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

HARMONY D7.6 Applications of the operational simulator and forecasting

Submission date: 01/06/2022

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
API	Application Programming Interface
BEB	Battery Electric Buses
CAV	Connected and Autonomous Vehicle
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DRT	Demand Responsive Transport
GHG	Green House Gas
KPI	Key Performance Indicator
LEZ	Low Emission Zone
LTZ	Limited Traffic Zone
MaaS	Mobility as a Service
MAPE	Mean Absolute Percentage Error
NMVOC	Non-Methane Volatile Organic Compounds
NOx	Nitrogen Oxides
OD	Origin – Destination
PM	Particulate Matter
SUMP	Sustainable Urban Mobility Plan
ZECL	Zero Emissions City Logistics

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EXECUTIVE SUMMARY

HARMONY develops an integrated modelling suite for evaluating transportation measures at strategic, tactical and operational levels. The developed suite offers decision makers a new generation of tools, which model and simulate new forms of passenger and freight mobility, allowing the formulation of solutions to long standing transport problems such as congestion, air pollution and problematic accessibility to services. The HARMONY proposition bridges an existing gap in current practices, by enabling authorities to assess the effects that new mobility services and innovative measures in the performance of transportation systems. Schemes such as Mobility-as-a-Service (MaaS) and Demand Responsive Transport (DRT) for passengers and utilisation of Micro-hubs for freight can be evaluated in conjunction with measures such as Low Traffic and Low Emission Zones, thus allowing the development of holistic and complementing solutions.

At the operational level, HARMONY offers integrated supply and demand tools that can realise the execution of with-in day simulations as to evaluate the performance of transport networks under different loading conditions (demand) and variable infrastructure and mobility services configurations (supply). This deliverable presents the application of the operational tools as part of different uses cases for the cities of Oxford, Rotterdam, Turin and Athens. The presented use cases cover both passenger and freight transport and demonstrate the potential of the HARMONY MS to analyse complex transport (supply and demand) scenarios and produce KPIs that can assist decision makers.

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1. Introduction

1.1. Background and Purpose

The operational layer of the HARMONY MS offers a collection of tools and models that can simulate within day supply and demand scenarios. The developed tools include (i) supply simulators implemented with commercial software such as Aimsun and VISUM, (ii) controllers for passenger and freight that allow the emulation of services such as MaaS, DRT, Micro-freight and others, (iii) energy consumption and emission models based on vehicle stocks and (iv) noise models. The purpose of this deliverable (D7.6) is to present the application of the different models as part of the following use cases:

- The application of a demand response transport service for the city of Oxford.
- The investigation of using cargo bikes for last mile delivery with the presence of micro-consolidation centres in the city of Rotterdam.
- Urban vehicle access regulation measures for the city of Turin.
- Public transport fleet electrification, micro-mobility and CAVs penetration for the city of Athens
- Application of the nowcasting module in the city of Oxford.

For each use case a description is provided together with assumptions and methodologies adopted. Additionally, relevant outputs in the form of KPIs are presented for each use case. It has to be noted that the above use cases have been analysed using only tools from the operational layer of the HARMONY MS and some of them will be extended further and be presented in D2.5 as part of the application of the integrated HARMONY solution.

1.2. Deliverable Objectives

This deliverable (D7.6) aims to present and describe:

- The application of the various tools and models at the operational layer of the HARMONY MS through selected use cases that cover a range of supply and demand scenarios.
- The presentation of results from the afore mentioned application, demonstrating the capabilities of the HARMONY MS in supporting decision making.

1.3. Report Outline

The remaining of the document includes 5 chapters, one for each of the use cases mentioned above. Chapter 2 presents the application of the DRT passenger controller in the city of Oxford, while chapter 3 demonstrates the application of the freight controller as part of a micro-hubs use case for the city of Rotterdam. Chapter 4 explores the impact of different zonal access restrictions for the city of Turin. Furthermore, chapter 5 presents the uses cases for the city of Athens while chapter 6 reports the results of the application of the nowcasting module using data from the city of Oxford. Finally, chapter 7 reports the main findings from the application of the operational simulators of the HARMONY MS.

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2. Demand responsive transport services: Oxfordshire

2.1. Use cases description

This use case investigates the effect of a demand responsive transport (DRT) service in a realistic network. In particular, the transport network of Oxford, UK and its surrounding area. The DRT service operates a fleet of vehicles that respond to trip requests, mimicking real-world, on-demand transport services, such as Uber. For each scenario tested, a fraction of the background traffic demand is replaced with trip requests.

Trip schedules for the DRT service are generated before run-time, and are scaled, based on the origin-destination matrices of the network. Generated schedules are similar to those that could be created and made available from the tactical layer, without the inclusion of associated activity information.

Since the hourly number of trips in the Oxfordshire region is large (~35,000), it is unrealistic to expect that all trips could be replaced with a DRT service. Trip numbers range from 1-10% of total demand. As explained below, trips were randomly generated from the origin-destination matrices supplied with the network model without reference to activity type information. The other variable that can be modified is fleet size. However, in both case a minimum of about 100 vehicles (and up to 1000 vehicles) would be required to fulfil demand.

2.2. Application of models

The Oxfordshire network (Figure 1) consists of a subnetwork enclosing the road network of Oxford, as well as the surrounding region. The majority of the 1019 centroids are contained within the subnetwork that delimits the city of Oxford. (Origin-destination trips are defined between pairs of centroids in the network.) The network contains 10889 “sections” or road segments, 928 bus routes, 45 OD matrices (for combinations of vehicle type, scenario and time period), and 15 control plans for signal control.

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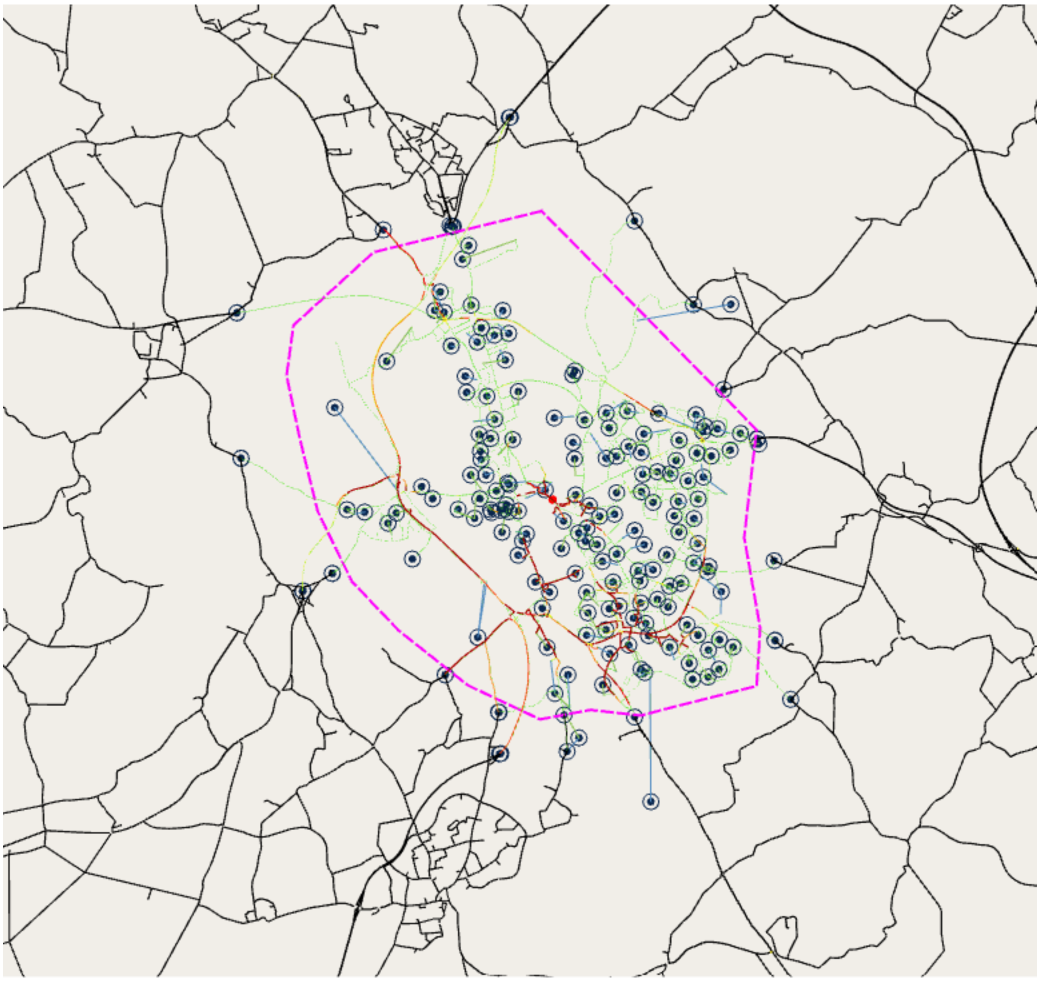

Figure 1: A portion of the Oxfordshire network in Aimsun with the Oxford subnetwork in the centre

For each time period of 15 minutes each, there is an OD matrix that specifies the number of trips between centroids. The trip schedule generation algorithm assigns a weighting to each cell for each OD matrix. The total number of generated trips is equal to the sum of all cells. For each trip, an origin-destination pair $(a, b) \in L^2$ needs to be selected, where L is the set of location points. An OD matrix applies to a particular time period $p \in I$, where I is the set of time period intervals. The probability of selecting a trip, $t \in L \times L \times I$, is

$$\Pr\big(t = (a, b, p)\big) = \frac{n_{abp}}{\sum_{(i,j,k)\in L\times L\times I} n_{ijk}}$$

where n_{abp} is the number of trips in the OD matrix for period p between the origin a and destination b. Rather than selected trips one by one, it is more efficient to select all trips in one function call. The trip generation code calls the Python `random.choices()` function to select trips, where the weightings are equal to the trip numbers in the OD matrices. However, activities are not included in the random trip schedule as there is no information about activities in the OD matrices.

2.3. KPIs and Results

Several scenarios were evaluated, including a base case and variations with differing penetration rates and fleet sizes. The simulation time occurred over the period from 8am to 9am, with a warmup period of 30 minutes. The complete set of KPIs from Aimsun for the base case is found in Table 1. The same set of statistics are available for all scenarios, and included here to show the full breadth of statistics that are available via the simulator.

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Time Series	Value	Standard Deviation	Units
CO2 - All	85209863.25	N/A	g
CO2 - Bus	0	N/A	g
CO2 - Car	78632940.52	N/A	g
CO2 - Truck	6576922.73	N/A	g
Delay Time - All	46.84	64.52	sec/km
Delay Time - Bus	33.9	23.64	sec/km
Delay Time - Car	47.01	64.8	sec/km
Delay Time - Truck	38.41	49.9	sec/km
Density - All	19.66	N/A	veh/km
Density - Bus	0.07	N/A	veh/km
Density - Car	19.19	N/A	veh/km
Density - Truck	0.41	N/A	veh/km
Flow - All	18679.33	N/A	veh/h
Flow - Bus	78.67	N/A	veh/h
Flow - Car	18357	N/A	veh/h
Flow - Truck	243.67	N/A	veh/h
Harmonic Speed - All	31.06	15.14	km/h
Harmonic Speed - Bus	17.52	4.1	km/h
Harmonic Speed - Car	31.1	15.1	km/h
Harmonic Speed - Truck	36.93	18.21	km/h
Input Count - All	75409	N/A	veh
Input Count - Bus	251	N/A	veh
Input Count - Car	74033	N/A	veh
Input Count - Truck	1125	N/A	veh
Input Flow - All	25136.33	N/A	veh/h
Input Flow - Bus	83.67	N/A	veh/h
Input Flow - Car	24677.67	N/A	veh/h
Input Flow - Truck	375	N/A	veh/h
Mean Queue - All	10858.99	N/A	veh
Mean Queue - Bus	30.11	N/A	veh
Mean Queue - Car	10588.98	N/A	veh
Mean Queue - Truck	239.9	N/A	veh
Mean Virtual Queue - All	4673.48	N/A	veh
Mean Virtual Queue - Bus	0	N/A	veh
Mean Virtual Queue - Car	4552.93	N/A	veh
Mean Virtual Queue - Truck	120.55	N/A	veh
Missed Turns - All	0	N/A	
Missed Turns - Bus	0	N/A	
Missed Turns - Car	0	N/A	
Missed Turns - Truck	0	N/A	
NOx - All	146833.67	N/A	g
NOx - Bus	0	N/A	g
NOx - Car	113974.39	N/A	g
NOx - Truck	32859.28	N/A	g
Number of Lane Changes - All	87.19	N/A	#/km

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Number of Lane Changes - Bus	0.48	N/A	#/km
Number of Lane Changes - Car	85.5	N/A	#/km
Number of Lane Changes - Truck	1.21	N/A	#/km
Speed - All	38.44	17.36	km/h
Speed - Bus	18.48	5.98	km/h
Speed - Car	38.43	17.3	km/h
Speed - Truck	45.91	19.53	km/h
Total Distance Travelled - All	360883.55	N/A	km
Total Distance Travelled - Bus	1732.6	N/A	km
Total Distance Travelled - Car	352427.09	N/A	km
Total Distance Travelled - Truck	6723.86	N/A	km
Total Distance Travelled (Vehicles Inside) - All	2955.18	N/A	km
Total Distance Travelled (Vehicles Inside) - Bus	0	N/A	km
Total Distance Travelled (Vehicles Inside) - Car	2909.84	N/A	km
Total Distance Travelled (Vehicles Inside) - Truck	45.34	N/A	km
Total Number of Lane Changes - All	62533	N/A	
Total Number of Lane Changes - Bus	345	N/A	
Total Number of Lane Changes - Car	61319	N/A	
Total Number of Lane Changes - Truck	869	N/A	
Total Travel Time - All	10617.79	N/A	h
Total Travel Time - Bus	97.22	N/A	h
Total Travel Time - Car	10356.21	N/A	h
Total Travel Time - Truck	164.36	N/A	h
Total Travel Time (Vehicles Inside) - All	32343.49	N/A	h
Total Travel Time (Vehicles Inside) - Bus	46.17	N/A	h
Total Travel Time (Vehicles Inside) - Car	31568.71	N/A	h
Total Travel Time (Vehicles Inside) - Truck	728.61	N/A	h
Total Travel Time (Waiting Out) - All	13599.23	N/A	h
Total Travel Time (Waiting Out) - Bus	0	N/A	h
Total Travel Time (Waiting Out) - Car	13249.74	N/A	h
Total Travel Time (Waiting Out) - Truck	349.48	N/A	h
Travel Time - All	115.91	68.51	sec/km
Travel Time - Bus	205.46	49.26	sec/km
Travel Time - Car	115.77	68.47	sec/km
Travel Time - Truck	97.47	54.27	sec/km
Vehicles Inside - All	25460	N/A	veh
Vehicles Inside - Bus	21	N/A	veh
Vehicles Inside - Car	24952	N/A	veh
Vehicles Inside - Truck	487	N/A	veh
Vehicles Lost Inside - All	0	N/A	veh
Vehicles Lost Inside - Bus	0	N/A	veh
Vehicles Lost Inside - Car	0	N/A	veh
Vehicles Lost Inside - Truck	0	N/A	veh
Vehicles Lost Outside - All	0	N/A	veh
Vehicles Lost Outside - Bus	0	N/A	veh

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Vehicles Lost Outside - Car	0	N/A	veh
Vehicles Lost Outside - Truck	0	N/A	veh
Vehicles Outside - All	56038	N/A	veh
Vehicles Outside - Bus	236	N/A	veh
Vehicles Outside - Car	55071	N/A	veh
Vehicles Outside - Truck	731	N/A	veh
Vehicles Waiting to Enter - All	19013	N/A	veh
Vehicles Waiting to Enter - Bus	0	N/A	veh
Vehicles Waiting to Enter - Car	18519	N/A	veh
Vehicles Waiting to Enter - Truck	494	N/A	veh
Waiting Time in Virtual Queue - All	534.55	1288.44	sec
Waiting Time in Virtual Queue - Bus	0.1	0.42	sec
Waiting Time in Virtual Queue - Car	531.29	1285.42	sec
Waiting Time in Virtual Queue - Truck	804.19	1498.15	sec

Table 1. Simulation outputs produced by Aimsun Next

Two alternative scenarios were tested for two DRT penetration rates, meaning four scenarios were tested with five different random seeds each. The random seeds enabled confidence intervals to be calculated for the metrics obtained. For each scenario, the start time was at 8am and DRT trips were allocated between 8am and 9am. However, the scenarios ran until 11am, allowing all DRT trips to complete. Metrics were obtained over the entire three hour period. The two alternative scenarios were for DRT and grouped DRT. Grouped DRT emulates a ride-sharing scenario by grouping together similar trips, that is, trips with the same origin and destination zone, departing within the same 15 minute period. Since trips with the same properties are grouped together, there are a fewer number of trips needing to be fulfilled by the DRT trips.

Table 2 compares various measures for ungrouped and grouped trip scenarios for 1% and 10% DRT. There was a greater reduction in trip counts (26% compared to 7%) for the 10% DRT case, compared to the 1% DRT case. In both cases, the average trip time (including the time required for the vehicle to reach the passenger's origin) was about 20 mins. The average delivery time (from passenger origin to destination) was about 10 mins. Therefore the fleet size required to accommodate all trips is approximately $T \div \frac{60}{20}$, where T is the number of trips. This equates to about 100 vehicles in the case of 1% DRT and 1000 vehicles for 10% DRT. For the purpose of testing these scenarios, a fleet large enough to accommodate all trip requests was created. In both cases, a large fleet is required to make a substantial difference to network performance metrics. It may be unrealistic to assume that a large enough fleet exists to service enough demand to make a substantial difference to network performance. However, by grouping trips together, the number of trips and therefore emissions is reduced, even if network congestion is not substantially improved.

Generally, the number of trips grouped together (and therefore the number of occupants) is low – between 1 and 2 people in both cases. However, the maximum number of occupants is 34 in the case of 10% DRT, indicating that a larger vehicle would be required to accommodate such a large number of occupants. Figure 2 shows the number of trips that were conducted for different ranges of occupants. As can be seen, the majority of trips require a capacity of less than 5 seats.

Percentage DRT (%)	1	10
Trip count	348	3482
Trip count (grouped)	324	2580
% reduction	7	26
Max occupants	7	34
Average occupants	1.07	1.35
Std dev occupants	0.47	1.80

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Avg trip total time (min) (including travelling to passenger)	18	19
Max trip total time (min) (including travelling to passenger)	51	92
Avg delivery time (min)	12	11
Max delivery time (min)	39	89

Table 2. Comparing metrics for ungrouped and grouped trip cases

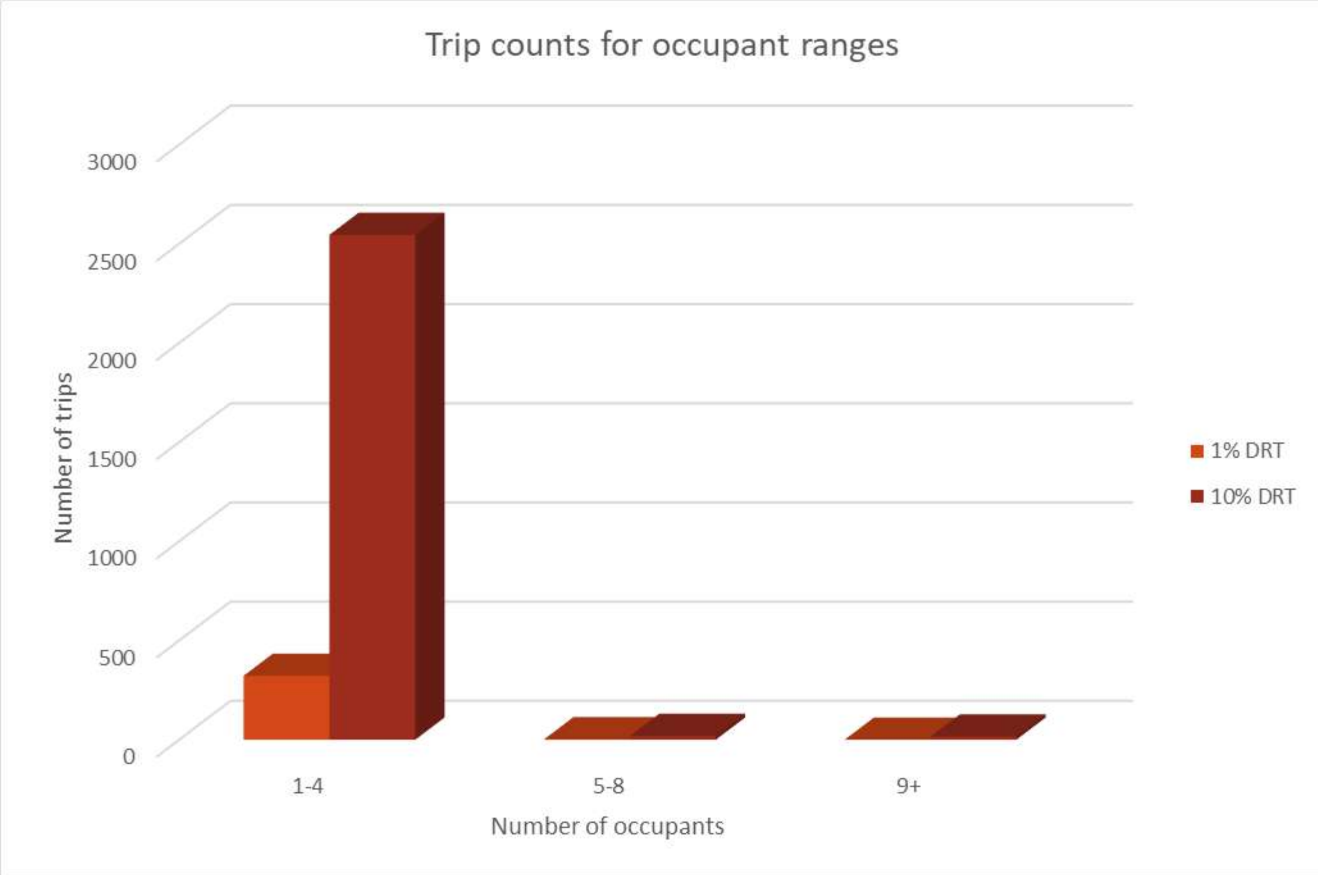

Figure 2. Number of trips for 1% and 10% DRT scenarios when trips are grouped.

Figure 3 and Figure 4 illustrate how these metrics changed as the percentage of DRT trips increased. With increasing penetration rate, the demand created as background traffic decreased by the same amount. For example, when DRT demand was 4% of the total demand, background traffic was 96% of total demand. The figures show that network performance may degrade a little when the penetration rate for DRT is only 1%. However, both total network travel distance and CO_2 emissions may decrease as the penetration rate increases to 10%. It should be noted, though, that the error bars are quite high and when they overlap, a definitive statement about the trend of the metric cannot be made. A reduction in emissions and travel distance is observed when trips are grouped together for the 10% DRT penetration rate scenarios.

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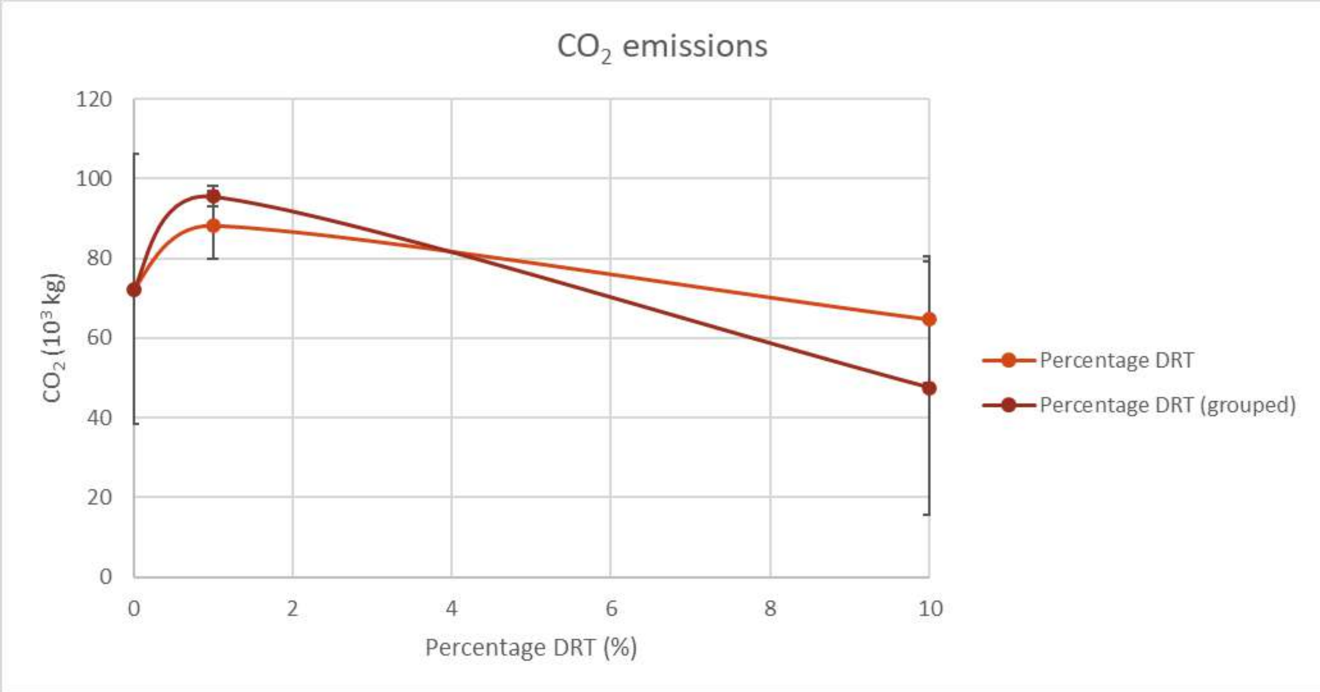

Figure 3. CO_2 emissions as percentage of DRT trips varies

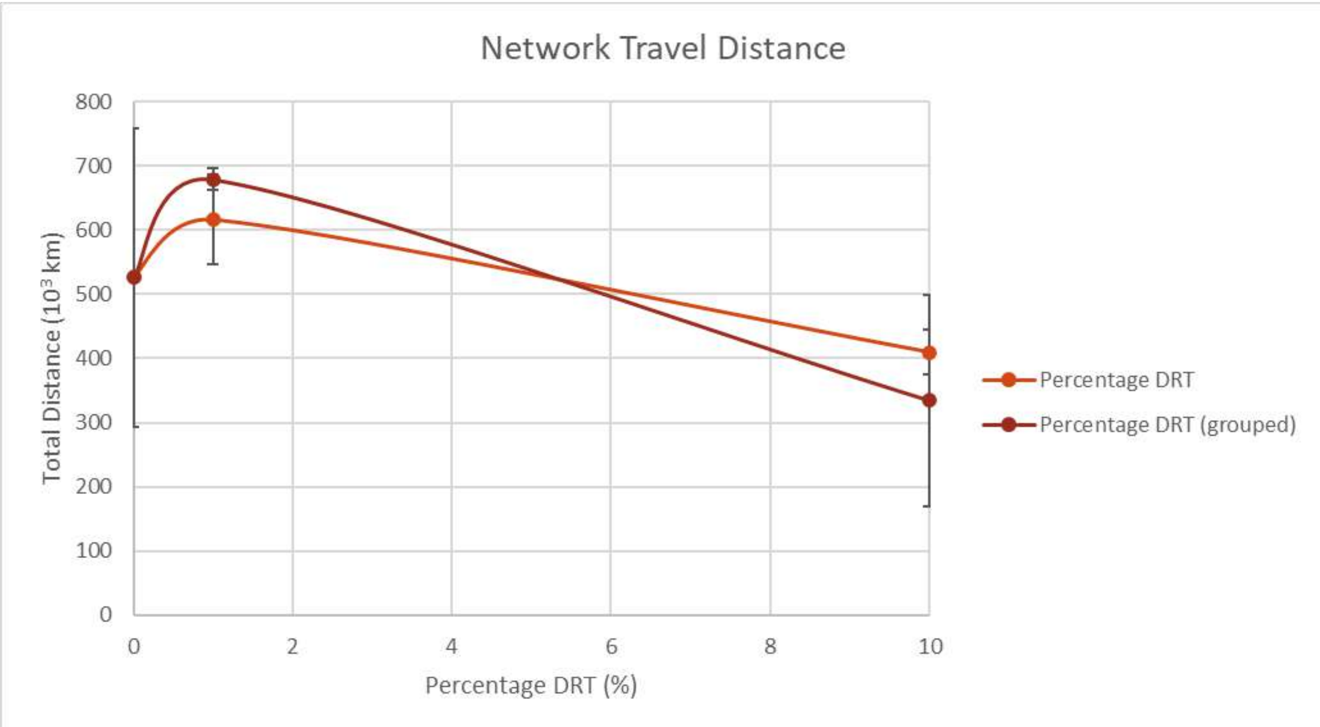

Figure 4. Total network (car) distance as percentage of DRT trips varies

3. Micro-hubs for parcel deliveries: Rotterdam (UoW)

3.1. Use cases description

Rotterdam is a port city, and the second largest city after Amsterdam, located in the province of South Holland in the Netherlands. The municipality of Rotterdam occupies an area of about 325 km^2 (208 km^2 of which is land), and is home to 640,000 inhabitants, about 25% of the population of the Rotterdam – The Hague metropolitan area.

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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 5. 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 5: Study area in Central Rotterdam - (source: Google Earth)

A screenshot of the Rotterdam network model area can be seen in Figure 6. 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.

The city of Rotterdam (GROT) sets a clear objective to reduce all the greenhouse gas emissions by 49% in 2030 and by 95% by 2050. This goal shapes the long- and short-term mobility plans of the Rotterdam City Council and is the basis behind the development of a roadmap for Zero Emissions City Logistics (ZECL). Specifically, the ZECL is developed around the “Trias Mobilica”, which includes the following three pillars: Cut back, Change and Clean up. Firstly, Rotterdam will make efforts to eliminate all unnecessary freight kilometres by developing consolidation centres to bundle freight outside the city centre. The freight bundling will be followed by a modal shift to zero emission vehicles such as electric/ autonomous vans and cargo bikes. The third pillar refers to “cleaning up” the existing vehicles and use technologies to turn them into zero emissions vehicles. GROT has the ambitious goal to make all logistics in the city centre emission-free by 2020 and it is currently challenged to design a concrete framework in combination with the adoption of effective policies to ensure the development of a zero

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emissions zone for city logistics where transport movements will be kept into low levels and will be carried out by zero emissions vehicles.

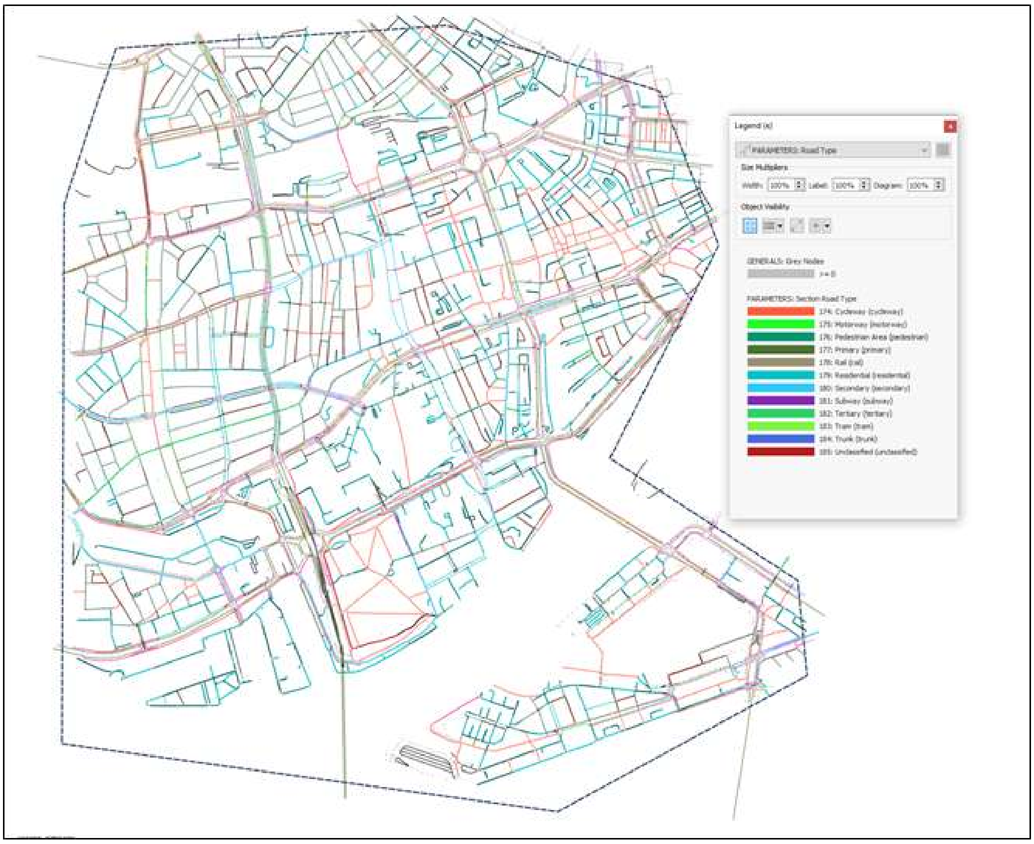

Figure 6: Rotterdam City Centre Network in Aimsun Next and Road Type

In accordance with the ZECL roadmap, GROT identified different use cases to be tested with the HARMONY model suite. One of these use cases simulated for the Rotterdam pilot area focuses on the usage of cargo bikes in urban deliveries.

The use case presented in this section investigates the impact that micro-consolidation (micro-hubs) centres combined with the use of cargo bikes for parcel deliveries has on the network. The design of various scenarios, as part of this use case, includes the location of the micro-consolidation points where packages are transhipped to cargo bikes, the expected demand for the system, and algorithms to translate the specified demand into shipment patterns.

In HARMONY project, the impacts and effects of using cargo bikes for parcel delivery in Rotterdam city centre (pilot area) are investigated and examined by comparing the following two scenarios. The base scenario represents the case of using several consolidation centres (or depots) positioned in the Rotterdam area (outside Rotterdam city centre) for parcel delivery by means of conventional vans. However, the cargo bike scenario represents the case of using several micro-hubs positioned inside the city centre for parcel delivery by means of cargo bikes (inside micro-hub zones only). Thus, this use case is designed to investigate the effectiveness and efficiency of considering and using such micro-hubs in Rotterdam city centre for parcel deliveries.

In the base scenario, there are several depots positioned in the Rotterdam area and allocated to parcel delivery. Therefore, the parcels to be delivered from each of these depots to any zone within Rotterdam area will be considered and delivered by the fleet of this depot (e.g. vans). Consequently, the parcels will be delivered to their final destinations by the different fleets of these depots. On the other hand, the micro-hubs scenario considers and deals with the parcels which are allocated for delivery from the different depots to the zones of the micro-hubs. Therefore, all the parcels dedicated for delivery from all the depots to the zone of each micro-hub (to the customers positioned within this micro-hub zone) will be delivered firstly by the fleets of these depots to the micro-hub (not to the final destinations –

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customers – of the parcels). Then, the micro-hubs are responsible for delivering the received parcels to the final destination – customers – of parcels by using their own fleet, which is composed of cargo-bikes. However, all the parcels allocated for delivery from the different depots to the non-micro-hub zones will be delivered by the depots' fleets as in the case of the base scenario.

3.2. Application of models

According to the parcel demand received from the HARMONY Tactical Freight Simulator (WP6), the demand covers a large geographical area around Rotterdam city. Figure 7, shows that there are about 15 consolidation centres or depots (red circles) distributed over this large area (around 2000 km²) and serve around 6625 zones.

As mentioned in the previous section, the Rotterdam city centre area has been selected as a study area (pilot area) at operational level to address the pilot use cases. Therefore, the use case of micro-hubs for parcel deliveries is simulated applying the Aimsun network model developed for the Rotterdam area (Figure 6). This network model performs the assignment of private cars, trucks and bicycle demand and provides output (both road/section or network level) in terms of average speed, traffic flow, travel time and delay. The demand has been specified in the form of OD matrices and is available for morning peak time (7:00 -9:00 am).

The parcel demand has been filtered out (spatially and temporally) and recalculated to fit the pilot area of Rotterdam and the simulation period. As the pilot area includes only 119 zones (Figure 8, pilot area zones), only the following demand/parcels will be considered:

1. Parcels which have a destination zone that is included in the supply model.
2. Parcels which have to be delivered between 7:00 and 9:00am.

Figure 7 demonstrates that this use case considers only the demand/parcels going from consolidation centres (red circles) to the pilot area zones (top-right box). As all the consolidation centres are positioned outside the use case area, it has been assumed that the demand in the baseline scenario will be delivered from one virtual depot (Figure 8, yellow circle marked with D) to all the pilot area zones by using a conventional fleet of vans. In case there are (P) parcels to be delivered by a van (one of this depot's fleet) to one of the pilot area zones, the van must make (P) visits to (P) different locations inside the destination zone.

In the micro-hubs scenario, parcels which have as destination a zone that includes a micro-hub (Figure 8, zones of the yellow circles – 12 micro hubs) are simulated in a different way. These parcels will be delivered from the depot to the micro-hubs by the depot's fleet (unloading all the parcels from the vans at the different micro-hubs). Subsequently, the fleet of each micro-hub (cargo bikes) is responsible for delivering the parcels within its zone.

As a result of filtering and recalculating the demand for the pilot area, there were 27 van tours (each tour represents a fleet van with full capacity to deliver the parcels to at least one pilot area zone), 139 van trips (each tour includes many trips, each trip includes the parcels to be delivered within one zone) and 4839 parcels (van visits). In the micro-hub scenario, there are only 3373 van visits, 11 cargo bike tours, 104 cargo bike trips and 1484 cargo bike visits.

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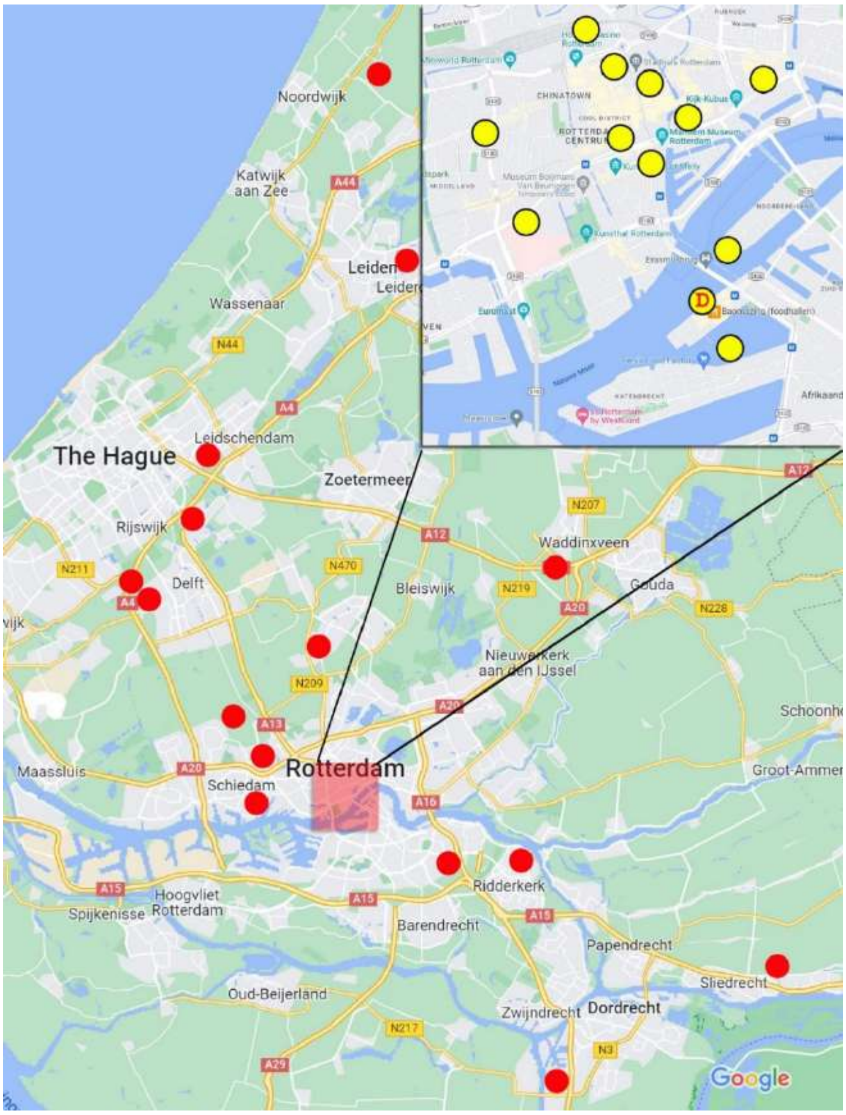

Figure 7: Rotterdam Pilot: Depots Locations (Red Circles) and Micro-Hubs Locations (Yellow circles) - (source: Google Maps)

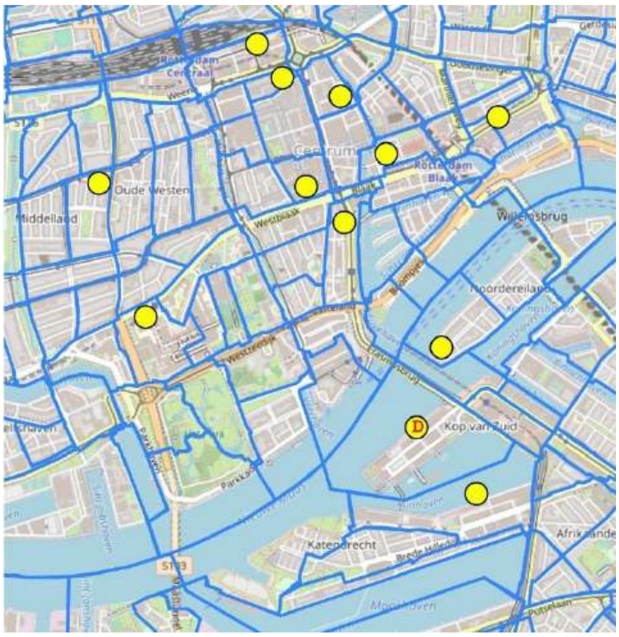

Figure 8: Rotterdam Pilot Area Zones (119 Zones) - (source: Google Maps)

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All the parcel demand in both scenarios (base and micro-hub) has been managed and fed into the Aimsun Next simulation via the Ride API[1]. The Aimsun Ride API enables and supports fleet management services in such a way where different operators (managers of fleets) can receive trip requests for individual vehicles. Therefore, the parcel demand of the base scenario is managed by using one operator integrated with the Aimsun Next simulator. Conversely, in the micro-hub scenario, two operators (one for depot fleet and another for micro-hubs fleets) have been integrated to run in parallel with Aimsun Next simulator and manage both parcel demands of vans and cargo bikes.

3.3. KPIs and Results

In the field of freight transport and city logistics, the goal of GROT is to reduce all the greenhouse gas emissions and to ultimately find out a Zero Emission City Logistics zoned (ZECL zone) around the city centre by 2025. Therefore, the microfreight controller model which has been described above is implemented to explore the effectiveness and efficiency of using micro-hubs for parcel deliveries in the pilot area (Rotterdam city centre). Various measures and metrics can be used to show the results of this tested use case such as network-level travel time, delay and pollutant emissions.

Several scenarios may be evaluated and compared with the base scenario which represents the case of using only conventional fleet, namely vans, for micro freight or parcel delivery. Therefore, the main aspects and features of the base scenario involves the fleet size required to deliver the full pilot area load or demand, the number of trips (each trip represents the delivery of all parcels from depot to one specific zone) required to deliver all the demand and the number of visits/deliveries required to deliver all the demand.

As mentioned above, the base scenario mainly represents the delivery of all demand form the depot inside the pilot area to all different zones and customers within this area. Therefore, all deliveries from depot to customer are accomplished by depot fleet or vans.

In addition to the depot and fleet of vans used in the base scenario, the micro-hubs scenario includes 12 micro-hubs positioned within 12 different zones inside the pilot area. The depot vans deliver all the demand/parcels which have destinations positioned inside the zones of the micro-hubs. Therefore, these micro-hubs receive all the demand of their zones and take the lead to deliver these parcels to their final destinations or customers by using cargo bikes. This use case significantly decreases the number of tours, trips and visits of conventional vans by substituting these visits or deliveries by an active mode – cargo bikes.

For both scenarios, Table 3 shows the number of zones which have demand, the number of tours which represents a full capacity tour (van or cargo-bike), the number of trips and the number of parcels delivered with the pilot area. Each trip represents a group of parcels delivered from depot/micro-hub to a zone by one vehicle.

The number of deliveries accomplished within the pilot area by micro-hubs and cargo bikes represents about 30% of the total number of deliveries. Therefore, the van deliveries have been reduced by 30% and substituted by active mode (cargo bikes) and this should reduce the emissions quite significantly.

Table 3: Number of parcels delivered by each vehicle type

	Zones	Tours	Trips	Parcels
Base (V)	86	27(max=180 parcel)	112	4838
Micro-Hubs (V)	86	27(max=180 parcel)	112	3372
Micro-Hubs (CB)	10	12(max=30 parcel)	52	1484

[1] https://www.aimsun.com/aimsun-ride-research-program/

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The performance of the supply network for the two scenarios can be seen in Figure 9. As it can be seen, marginal decrease in a number of network performance KPIs has been achieved due to the utilisation of cargo-bikes for part of the delivery trip.

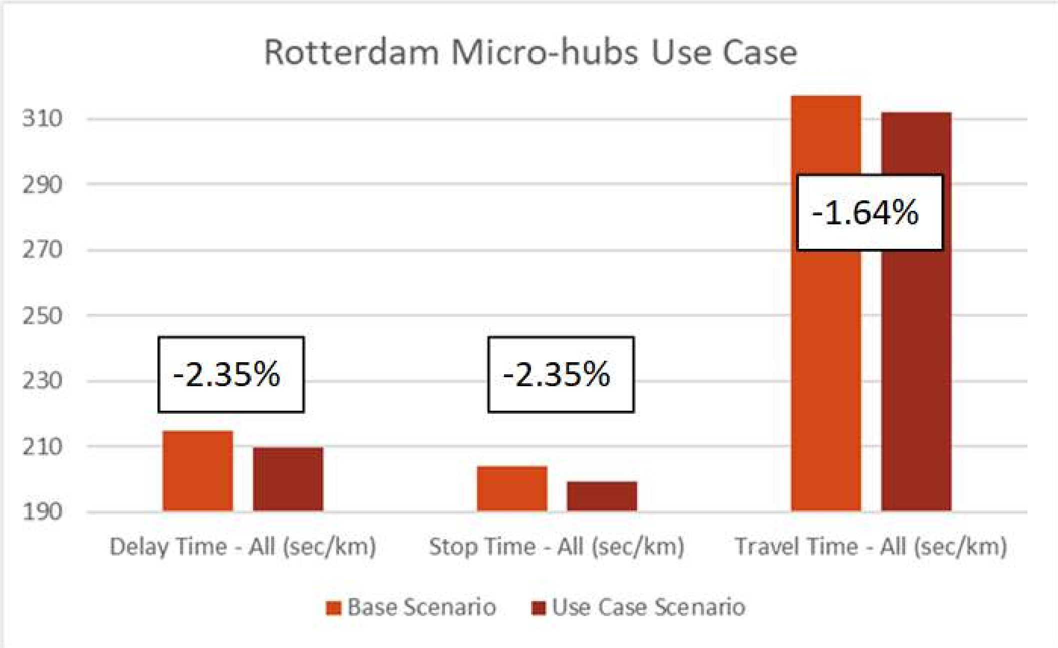

Figure 9: Supply network performance

A number of KPIs related to the performance of freight operations can also be produced by the freight controller. These can be seen in Table 4 below.

Table 4: Freight operations KPIs

	Base Scenario	Micro-hubs Scenario	
	Vans	Vans Micro-hubs	Cargo Bikes Micro-hubs
Veh-KM / Parcel	0.729	0.669	0.643
Average delivery time per parcel (sec)	243.5	184.67	129.89
Number of vehicles	58	48	77

As expected, the introduction of the micro-hubs has reduced both the veh-km per parcel and average delivery time per parcel for vans, due to the reduced number of stops and subsequent shorter distances that this type of vehicles have to travel.

4. Urban vehicles access regulation measures: Turin

4.1.Use cases description

The Turin municipality pursues the goal of rebalancing the demand for transport between collective and individual modes, in order to reduce congestion and improve the accessibility to the various urban functions. Pursuing this strategy implies an incisive mobility policy, pushing the collective transport use through large infrastructure implementation (such as the underground and the metropolitan railway

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service) and through new ITS technologies development, while, on one hand, improving the economy in the use of these services and, on the other hand, developing new sharing services.

With this respect, one of the use cases simulated for the Turin metropolitan area focuses on urban vehicles access regulation, implementing a combination of measures in order to support mode shift from private cars as well as the diffusion of cleaner vehicles. The objectives are therefore related to road congestion reduction, mode shift and air pollutant and GHG emissions reduction.

This use case (to be referred as use case 1 thereafter) stipulates land use developments and new public transport infrastructures in place at the year 2030 as reported in the Table 5. The area of analysis is the Turin Urban Functional area, which includes the municipality of Turin and 87 municipalities within the province of Turin.

Table 5: Planned land use developments and new public transport infrastructures at 2030 in Turin

Area		**Interventions**
PT infrastructure	Urban and suburban public transport network	Extension of the Metro Line n. 1 towards Rivoli-Cascine Vica
		New Metro Line n. 2, from Rebaudengo Fossata / Pescarito to Orbassano
		Extension of Tram line 3 to piazzale Toselli
		Extension of Tram line 4 to Stupinigi
		Extension of Tram line 15 to Grugliasco
	Metropolitan Railway System (SFM)	New SFM3 line, which will connect the Porta Susa railway station with the Caselle International Airport Sandro Pertini.
		The SFM5 line, connecting the Torino Stura railway station to the City of Orbassano. Three new railway stations: Orbassano Ospedale S.Luigi, Grugliasco – Le GRU and Torino-San Paolo
Land use deveopment	Torino	Lingotto area: - offices (Regional administration headquarter), - hospital (Città della Salute) - health research area, university (Città della Salute)
	Grugliasco	University extension
	Moncalieri e Chieri	Closing existing hospitals
	Trofarello	New hospital

Concerning Urban Vehicles Access Regulation, the following measures are considered in the Use Case at the projection year 2030:

- **Extension of application of Limited Traffic Zone** in the central area of Turin municipality. The area is currently defined as Limited Traffic Zone (ZTL) and applied only in the morning 7:30 to 10:30 during working days (Figure 10). The assumption of the use case is to implement in the model an extension of the ZTL application, during working days from 7.30 to 19.30.

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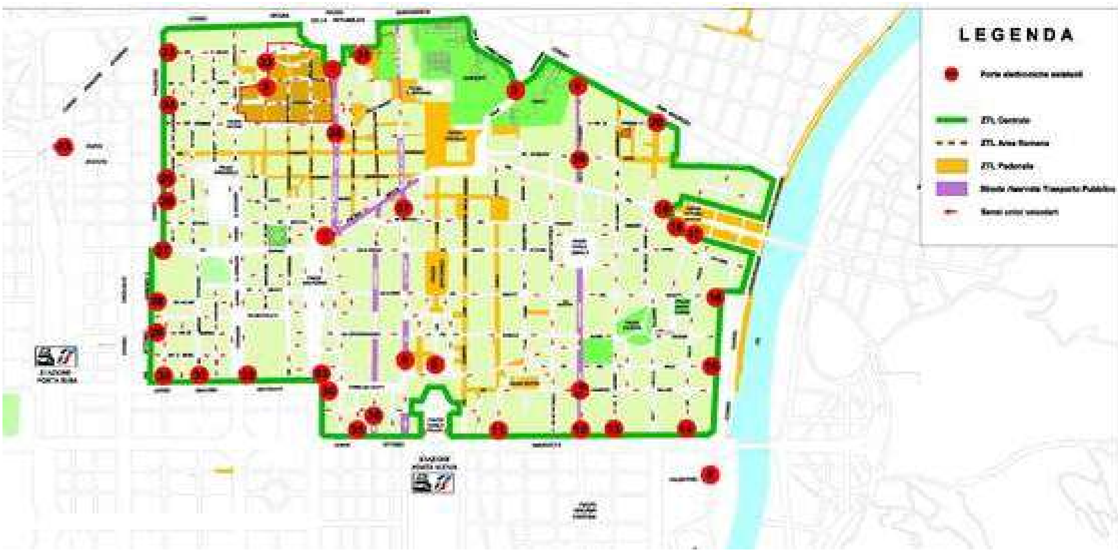

Figure 10: Limited Traffic Zone in the central area of Turin municipality (www.comune.torino.it)

- **Traffic calming areas** (zone 30) implemented extensively in Turin municipality, as well as in the neighbouring municipalities of Settimo Torinese, Venaria Reale, Collegno, Rivoli, Grugliasco, Orbassano, Moncalieri, Nichelino. The extension of the area is defined according to the SUMP scenario of the Metropolitan City of Turin[2] (adopted in August 2021) and reported in Figure 11.

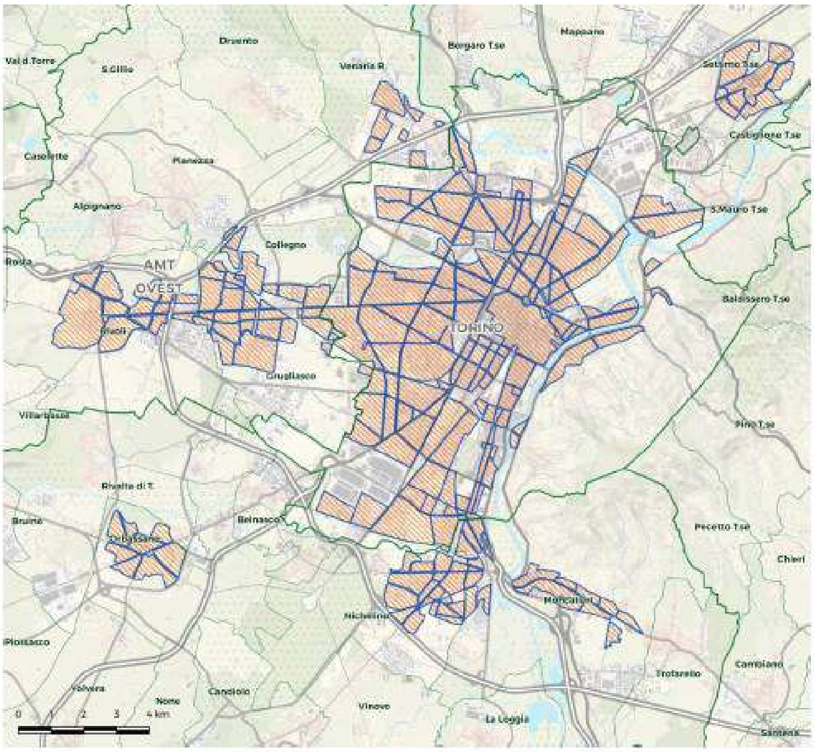

Figure 11. Traffic calming zones in Turin and other municipalities of the Turin Urban Functional area according to the SUMP scenario [August 2021]

- **Low Emission Zone** in the area including several municipalities of the Turin Urban Functional Area, assuming that only vehicles complying with Low emission standard can travel within the

[2] http://www.cittametropolitana.torino.it/cms/risorse/trasporti-mobilita-sostenibile/dwd/pums/RapportoFIN_v10.pdf

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area shown in Figure 12. The municipalities involved are the same considered in the Air pollutant emission winter Emergency Plan[3] already in place in the North Italian regions, namely those reported in the following Table 6. The measure should allow the circulation of petrol and diesel vehicles with a minimum standard of EURO6, as well as hybrid and electric vehicles.

Table 6. List of municipalities of the Turin Urban Functional Area included in the LEZ at 2030

Municipalities of the LEZ				
Alpignano	Caselle Torinese	Leini	Pino Torinese	Settimo Torinese
Baldissero Torinese	Chieri	Moncalieri	Piobesi Torinese	Torino
Beinasco	Collegno	Nichelino	Piossasco	Trofarello
Borgaro Torinese	Druento	Orbassano	Rivalta di Torino	Venaria Reale
Cambiano	Grugliasco	Pecetto Torinese	Rivoli	Vinovo
Candiolo	La Loggia	Pianezza	San Mauro Torinese	Volpiano
Carignano				

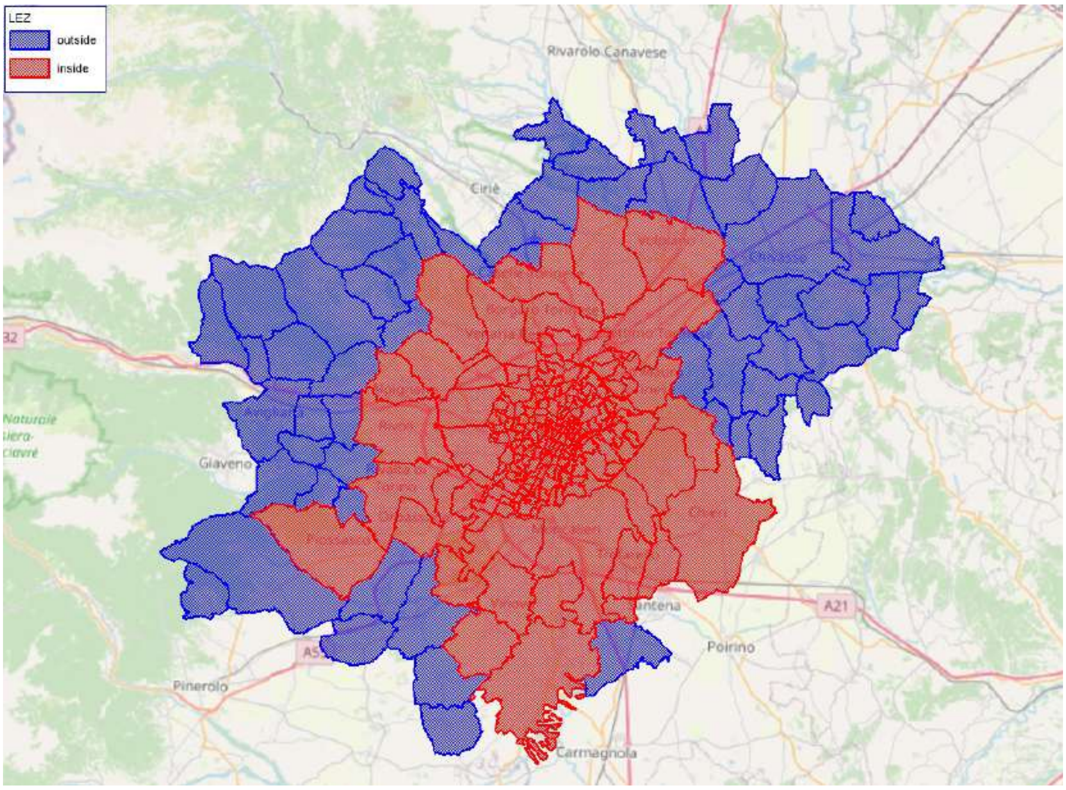

Figure 12. Extension of the LEZ in the Turin Urban Functional area under analysis

4.2.Application of models

The use case is simulated applying the VISUM multimodal network model developed for the Turin Urban Functional area, in combination with the Energy and Emission Model and vehicle stock model at (i) the base year 2019 and (ii) the projection year 2030 for both the use case 4 (urban vehicles access regulation measures) on urban access regulation and a simplified simulation of use case 1 (to have a reference scenario without those measures).

The network model provides output in terms of road traffic flow by vehicle (car, buses) by network link including average speed and distance travelled. This data is used as an input from the energy and emission model, which combines the road traffic flow projections with aggregate qualities of the regional

[3] http://www.arpa.piemonte.it/approfondimenti/temi-ambientali/aria/aria/semaforo-qualita-dellaria-pm10

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vehicle fleet, as estimated by the vehicle stock model, to estimate tailpipe and fuel lifecycle CO_2 emissions, energy consumption and air pollutant emissions such as NOx and $PM_{2.5}$.

4.2.1. Multimodal land network model

The multimodal land network model performs the assignment of both private and public transport demand, therefore including the representation of various transport modes and services. The following are considered for the application of the use case:

- Private: car, bike, moped scooters,
- Public Transport: bus, tram, metro, train,
- Sharing mobility services: car sharing, bike sharing, shared e-scooters, shared moped scooters.

The model focuses only on the assignment phase of transport demand, since the mode choice process within the HARMONY MS is performed by the tactical passenger simulator, with an agent-based model providing the output to the network model in terms of matrices by mode. The matrices are disaggregated for two time periods - morning peak hour (8:00-9:00) and off-peak hour (e.g., 11:00-12:00) – and four different purposes - commuting, study, other and return home.

Nevertheless, to simulate the use case on vehicle access regulation measures reported in this Deliverable, the network model has been applied without the linkage with the tactical model (which is under development). Therefore, exogenous assumptions have been implemented in order to show the potential mode shift in terms of demand, resulting especially from the application of the LEZ.

The assumptions implemented off-line on mode shift are differentiated by purpose and type of trips generated within the LEZ (i.e. urban or non-urban, by distance thresholds, within the Turin municipality or other municipalities, etc.).

The urban access regulation measures are simulated within the network model as follow:

- The **ZTL area** is represented by links which can't be used by car mode in the selected time periods (both morning peak hour and off-peak hour). Only car trips made by inhabitants of the ZTL area are allowed.
- The **traffic calming areas** are represented by lowering the free-flow speed of the links involved to 30 km/hour.
- The simulation of the **LEZ area** based on car vehicle Emission Standard has been implemented by splitting the car passenger demand into two different segments, one for the drivers with a car that fits the LEZ emission standard (Euro 6 or more) and the other one for the drivers whose car cannot enter the LEZ. The car passenger demand has been split based on data of projected vehicle stock composition simulated by the Vehicle stock model i.e., with a share of vehicles non-complying with the LEZ requirement at 2030 of about 12-13% (see fleet composition below). For this latter share of matrix, drivers cannot use the links included within the LEZ area.

The changes in travel time for car mode (differentiated by vehicle type) resulting from the application of urban access regulation measures drive the reaction of the model, making this mode less attractive (or even not available for trips within the LEZ of not complying vehicles). Therefore, an impact on passenger demand is expected. For this first simplified stand-alone simulation of the use case, it has been assumed that demand could only change mode according to exogenous assumptions mentioned above, implemented to mimic the mode choice procedure (but excluding the possibility to avoid trips, as it could be simulated with the agent-based model instead). The car demand matrix with vehicles not complying to LEZ has been estimated on the basis of the car vehicle fleet composition (see paragraph below on the energy and emission model).

The model performs the assignment of demand matrices by mode to the network. As a result, road traffic flows by car (including car sharing) and buses are estimated on each link. Car flows distinguish vehicles complying or not with the LEZ requirements, in order to estimate the related emissions accordingly. The whole car sharing vehicle fleet is assumed to be complying with the LEZ requirement.

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For buses, it is assumed that a change of the volume of passengers travelling is not directly translated into a change of the number of vehicles, until the occupancy factor of the vehicle increases (or decreases) until a certain threshold.

The model estimates times and costs and assigns trips also for the other passenger modes, which are nevertheless not covered by the energy and emission model.

4.2.2. Energy and emission model

The Energy and emission model uses as input the transport performance by vehicle type from the network model, in order to estimate the related environmental impacts. For each reference vehicle, energy use, CO_2 and air pollutant emissions arising from the vehicle activity are simulated through speed-versus-time drive cycles. The vehicle categories considered by technology are reported in Table 7 (vehicles categories are differentiated also by Emission standard until Euro VII, and car also by size).

Table 7. Vehicle categories of the Energy and emission model in Turin

Cars	Buses	Powered 2-wheelers
Gasoline Diesel Hybrid electric Plug-in hybrid electric Battery electric LPG CNG	Gasoline Diesel Battery electric CNG	Gasoline Diesel Battery electric CNG

The vehicle stock model provides the projections shown in Figure 13 (for cars) and Figure 14 (for buses) of vehicle fleet composition in Turin province at the base year 2019 and at projection year 2030. In principle an impact on car vehicle stock composition could be expected following the application of the Low Emission Zone. Nevertheless, for the purpose of the simulation reported in this deliverable, no assumptions have been made or implemented in this sense and the same composition is assumed for both simulations in 2030. From the projections it can be noted that for cars, in 2019 about 72% of the vehicles is Euro5 or less (not complying with the LEZ requirement), while in 2030 the same category is about 12%.

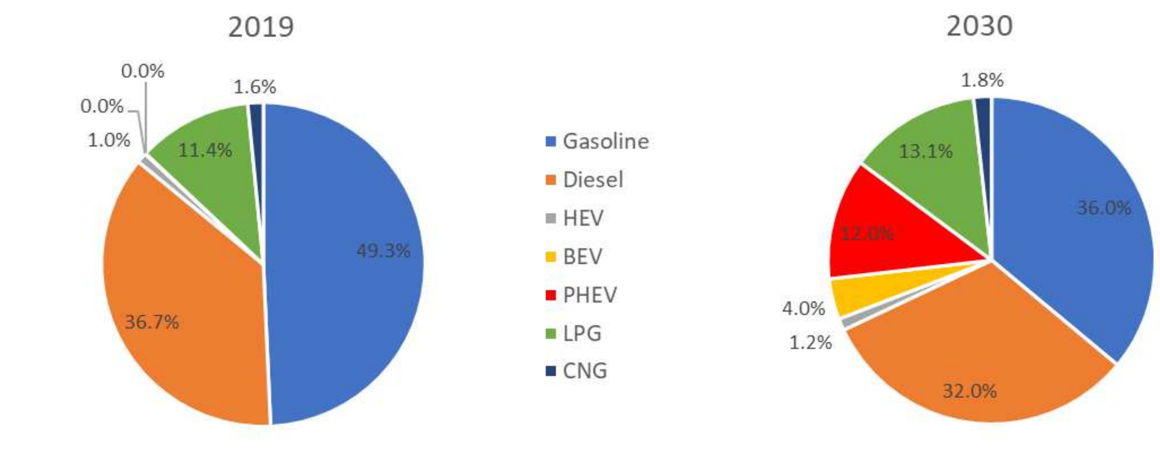

Figure 13. Car vehicle stock composition in Turin province at 2019 and 2030. Vehicle stock model projections.

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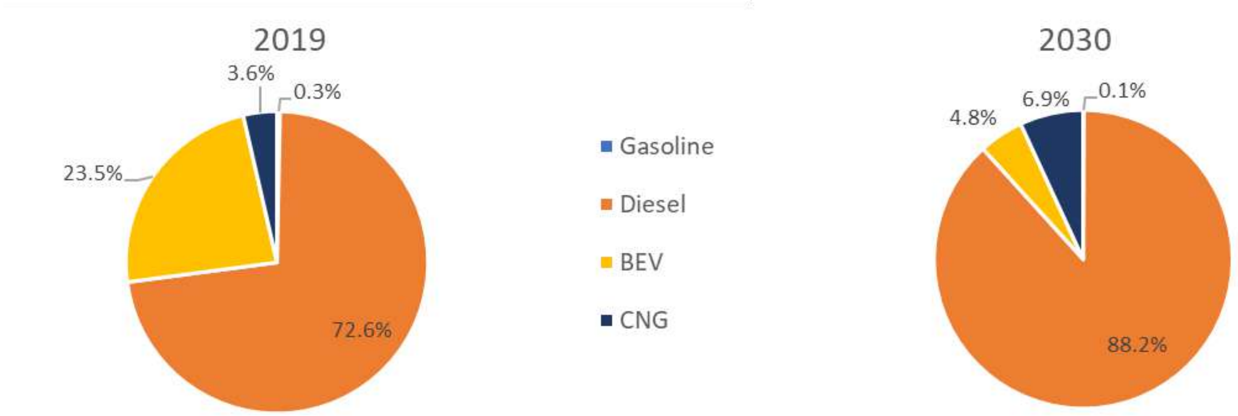

Figure 14. Bus vehicle stock composition in Turin province at 2019 and 2030. Vehicle stock model projections.

4.3.KPIs and Results

The models have been simulated for

- the base year 2019,
- a reference scenario at 2030 (to have a comparison scenario without urban access regulation measures)
- the use case 4 at 2030, with the implementation of the measures as described in previous paragraph.

This section reports the results of the application, including KPI related to transport and environment. The indicators analysed are:

- modal shares,
- passengers-km by car, bus and rail (where rail includes tram, metro and train),
- change of traffic flows on the road network
- energy consumption,
- CO_2 emissions,
- air pollutant emissions (PM2.5, NOx, CO, NMVOC).

4.3.1. Modal shares

Figure 15 shows the modal split for the base year 2019 in the whole Turin functional area (estimated on passenger trips). For this stand-alone simulation the reference scenario in 2030 has been simulated in a simplified way, i.e. assuming demand is unchanged at 2030 (since population basically is constant over time) and assuming the new public transport infrastructures are available. Nevertheless, without the linkage with the agent-based model, no changes are simulated in terms of mode split: therefore, the same modal split is assumed for both the base year 2019 and the reference scenario in 2030.

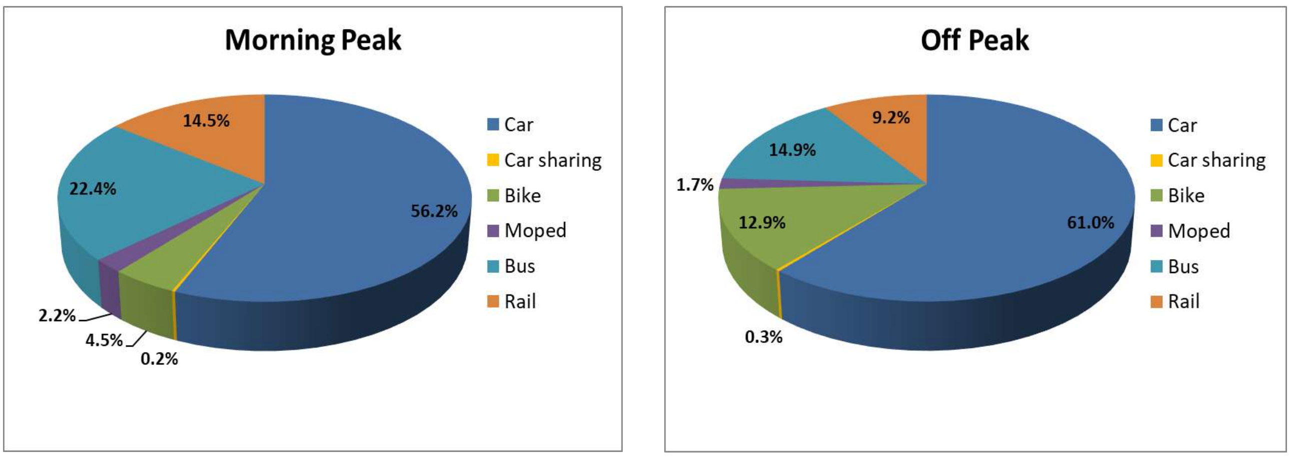

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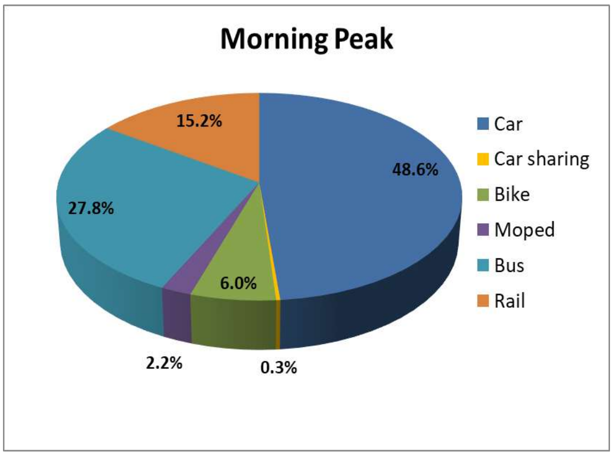
Figure 15. Modal shares at the base year 2019 and reference scenario 2030 during morning peak hour and off-peak hour

As a result of the implementation of urban access regulation measures at year 2030, two impacts are simulated: (i) car demand related to vehicles not complying with LEZ requirements and travelling to / through the LEZ is forced to change mode, (ii) car demand of vehicles complying with the LEZ is reacting to the implementation of ZTL and traffic calming areas, i.e. changing travel path. The choice of the substitution mode for trips by car not complying with the LEZ requirement is driven by the exogenous assumptions mentioned above. As a result of these external assumptions, the modal shares show (Figure 16) a decrease in car demand by about -8% in both peak and off-peak hour and an increase especially for bus (5% in peak hour and 6% off-peak). Rail (including metro and tram) and bike modes are also increasing their mode share in the range of 1%.



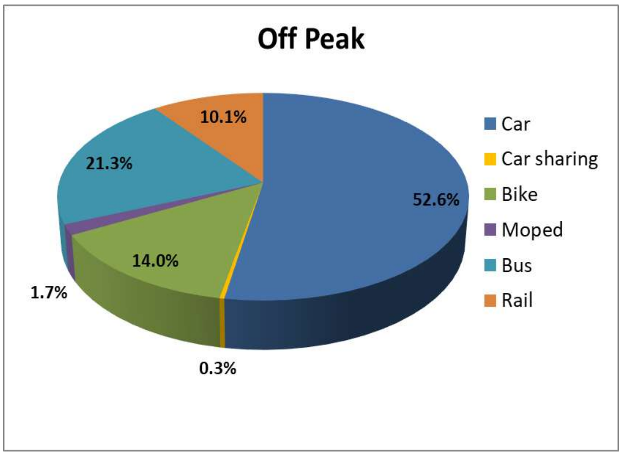


Figure 16. Modal shares at the for UC 04 at 2030 during morning peak hour and off-peak hour

4.3.2. Passengers-km

Table 8 and Table 9 below show the changes in terms of passenger-km due to the assignment of the demand matrices to the transport networks at the base year, for the reference scenario in 2030 and the use case 4 in 2030. As mentioned above, the rail mode in the tables includes metro, tram and rail services.

Table 8. passengers-km at the base year (2019)

		Car	Bus	Rail
Morning peak	**Turin**	6,886,464	218,834	59,420
	Belt	3,881,859	48,350	57,536
	Rest of FUA	1,255,572	11,387	11,202
	Total	12,023,895	278,571	128,158
Off peak	**Turin**	3,917,103	65,806	20,993
	Belt	2,170,228	16,161	18,987
	Rest of FUA	787,319	3,336	3,456
	Total	6,874,650	85,303	43,435

Table 9. passengers-km for the reference scenario (2030)

		Car	Bus	Rail
Morning peak	**Turin**	6,856,050	217,496	60,143
	Belt	3,883,462	47,671	58,890
	Rest of FUA	1,250,028	11,303	11,236
	Total	11,989,540	276,470	130,269

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Off peak	Turin	3,867,516	65,965	20,955
	Belt	2,178,829	15,911	20,237
	Rest of FUA	782,523	3,273	4,002
	Total	6,828,868	85,149	45,194

Table 10. Percentage difference between base year (2019) and reference scenario (2030)

Morning Peak		Car	Bus	Rail	Off Peak		Car	Bus	Rail
	Turin	-0.44%	-0.61%	1.22%		Turin	-1.27%	0.24%	-0.18%
	Belt	0.04%	-1.40%	2.35%		Belt	0.40%	-1.55%	6.58%
	Rest of FUA	-0.44%	-0.74%	0.30%		Rest of FUA	-0.61%	-1.89%	15.80%
	Total	-0.29%	-0.75%	1.65%		Total	-0.67%	-0.18%	4.05%

It can be noticed that, although the demand matrices are the same at the base year and for the reference scenario in 2030, there are differences in terms of passenger-km. The reason is related to different paths triggered by the new implemented infrastructures for public transport (metro, tram and rail). In the whole FUA, the rail mode shows an increase of about 1.6% in peak hour and 4% off-peak in terms of passenger-km with respect to the base year. The percentage differences between base year 2019 (Table 8) and the reference scenario 2030 (Table 9) can be shown in Table 10.

Table 11. passengers-km for use case 04 (2030)

		Car	Bus	Rail
Morning peak	Turin	5,895,590	263,665	67,459
	Belt	3,384,958	69,435	68,464
	Rest of FUA	1,169,555	15,535	13,353
	Total	10,450,103	348,635	149,276
Off peak	Turin	3,224,712	90,614	25,917
	Belt	1,819,728	30,038	26,634
	Rest of FUA	723,197	6,007	5,560
	Total	5,767,637	126,659	58,111

Looking at the results of the use case 4 in comparison to the reference scenario at 2030, Table 11 shows a decrease of about -13% in passenger-km for car within the whole FUA during morning peak, with an increase of bus and rail passenger-km respectively of 26% and 15%. During the off-peak period, passenger-km by car decrease by about 16%, while bus and rail increase respectively by 49% and 29%. All the percentage differences between these two scenarios can be seen in Table 12. The increase of passenger-km travelled by public transport modes is therefore significant, underlying the need of evaluating carefully the service which would be required to face such an increase in transport demand. Figure 17 below shows the trend of passenger-km across modes.

Table 12: Percentage difference between reference scenario (2030) and use case 04 (2030)

Morning Peak		Car	Bus	Rail	Off Peak		Car	Bus	Rail
	Turin	-14.01%	21.23%	12.16%		Turin	-16.62%	37.37%	23.68%
	Belt	-12.84%	45.65%	16.26%		Belt	-16.48%	88.79%	31.61%
	Rest of FUA	-6.44%	37.44%	18.84%		Rest of FUA	-7.58%	83.53%	38.93%
	Total	-12.84%	26.10%	14.59%		Total	-15.54%	48.75%	28.58%

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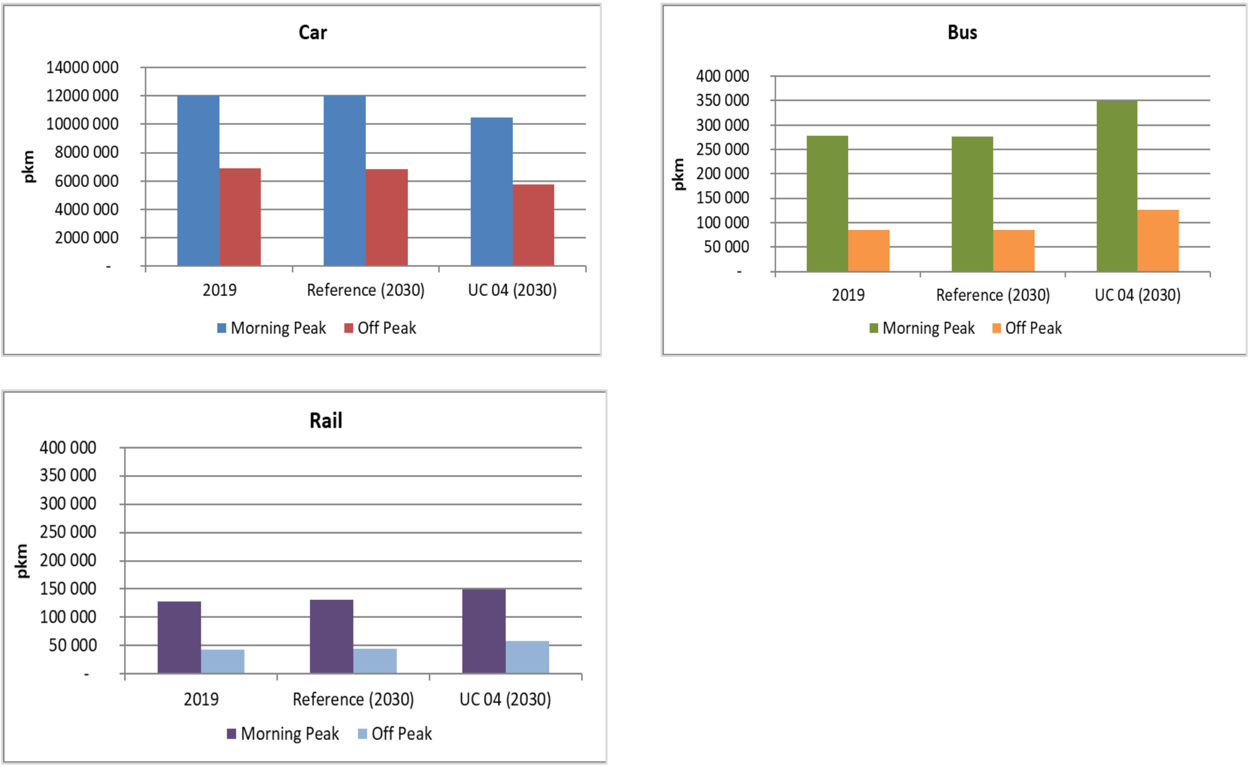

Figure 17. Passenger-km by mode at the base year 2019, reference scenario 2030 and use case 4 during morning peak hour and off-peak hour

4.3.3. Traffic flows on the network

Figure 18 shows the changes in terms of road traffic flows on the network in use case 4 with respect to the reference scenario 2030 during morning peak hour.

In general, an overall decrease of road traffic flows in the whole LEZ area is estimated, resulting from the mode shift due to the implementation of urban access regulation measures.

In some cases, a slight increase in traffic flows can be observed due to the combination of ZTL and traffic calming areas that induce paths changes.

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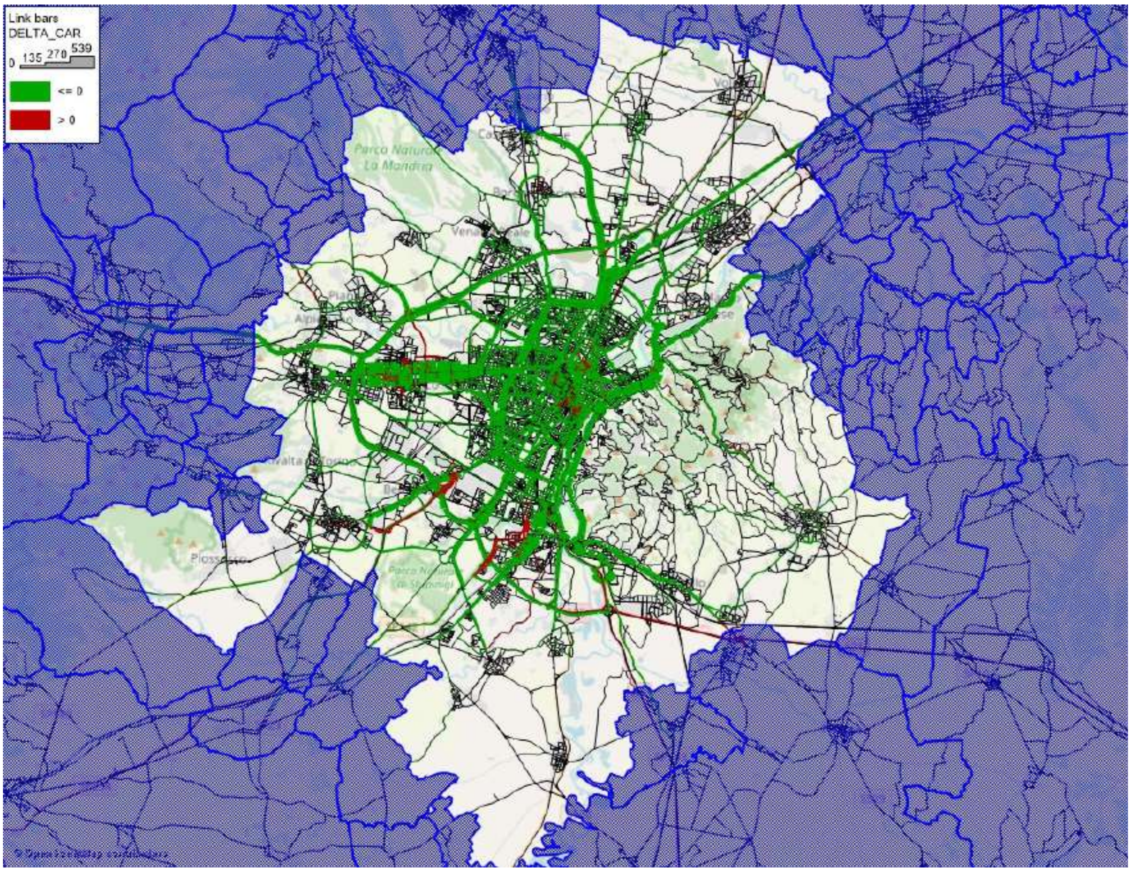

Figure 18. Change of traffic flows on the road network in use case 4 with respect to the reference scenario 2030 during morning peak hour

4.3.4. Energy consumption

Figure 19 shows results in terms of energy consumption by fuel type for the base year, the reference scenario and the use case 4 in 2030. In the reference scenario in 2030, the impact of the evolution of car vehicle fleet composition can be observed in terms of reduction of energy consumption for conventional fuels (about -22%), with a huge increase of electricity. Comparing the use case 4 with the reference scenario at 2030, the impact on conventional fuels (-17% to -21%) results from the mode shift (decreasing car share) and change in passenger-km, which affects especially vehicles not complying with the LEZ requirement (having also higher fuel consumption factor).

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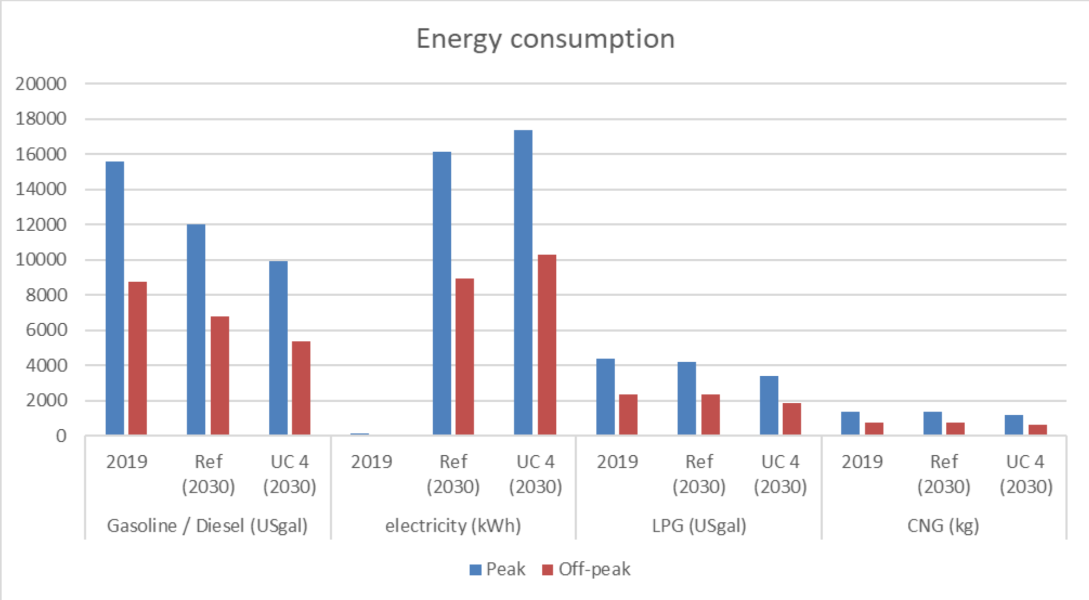

Figure 19. Energy consumption by fuel at the base year 2019, reference scenario 2030 and use case 4 during morning peak hour and off-peak hour

4.3.5. CO_2 emissions

Table 13 and Figure 20 summarise the impacts in terms of CO_2 emissions (considering both combustion and lubricant oil) by mode for the three applications.

In line with the energy consumption impacts, the reference scenario shows a reduction with respect to the base year of about -20%, mainly due to the car vehicle fleet composition projections where conventional vehicles decrease their relevance in the stock. The emissions related to buses are also decreased (about -11%), thanks to the fleet renewal. When comparing the use case 4 results with the reference scenario in 2030, a further decrease is observed and explained by the mode shift from car to the other modes. Accordingly, the emissions from bus mode are increased as an increase of the service is required to face the increase of demand in terms of passenger-km.

Table 13. CO_2 emissions by mode at the base year 2019, reference scenario 2030 and use case 4 during morning peak hour and off-peak hour

CO_2 (tons)		**2019**	**Reference (2030)**	**UC4 (2030)**
Car	**Peak**	185.9	147.8	121.0
	Off-peak	103.9	84.1	65.6
Bus	**Peak**	5.5	4.9	5.5
	Off-peak	2.6	2.3	2.4
TOT	**Peak**	191.4	152.7	126.5
	Off-peak	106.6	86.4	68.0

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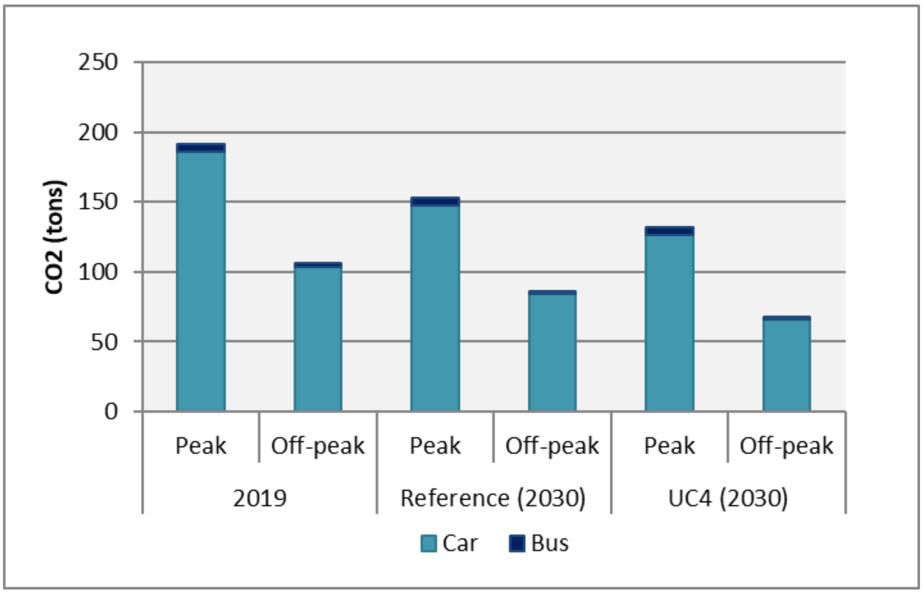

Figure 20. CO_2 emissions at the base year 2019, reference scenario 2030 and use case 4 during morning peak hour and off-peak hour

4.3.6. Air pollutant emissions

In terms of air pollutant emissions, the impacts are reported in Table 14 for $PM_{2.5}$, NOx, CO and NMVOC.

In general, as already mentioned for energy consumption and CO_2, emissions are reduced in the reference scenario 2030 with respect to the base year, thanks to the projections of vehicle fleet composition. This is particularly relevant for emission of $PM_{2.5}$, where the reduction is about -55%, while for NOx the reduction is about -42% and for the other pollutants it ranges from -26% to -32%.

Comparing the use case 4 with the reference in 2030, a further reduction is observed as a result of mode split penalising car mode and reducing the related passenger-km. Again, emission of $PM_{2.5}$ show the larger reduction (about -37% to -44%), while for the other pollutants the decrease ranges from -17% to -29%.

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Table 14. Air pollutant emissions by mode at the base year 2019, reference scenario 2030 and use case 4 during morning peak hour and off-peak hour

PM2.5 (kg)		2019	Reference (2030)	UC4 (2030)
Car	Peak	3.25	1.55	0.98
	Off-peak	2.20	1.02	0.57
Bus	Peak	0.31	0.06	0.03
	Off-peak	0.19	0.04	0.02
TOT	Peak	3.56	1.61	1.02
	Off-peak	2.40	1.06	0.59
NOx (tons)		**2019**	**Reference (2030)**	**UC4 (2030)**
Car	Peak	196	114	87
	Off-peak	118	70	50
Bus	Peak	15	6	5
	Off-peak	9	4	2
TOT	Peak	210	120	92
	Off-peak	127	74	53
CO (kg)		**2019**	**Reference (2030)**	**UC4 (2030)**
Car	Peak	518	376	306
	Off-peak	335	228	175
Bus	Peak	3	1	1
	Off-peak	2	1	1
TOT	Peak	521	377	307
	Off-peak	337	228	176
NMVOC (kg)		**2019**	**Reference (2030)**	**UC4 (2030)**
Car	Peak	49.8	37.3	30.9
	Off-peak	31.6	22.4	17.7
Bus	Peak	0.6	0.1	0.1
	Off-peak	0.4	0.0	0.0
TOT	Peak	50.4	37.4	31.0
	Off-peak	31.9	22.5	17.8

5. Public transport electrification, micro-mobility and CAVs penetration: Athens

5.1. Use cases description

Athens, the capital city of Greece, is a densely populated area with the number of inhabitants across its metropolitan extensions estimated around 3,750,000. Athens is also the centre of political, social and business activities in Greece as well as a world-wide known tourist destination. In addition, the port of Piraeus, 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.

In this context, transportation planning in Athens arises as a key element of its everyday functionality. As such, the Athens Public Transport Organization (OASA), the sole mass transit operator in the Attica region, has developed a spatially extensive transport network model that covers the entire Athens metropolitan area. The model is used for experimentation with different transportation policies and measures and the evaluation of their expected performance before proceeding with their actual

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implementation on the network. The model is also used for the verification of the performance of existing measures and modelling assumptions and the suggestion of possible improvements and/or changes where needed.

The Athens network model is a spatially extensive transportation analysis tool that has been created in the traffic planning software PTV VISUM. The software belongs to the category of macroscopic simulation tools. The transport model covers the entire Athens metropolitan area and consists of a large number of links (over 22,000), nodes (over 7,000) and zones (1284 in total) as well as considers different types of transportation modes, with a distinction made between public and private transport. The public transport system in particular, accounts for six different types of modes, that is bus, intercity bus, tram, subway, trolley and rail.

In the framework of the HARMONY project, OASA decided to investigate different scenarios that would be of interest to the Authority and that, if applied, could have implications to the city's day-to-day operation of transportation means. Three case studies have been examined in this regard.

a) *The electrification of public transport:* This case study investigates the transition from conventional fuel buses to battery electric ones. It is based on the actual initiative currently undertaken in the city of Athens, which is expected to be fully realized over the next years. The main goals of the initiative are to: (a) renew the existing bus fleet and increase the passengers' Level of Service (LoS), (b) promote the use of public transport through the improved level of service provided and attract more passengers from the private means of transport, (c) promote the contemporary image of Athens, (d) conform to the European transport and environmental guidelines, and (e) improve the air quality in the capital, and thus provide health benefits to the residents over the short and long run.

b) *The electrification of public transport with additional consideration of micro-mobility interventions:* In this case study, the previous scenario is enriched with the consideration of micro-mobility schemes on the network. The micro-mobility interventions simulated in this regard are based on the actual plans devised for the construction of two major bicycle paths in the city. Smaller scale (on the municipality level) micro-mobility interventions may have also been proposed as part of the Sustainable Urban Mobility Plans (SUMPs) that are currently undertaken in the greater Athens metropolitan area. However, as a first step, these were not simulated in the present use case. The scope of incorporating micro-mobility interventions is to gradually shift passengers from more traditional modes of transport to more environmentally friendly ones, thus, once again, providing air quality and health benefits to the residents.

c) *The operation of autonomous vehicles (AVs):* This case study examines the effect of different AV penetration rates on the network through the adjustment of the model's Volume - Delay Functions (VDFs). Although not a scenario that is expected to be realized in the near future in Athens (at least when considering significant penetration rates), the study of this hypothesis is interesting as an indication of the future operation of the transport system.

All three case studies were simulated in the Athens PTV Visum model, which was, each time, appropriately adjusted to fit the modelling requirements.

5.2.Application of models

Application of the aforementioned use cases in the Athens pilot is described below, with a separate section dedicated to each use case.

5.2.1. Public transport electrification

The electrification of public transport is viewed as the first step towards the transition of the capital to a new, more sustainable and environmentally friendly, mobility era. Along with the gradual shift of the public to private electric cars and other initiatives that are to be undertaken in the future, it is strongly believed that it is going to contribute towards improved air quality in the city and better health for the residents.

As it is known, battery electric buses (BEBs) produce no tailpipe emissions. However, in a wider perspective, emissions associated with electricity production and transfer should also be taken into account when estimating the actual environmental footprint of the electric buses. Nevertheless, till

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now, the tender for the BEBs is not completed yet and, thus, there is no data on the energy consumption and the charging efficiency of the buses that will operate on the system. Therefore, the present analysis can only be based on the tailpipe emissions of the conventional buses with consideration of their gradual substitution by BEBs. For this reason, the analysis takes into account the gradual electrification of some of the bus lines operating on the system with the simultaneous replacement of the most polluting buses and the redistribution of the rest of the conventional fleet to the other bus lines. As a result of this process, the number of veh-km run by conventional buses gradually drops, in addition to the conventional fleet being progressively composed by less polluting buses, thus leading to a decrease of air pollutants.

5.2.2. Public transport electrification with consideration of micro-mobility interventions

Athens has, for many years, allowed an excessive increase in the use of private vehicles, a trend that was only partially limited by the operation of the three Athens subway lines in 2000, followed by the economic recession of years 2009 - 2019 and the 2020 - 2022 covid-19 pandemic. In spite of all of these, Athens is currently shifting to more sustainable forms of transport, with the electrification of public transport being the first measure in this direction, followed by the application of other soft mobility measures. In this context, in June 2020, the Minister of Environment and Energy announced the construction of two major bicycle paths in Athens (Figure 21). These are the following:

- *Bicycle path 1: Faliro - Gazi – Kifisia (completed section: Faliro – Gazi)* - The total length of the path is about 27 km. The bicycle path crosses the entire Athens metropolitan area and densely populated neighbourhoods, in order to help alleviate some of the congestion occurring. The southern part of the path (Faliro – Gazi, about 10km) has already been constructed, while the northern part (Gazi – Kifisia, about 17km), when initiated, is expected to be completed in 18 - 20 months. The total project budget is 7,000,000€ and it is funded by the Green Fund.
- *Bicycle path 2: Katehaki – Polytechnioupoli – Panepistimioupoli – Evangelismos* - The total length of the path is about 10km and, when constructed, it will be connected with the current bicycle path in Polytechnioupoli (about 4km). When initiated, the project is estimated to be completed in about 15 - 18 months. The total project budget is 3,000,000€ and it is funded by the Green Fund.

Both bicycle paths are designed to be connected to subway stations in order for them to allow for intermodal transport. As already explained, these are part of a greater plan to gradually transform the transportation patterns in Athens to more environmentally friendly forms. Indeed, many of the SUMPs currently undertaken in the municipalities across the Attica region also propose the operation of micro-mobility schemes.

In this light, the present use case integrates the public transport electrification scenario with the modelling of these two major bicycle paths that are going to be realized in Athens in order to assess their combined environmental impact on the network.

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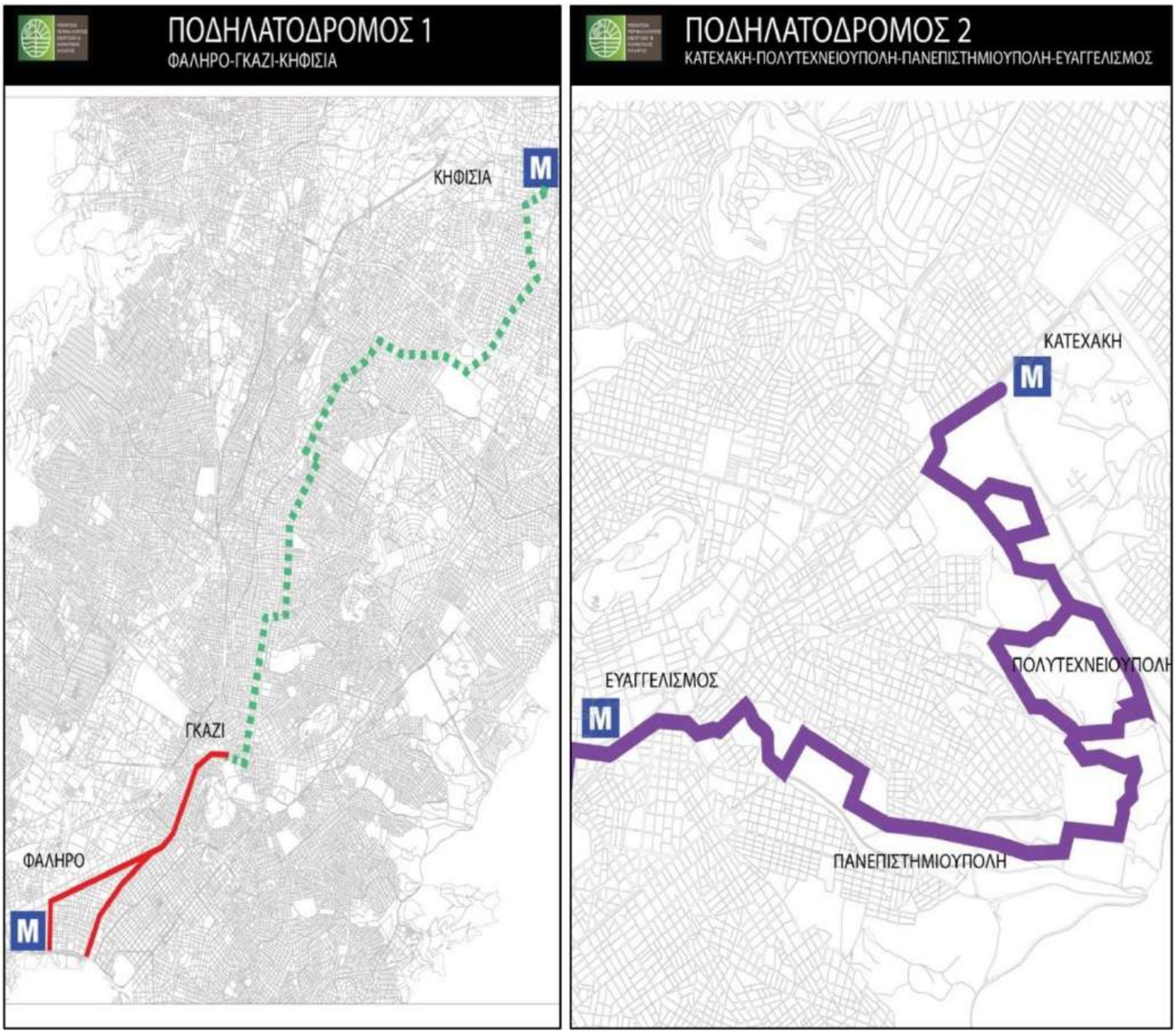

Figure 21: a) Bicycle path 1: Faliro - Gazi - Kifisia, b) Bicycle path 2: Katehaki – Polytechnioupoli – Panepistimioupoli - Evangelismos

5.2.3. Operation of autonomous vehicles (AVs)

Although not a scenario to be witnessed on the streets of Athens in the near future, mixed traffic, composed of both conventional and autonomous vehicles, is expected to be the norm over the years to come, with increasing AV penetration rates. Among their other characteristics and according to the literature, higher AV penetration rates can have a beneficial effect on the network by increasing the traffic flows due to the shorter headway needed by the autonomous vehicles and the less reaction times that they exhibit.

In this case study, with the help and guidance of Aimsun, the methodology developed by the Levitate project (https://levitate-project.eu/tag/traffic-microsimulation/), which intends to upscale the effects of different AV penetration rates from the microscopic simulation level to the macroscopic one, is applied on the city of Athens. The scope of this use case is to investigate how the penetration of different AV rates is going to affect the traffic flows and the travel times on the network. In this regard, the Levitate methodology can be summarized as follows:

- First, microscopic simulation-based experiments are run in order to derive network capacities for scenarios with mixed traffic flow consisting of both conventional and autonomous vehicles.
- Then, a statistical analysis is carried out in order to identify the effect of the relative change of the capacities when considering different types of mixed flow (different AV penetration rates) on the

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estimation of the Passenger Car Unit (PCU) factors. This results in the estimation of a functional relationship between the PCU factors and the AV penetration rates.

- Finally, the derived PCU relationship is provided as input to the Volume Delay Functions (VDFs) of the macroscopic demand model in order to forecast the potential macroscopic implications induced by different AV penetration rates on the network performance.

5.3.KPIs and Results

The results of the analyses conducted are provided herein, with a separate section dedicated to each one of the use cases.

5.3.1. Public transport electrification

Since the ultimate goal of the Ministry of Infrastructure and Transportation is the gradual electrification of all bus lines in Athens, this case study is broken down into five scenarios, each one considering a different number of bus lines operated by battery electric buses. These are illustrated in Table 15.

Table 15: Scenarios examined for the operation of Battery Electric Buses (BEBs) use case

Scenario	Number of BEB lines	Scenario	Number of BEB lines
1	0	4	150
2	50	5	200
3	100		

The aim is the investigation of the effects of electrification in terms of the each time remaining in operation conventional buses' exhaust emissions (CO, NOx, PM2.5 pollutants). With a total of 284 bus lines, gradual electrification of some of the lines with simultaneous replacement of the most polluting buses and redistribution of the rest of them to the other bus lines can result in substantial decrease of air pollutants.

In this analysis, the first 50 electrified lines have the potential to cut the remaining in operation conventional buses' CO emissions in half and decrease the respective NOx emissions by 46% (Figure 22). Naturally, results may vary on the basis of the number of BEBs available at the various stages of the procurement and the combination of the lines electrified.

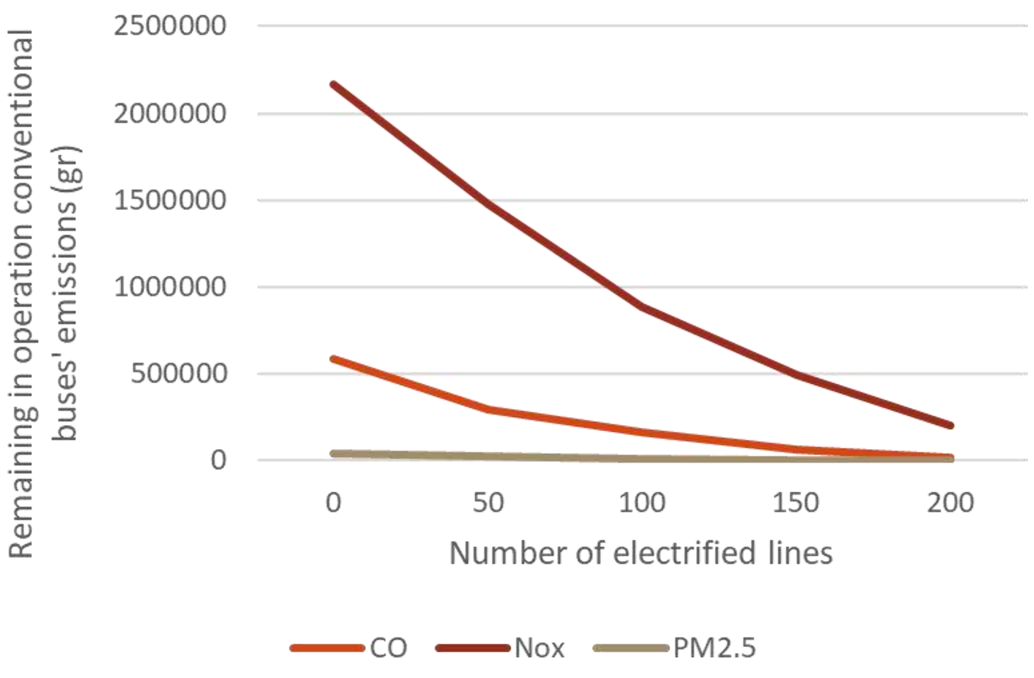

Figure 22: CO, NOx, and PM2.5 emissions of the remaining in operation conventional buses per number of electrified lines

5.3.2. Public transport electrification with consideration of micro-mobility interventions

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When considering the combined operation of Battery Electric Buses (BEBs) and micro-mobility schemes on the Athens network, the results from the analyses show that the additional impact of the two bicycle paths on the overall environmental footprint of the traffic is negligible. As expected, the decrease of the emissions is driven by the electrification of public transport.

In this respect, the construction of an extensive network of associated micro-mobility infrastructure could possibly hold the potential of a notable impact on air quality. As such, further scenarios need to be investigated in this respect.

5.3.3. Operation of autonomous vehicles (AVs)

10 scenarios were developed and examined on the Athens network on the basis of different AV penetration rates. These are illustrated in Table 16.

Table 16: Scenarios examined for the operation of autonomous vehicles (AVs) use case

Scenario	AV penetration rate (%)	Scenario	AV penetration rate (%)
1	0	6	60
2	10	7	70
3	20	8	80
4	40	9	90
5	50	10	100

For each of the scenarios, the new PCU factors (dependent on the AV penetration rates and calculated through the Levitate methodology) were used as input in order to update the respective VDF functions. For the base case scenario (operation of only conventional vehicles, AV penetration rate = 0%), the PCU factor is equal to one. For all other scenarios, the PCU factors range from 0.98 to 0.82, with lower PCU factors corresponding to higher AV penetration rates.

Although the total veh-km will remain the same, it can be concluded that since higher AV penetration rates are related to lower PCU factors, a greater number of autonomous vehicles theoretically increases the available roadway capacity. It can be noted that the extra capacity might lead to an increasing demand for car modes which might negate the benefits from the high AV penetrations. This however requires a demand modelling framework that will capture these induced demand effects which is out of this deliverable's context. Furthermore, and as a result of the capacity increase, travel times also drop as the AV penetration rates increase. Indeed, the difference of total network travel time between the base case scenario and the 100% AV penetration rate scenario is -8.97% (Figure 23). The results are in accordance with the ones derived for the Barcelona network in the Levitate program.

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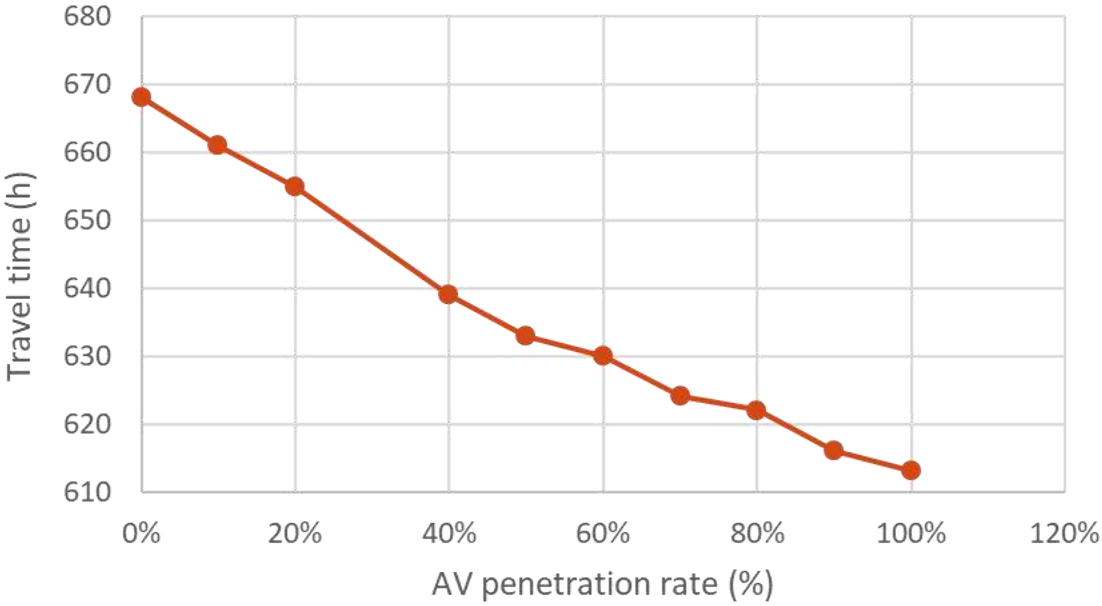

Figure 23: Total network travel time per different AV penetration rates

6. Application of the nowcasting module: Oxfordshire

6.1.Application of module

This section presents the application of the nowcasting module using incident and traffic data for the city of Oxford. The full functionality of the module has been reported in deliverable 7.5 and is therefore excluded from this document. The application of the module entails the use of different real traffic events as inputs to examine the functionalities of the developed nowcasting module and provide relevant implementation results. For the purpose of nowcasting module validation, such real traffic events are required along with the network traffic data (i.e. network speed and flow data). Therefore, the HERE Traffic API is used to collect real events and traffic data for one week (210 events). For the application of the module 11 of these valid events have been used. Each event starts and finishes during the data collection period, maximum duration of one hour, the simulation section of this event is located within the scope of the network model and the speed values of this simulation section are available.

6.2.Application Results

In order to apply the nowcasting module, input data needs to be specified and identified by the user. Input data represents the main attributes of the real events, which might be assumed or predicted, such as event type, criticality, start time, duration and location. Table 17 shows examples of such input data for some real events collected by the HERE Traffic API (4 out of the 11 events mentioned above). Essentially, the nowcasting module takes these input event data and performs the following procedure for each real event:

- Calculates the simulation section (sim_section in **Error! Reference source not found.**) d epending on the location of the event, the simulation network model and the scripting approach.
- Captures the attributes of event's simulation section/road such as road type, lanes and maximum speed.
- Calculates the event class (Table 18) by using the ML event classification model which is generated and stored on the disk.

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- Depending on the event's class and the number of road lanes, retrieves the corresponding incident category (Table 18) by using event-to-incident map which is generated and saved.
- Creates the incident category which is related to the real event, inserts this traffic condition in the simulation model (considering event time and duration), saves the model and runs the simulation.
- Reads the simulation results (i.e. speed values) related to the event's section and for the event's duration.

Table 17: Examples of some real events required for nowcasting module implementation

Event_Id	Event_Type	Event_Criticality	Event_Duration	EvStart_Hour	EvStart_Minute	Event_Latitude	Event_Longitude
3183530235280393721	3	2	15	15	26	51.86324	-1.19031
1558508917686200216	3	2	13	16	1	51.92722	-1.20192
1565438259706994919	3	2	11	16	12	51.91059	-1.20493
4048548091872989792	3	2	13	16	20	51.86583	-1.19503

Table 18: The results of nowcasting module implementation

Event_Id	sim_section	Road_MaxSpeed	Road_Lanes	Road_Type	Event_CLASS	Incident_CATEGORY	eventAllSpeed	eventAveSpeed
3183530235280393721	9411	70	4	5	1	232	[15 elements]	82.7920781901188
1558508917686200216	1121	70	4	5	3	130	[13 elements]	74.50277435110962
1565438259706994919	1121	70	4	5	4	238	[11 elements]	68.7237085355053
4048548091872989792	1099	70	3	5	3	228	[13 elements]	35.45383103318875

The application of the nowcasting module updates the simulation network model in such away to be as similar as possible to the real network. Also, the effects of different real events, which may be assumed or predicted in the real transport network, on the real network performance can be calculated and predicted. However, predicting the status of the traffic network as a result of various events (in type, criticality, duration and location) could be very useful for transport network management and many other systems. In HARMONY for example, the nowcasting module can be used and integrated with operational level models for assessing the supply network performance when an event occurs. For example, in combination with the operational freight controller, the nowcasting module can be used to evaluate the impact that an event may have in the delivery times of freight fleets. Moreover, some countermeasures for such events may be analysed and determined to alleviate severe deviations in the delivery time of vehicles.

6.2.1. Nowcasting Module Validation

In this section, the results and performance of nowcasting module will be examined against the real network observations and collected data. This will show how the nowcasting module is valid in representing the real traffic events in the simulation environment by comparing its application results with the traffic data collected.

For each event, the actual event class is calculated from the real data collected (event and speed data) while predicted event class is calculated by using the ML event classification model. Figure 24 shows the comparison between these two classes for all the events tested. Then, the relative average speed (average speed value over the incident duration with the presence of incident to that without the incident) of the incident's simulation section (AvSpeed_predicted in Figure 25) is compared to the relative average speed calculated for the real event from the collected data (AvSpeed_actual in Figure 25). The comparison in Figure 25 validates the performance of both event classification model and the event-to-incident mapping at the same time. It does not show a perfect matching between actual and predicted values, but the results may be considered as good. In order to measure the accuracy of the nowcasting module, the Mean Absolute Percentage Error (MAPE) is calculated as it represents a very common KPI to measure forecasting accuracy. Figure 26 shows the MAPE values for the tested events and the average MAPE of these 11 MAPE values. The average MAPE value is about 17.8% which might allow us to consider the nowcasting module performance as good. It can also be seen that in the majority of the cases the predicted average speed is lower than the actual one. This can be attributed to the way the accident is modelled in the simulation. The above described errors can be further reduced by further training the developed models with additional data under real-time conditions.

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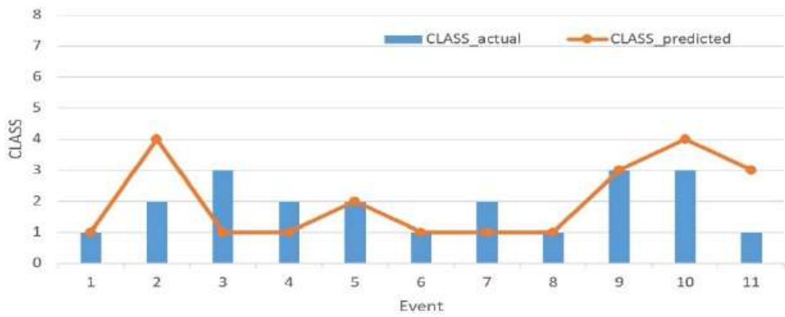

Figure 24: Event CLASS: actual vs. predicted

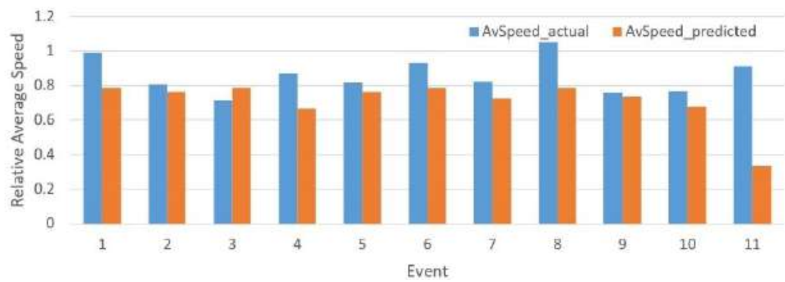

Figure 25: Event Average Speed: actual vs. predicted

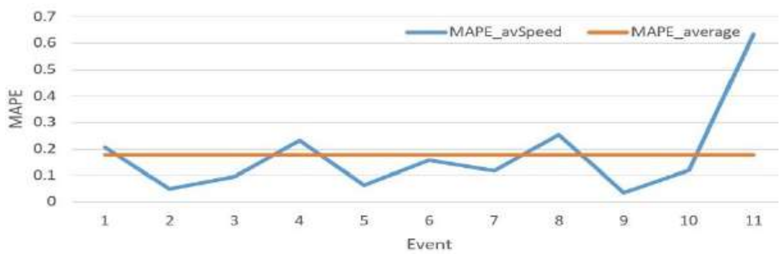

Figure 26: Event Average Speed: prediction error

7. Conclusions

This deliverable presented the application of the individual models developed as part of the operational layer of the HARMONY MS. The key findings are as follows:

- For the application of a demand response transport service for the city of Oxford, fractions of the existing demand (ranging from 1-10%) is replaced with trip requests that can be facilitated by the DRT service and different scenarios have been realised to this extend. Indicative outputs illustrate that metrics related to CO2 emissions and delay time do not fluctuate significantly when the penetration rate of DRT services increase from 1 to 10%. Similarly, increase of the demand of DRT services doesn't result in substantial change of load balance of individual DRT vehicles, meaning that each vehicle travels roughly an equal distance throughout the different simulation scenarios.
- The investigation of using cargo bikes for last mile delivery with the presence of micro-consolidation centres in the city of Rotterdam. In this use case, the number of deliveries accomplished within the pilot area by micro-hubs and cargo bikes represents about 30% of the total number of deliveries. Therefore, the van deliveries have been reduced by 30% and substituted by active mode (cargo bikes) and this should reduce the emissions quite significantly.
- The use case related to the urban vehicle access regulation measures for the city of Turin assesses the impact that three different access regulation measures, namely (i) limited traffic zone; (ii) traffic calming areas; and (iii) low emission zone, has in modal shares, traffic flows, energy consumption and transport emissions. Results from the simulations demonstrate a significant reduction in modal share and passenger-km made by car due to the aforementioned measures. In contrast, the new public transport infrastructures that will accompany the measures will result in a

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substantially increase in the passenger-km made by bus (49%) and rail (29%). Due to the above stated modal shift and the decrease of conventional vehicles as part of the overall stock, the results also reveal a considerable reduction in fossil fuel consumption and CO2 emissions. The former ranges from 17%-21%, while the latter between 11%-20% depending on the scenario and vehicle type. Finally, considerable reductions in emissions of pollutants such as PM2.5, NOx, CO and NMVOC are also observed.

- The application of the models in the use cases for the city of Athens revealed that electrifying 50 bus lines has the potential to cut the remaining in operation conventional buses' CO emissions in half and decrease the respective NOx emissions by 46%. In addition, the future substitution of conventional vehicles by AVs can reduce the total network travel time by -8.97%.
- The application of the nowcasting module with incident and traffic related data from the city of Oxford demonstrated the potential of the platform to enable the incorporation of real-time events as part of the simulations performed. This is a rather complex functionality due to the uncertainty incorporated in the transferability of the real event conditions in a simulated environment and only based on traffic data. The resultant 17.8% MAPE between actual and estimated average speeds during the evolution of a real event can be considered as a positive result for the implementation of nowcasting functionality as part of simulated scenarios.

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