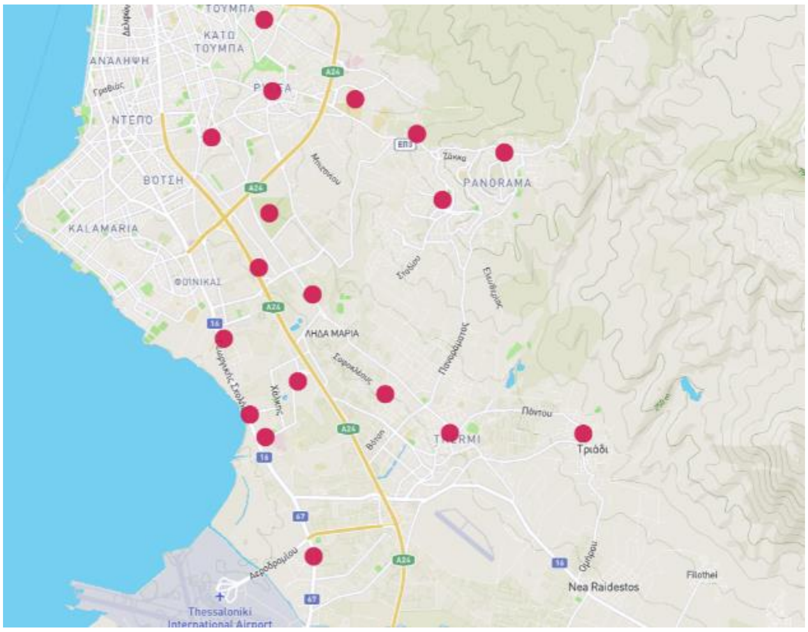

Figure 67. DRT stations network

Based on data of taxi trips the estimated demand is 80 trips per hour or less in the low demand case and 120 trips per hour in the high demand hours. However, there is a need to design a system for future demand that might be induced as the service success. For that reason, the scenarios of 160 and 200 trips per hour also examined.

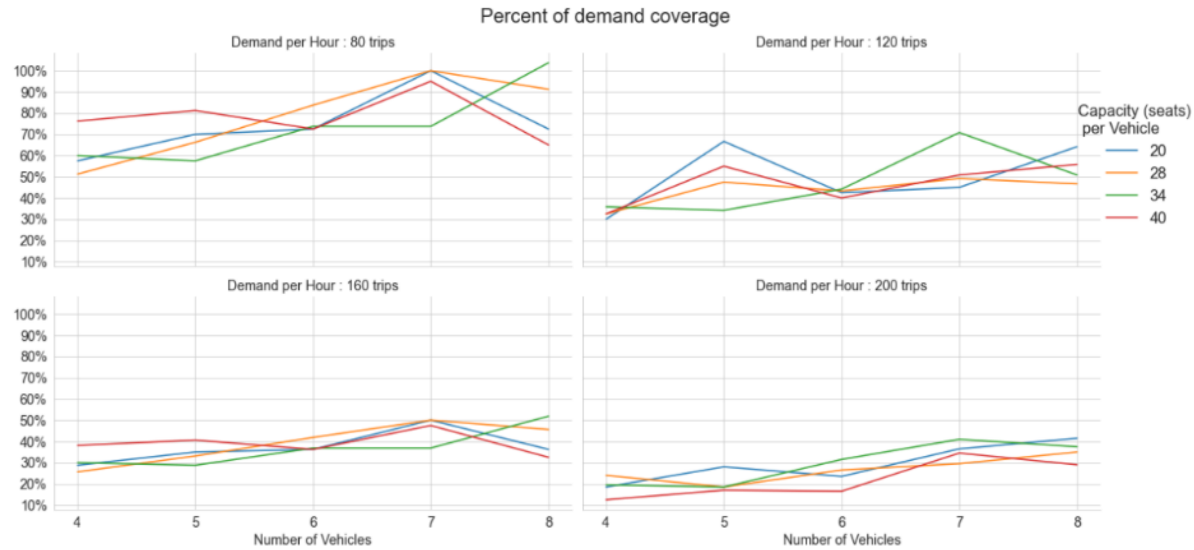

Figure 68. Demand coverage over different capacity and fleet size parameter configurations

Need to cover demand of 70% - 80%. The base scenario is that we will have 80 trips per hour during peak hours. Thus, the available options are to use:

- 6 vehicles of 20 or 28 seats.
- 4 vehicles of 34 seats

- 4 vehicles of 40 seats

In case that the demand increases to 160 trips per hour (+100%) Figure 68 the system will need extra resources in some cases. For instance, in case of 24 seats vehicles the system will need more that 7 vehicles το achieve the same goal. Similarly, the same demand can cover with 1 more 34 seat vehicles. However, in case we choose 4 vehicles of 40 seats vehicles we can also respond to that rapid increment of the demand.

Figure 69. Mean occupancy over different capacity and fleet size parameter configurations

In level 3, for the case examined, the fleet configuration consists of 4 DRT vehicles with 40 seats capacity. This scenario aims to examine the schema of small fleet size with large capacity and how affects the travel time. Indeed, the serve of the whole demand costs higher travel times. Small capacity vehicles of 20-28 seats in a size of 7 vehicles would be more appropriate. Relevant KPIs can be obtained from the service. Preliminary results that correspond to the KPIs of the requests assigned to the DRT service in Thessaloniki are summarized in Table 14. The KPIs presented, describe the results of 4 DRT buses serving the 170 requests. For the given fleet supply and according to the solution obtained from the fleet optimization algorithm, 6 requests could not be served.

Table 14: Aimsun Ride Level 3 KPIs of the service

KPIs	Values
Requests served	96%
Number of vehicles used	4
Number of requests completed	164
Average Total Travel Time (minutes)	72.3
Max Total Travel Time (minutes)	115,1

Min Total Travel Time (minutes)	34.6
Average “in vehicle” travel time (minutes)	49.3
Max “in vehicle” travel time (minutes)	105.7
Min “in vehicle” travel time (minutes)	6.3
Average Waiting Time (minutes)	23
Max Waiting Time (minutes)	44.7
Min Waiting Time (minutes)	7.3

Details about the 4 vehicles operating in the preliminary test of the DRT service in the city of Thessaloniki, are summarized below, in the Table 15.

Table 15. Aimsun Ride fleet utilization statistics from level 3

Vehicles id	Requests served	Travelled Distance (km)	Time Busy (minutes)
2a021bc0-0aaa-4e22-a029-8069f3b41eab	23	40,08	189
b30ad759-9e69-434b-8073-cf8c3638bf7b	43	62,87	300
6d678585-fec7-4d88-8ff0-e1d891d7950e	48	45,69	238
bd6925c9-5ebb-48f8-bd94-38c627dd912e	50	56,12	290

The exported results from the online Decision Support Toolset are presented in the figures below. In the Figure 70 depicted all routes for the 164 requests served for the DRT service in Thessaloniki. In this figure you can see the origin and the destination of every accepted request, along with the followed routes of the buses.

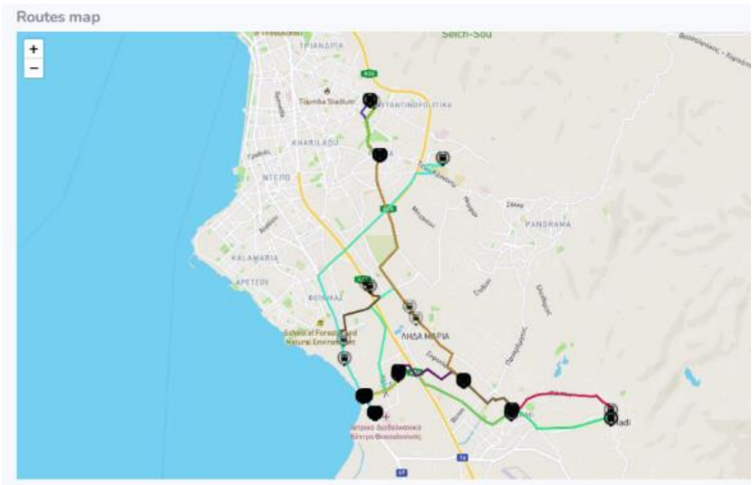

Figure 70. Example of DRT illustrated routes from DST Level-3

5.4.4. Ridesharing

In this section, the ridesharing system in the city of Thessaloniki is examined, using the implementation of Level 1 available tools. In this section, three different scenarios were examined with different demand values. For the area where the ridesharing was tested in Thessaloniki, the calculated demand was 120 trips/hour. The 3 scenarios include an overestimation of the demand, so the real demand falls to 80trips/hour, a future increment of the demand or an under estimation of current situation to 200 trips/hour, and the average/base scenario of 120 trips/hour. Thus, for the examined scenarios different values of demand were tested. The remaining input values needed for level 1; the default values calculated for Thessaloniki were used. Two different values for the maximum waiting time parameter are tested. The other parameter is the maximum number of passengers sharing the trip. The higher the number of this value and the maximum waiting time value the more profitable is the service for the operator. However, extensive waiting time and overcrowded trips are inconvenient for the passengers. Moreover, the fleet size should be easily extensible for a future increment of the demand induced due to the success of the service, while in parallel considering the case of an optimistic estimation of the demand that will cause low utilization of the service. For instance, for the 3 pax and 10 minutes max WT scenario the optimal fleet size is 18 vehicles. The same value for the 5 minutes max WT increases to 28. Indeed, the service willing to operate in high quality standards to encourage citizens adopt such sustainable sharing services. So, even that reducing the waiting time by 50% requires 10 more vehicles according to Table 16 that fleet could also serve higher demands even in the case of 200trips/hour. However, for the starting phase the service chooses to start with 24 vehicles with even 4 passengers each and waiting time if 5 minutes.

Table 16. Fleet size of Ride Sharing Service with max WT: 10 minutes

Max waiting time: 10 minutes	Max Capacity: 4 passengers	Max Capacity: 3 passengers
Scenario 1 – 80 trips/hour	8	10
Scenario 2 – 120 trips/hour	11	18

Scenario 3– 200 trips/hour	19	20

Table 17. Fleet size of Ride Sharing Service with max WT: 5 minutes

Max waiting time: 5 minutes	Max Capacity: 4 passengers	Max Capacity: 3 passengers
Scenario 1- 80 trips/hour	18	22
Scenario 2 – 120 trips/hour	**24**	28
Scenario 3– 200 trips/hour	26	30

5.5. Conclusions

The results extracted through the MOMENTUM DST gave to the municipality of Thessaloniki some useful insights on the questions set in the beginning of the project.
The definition of the specific area that could offer the most suitable conditions for the implementation of the new mobility services was among the main priorities of the municipality. This topic was examined through data exploratory analysis in the WP3, and the characteristics of the defined areas results were considered during the design phase.

Therefore, the bike sharing and micromobility schemes are more suitable for urban areas with existing bike lanes network since it is easier to develop additional infrastructure for their operation in these areas. Moreover, such urban areas are characterised by short distance trips including last-mile and for this reason they seem to offer better conditions for the successful development of these services. It is worth mentioned that the number of the suggested stations for the bicycles is quite smaller than the one of the e-scooters due to the lower bicycle demand in the examined area.

Regarding the DRT service, the aim of the municipality was the connection of the urban areas with the peri urban ones. The DRT service will feed some existing public transport stops in the border of the urban area, combining thus this new on demand mode with the currently operating public transport to reach the city center. According to the experiments that were conducted, larger fleets with smaller capacity significantly reduce the trip duration of the passengers while also increasing the demand coverage capability of the services.

Finally, examining the operational parameters of a ride sharing service, it was concluded that such services are more attractive in the beginning when they offer low waiting time to the passengers in the lower possible cost. For this reasons, larger fleets were suggested and as the demand raises the waiting time also increases while the mean occupancy and the trip duration are decreased.

The CoP of Thessaloniki participated actively in two sessions-workshops in which the different perspectives of a wide range of needs of the local ecosystem related to the examined shared mobility services were investigated thanks to the MOMENTUM decision support tool. Through the assessment procedure, the responsiveness of the KPIs extracted of the DST to the community needs and its usability was evaluated, having always in mind the achievement of an effective policy mix of new mobility solutions that will ensure the sustainability and resilience of the city's transport system.

6. Final outlook

D6.2 gathers the policy assessments carried out in the four cities regarding the different use cases, as well as a summary of the extensive and deeper analysis developed within the technical work packages of the project, with the aim to also help and feed onto WP7 for the development of guidelines and recommendations for other cities to maximize the replication potential of MOMENTUM successes.

All city partners and their CoPs agree on the relevance of the analyses and developments carried out in the framework of the MOMENTUM project and the importance of being able to incorporate all the new mobility services that are appearing in the transport modelling processes to be able to develop better urban policies that allow extracting the full potential and minimising the possible negative impacts.

As an overall conclusion, the four MOMENTUM cities remark that:

- Cooperation is essential, thus the relevance of using a Community of Practice not only to promote more fluent exchange of information and approaches but also to promote a better public-private cooperation.
- It is a challenge to cope with fast and dynamic evolution of new mobility solutions (e-scooters, CAVs...)
- Digitalization puts new fine-grained data sources on the table as an opportunity for disaggregating our models and therefore, sharing data, data collection and data standardization plays a key role.
- Modelling efforts have to deal not only with use but also with adoption and its impacts (e.g. car ownership. Besides the traditional transport modelling approaches, data-driven approaches can also enable insights on travel behaviour of users or target groups for shared mobility options. These insights can support policymaking.
- Cities require flexible tools to be able to deal with evolving services, but also to be aware of different data availability and technical skills contexts. Practical tools, such as the DST developed under the scope of MOMENTUM, help cities improving the decision-making process.
- Still room for improvement regarding simulation and planning of shared mobility solutions: operational costs, externalities (i.e. environmental costs).
- Local context matters. Implementations of mobility services can differ significantly from one city to another, so it is difficult to have one tool that can deal with all possible configurations and uses of these services.