HARMONY

Holistic Approach for Providing Spatial & Transport Planning Tools and Evidence to Metropolitan and Regional Authorities to Lead a Sustainable Transition to a New Mobility Era

D7.1 Multimodal Land Networks- Initial version

@Harmony_H2020
#harmony-h2020

https://www.linkedin.com/company/harmony-h2020/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

Part of: CIVITAS

SUMMARY SHEET

PROJECT

Project Acronym:	HARMONY
Project Full Title:	**Holistic Approach for Providing Spatial & Transport Planning Tools and Evidence to Metropolitan and Regional Authorities to Lead a Sustainable Transition to a New Mobility Era**
Grant Agreement No.	**815269 (H2020 – LC-MG-1-2-2018)**
Project Coordinator:	**University College London (UCL)**
Website	**www.harmony-h2020.eu**
Starting date	**June 2019**
Duration	**42 months**

DELIVERABLE

Deliverable No. - Title	**D7.1 Multimodal Land networks - Initial version**
Dissemination level:	**Public**
Deliverable type:	**Report**
Work Package No. & Title:	**WP7 - Supply and multimodal network models**
Deliverable Leader:	**Aimsun**
Responsible Author(s):	Grant Mackinnon (AMS), Thorsten Schneider (AMS) Tamara Djukic (AMS)
Responsible Co-Author(s):	Francesca Fermi (TRT), Angelo Martino (TRT) ,Nellie Tzivelou (OASA), Sridhar Raman (OCC), George Economidas (OCC),Jos Streng (RDAM)
Peer Review:	Manos Chaniotakis (UCL), Angelica Salas Jones (UoW)
Quality Assurance Committee Review:	Lampros Yfantis (UCL-MaaSLab), Manos Chaniotakis (UCL-MaaSLab)
Submission date:	28/12/2020

DOCUMENT HISTORY

Version	Date	Released by	Nature of Change
0.1	10/11/2020	Aimsun	**Initial version for internal review**
0.2	25/11/2020	Aimsun	**Draft version for internal review**
0.3	12/12/2020	Manos Chaniotakis, Angelica Salas Jones, Lampros Yfantis	**Revision and comments**
0.4	24/12/2020	Aimsun	**Authors addressed comments**
0.5	28/12/2020	Aimsun	**Final version**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

EXECUTIVE SUMMARY

This document provides an overview of methodology and data used for building and updating multimodal land transport networks, required for the design, implementation and testing of the models within the Operational simulator of the HARMONY MS. The data-driven and simulation-based models to predict the traffic state and demand in the network, require different level of multimodal transport network representation. This document details how graph and network model for the various levels of simulation models are constructed, as well as a workflow to build a network model. The simulation software Aimsun Next and VISUM are used in this project. They represent a true advantage of the HARMONY Model Suite – that is a software-agnostic integrated land-use and transport model system, capturing the transport system dynamics that new services and technologies introduce; based on state-of-the-art behavioural and operational modelling approaches. It is worth noting, that this report represents a set of guidelines in the land network models development process, while actual built models can be demonstrated in corresponding traffic simulation software tools, Aimsun Next and VISUM.

The presented multimodal land networks in this Deliverable represents supply, in terms of existing infrastructure and public transport services resulting as updates, or extensions of existing network models for the participating pilot sites in Oxforsdhire, Rotterdam, Turin and Athens. The level of graphs and infrastructure detail, whether macro-, meso- or micro- scopic, depends on the requirements and maturity of existing models and use cases at the pilot sites. The developed networks have the capability to simulate demand and supply at the operational level of the HARMONY MS, representing within-day interactions of simulated agents. The demands to be used as part of the simulated networks will be the ones generated from the models resulting from the activities of WP5 (passenger) and WP6 (freight).

Results from all four pilot sites (Oxfordshire, Rotterdam, Turin and Athens) and their further update and extension based on a performance assessment, use cases and calibration and validation study, will be provided in D7.1 “Multimodal Land network – Final version” in M33 of the HARMONY project.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269
Part of: 2020 CIVITAS

1. Introduction

1.1. Project summary

HARMONY's main vision is to develop a new generation of harmonised spatial and multimodal transport planning tools, which comprehensively model spatial organization and the changing transport sector's dynamics, enabling in such a way regional and urban planning organizations to lead the transition to a low carbon new mobility era in a sustainable manner. At the same time, though, HARMONY goes beyond the design of just a model suite in many ways. Stakeholders from both the public and private sector are actively engaged in both regional and cross-metropolitan co-creation labs to share their requirements with regards to integration of traditional and new transport modes, utilization of new technologies and sustainable regional developments. In such a way, a co-creation philosophy is adopted, where project developments and processes are based on stakeholder's needs. The facilitation of the co-creation labs will be enabled through activities taking place in six EU metropolitan areas (HARMONY pilots) on six TEN-T corridors, i.e., Rotterdam (NL), Oxfordshire (UK), Turin (IT), Athens (GR), Trikala (GR), Upper Silesian-Zaglebie Metropolis (PL).

Furthermore, due to the well-known complexity of transportation systems in our cities, together with their fundamental role in terms of environment, quality of life and economic growth, research in analysis and prediction of traffic phenomena is gaining a growing importance. While we now have more data, more computing power and higher recognition of the importance of understanding traffic in our cities, the problem is still very complex as it quickly reaches high dimensionality with large networks, multiple measurements, data sources, traffic control systems, and high and heterogeneous demand patterns. An approach to deal with this complexity is by using traffic simulation models. In HARMONY, simulation of transport systems and mobility plays an important role, because it can be used to study models too complicated for analytical or numerical treatment, can be used for experimental studies, can study detailed relations that might be lost in analytical or numerical treatment, and can produce attractive visual demonstrations of present and future scenarios.

The concept of HARMONY is to assist metropolitan areas by providing a state-of-the-art model suite that quantifies the multidimensional impact of various concepts, soft and hard policies on citizens' quality of life, sustainability, economic growth, while identifying the most appropriate solutions and recommending ways to exploit advances in mobility concepts to achieve their goals. As illustrated in Figure 1, the fundamental complexity of such an endeavour is addressed by disentangling and organizing the workload into six main axes (A1- 6).

This deliverable contributes to the fulfilment of HARMONY Axis A4. The methodology and data documented in this deliverable were developed in the context of Task 7.1 in the HARMONY project as part of phase 1 which corresponds to the first half of the project. The presented methodology and data relate to how existing transport models in HARMONY pilot areas have been leveraged to meet use cases and operational models' requirements. Since the HARMONY Model Suite will be implemented, either partly or fully, for the trailblazing (Rotterdam (NL) and Oxfordshire (UK) and aspiring (Turin (IT), and Athens (GR)) areas, in this deliverable an extension of simulation models in Trikala and GZM has been omitted.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

Part of: 2020 CIVITAS

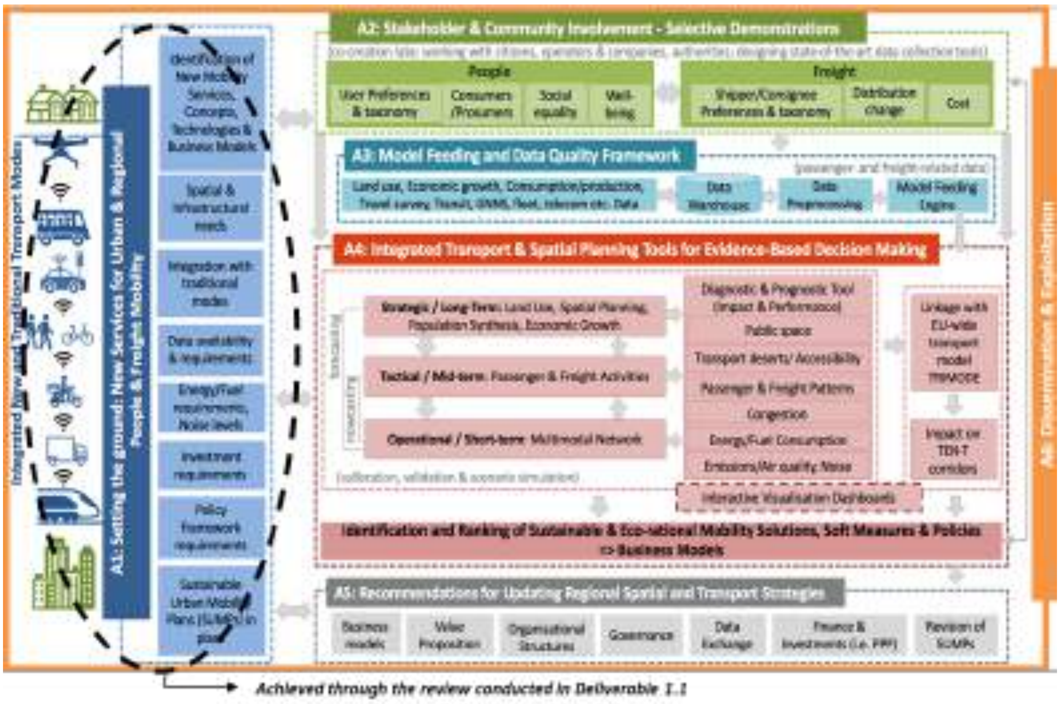

Figure 1. The HARMONY conceptual architecture.

The land network models reported in this deliverable, will be further refined and calibrated during the second phase of the HARMONY project, to cope with specifications of each HARMONY pilot's use case defined in Deliverable 9.1 and the modelling tools developed in WP4-WP7.

1.2. Deliverable Objectives

The aim of this report is to document the development of demonstrators and to provide a technical view explaining the methods with initial preliminary results. Each section starts with an overview that provides a general introduction to the topic followed by a more technical description of the network modelling techniques. For this Deliverable 7.1, data on the existing models has been collected and use cases as well as the scope were defined. The network has been extended and updated as well as data sources assessed and evaluated.

A network model corresponds to multimodal land network representation of transport system supply side at macroscopic, mesoscopic or microscopic level in traffic simulation software, and essentially constitutes an extension of the objects and attributes to represent transport network and individual vehicle behaviour. The network representation requires more detailed data including, public transport system, freight system, traffic control plans, pedestrian crossings, signalized nodes and intersection control type.

Once the network representation is built in traffic simulations software, the essential challenge in building the network model becomes the calibration of all the supply and demand parameters in order to reflect the real traffic phenomena. We do not describe extensive verification or calibration and validation of the updated multimodal land networks against data, as this will be the subject of Deliverable 7.6.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

1.3. Deliverable structure

The body of this report consists of seven chapters:

- **Chapter 2** describes model development and utilisation process, and defines data for network representation in traffic simulation software tools
- **Chapter 3, 4, 5 and 6** presents how each of the HARMONY pilot area networks – Oxfordshire, Rotterdam, Turin and Athens – is defined in terms of its geographical demarcation and the respective data that has been collected to construct a network model. The latter consists of a graph representation embedded with traffic and transit information as well as traffic control and MaaS services.
- Finally, **Chapter 7** describes the plan for implementing the multimodal land networks detailed in this deliverable to HARMONY case studies and discusses the outlook for further update and extension of presented network models in the context of the project.

2. Network Representation and Simulation Models

2.1. Model development and utilisation process

The general process that has been followed for the development and utilization of network models for HARMONY in the simulation software Aimsun Next or any other traffic simulation tool is presented in the list below. It follows the typical network model development and data utilization steps:

1. **Identification of use case scope** – Identification of the use case's purpose, spatial extent, appropriate model, and level of expertise.
2. **Selection of modelling approach and simulation model** – Identification of the modelling approach and type of simulation (microscopic / mesoscopic / macroscopic / hybrid) to be used.
3. **Data collection and preparation** – Collection of data required for the development of the network model. This step includes collecting data from traffic monitoring systems, conducting field data collection, reviewing base maps, retrieving information from data warehouses, or requesting data from specific agencies. It also includes checking data validity, processing and reducing data to extract specific information, and formatting data for their use in data-driven and simulation-based models.
4. **Base network model development** – Creation and coding of sections, nodes and turns representing the road network geometry, definition of the geometric characteristics of each section, node and turn, insertion of traffic control elements and public transport, specification of travel demand matrices, and setting of simulation parameters.
5. **Error checking** – Checks for coding errors that can affect the execution of data-driven and simulation-based models. Refinement of the geometry to fit technologies requirements and error-checking is an important modelling step as coding errors and geometry shape carried through calibration or delivered to HARMONY project partners can significantly affect results. This is an iterative process with step 4, where parameters, modelling network geometry, traffic demand, traffic control devices and driver behaviour are reviewed to ensure they provide valid and logical values.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

6. **Network model calibration** – Adjustment of network and simulation model parameters to reproduce traveller behaviour and traffic performance. This involves the establishment of calibration targets, selection of appropriate calibration parameters to reproduce observed roadway capacities and route choice patterns, and calibration of model parameters so that its performance matches data from field observations.

Transport network graph is typically output after steps 4 (base network model development) and 5 (error checking), while the full network model requires further calibration and validation developments. Once the network graph and model development is completed, network models are delivered to the use cases leaders for approval, before it could be used to evaluate WP4-7's technologies or shared with other HARMONY work packages. In many cases during this development process, the approval process was done iteratively with the network graph development and network model calibration.

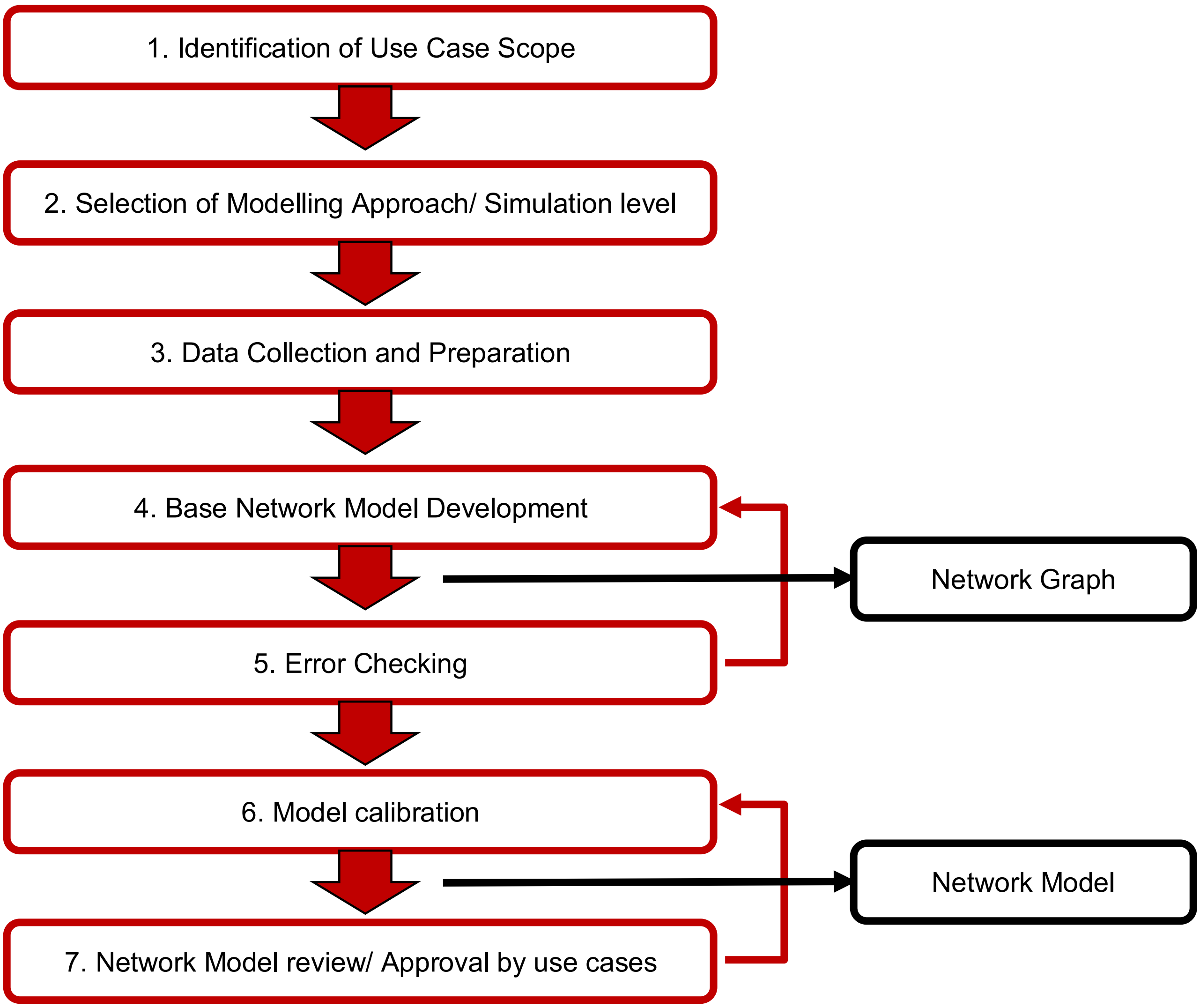

Figure 2. Workflow process for network graph and network model development

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

2.2. Data Requirements to build model

Building network model for application in microscopic simulation models typically requires more data than other types of modelling approaches, such as macroscopic models. For example, microscopic models have typically greater data requirements due to the need to model individual vehicle behaviour in detail. Mesoscopic models may require slightly less data depending on the simplifications made in their behaviour models. Macroscopic models typically require the least amount of data, as traffic behaviour is usually only characterized by flow rates, average observed speeds, and observed link densities.

The required data to build the network model for each use case can typically be grouped into the following categories:

- **Network geometry** – Data describing geometrical aspects of the use case area, such as the location of intersections, road widths and shapes, slopes, the number of lanes on each section, equipment used for monitoring traffic performance, etc.
- **Demand** – Data, expressed in number of trips, capturing distribution of trips between the various origin and destination nodes for different modes. Rules followed by travellers to select a path within a network may also be included in this category.
- **Traffic control** – Data characterizing the operation of traffic signals and ramp meters, priority schemes for transit vehicles at signalized intersections, etc.
- **Transit operation** – Data characterizing the operation of public transport, such as transit routes, vehicle composition, stop locations and service schedule.
- **Network traffic state and performance –** Data characterizing how traffic behaves along roadway elements, such as volumes, speeds, travel times, location of bottlenecks, etc. Data should be collected for all critical time periods being studied, e.g. AM peak, Midday peak, PM peak, event-based period (e.g. service operation period).

More specifically, Table 1 provides a more detailed presentation of data required for the development a network model.

Table 1:Overview of data required for building use case's graph and network models in HARMONY

Data Category	Data Sub-Category	Data items
Network geometry	Road geometry elements	• **Road/section shape, length, curvature and slope** • **Road category** • **Number of lanes** • Purpose of lane (general traffic, HOV vehicles, managed lane, etc.) • **Allowed turnings directions at the node** • Lane utilization: turnings from lane to lane (through lane, left-turn lane, etc.) • Pedestrian crossings • Placement of traffic signs along roadway links • **Node/intersection layout** • Slope

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269
Part of: 2020 CIVITAS

Data Category	Data Sub-Category	Data items
	Basic Functional parameters	• **Section maximum speed** • **Section Capacity** • Section user defined costs • Turn maximum speed
	Traffic Monitoring	• **Location and type of traffic sensors**
Traffic control	Intersection control	• **Type of intersection control (stop sign, yield sign, traffic signals)** • **Type of traffic signal control (fixed time, actuated, traffic responsive)** • Signal timing plan (start time, cycle length, yellow, phases, green) • Arterial signal coordination plan (offset relative to other control plans) • Data interchange interface for actuated and adaptive control plans
	Ramp metering	• Type of ramp meter • Metering plan • Location of traffic sensors
Demand	Vehicle fleet characteristics	• Vehicle mix • Truck percentages and/or volumes • Vehicle occupancy
	Traffic zones	• Zone boundaries • Centroids and connectors
	Travel patterns	• OD flow matrices • Network entry flows, if OD matrices are not used • Mode shares (*only if for models including transit or non-vehicle modes*)
	Motorway traffic patterns	• Freeway mainline counts • Freeway ramp volumes
	Arterial traffic patterns	• Link counts along major arterial segments • Intersection turning counts
Transit operations	Public transport data	• **Transit routes (ideally GPS based, GTFS file)** • **Stop locations** • **PT Service schedules and headways (including stop-time mean and deviation**) • Fleet size and composition • Signal priority scheme
Network performance	Traffic state and behaviour	• Volume, speed and occupancy data from mainline loop detector stations, on-ramps, off-ramps, tube counts • Travel times along major arterial segments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

Data Category	Data Sub-Category	Data items
	Bottlenecks	• Time bottleneck stations • Location and extent • Cause of bottleneck

Two major factors often drive data requirements: developing an accurate graph representation of the existing transport network elements and ensuring that simulated and/or predicted flows replicate observed behaviour. The modelling of network geometry in a graph form can be seen as a relatively straightforward process since it generally relies on the fixed and well-defined elements, that can be imported from Open Street Maps (OSM) and other GIS-based files, or from the existing network models available in traffic simulation software. Data items in bold format presented in Table 1 represent the minimum information required to build abstract transport network representation as a graph. The remaining data listed in Table 1 are used to ensure that simulated and/or predicted flows replicate observed behaviour in the network.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

3. Oxfordshire supply network model

3.1. Definition of the network model scope for Oxfordshire use case

Oxfordshire is a county in South East England, covering an area of more than 2500 sq. km. Oxfordshire is home to around 666,000 people, an increase of over 10% in the past decade. The county is divided into five district council areas, with a quarter of the county's residents living in Oxford city.

It sits on the busy road and rail transport corridor between the south coast ports, the Midlands and the north and enjoys easy links to London and West Midlands. However, it suffers a lack of connectivity to and from the east, in particular to the high-value growth areas around Milton Keynes and Cambridge. The county is the second more rural area at the UK's South East, with a combination of urban (both historic and modern), peri-urban, highways and rural locations.

The urban region of Oxford city, and two counties of Bicester and Didcot have been selected for use case, described and defined in Deliverable 9.2, as depicted in the pink area in Figure 3.

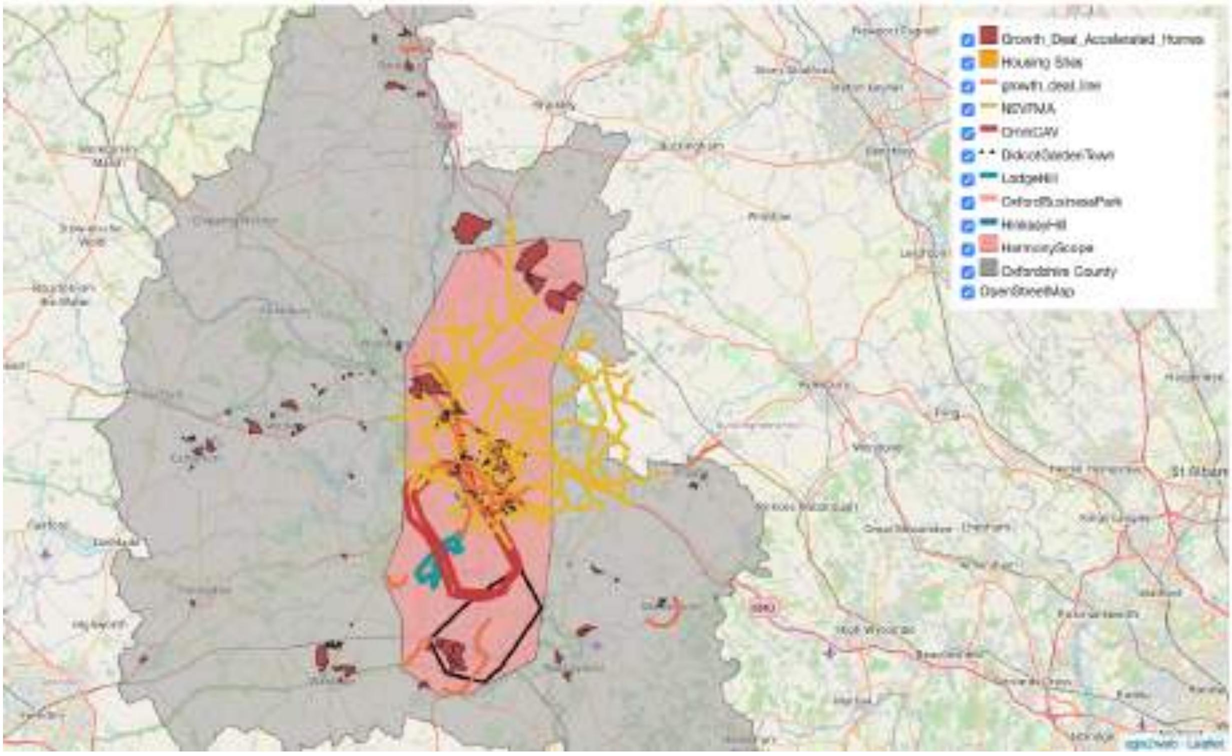

Figure 3. Overview of the Oxfordshire network model scope for HARMONY project.

The generic characteristics of the transport network's representation that covers the urban region of HARMONY'S Oxfordshire network model are:

- Size (km): 11,00 x 40,00
- Network type: Urban and Interurban
- Number of Centroids: 256, the final to be determined

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

- Number of Detectors: 230
- Number of sections: 3234, the final to be determined
- Number of nodes: 1672, the final to be determined
- Type of signal controllers: Fix

This area was chosen based on its complexity and data availability, the need to address fairly high congestion levels, the main mobility critical points inside the city and the fact that part of the network is already available in the Aimsun Next simulation software. By modelling this area, we can leverage prior work, support utilization of the model in other projects for Oxfordshire county and ensure its compatibility with regional travel demand model for mobility planning needs. The result is a dynamic, lane-based network model, with individual vehicle generation and an extensive toolkit for representing traffic management operations, from local area to complete urban level, that can ensure complete consistency with Santander use cases and mobility goals.

The existing transport system and policies relevant to use cases in the Oxfordshire county area can be summarized as follows:

- *Oxford*

Oxford town is located in the centre of the county. Its metropolitan area houses nearly 250,000 people. The M40, connecting London and Birmingham, passes Oxford City in the east. Originally planned to be implemented by the end of the year the introduction of the Zero Emission Zone (ZEZ) has been postponed to presumably summer 2021. Based on a road user charging scheme the city centre would be open free of charge for zero emission vehicles. Other vehicles will have to pay £10 from 2021 and £20 from 2025. Later the initial red zone is to be extended to a green zone covering nearly the whole town.

Oxford is served by multiple bus and coach lines by different operators. Numerous buses are using hybrid technology. Also, it is worth mentioning that according to the latest census data, Oxford is the UK town with the second highest percentage of people cycling to work.

Figure 4. Oxford (Google Earth) and Didcot and Milton Park (Google Earth)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

- *Bicester*

Northeast of Oxford the town of Bicester can be found. The fourth most populated town in the county is home to over 32,000 people. Bicester is connected to the M40 via Junction 9 in the west of the town. It also features a ring road. Stagecoach offers services to Oxford and Banbury. Also, the X5 bus line from Oxford to Cambridge stops in Bicester

- *Didcot*

Didcot is a small town of more than 25,000 inhabitants (6th most populated in Oxfordshire) just south of Oxford. West of Didcot the mixed-use business and technology park “Milton Park”, served by bus lines X2 (Oxford-Didcot-Wallingford) and X32 (Oxford-Didcot-Wantage), can be found.

3.2. Data collection and application to extend and refine the network model

Table 1 compiles the data that are, most commonly, used to develop network models in simulation software, such as Aimsun Next. The provided and collected data for Oxfordshire use cases are generally consistent with the requirements outlined Table 1. This consistency was expected since data and network model have been provided by Oxfordshire that actively participated in the definition of the model scope and use cases.

Major sources of data available in Oxfordshire for the network model extension and update at mesoscopic and microscopic level include the following:

- **Existing network model** – Network model with geographical representation of the network at microscopic level in Aimsun Next software has been developed for NEVFMA[1] project (the Network Emissions / Vehicle Flow Management Adjustment (NEVFMA)), owned by Aimsun. The NEVFMA project, funded by Innovate UK program for R&D, aimed to prove that linking the technology is useful in improving network understanding and decision support, allowing traffic operators to holistically balance their road network. The project proved that further development of connected multiplatform ITS reaps the full potential of existing assets: existing technology that was previously unconnected can now provide never-seen-before levels of network traffic state understanding, proving the benefit of various technology, data and models integration. The NEVFMA model represents two levels of the transport network supply:
    - Mesoscopic area – inner green area with a high degree of transport system supply representation. Vehicle interaction is modelled at the individual vehicle level. The roads have lane based geographic capacity and can represent horizontal queuing. This gives a very detailed network with all the implication of junction delays modelled.
    - Macroscopic area – area outside of the green circle, that extends within scope of the strategic Oxfordshire Strategic Model from 2013, with less detailed transport system supply representation. Traffic flows are modelled at a macroscopic level with speed flow curves applied.

[1] https://gtr.ukri.org/projects?ref=971680#/tabOverview

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

As can be seen in Figure 5, no minor roads are represented in the Aimsun Next model and only zones within the NEVFMA area are defined. Also, bus lines are cut off at the green dashed line.

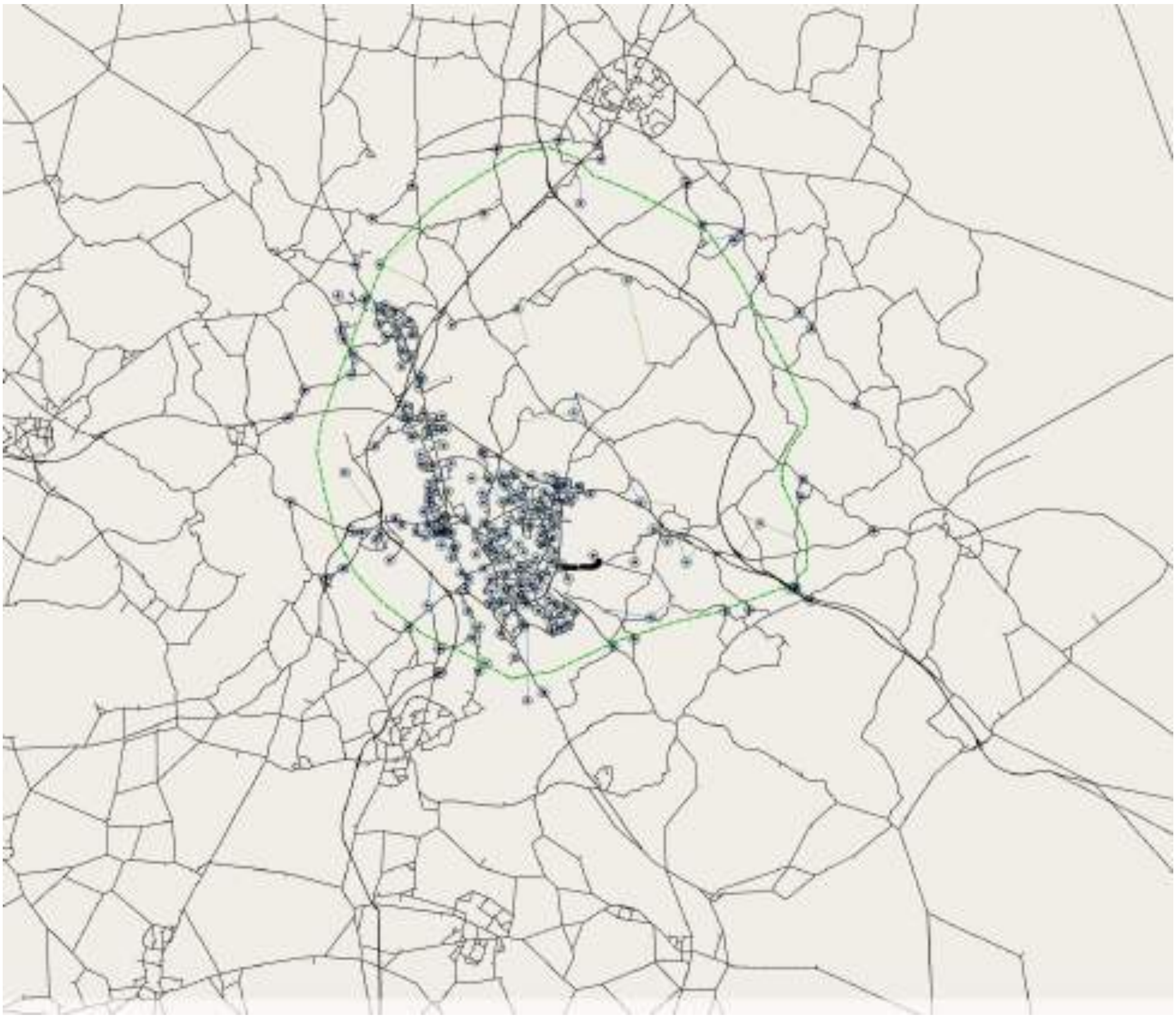

Figure 5. Extend NEVFMA Model in Aimsun Next

- **Road Network - Link Detail**: The OpenStreetMap source (Highway layer) contains significantly more links than the NEVFMA network for the Bicester and Didcot areas, as shown in Figure 6 and Figure 7. Such links are expected to be required for the use cases, so OpenStreetMap network imports for the detailed study areas will be the basis for the highway network, with relevant information brought down from the NEVFMA import where necessary. This new network will be connected to the Harmony Area network to support wider spatial coverage of the scenarios.

Link properties include:

- Road classification - general classification of the way e.g. Primary, Secondary, or Residential.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

- Speed - posted speeds are included in the OpenStreetMap source or applied according to road classification. Speeds may be modified to reflect local conditions, e.g., way geometry, narrow nature of passable way, or as a result of other interactions.
- Number of Lanes - lane information is included in the OpenStreetMap source
- Vehicle restrictions - such as lane reservation for buses, taxis, cycles

Elevation is not expected to be relevant to the sites or use cases selected.

The imported network geometry will be edited to improve the state of the network for modelling (for example to adjust alignment, to remove unwanted artifacts, or to update lane availability)

Model level specific properties, such as:

- Static level properties - Volume Delay Functions, Capacities
- Dynamic level properties - Jam Density, Reaction time variation

will be assigned at the calibration stage.

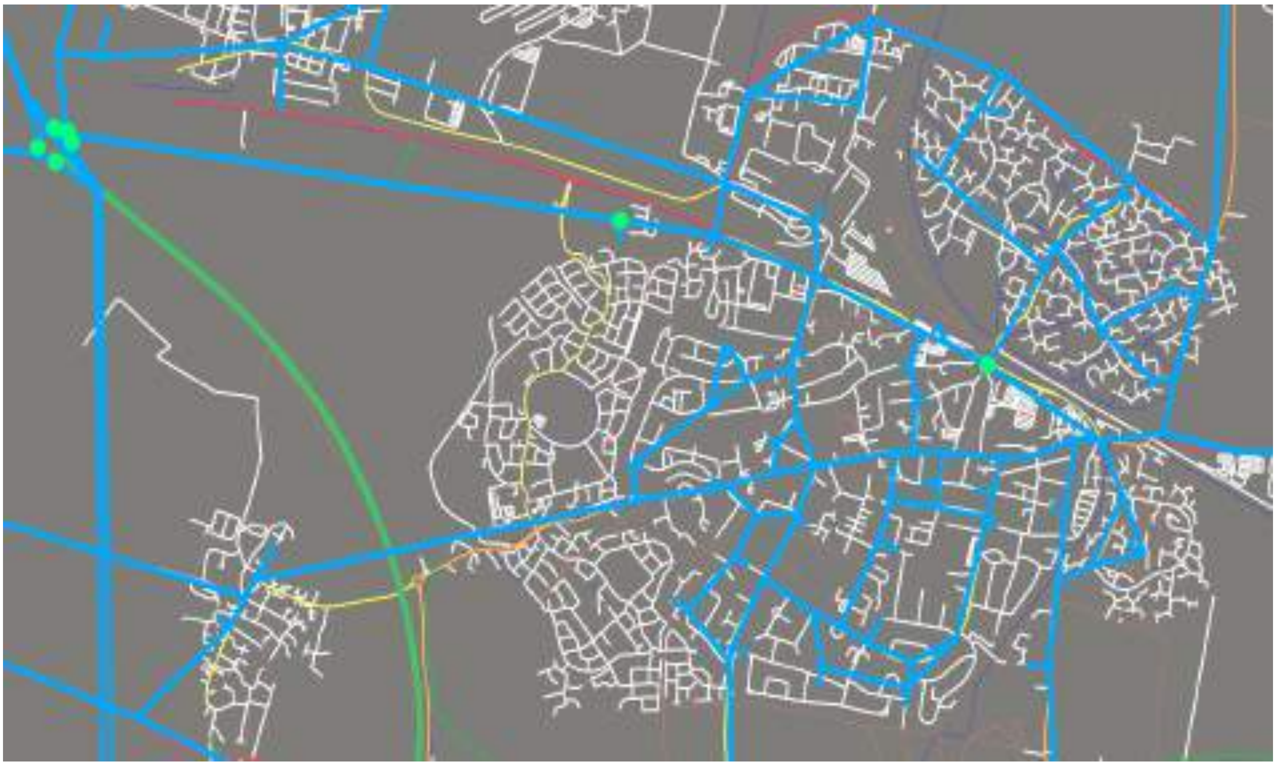

Figure 6. NEVFMA network (blue) compared to OpenStreetMap network for Didcot study area. Green spots show traffic signals in the NEVFMA model

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

Figure 7. NEVFMA network (blue) compared to OpenStreetMap network for Bicester study area, Green spots show traffic signals in the NEVFMA model

- **Road network - Intersection detail:** Traffic Signals (locations, settings)**,** Priority Intersections

UK roads consist of a variety of intersection types including grade separated junctions, give-way junctions, roundabouts and signalized intersections.

Unsignalized intersections can be coded based on explicit priority information, or priority may be inferred from road classification of links into the intersection, with checks based on aerial photography, public sources of local photography, site drawings, etc. Such sources can indicate available movements, as well as restrictions for certain vehicle classes (e.g., no right turn except for buses or taxis).

Signalized intersections are generally more challenging to model. Where the locations of intersections are often indicated on the network, precise details of traffic signal operation are more difficult to obtain. Signal operation can be based on fixed time plans that might be varied based on current time of day, or on timings that vary based on current local conditions (calls for green time from local detection, such as MOVA, which can be described as actuated) or regional traffic conditions (adaptive systems such as SCOOT which attempt to optimize traffic flow for a region). Depending on the goal of the model, plus availability of information, fixed time plans may be sufficient to represent typical signal operation of an actuated controller or controller in an adaptive system.

Figure 8 and Figure 9 show the indicated positions of traffic signals (including those for pedestrian crossings) according to the OpenStreetMap source.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

Figure 8. Location of traffic signals in the Didcot study area (green circles)

Figure 9. Location of traffic signals in the Bicester study area (green circles)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

Details of traffic signals will be requested for signalized intersections in the study area. However, details of system functionality can often be difficult to obtain (under control of various entities) or indeed reproduce (complex logic), so traffic signal information might be brought down from the NEVFMA model (only certain locations are available), or other existing models where identified or available, or will be requested from the road authority.

- **Public Transport Supply -** Public transport systems in the base model will include bus and rail services.
- **Bus services -** Bus services are imported from the UK TransXChange/NaPTAN2 data sources (i.e, the UK nationwide standard for exchanging bus schedules and related data) using a custom script. Bus services run along the highway network, so public transport lines and stops are assigned to the highway network. PT schedule plan information is also imported. Figure 10 and Figure 11 show the results of an initial import onto the OpenStreetMap network.

Figure 10. Result of the Import of public transport from NaPTAN/TransXChange onto the Didcot area OpenStreetMap network (lines in blue, stop locations as red spots)

[2] https://www.gov.uk/government/collections/transxchange

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

Figure 11. Result of the import of public transport from NaPTAN/TransXChange onto the Didcot area OpenStreetMap network (lines in blue, stop locations as red spots)

- **Rail Services -** Rail services are imported from a corrected General Transit Feed Specification (GTFS)[3] file, which will be used to generate a skeleton point to point network for the study area, including location of stations. A resulting network of an initial import is shown in Figure 12.

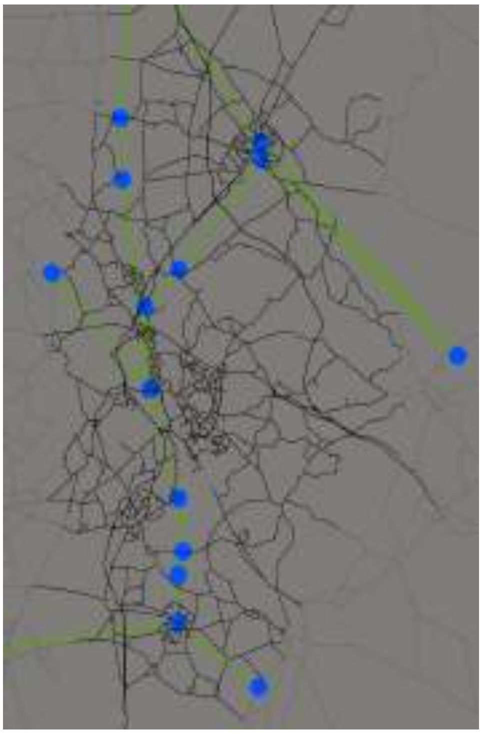

Figure 12. Rail network (green lines) and stations (blue spots) for the Harmony project area. The existing road network from the NEVFMA network is shown in the background black.

3 https://developers.google.com/transit/gtfs/reference/#general_transit_feed_specification_reference, https://en.wikipedia.org/wiki/General_Transit_Feed_Specification

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

- **Cycle network** - The cycle network provided by OCC, shown in Figure 13, has been imported into the model to assist in the lane reservation tasks, identification of interaction points with other road traffic for calibration tasks, as well as for connection of additional links for active transport scenarios.

Figure 13.Existing Oxfordshire identified cycling network in the Oxfordshire Harmony model area, shown in orange

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269
Part of: 2020 CIVITAS

4. Rotterdam supply network model

4.1. Definition of the network model scope for Rotterdam use case

Rotterdam is a port city, and the second largest city after Amsterdam, located in the province of South Holland in the Netherlands. The extensive distribution system including rail, roads, and waterways have earned Rotterdam the nicknames "Gateway to Europe" and "Gateway to the World". The municipality of Rotterdam occupies an area of about 325 km2 (208 km2 of which is land), and is home to 640,000 inhabitants, about 25% of the population of the Rotterdam–The Hague metropolitan area. The metropolitan area consists of almost 66 municipalities and is inhabited by almost 4 million people.

In terms of transport infrastructure, Rotterdam offers connections by international, national, regional and local public transport systems, as well as by the Dutch motorway network. At urban level, public transport services include an extensive metro network of about 78 km, operated by 5 lines, a tram network of about 93 km, offering 13 lines, as well as 55 city bus lines with a total length of about 430 km. Finally, there is a Waterbus network consisting of seven lines.

According to the Netherlands Mobility Survey (MON), about 49% of trips are made by cars, 17% by public transport and the residual 34% with active modes (16% by bike and 18% walking).

The Rotterdam city centre area has been selected as a study area at operational level, to address use cases described and defined in Deliverable 9.2. The extent of the network model scope with main roads is presented in Figure 14. The area covers the central train station in the north, the S100 in the west, Coolsingle and Schiedamsedijk in the east and Katendrecht in the south.

Figure 14. Study area in Central Rotterdam (Google Earth)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269
Part of: 2020 CIVITAS

The characteristics of the transport network representation that covers Rotterdam central area are:

- Size (km): 6,00 x 11,00, the final to be determined
- Network type: Urban
- Number of centroids: agent-based simulation
- Number of detectors: 234, the final to be determined
- Number of sections: 14882, the final to be determined
- Number of nodes: 7803, the final to be determined
- Type of signal controllers: Fix

This area was chosen with the support and advise of the Rotterdam City Council and led by network model availability in the Paramics and OmniTRANS simulation software, provided by Significance and Rotterdam city. By modelling this area, we can leverage prior work, support utilization of the model in other projects and ensure its compatibility with other models available in Rotterdam city for delivery and freight planning and management, as well with city passenger mobility planning. Further network model development in Aimsun Next provides Rotterdam city the opportunity to work together with compatible tools and benefit from both to answer the questions at hand. Here, we illustrate the opportunity of modelling in Aimsun Next using network model at macroscopic level in OmniTRANS and microscopic model in Paramics as a starting point.

4.2. Data collection and application to extend and refine the network model

The provided and collected data for Rotterdam use cases are generally consistent with the requirements outlined in Table 1. This consistency was expected since data and network model have been provided by Rotterdam city that actively participated in the definition of the model scope and use cases.

Major sources of data available in Rotterdam for the network model extension and update at mesoscopic and microscopic level include the following:

- **Road network - link detail:** Road and infrastructure geometry of the Rotterdam city centre area, imported from OpenStreetMap in Aimsun Next, is shown in Figure 15 a. The graph model includes a metro and tram public transport system. Figure 15 b) shows a closer look for more detailed view of imported cycle lanes (orange), footpaths and pedestrian areas (right side).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

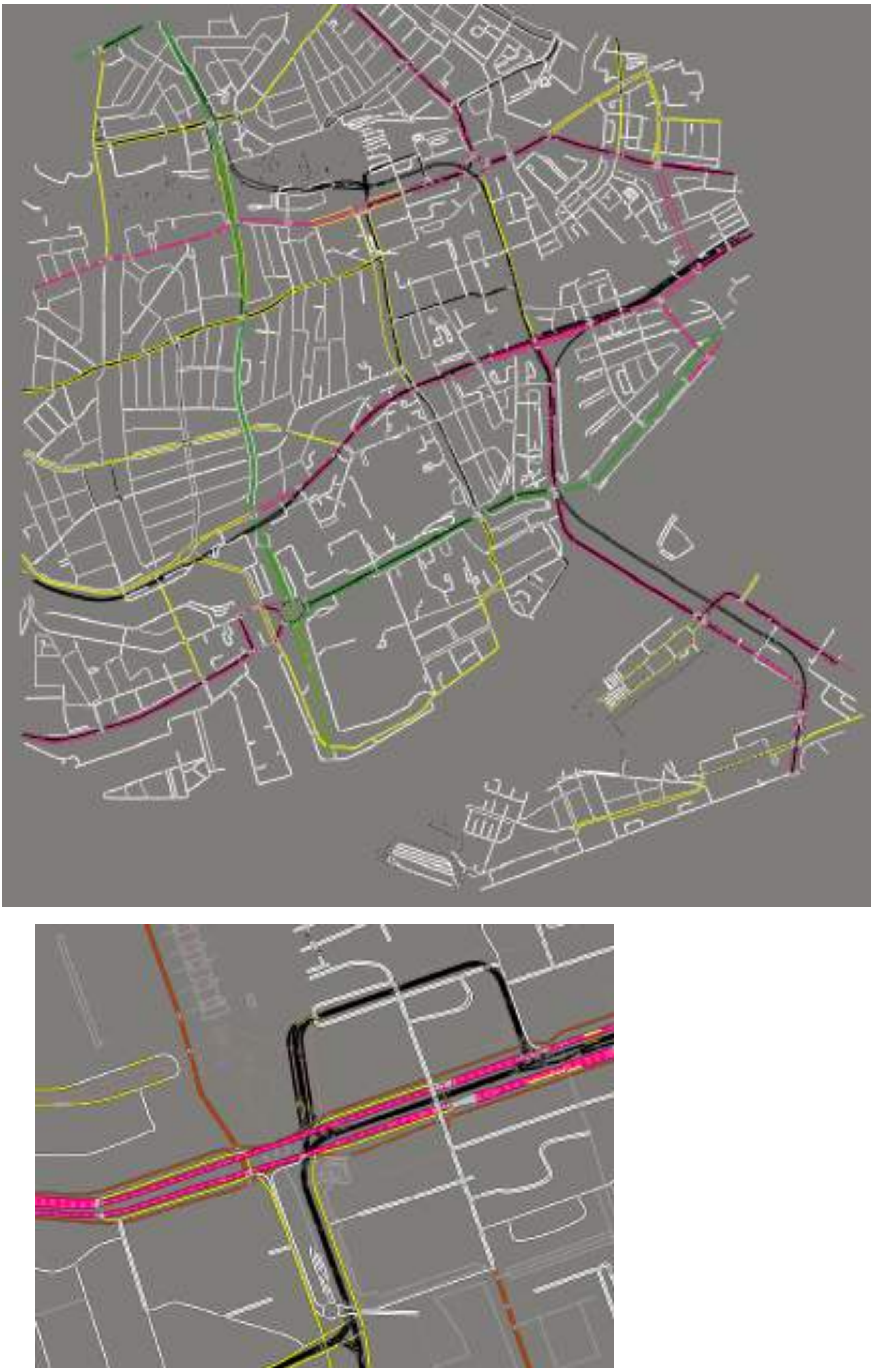

Figure 15. a) Graph model of Rotterdam pilot in Aimsun Next, imported from OpenStreetMap, including Tram and Subway lines, b) detailed view of tram and subway network in the graph model.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

Import of the land network models from Paramics and OmniTRANS traffic simulation software, as presented in the Figure 16, shows the difference in detail of both networks compared to the OpenStreetMap background. To support use case scenarios, we expect that network elements missing from existing models will be required, so the supply network will be detailed to this link level.

Figure 16. Graph networks of Rotterdam study area with import of the microscopic network model in Paramics software (blue) and macroscopic network model in OmniTRANS software (orange)

- **Road network - Intersection detail:** traffic flow priority settings for non-signalized intersections may be inferred from the imported road hierarchy, determined from aerial photography, or be indicated by attributes in the existing model networks. The network model in Paramics contains traffic signal information which may be brought down to our network layer. Comparison in Figure 17 shows good coverage of signal locations.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

Part of: 2020 CIVITAS

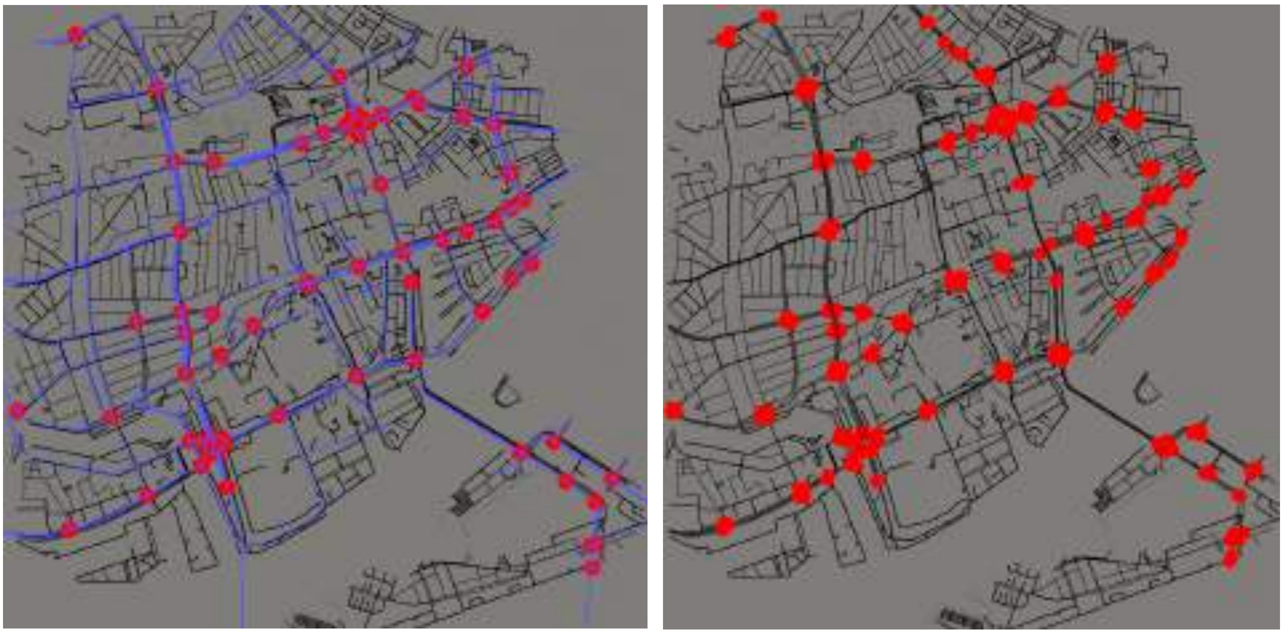

Figure 17. Location of traffic signals in Paramics model (left) compared with indicated positions of traffic signals from OpenStreetMap (right)

- **Public Transport Supply -** While public transport has not been explicitly mentioned in scenarios for Rotterdam use case, public transport operations can have significant impact on other vehicles traversing the road infrastructure. Figure 18 shows the result of public transport GTFS data for the Netherlands (filtered for bus and tram only) import onto the OpenStreetMap graph network in Aimsun Next.

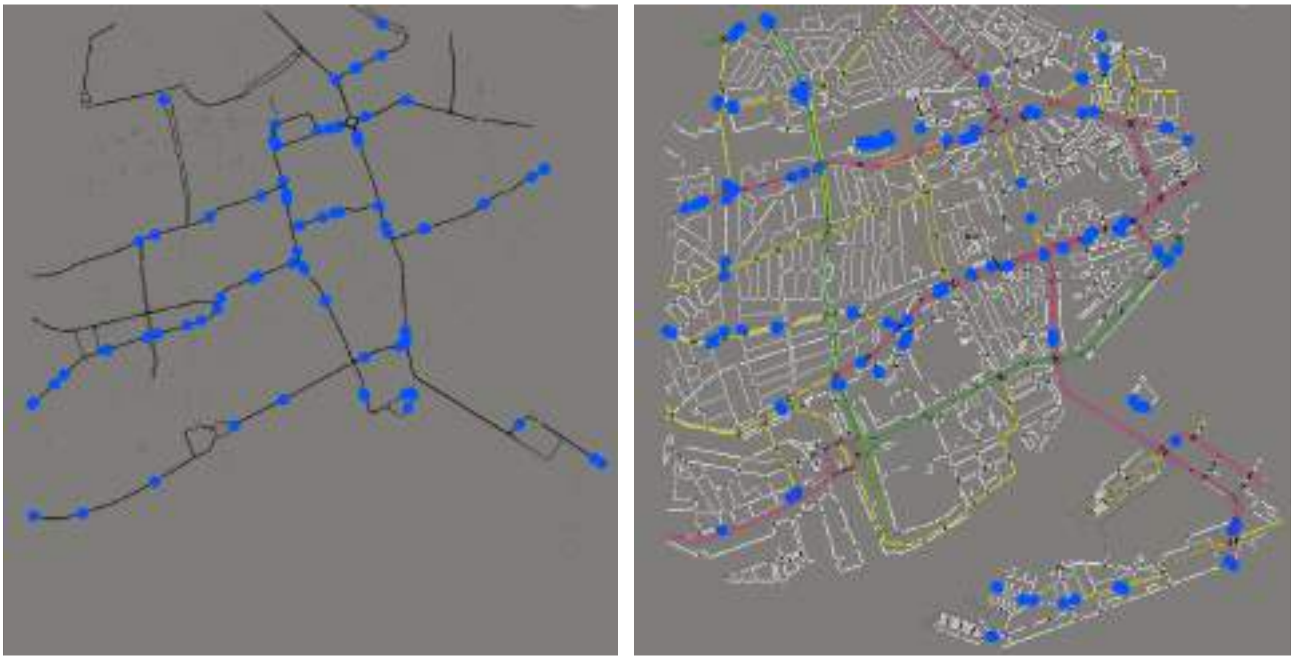

Figure 18. Result of GTFS import for study area. On the left is shown the tram network and served stops by imported services, on the right the same for bus services

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

5. Turin supply network model

5.1. Definition of the network model scope for Turin use case

The study area is the Turin Functional Urban Area (FUA) which includes the municipality of Turin and 87 municipalities within the province of Turin. The total population of the FUA is about 1,75 million inhabitants (as of 2018), of which about 870,000 inhabitants live in the Municipality of Turin. Figure 19 shows the location of the Turin Municipality within the FUA area and the Turin province in Piedmont, Italy.

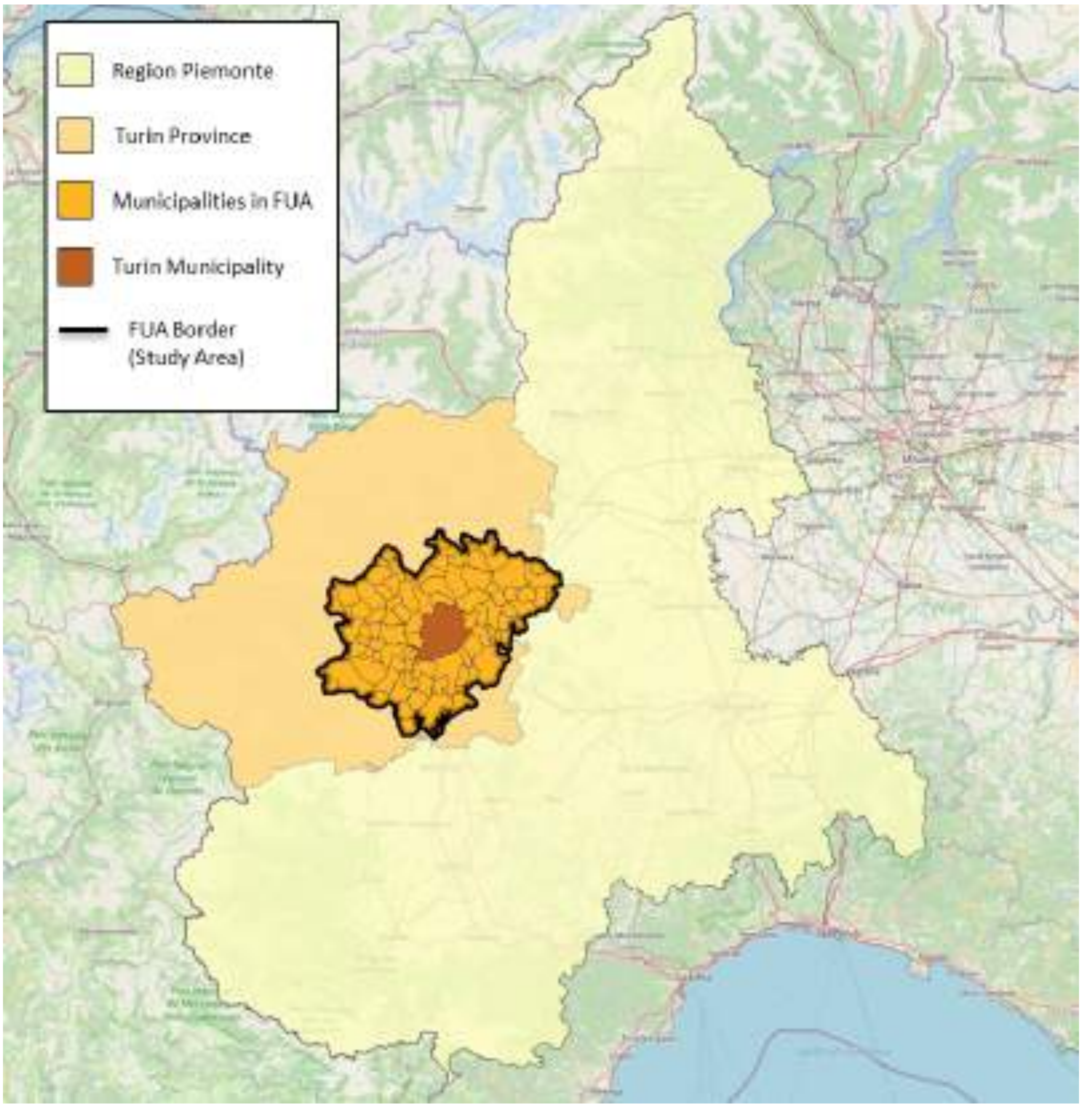

Figure 19. Study area in Turin FUA

Within the FUA area, the Municipalities are split in several zones to better reproduce urban settlements. The total number of zones in the FUA is 443, with about 183 zones covering the Municipality of Turin (see Figure 20 (a)); the population distribution is not homogenous and Figure 20 (b) shows zones' population ranges in details. On average, each zone within the municipality of Turin accounts for about

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

4,800 inhabitants while the other zones of the FUA include a population of about 3,300 inhabitants per zone.

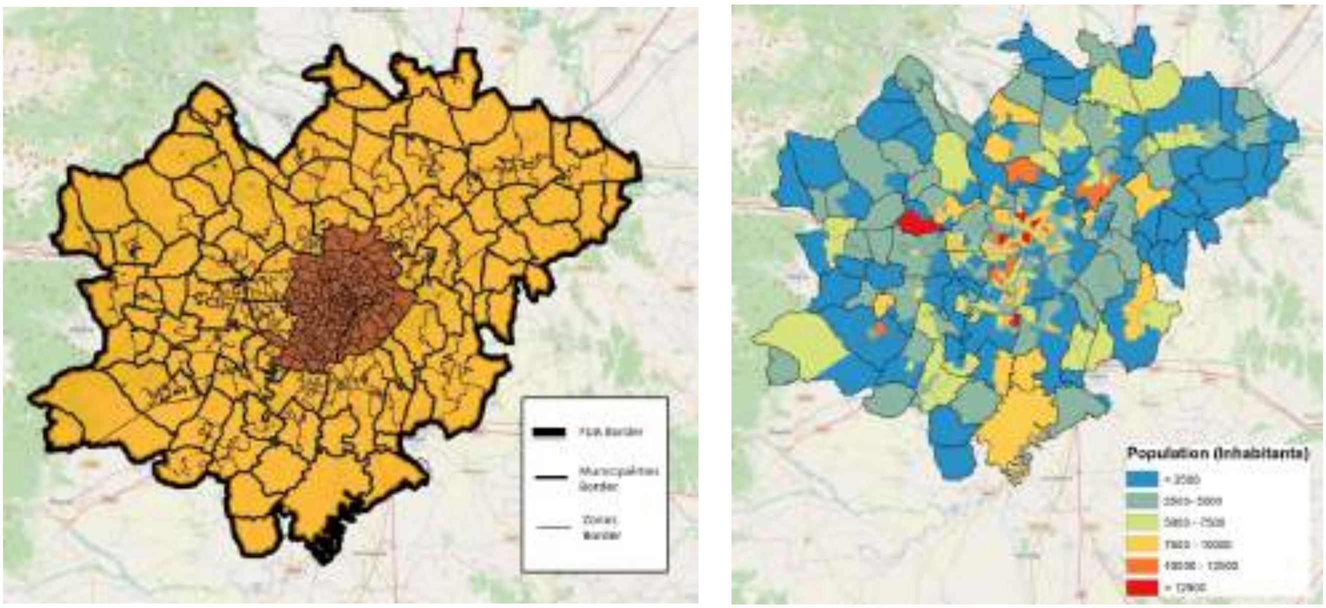

Figure 20. (a) Zonning system in Turin FUA and (b) Population density per zone

The characteristics of the transport network representation that covers Turin metropolitan area are:

- Size (km): 36,00 x 46,00
- Network type: Metropolitan
- Number of centroids: 433 (167281 OD pairs)
- Number of detectors: 1334
- Number of sections: 14882
- Number of nodes: 7803
- Type of signal controllers: Fix

In HARMONY project, the objective for the Turin case study is to have an integrated VISUM network model including both private and public transport demand. Therefore, the refinement and extension of the model is intended in terms of merging the available information and enlarging where needed the scope of the study area and the representation of transport modes and services, to address use cases described and defined in Deliverable 9.2. This objective was defined with support and advise by Turin City Council, TRT and 5T[4], and led by network model availability in the VISUM simulation software provided by 5T and GTT[5] public companies. By modelling this area, we can leverage prior work, support utilization of the model in other projects and ensure its compatibility with other models available in Turin city for strategic and tactical mobility planning. In the following section we illustrate the opportunity of merging two models for private and public transport using network model at macroscopic level in VISUM as a starting point.

[4] http://www.5t.torino.it/5t/en/home.jsp
[5] http://www.gtt.to.it/cms/en/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

5.2. Data collection and application to extend and refine the network model

In the Turin pilot, the existing network models are integrated and complemented in order to be linked to the strategic and tactical HARMONY MS. In other words, the application of the HARMONY MS will allow to estimate OD matrices by vehicle type which will be assigned to the network models (road and public transport). The static assignment using the road and public transport network models will allow to estimate complementary performance indicators to evaluate the impacts of the use cases.

Two separate VISUM network models are available:

- Road Private vehicles (including also exogenous trucks flows), developed by 5T at regional level,
- Public Transport (buses, tram, metro and rail) and private cars, developed by GTT for the Municipality of Turin and the related suburban area.

Since these two sources have different segmentation both at zoning level and demand matrices, the HARMONY Turin model is built as a combination of the information gathered from both 5T and GTT models, complemented with data of statistical survey where needed.

It is worth noting that, the provided and collected data for Turin city are generally less consistent with the requirements outlined in Table 1. This slight decrease in data availability is a result of the previous practice for the network model developments in Turin city, that are based on macroscopic level of the network representation. In general, macroscopic models require less detailed network representation, e.g., there is no information on the lane by lane turns, pedestrian crossing, public transport reserved lanes, signal control plans, etc. Following the data availability and Turin´s use cases objectives in HARMONY project, the existing network models will be integrated and modelled at the macroscopic level, which enables the consistent evaluation of the developments within WP4-WP5 with existing technologies available in Turin city.

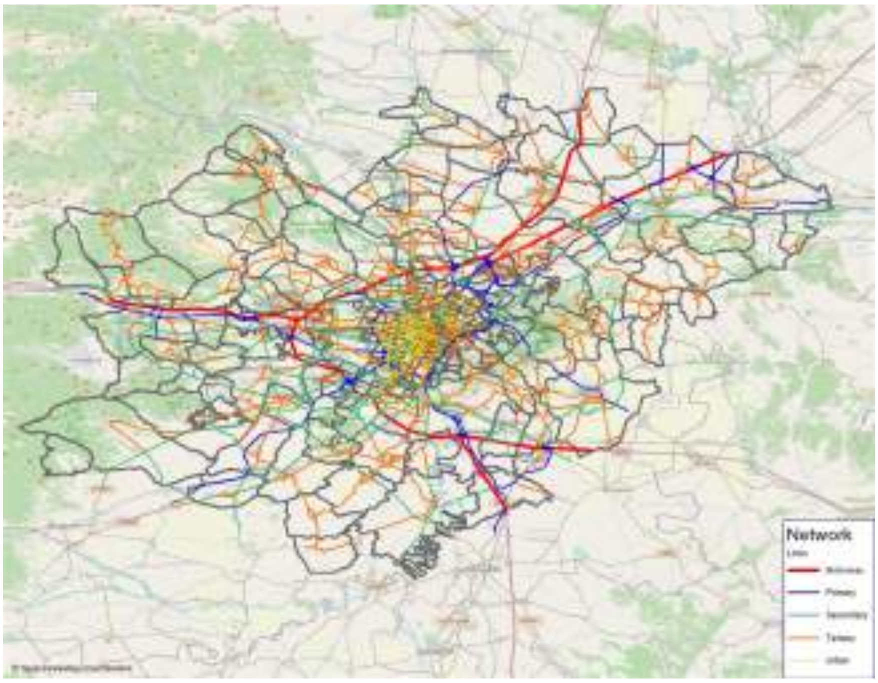

Figure 21. Road network hierarchy of the Turin model.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

Major sources of data available in Turin for the network model extension and update at macroscopic level include the following:

- **Road network model (5T) -** The road network model of 5T is developed in traffic simulation software VISUM and assigns private traffic matrices (car and freight vehicles) in the network. The road network includes 6 road categories (from motorway to urban roads, see Figure 21).

- **Public and private transport Model (GTT):** The public and private transport model of GTT is developed in VISUM and includes the passengers demand matrices for the following modes: Car, Car passenger, Urban Bus, Tramway, Subway / metro, Interurban Bus, Rail, Motorbike, Bicycles, and Walk. The model simulates 3 time periods for the assignment: AM peak hour, PM peak hour and Off-peak hour. The entire road network in Turin metropolitan area developed in VISUM is integrated with the model from 5T using the embedded VISUM importer, including geometric data of sections, nodes and turns and their parameters. Refinement of geometry and error-checking after the importation process has been performed to ensure they provide valid and consistent values. Further, this geographical representation of the network at macroscopic level in VISUM has been used to create the network graph and transport supply system representation of Turin pilot area.
- **Loop detector data:** Traffic observations are available for 1334 individual traffic loop detectors located along major streets and highways across metropolitan region of Turin, and 6 sensors on bike paths. For each detector on the network, traffic counts and speeds are provided with 5-minute aggregation level for an entire 24-hour period over one year period. The system is managed daily through a traffic operation centre whose main task is to manage the infrastructures installed on the territory (traffic sensors, info panels, traffic cameras etc...) in order to monitor urban traffic and promptly inform citizens.

- **Public transport and MaaS services**: Information related to public transport is available for the area of interest from the GTT model. Public transport network contains rail lines, subway, tramway, urban and interurban bus lines. Information related to the other services (sharing, taxi, etc.) are collected exogenously.

- **Demand:** Since demand information of public transport model (GTT) is very detailed for Turin and the first belt, this information has been taken as basis, integrating the information of the road transport model (5T) as well as other sources, i.e. the national statistical institute (ISTAT) and IMQ travel survey. The national statistical institute provides information on origin/destination commuting and study trips by municipality segmented by modes. The IMQ Survey 2013[6] provides information on origin/destination trips with a zoning system similar to the one of GTT model. From this survey shares of trips for purposes different from commuting and study have been derived.

[6] http://mtm.torino.it/it/dati-statistiche/indagine-imq-2013/base-dati-imq-2013

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

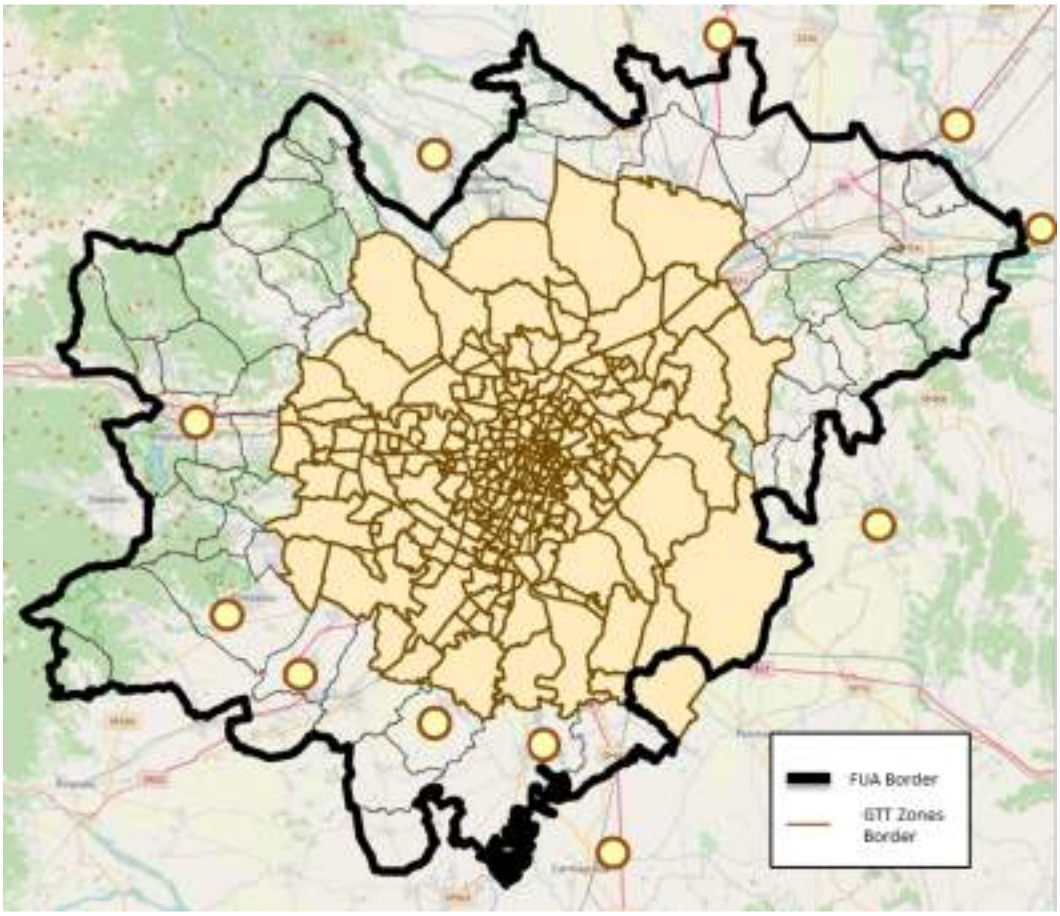

Figure 22. GTT zoning sys

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

6. Athens supply network model

6.1. Definition of the network model scope for Athens use case

Athens, the capital city of Greece, is a densely populated area with the number of inhabitants in the municipality estimated around 660,000 and across its metropolitan extensions being around 3,750,000. In addition, the port of Piraeus, which is located in the south-west end of the broader city area, is the largest passenger port in Europe and the second largest in the world. As a result, the Athens metropolitan area is in need of an extensive transportation network that is able to provide efficient and effective transportation services to all of its citizens and visitors in order to sufficiently support and satisfy the city's needs as well as establish and promote its image as one of the largest capital areas in Europe.

In this context, transportation planning in Athens arises as a key element of its everyday functionality. The Athens Public Transport Organization (OASA), the sole mass transit operator in the Attica region, with exclusive control over its bus, tram, trolley and subway networks, sets high standards in its operation and has proceeded with the generation of a spatially extensive transport network model that covers the entire Athens metropolitan area. An overview of the model's layout can be seen in Figure 23, with the blue dots corresponding to the nodes of the network and the yellow dots with the H symbol in them to public transportation stops.

Figure 23. Study area in Athens covered by OASA model in VISUM traffic simulation software

The characteristics of the transport network representation that covers Athens metropolitan area are:

- Size (km): 38,00 x 43,00
- Network type: Metropolitan
- Number of centroids: 1,284

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

- Number of detectors: 1573
- Number of sections: 22000
- Number of nodes: 7000
- Type of signal controllers: Fix

In the HARMONY project, the main objective is to refine and calibrate the OASA model, or pilot areas within OASA model, that correspond to use cases addressed at Strategic, Tactical and Operational level and described in Deliverable 9.2. In this way, the model will be used for modelling a wide range of different transportation policies and measures, and their impact assessment before proceeding with their actual implementation in the network. The model is also to be used for verifying the performance of existing measures and modelling assumptions and suggesting possible improvements and / or changes where needed. For example, the use case areas to evaluate transport policies at operational level cover city centre of Athens, port of Athens and Dasos-Haidari neighbourhoods. The areas were selected with support and advice by OASA, Athens use case leader. By modelling this area, we can leverage prior work, support utilization of the model in other projects and ensure its compatibility with other models available in Birmingham city for dynamic traffic management control and mobility planning. At the time being, the model's reference year is 2019, which implies that all its basic characteristics and parameters, extending from the network configuration to the bus network layout, correspond to the ones prevailing in that year.

6.2. Data collection and application to extend and refine the network model

The provided and collected data for Athens pilot area are generally less consistent with the requirements outlined in Table 1. This slight decrease in data consistency is a result of the previous practice for the network model developments in Athens metropolitan area, based on regional transport models and other models with macroscopic level of the network representation. Following the data availability, the network graph of transport supply system is developed based on network representation in OASA model built in VISUM traffic simulation software and other data sources provided by OASA. Furthermore, in the areas for evaluations at operational level, that require more detailed network representation, network graph will be developed based on OpenStreetMap (OSM) and other open data sources provided by OASA.

Major sources of data for the network model development at mesoscopic level for Athens pilot area include the following:

- **Network model:** Athens network model is a spatially extensive transportation analysis tool that has been created in the traffic planning software PTV VISUM which is used to: (a) conduct traffic analyses, forecasts and GIS-based data management, (b) model all road users and their interactions, (c) plan public transport services, and (d) develop advanced and future-proofed transport services and solutions. The software belongs to the category of macroscopic simulation tools, which model traffic flow on the basis of general traffic characteristics like speed and density but can be easily integrated with PTV Vissim which is its microscopic counterpart. The transport model developed in PTV VISUM covers the entire Athens metropolitan area (see

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

Figure 23) and models a different types of transportation modes, with a distinction made between public and private transport. The modelling analysis extent covers the main scope of the Athens Public Transport Organization which is to test and evaluate transportation policies and develop future transportation plans on the basis of reasonable modelling assumptions; this is the reason why its extension to the microscopic level has not till yet been pursued.

- **Traffic control system**: The great spatial extent of the Athens transportation model and its macroscopic simulation character have prevented the detailed signal control simulation of its junctions. As such, there are currently no signal timing plans incorporated in the model. The effects of traffic control are, therefore, implicitly considered by applying appropriately formulated volume - delay functions on its nodes, links and turns, taking, thus, into account both the saturation of the respective network elements and the possible delays due to traffic control.

- **Public transport and MaaS services**: The public transport system in the Athens transportation model accounts for six different types of modes: bus, intercity bus, tram, subway, trolley and rail. All modes are currently operating in the greater Athens metropolitan area and their respective layouts have been updated to match their 2019 characteristics.
  More specifically, the bus network consists of a total of 474 line routes, with some of them corresponding to bus lines with two branches while others being cyclic routes. Existing measures that facilitate the operation of public transport (bus lanes) have also been incorporated in the model by reserving one lane for exclusive use by this specific type of mode on roadways where this measure is implemented. In addition, the model also simulates the routes of the existing three subway lines in Athens, three tram line routes, thirty eight trolley line routes, thirty four intercity bus line routes and six rail line routes.
  Finally, although probably beneficial for the whole population mobility concept, there currently do not exist any operating MaaS infrastructure and application platforms in Athens, nor has any such plan reached completion yet. As such, the model does not include this type of service provision. However, the Athens Public Transport Organization has great interest in becoming a MaaS provider, with a clear intention to cooperate with other operators as well towards achieving this joint objective.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269

7. Next steps

This report details the development of multimodal land network, i.e., transport system supply, models in traffic simulation software tools, for evaluation of a wide range of emerging transport policies in HARMONY pilot areas, for private vehicular traffic, public transport systems and freight transport system. In addition, the construction of the underlying network graphs, representing transport supply for the four pilot areas involved in the HARMONY project is detailed. It is worth noted, that this report represents a superset of guidelines in the land network models development process, while actual built models can be demonstrated in corresponding traffic simulation software tools, Aimsun Next and VISUM. These traffic simulation software can be plugged-in in the HARMONY MS, whose architecture is designed to be software agonistic, enabling interaction with various traffic simulation software. More details on the HARMONY MS platform software agnostic design can be found in Deliverable D1.3.

The land network models built insofar and reported in this deliverable, will be extended and refined during the course of the second phase of the HARMONY project. The land network models will be refined to cope with specifications of each use case and modelling tools developed in WP4-WP7. The data used for generating and validating land network models will be enriched with data collected using new social and physical passive, participatory and opportunistic sensing available from WP3-WP6, and fused to generate calibrated multimodal traffic state in WP7 to support Task 7.6 and Task 7.7. Furthermore, the multimodal land networks reported in this Deliverable will feed into the large-scale visual analytics and decision making developed in WP3 and WP9.

Results from all four pilot sites (Oxfordshire, Rotterdam, Turin and Athens) and their further update and extension based on a performance assessment, use cases and calibration and validation study, will be provided in D7.1 “Multimodal Land network – Final version” in M33 of the HARMONY project.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 815269