Deliverable 4.2

Consolidated Use Case Evaluation and Assessment Report

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Project Executive Summary

The EU-funded 'Predictive Approaches for Safer Urban Environment' (PHOEBE) project aims to develop an integrated, dynamic human-centred predictive safety assessment framework in urban areas. This will be achieved by bringing together the interdisciplinary power of traffic simulation, road safety assessment, human behaviour, mode shift and induced demand modelling and new and emerging mobility data.

Focused on vulnerable road users' safety, the 3.5-year-long PHOEBE project will draw inspiration from real-world scenarios in the three pilot cities of Athens, Greece (GR), Valencia, Spain (ES) and West Midlands, United Kingdom (UK). Testing activities will be performed across the Use Cases to simulate and forecast the impact of changes on safety in different scenarios of disruptions or transitions across urban transport networks.

Predicting and visualising the safety and socioeconomic outcomes of new forms of transport, new technologies, or regulatory and behavioural changes from the individual (micro) level up to the network-wide (macro) level will also be a significant game-changer for urban stakeholders. The results of PHOEBE can be used as a blueprint by other European cities to develop their knowledge products, such as socioeconomic analysis model, urban road safety assessment, human behaviour and choice modelling.

PHOEBE pilot cities

List of participating cities:

- Athens (Greece)
- Valencia (Spain)
- West Midlands (United Kingdom)

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Project Partners

Organisation	Country	Abbreviation
EVROPSKI INSTITUT ZA OCENJEVANJE CEST - EURORAP	SI	EIRA
ETHNICON METSOVION POLYTECHNION	EL	NTUA
TECHNISCHE UNIVERSITEIT DELFT	NL	TUD
TECHNISCHE UNIVERSITAET MUENCHEN	DE	TUM
AIMSUN SLU	ES	AIM
POLIS AISBL	BE	POLIS
FACTUAL CONSULTING SL	ES	FC
UNIVERSITAT POLITECNICA DE VALENCIA	ES	UPV
OSEVEN SINGLE MEMBER PRIVATE COMPANY	EL	O7
THE FLOOW LIMITED	UK	FLOOW
INTERNATIONAL ROAD ASSESSMENT PROGRAMME	UK	iRAP

List of abbreviations and acronyms

Acronym	Meaning
ASAP	As Soon As Possible
B2B	Business-to-business
B2C	Business-to-Consumer
CO_2	Carbon dioxide
EC	European Commission
ES	Spain
FSIs	Fatal and Serious Injuries
GA	Grant Agreement
GR	Greece
iRAP	International Road Assessment Program
KoM	Kick-off Meeting
KPI	Key Performance Indicator
NO_x	Nitrogen oxides
RTC	Road Traffic Collision
TfWM ATC	Transport for the West Midlands
UK	United Kingdom
VRU	Vulnerable Road Users
WMCA	West Midlands Combined Authority
WP	Work Package

Table of Contents

List of figures

List of tables

Deliverable executive summary

Deliverable D4.2 marks a pivotal milestone in the PHOEBE project, presenting the consolidated evaluation and assessment of the PHOEBE predictive safety evaluation framework across three pilot urban contexts: Athens, Valencia, and the West Midlands. This document synthesises the outcomes arising from the application of the framework in real-world settings, capturing methodological execution, key data insights, and feedback from diverse stakeholders.

A major innovation highlighted in D4.2 is the framework's deployment in three varied urban environments, demonstrating its adaptability and scalability across different city contexts. The report also introduces a robust stakeholder engagement process, ensuring meaningful participation from local authorities, planners, and community representatives in tailoring and validating the interventions.

D4.2 further details a rigorous evaluation process that unifies inputs from operational, environmental, and safety indicators into a cohesive, multi-dimensional framework. This approach not only consolidates and builds upon findings from earlier PHOEBE work packages—WP1 (theoretical foundations), WP2, and WP3 (model development)—but also sets a new benchmark for holistic urban mobility assessment.

Through the demonstration and validation of the predictive safety assessment framework, Deliverable D4.2 delivers actionable insights and establishes a foundation for scaling the PHOEBE framework network-wide. It solidifies the project's commitment to advancing urban mobility planning with a particular emphasis on the safety of vulnerable road users, and positions PHOEBE as a leader in the next generation of data-driven, anticipatory urban safety evaluation.

Progress beyond the state of the art

PHOEBE D4.2 advances the state of the art by demonstrating the results of the implementation of the predictive safety evaluation framework that integrates behavioural modelling, traffic simulation, and risk assessment. Unlike traditional methods focused on reactive approaches to evaluate safety, WP4 uses simulation-based forecasts to anticipate the safety impacts of urban mobility interventions before they are implemented. This forward-looking approach enables cities to make informed decisions based on projected outcomes rather than reactive analysis.

Another key innovation lies in the application of the PHOEBE framework across three diverse urban contexts—Athens, Valencia, and the West Midlands—demonstrating its flexibility and scalability. The deliverable also introduces a structured stakeholder engagement process, ensuring that local authorities, planners, and community representatives are actively involved in shaping and validating the interventions.

Additionally, D4.2 introduces a rigorous evaluation process that consolidates inputs from various sources into a unified format that will inform the project's next steps. By building on the outputs of WP1, WP2 and WP3, D4.2 delivers a holistic, multi-dimensional evaluation framework that combines operational, environmental, and safety indicators, setting a new benchmark for urban mobility assessment.

1 Introduction

This deliverable, D4.2, presents the consolidated evaluation and assessment of the PHOEBE framework across the three pilot Use Cases: Athens, Valencia, and the West Midlands. With the completion of **D4.2** the PHOEBE project achieves an important Milestone: the completion of the framework demonstration and the preparation to scale the results network-wide.

The document synthesises the outcomes of the framework's application in real-world urban environments. It documents the methodological execution, data-driven insights, and stakeholder feedback gathered during the implementation phase. It reflects the collaborative efforts of project partners to validate the predictive safety assessment framework developed in earlier work packages, particularly WP1 (theoretical foundations) and WP3 (model development). The evaluation focuses on the framework's ability to assess safety impacts, support decision-making, and enhance urban mobility planning with a strong emphasis on vulnerable road users.

The work presented in this report builds directly upon the foundational and technical advances documented in earlier PHOEBE deliverables (see Figure 1-1). The experimental designs and stakeholder engagement strategies introduced in **Deliverable D4.1** have shaped the structure and scope of the interventions evaluated herein, ensuring continuity in methodological approach and stakeholder relevance.

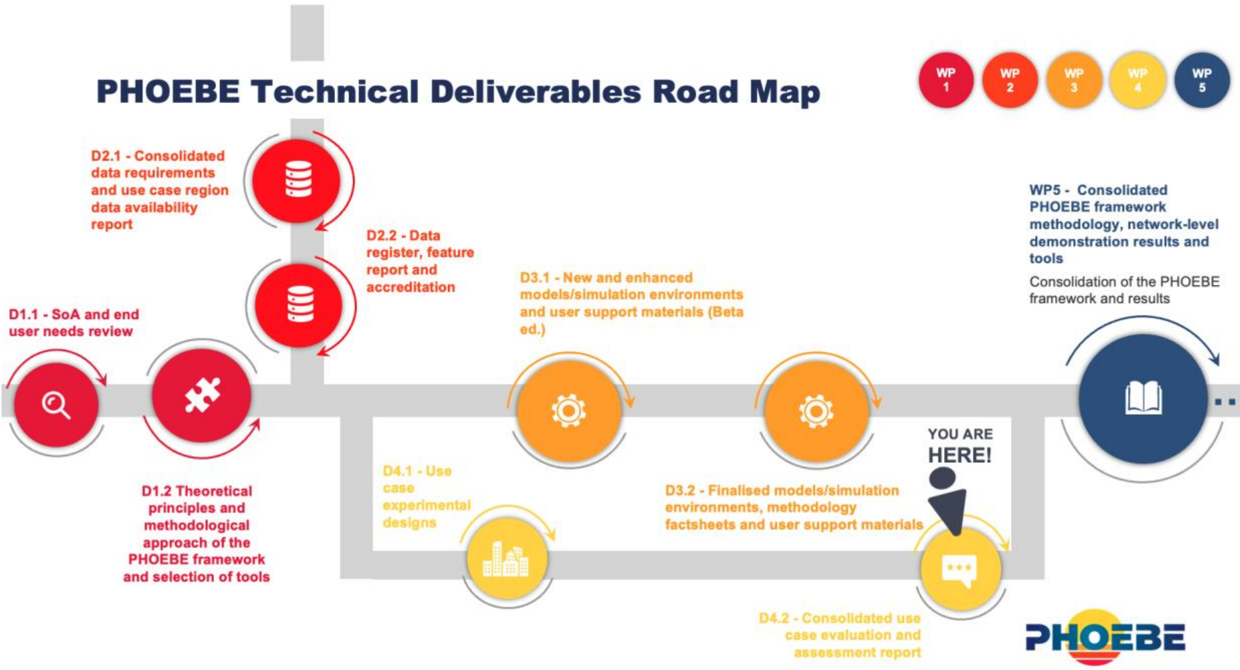

Figure 1-1 PHOEBE Techinical Deliverables Road Map

Deliverables **D2.1 and D2.2** provide the comprehensive data architecture that underpins this evaluation. They define the data requirements, sources, and processing protocols essential for estimating the models and operationalising the PHOEBE framework across the pilot sites. This data backbone ensures that the simulations and assessments in **D4.2** are grounded in robust, context-specific evidence.

The conceptual framework and modelling rationale are rooted in the theoretical groundwork laid out in **D1.1 and D1.2**. These documents articulate the state-of-the-art in predictive safety modelling and justify the modelling choices made throughout the project. Understanding these foundations is critical to interpreting the results presented in this deliverable, as they inform both the structure of the models and the assumptions embedded within them.

Finally, **Deliverables D3.1 and D3.2** provide the technical backbone for the implementation and evaluation activities reported in this document. These deliverables detail the development and refinement of the PHOEBE modelling suite, including significant advancements in behavioural and demand modelling, safety impact estimation, and the integration of these models into simulation environments. In particular, **D3.2** should be consulted for detailed information on the provenance, assumptions, and technical parameters of the models used. It serves as the primary reference for understanding the scope and limitations of the results discussed in this deliverable.

Deliverable D4.2 also integrates feedback from local stakeholders and technical experts, ensuring that the evaluation reflects both quantitative performance indicators and qualitative insights. Moreover, this deliverable marks a pivotal transition in the project's trajectory. While earlier phases focused on conceptual development, data infrastructure, and technical modelling, **D4.2** opens the door to the next stage—where the emphasis shifts towards the end user. The insights gathered here lay the groundwork for enhancing the framework's usability, accessibility, and practical deployment in diverse urban contexts.

The results and lessons learned from this evaluation will directly inform the integration and transferability activities in WP5, where the framework will be adapted for broader application. In parallel, they will contribute to the dissemination and exploitation strategy under WP6, supporting the project's ambition to scale its impact and foster adoption among policymakers, planners, and mobility stakeholders.

2 Methodology

2.1 SELECT–SIMULATE–EVALUATE–EXTRAPOLATE

The PHOEBE framework employs a four-stage process (**SELECT, SIMULATE, EVALUATE, and EXTRAPOLATE)** to assess the safety impacts of urban mobility interventions. This structured approach ensures that interventions are grounded in evidence, tested through simulation, and scaled for broader policy relevance. Figure 2-1 illustrates the PHOEBE Framework Concept.

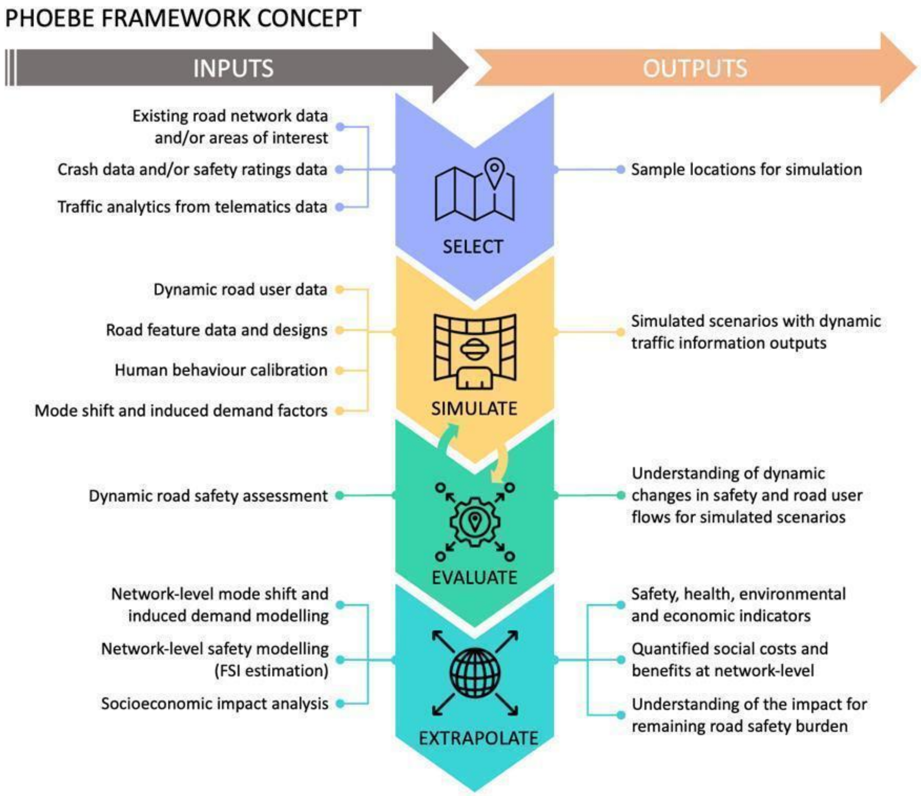

Figure 2-1 PHOEBE Framework Concept

This initial phase **SELECT** involves identifying and selecting specific sites, corridors, or road networks for simulation. This select process is important due to the micro-component of the analysis which starts to focus on local intervention to growth network wide later in the process. This stage was performed at the beginning of WP4 with the selection of the intervention that aligns with the Use Case mobility plans and future actions. The **SELECT** stage is documented in **Deliverable 4.1**.

Once sites are selected, the **SIMULATION** phase begins. The PHOEBE framework simulates traffic, behavioural dynamics and calculates the performance indicators under both baseline and intervention scenarios. Simulations in the framework mean the complete integration of PHOEBE components which were designed and enhanced to reflect real-world complexity and variability. The **SIMULATION** stages are presented in **Deliverable D3.2.**

The PHOBE project has reached the **EVALUATION** stage, where the simulated outputs are evaluated quantitatively through the provided indicators and qualitatively through stakeholders' perceptions of the results, to assess whether the impact of the intervention reflects what was expected for each Use Case.

The **EVALUATION** should encompass:

- Analysing changes in crash risk, particularly for vulnerable road users
- Estimating fluctuations in fatalities and serious injuries (FSI)
- Review model developments to provide feedback suggestions to refine behavioural assumptions and model parameters

Finally, the evaluated impacts are scaled up to the network level to estimate broader outcomes in the **EXTRAPOLATE** phase. This includes projecting safety benefits across the wider transport system, estimating socioeconomic impacts of reduced FSI, and aligning results with European policies and global benchmarks such as the UN Global Plan for Road Safety. This phase will be completed under WP5.

2.2 DATA SOURCES AND TOOLS

PHOEBE's data architecture is structured around several core categories, beginning with **Route Data**, which captures the geospatial and physical characteristics of the road network. This includes mapping and segmentation of roads, route attributes such as surface condition, signage, and intersection types, and other geospatial data relevant to vulnerable road users (VRUs). Attributes like visibility, curvature, facility types and crossing presence are used to assess risk potential across the network. The data is consolidated and aligned with existing traffic and safety models to ensure compatibility and relevance for PHOEBE's predictive frameworks.

Complementing this are behavioural and demographic datasets. **User Behaviour data** includes network monitoring (e.g. traffic counts), attitude surveys, and outputs from existing transport models, offering insights into how people interact with the network. **User Data** captures demographic profiles and mode availability, while **Mode Choice data** reflects actual transport selections, either at the individual or population level. Additional categories include **Incident Records** which provide context for risk modelling and scenario analysis. These diverse data types are unified under a shared taxonomy to support data discovery and application across PHOEBE's Use Case regions, ensuring that both producer and consumer needs are met through a consolidated and flexible data framework. **Deliverable 2.1c** presents the data structure in detail and **Deliverable D2.2** explores the different data sources and their path for access.

There are certainly differences in the Use Cases in terms of data requirements and data availability.

The West Midlands stands out for its comprehensive access to road traffic collision (RTC) data, thanks to the UK's STATS19 database, which includes detailed incident participant information. It also benefits from rich demographic data via the 2022 UK Census and extensive telematics data from The Floow, covering speed, acceleration, turning behaviours, and origin-destination matrices. Additionally, it has six distinct sources for motor traffic volume data, including TfWM ATC surveys, Vivacity sensors, and Department for Transport datasets. However, it lacks direct data on certain behavioural aspects such as mobility under the influence and VRU-specific behaviours like crossing outside of the crossing marks or micromobility routing, which required the project to collect new data.

Valencia, while not using telematics data, has strong micromobility insights from field observations and video analysis. It also benefits from COLECAMINS GIS data for safe school routes and multiple sources for motor traffic volume, including city council data. However, it lacks exclusive data types and relies on targeted data gathering to support cycle behaviour analysis.

Athens offers unique access to data on mobility under the influence of alcohol or drugs and has implemented a custom video analysis pipeline using YOLO and DeepSORT to monitor red-light violations and pedestrian risks. It also uses telematics data from OSeven for behavioural metrics and has access to the SANTRA database for incident locations and severity.

Regarding the tools and models used, we have applied the PHOEBE framework comprehensively throughout all the Use Cases. It means that the project team had delivered simulations, risk assessments and dedicated demand and human behaviour models for the three Use Cases and all the tested interventions.

2.3 Description of evaluation metrics (safety, behavioural, modal shift, socioeconomic)

The PHOEBE framework defines a comprehensive set of indicators, structured into four main categories:

- Health and Safety Indicators: Focused on assessing the safety outcomes of interventions, particularly for vulnerable road users.
- Mode Shift and Induced Demand Indicators: Designed to capture travel decision changes, these indicators provide insights into modal shifts across different age and gender groups.
- Operational Indicators: These evaluate traffic performance and network efficiency
- Environmental Indicators: These measure pollutant emissions

Each indicator is assessed across both baseline and intervention scenarios, enabling comparative analysis not only between the baseline and each intervention but also among different interventions. While certain indicators may be more relevant in specific contexts (e.g., as a reduction in cyclist risk where new cycling infrastructure is introduced) the indicator set has been designed to be holistic and universally applicable.

The full list of indicators is intended to be used across all PHOEBE Use Cases and remains suitable for future applications of the framework. However, this does not preclude the possibility of exploring additional insights. The outputs of the PHOEBE framework, particularly from the traffic simulation and risk assessment models, are rich and multidimensional, offering a wide array of supplementary metrics at varying levels of granularity that extend beyond the core indicator set.

The complete set of indicators, along with their calculation methods, expected trends, and results across the Use Cases, is detailed in **Deliverable D3.2**. The following summary is provided to support interpretation of the subsequent sections. **Deliverable D3.2** also includes a set of behavioural change indicators. These indicators reflect the anticipated shifts in user behaviour resulting from the interventions. However, rather than being measured directly, these effects were inferred indirectly through observed changes in speed and traffic flow within the Use Case simulations.

2.3.1 Health and Safety Indicators

The PHOEBE framework includes a dedicated set of 19 Health and Safety Indicators, all derived directly from the risk assessment methodology, the iRAP Star Ratings[1]. These indicators are designed to quantify how proposed interventions affect road safety risk.

At the core of these indicators is the estimation of fatal and serious injuries (FSIs) per year—both under baseline conditions and with interventions applied. This estimation serves as the key objective metric for subsequent socio-economic analysis, enabling stakeholders to assess the cost-effectiveness and life-saving potential of different urban mobility interventions.

These indicators also capture the impact of infrastructure modifications that prioritise VRU safety while aiming to enhance safety for all road users.

[1] To know more about the iRAP Star Rating one can access PHOEBE Deliverables D3.1 and D3.2 in project library or directly in the iRAP website .

The Healthy and Safety Indicators can be summarized as:

- Total number of fatalities and severe injuries on the network
- % of the network achieving 3-stars or better for vehicle occupants, motorcyclists, bicyclists and pedestrians
- Average road safety risk on mid-block (sections) for vehicle occupants, motorcyclists, bicyclists and pedestrians
- Average road safety risk on intersections (nodes) for vehicle occupants, motorcyclists, bicyclists and pedestrians
- % of the road network where operating speed is greater than the speed limit
- % of road network with good quality sidewalk, high speed, pedestrians' flows
- % of road network with crossing facility, high speed and pedestrians' crossing flows
- % of good quality pedestrians' crossings
- % of road network with bicycle facility, high speed and bicyclists' flows

2.3.2 Mode Shift and Induced Demand Indicators

The Mode shift and Induced Demand indicators are intended to quantify and evaluate the impact of interventions on travel behaviour, with a focus on promoting sustainable and non-motorised transport modes. This category includes 24 Performance Indicators that track changes in travel behaviour across motorised and non-motorised modes for different demographic groups. The indicators are segmented by gender (women and men) and age groups (18–24, 25–34, 35–44, 45–54, 55–69, 70+).

The mode shift and induced demand indicators can be summarized as:

- Participation in non-motorised trips per mode and gender
- Participation in motorised trips per mode and gender

2.3.3 Operation Indicators

The operational indicators are derived from simulation outputs generated by AIMSUN Next. While these outputs are based on AIMSUN's internal models, they align with standard simulation software outputs, making the indicators adaptable for use with other traffic simulation platforms.

The indicators include:

- Network travel time: Total time spent by all vehicles in the network.
- Network travel distance: Aggregated distance travelled
- Network delay: Additional time spent due to congestion or inefficiencies

2.3.4 Environment Indicators

Environmental performance is evaluated using outputs from traffic simulation. While these are based on AIMSUN Next's internal emission models, they reflect standardised emission indicators commonly produced by simulation tools, ensuring compatibility and adaptability across different platforms.

The environment indicators include:

- CO_2 Emissions (g)
- NO_x Emissions (g)

2.4 Stakeholder engagement methods and feedback (e.g. workshops, surveys)

2.4.1 Athens

Within the scope of the Athens Use Case, stakeholder engagement was performed through a series of focus workshops and feedback questionnaires with the aim of evaluating the methodology and outcomes of the PHOEBE project. Representatives of Athens Urban Transport Organisation, Hellenic Institute of Transport Engineers, Athens Anaplasis and STASY joined the workshops. The methodological process combined Discrete Choice Analysis, Extreme Value Theory, and Aimsun API-based simulation for the ultimate purpose of simulating behavioural risks and traffic behaviour within cities. Stakeholders including transport planners, safety professionals, and local government provided detailed comments on representativeness, policy usefulness, and sufficiency of the models. Feedback was largely positive in supporting the strengths of mixing real-world data with stated preferences and simulation, with strong positive support for the project emphasis on behavioural modelling and predictive risk assessment. In general, the Athens strategy was groundbreaking, namely its interoperability between the data sets and its capacity to inform real-life urban security initiatives.

2.4.2 Valencia

To support the Valencia Use Case, various stakeholder engagement methods were employed. The Reflection Workshops were followed by a questionnaire shared with participants to collect feedback. Additionally, a joint workshop with the JULIA project was organised, focusing on the application of the Lane Patrol method in Valencia. During the General Assembly held in Valencia, further engagement took place through meetings with the local Community of Practice. The Final Presentation Workshop took place on 24 July 2025, aiming to present the outcomes of the Valencia Use Case to the participants, focusing on the different scenarios. ETRA and Valencia company for Traffic and Mobility Services were invited fro the workshop. At the end of the session, attendees had the opportunity to ask questions and share their feedback on the results.

2.4.3 West Midlands

The West Midlands is different to other Use Case regions because it is a combined authority area; a region comprising multiple cities and towns for which certain transport and planning activities are carried out by a strategic body. For the West Midlands, the strategic transport body is Transport for the West Midlands (TfWM), which sits under the West Midlands Combined Authority (WMCA). Most of the work on infrastructure projects is still paid for and carried out by the local authorities, controlled by the elected council of each city.

Combined authority bodies can be particularly useful when it comes to trying to produce consistent standards or approaches across a region. For example, one city might be following a particular approach that achieves better or more efficient impacts in their transport projects, however, there's no certainty that civil servants working for other authorities would be aware of this approach. It is for this reason that PHOEBE produced a road safety workshop, hosted by TfWM, which brought together transport professionals from the different local authorities to discuss their active travel projects and to raise awareness of the capabilities and data being utilised by the project. The workshop consisted of two sessions; an initial demonstration session that introduced the project, technologies, data, and the initial iRAP results in the West Midlands, followed by a focus group session that discussed many of the barriers to using new technologies towards active travel projects. These discussions saw local stakeholders share experiences and lessons learnt from their respective projects and also feed back into how new tools could help to make the public case for road safety improvements.

We arranged regular working meetings with the TfWM Regional road safety manager as the Second Reflection Workshop and Final Workshop, who served as our principal stakeholder in the project. This contact gave the project the means to regularly review our road risk analysis in context by accessing local knowledge of the road network. This review activity took the form of a questionnaire that would serve as a basis for discussion in the working meeting and also for the stakeholders to use while reflecting on our results with colleagues in the interim period between meetings. This contact also provides the project with a means to distribute insights to workers at the road-safety coalface.

3 Use Case Evaluation

3.1 Athens

3.1.1 Interventions

In June 2020, Athens implemented a series of mobility interventions in the city center to promote sustainable transport, improve pedestrian safety, and reorganize traffic. The key measures included:

(1) Widening of sidewalks on major streets with high pedestrian activity, notably:

Panepistimiou Street: Sidewalks have been expanded, reducing the number of traffic lanes from 5 to 4, introducing a dedicated bus lane, bike lanes, and improving pedestrian pathways. See before and after in Appendix Figure A-1.

Syntagma Square: The sidewalks along the western side have been widened, optimising space for pedestrians, buses, and preventing illegal taxi stops, with relocated taxi and tour bus stops. See before and after in AppendixFigure A-2.

(2) Pedestrianisation of streets:

Vasilissis Olgas Avenue: Fully closed to private vehicle traffic, creating exclusive space for pedestrians and cyclists, while maintaining controlled access for emergency vehicles during off-peak hours. See the extension of the intervention in Appendix Figure A-3.

(3) Introduction of new exclusive bus lanes:

Panepistimiou Street: A new parallel-flow bus lane replaced the previous contra-flow lane, increasing bus line coverage from 3 to 26 lines and optimising public transport routes.

(4) Motorcycle parking management:

Ermou Street: Designated motorcycle parking spaces were introduced to prevent illegal parking on sidewalks. The extension of the intervention is presented in Appendix Figure A-4.

These interventions in important road segments in the city of Athens, as showcased in overview in the picture below, aimed to enhance pedestrian and cyclist safety, promote public transport, reduce vehicle traffic in the city center, and improve overall urban mobility. Figure 3-1 present the full intervention plan.

Figure 3-1 Athens Interventions: Full plan

3.1.2 Baseline and intervention scenarios

Baseline Scenario

Before June 2020, Athens' city center was characterized by high vehicle traffic volumes, inadequate pedestrian infrastructure, absence of cycling space, and limited public transport prioritization. The road network primarily consisted of motorized traffic, with not much space for VRUs such as pedestrians and cyclists, reduced enforcement of speed regulations, and occasional initiatives to promote sustainable mobility modes.

Intervention Scenario 1 – Pilot Phase (2020)

In response to new mobility requirements, in particular to those increased during the pandemic, Athens launched a pilot implementation of targeted interventions starting from June 2020 called The Great Walk project. These interventions aimed to reclaim public space, improve safety, and promote sustainable transport modes. The interventions, as mentioned above, refer to the pedestrianization of Vasilissis Olgas Avenue, the reconfiguration of Panepistimiou Street, the Syntagma Square enhancements, and the Ermou Street parking and pedestrian improvements. The intervention area covered critical roads directly affected by these measures, alongside surrounding streets expected to experience indirect effects.

Intervention Scenario 2 - City-wide 30km/h speed limit.

One of the planned and already integrated interventions in the Greek Road Traffic Regulation Code is a network-wide reduction of speed limits to 30 km/h, enforced through law enforcement and automated speed control (radars, cameras), aiming to reduce road risks. The timeline for this intervention is expected to start from the beginning of 2026. For the PHOEBE project, the pilot interventions from 2020 are considered the first scenario, as the second scenario represents conditions after interventions implementation with a 30 km/h speed limit.

3.1.3 Simulation outcomes (traffic, safety, mode shift)

The Athens Use Case simulation explored the impacts of urban interventions on traffic conditions, safety, and mobility behaviour, focusing on three distinct scenarios presented above.

3.1.3.1 Traffic

The simulation results present evident modifications in traffic dynamics and mobility patterns across the investigated area. Regarding traffic flows, the interventions led to a redistribution of vehicle movements, particularly within the central network surrounding Panepistimiou Street and Syntagma Square. The map presented in Figure 3-2 demonstrate the **operating speeds** for the aforementioned three scenarios. In the baseline scenario, large sections of the network, particularly in the city center, are shown in red tones, indicating high operating speeds that exceed recommended safety levels. In terms of operating speeds, Scenario 1 already shows a moderate decrease in speeds within key urban areas, driven by the reallocation of space and the prioritisation of non-motorised transport. The largest decline in speeds, however, is observed in Scenario 2, subsequent to the integration of the 30 km/h limit, showcasing the impact of this intervention to road safety.

The second set of maps (Figure 3-3) shows the **traffic flow (volume)** distribution across the same scenarios. In the baseline scenario, traffic volumes are concentrated into specific central corridors, depicted in red and yellow tones. Following the interventions (Scenario 1), traffic is distributed more evenly across the network, with reduced congestion on some principal links as marginal roads absorb some of the diverted traffic. In Scenario 2, the implementation of the 30 km/h limit does not disturb traffic flow, and although the speed reduces, there is no indication of severe congestion or deterioration in traffic.

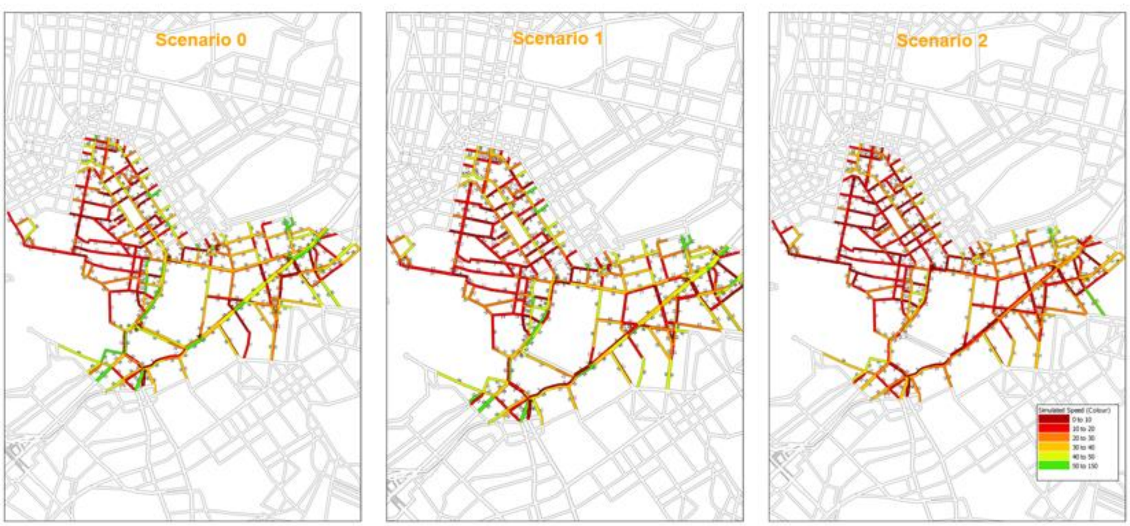

Figure 3-2 Athens Simulation Results - Speeds

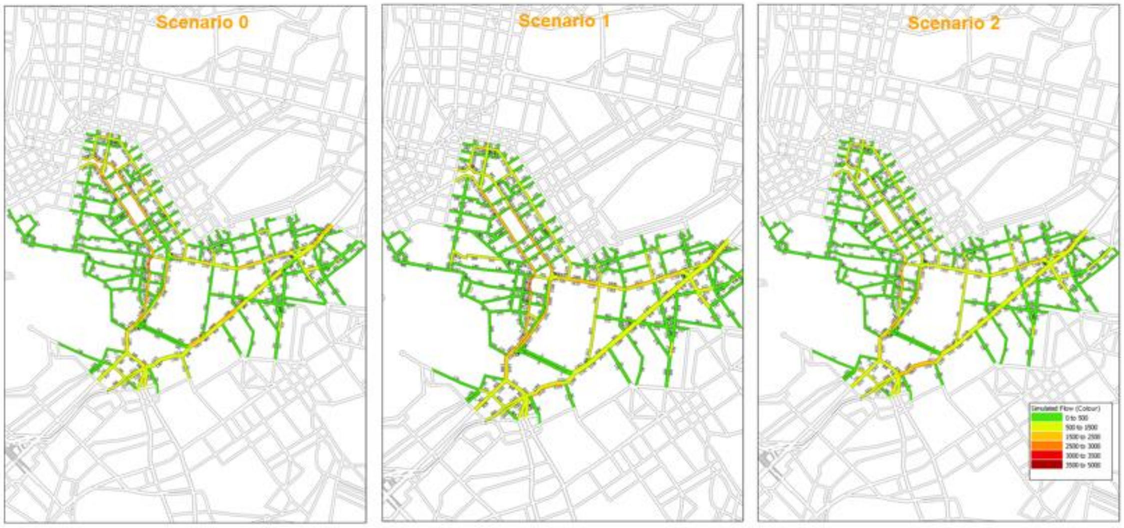

Figure 3-3 Athens Simulation Results - Flows

3.1.3.2 Road Safety

The statistical analysis of the Athens Use Case provided important insights into the factors influencing speeding behaviour among drivers and red-light running behaviour among pedestrians, both of which are key contributors to urban road safety risks.

For driver speeding behaviour, several significant factors were identified (see Table 1). A strong reduction in the likelihood of speeding (estimate = -0.437, $p < 0.001$) is linked with high traffic volumes, meaning congestion naturally limits excessive speeds. Similarly, due to increased traffic complexity and safety features that promote more cautious driving, the presence of multi-lane roads and physical medians reduced the tendency to speed. The implementation of a 50 km/h speed limit was shown to significantly reduce speeding behaviour (estimate = -0.676, $p < 0.001$), confirming the effectiveness of regulatory interventions. Likewise, speed cameras had a strong deterrent effect on speeding, with an estimated impact of -0.932, highlighting the importance of enforcement tools in promoting compliance.

Age was negatively associated with speeding (estimate = -0.023, $p = 0.018$), indicating that older drivers tend to adopt driving practices which are safer than the others. Moreover, individuals with higher social value orientation (SVO), i.e., more social responsibility, were less likely to speed (estimate = -0.024, $p = 0.003$). Finally, drivers with a history of disobeying speed limits on motorways were more likely to speed in the urban center (estimate = 1.012, $p < 0.001$), showing cross-contextual continuation of risky driving behaviours.

Regarding pedestrian red light running, the analysis revealed key behavioural triggers. High traffic volumes significantly reduced the likelihood of violations (estimate = -1.09, $p < 0.001$), indicating that pedestrians are less likely to cross the road when traffic is high. In contrast, wider crossing widths were associated with an increased probability of red-light violations (estimate = -0.68, $p < 0.001$), due to the fact that pedestrians feel the need to cross prior to waiting times. Being in a rush significantly increased red light running (estimate = 0.497, $p < 0.001$), confirming the role of situational urgency in dangerous crossing behaviour. Age was also negatively associated with violations (estimate = -0.020, $p = 0.003$), suggesting that older pedestrians adopt more cautious behaviours at intersections. Moreover, baseing the analysis on pedestrian past behavior, pedestrians with a history of red-light violations were significantly more likely to repeat it (estimate = 0.777, $p < 0.001$), and those who reported crossing without looking when in a hurry exhibited higher risks (estimate = 0.483, $p = 0.003$).

Table 3-1 Athens Speeding behaviour of car drivers

Variables		Estimates	z value	Pr(>|z|)	95% CI	
					L	U
Intercept		2.762	4.849	0.000	1.645	3.879
High traffic		-0.437	-13.033	0.000	-0.503	-0.371
Multi-lane		0.894	20.935	0.000	0.810	0.978
Presence of physical median		-0.212	-5.245	0.000	-0.291	-0.132
Speed limit	50 km/h	-0.676	-19.961	0.000	-0.742	-0.609
Presence of speed Camera		-0.932	-27.213	0.000	-0.999	-0.865
Age		-0.023	-2.359	0.018	-0.043	-0.004
Social value orientation (SVO)		-0.024	-2.930	0.003	-0.041	-0.004
Past behaviour	Disregarding the speed limit on urban highways	1.012	7.961	0.000	0.763	1.262

Table 3-2 Athens Red Light Running Behaviour of pedestrians

Variables		Estimates	z value	Pr(>|z|)	95% CI	
					L	U
Intercept		2.833	5.914	0.000	1.894	3.772
High traffic		-1.098	-22.642	0.000	-1.193	-1.003
Wide crossing width		-0.682	-14.383	0.000	-0.774	-0.589
Being in a rush		0.497	10.534	0.000	0.404	0.589
Age		-0.024	-2.950	0.003	-0.040	-0.008
Past behaviour	Red light violation	0.777	6.378	0.000	0.538	1.015
	Not looking when in hurry	0.483	2.923	0.003	0.159	0.808

3.1.3.3 Mode Shift

Figure 3-4 presents the overall results of the mode shift analyses. Trip-kilometre data indicates a reduction in the use of private cars and motorcycles, most notably among younger age groups aged 18 to 34. Simultaneously, public transport use increases consistently across all age groups as a result of enhanced accessibility and the introduction of new dedicated bus lanes. Walking trips rise under both intervention scenarios, confirming the positive impact of pedestrian infrastructure. Shared micromobility, such as e-scooters and bicycles, also exhibits a rise, particularly among younger users.

Comparing the trip-kilometres across the three different scenarios reveals key trends in modal shift and mobility behaviour after the interventions in the city of Athens. Firstly, the use of **private cars**, showed a decline in trip-kilometres, particularly among younger age groups (18–34), with Scenario 2, the one combining pedestrianisation with the 30 km/h speed limit showing the most substantial reduction. This suggests that younger users are more responsive to urban interventions that aim at reducing car dependency.

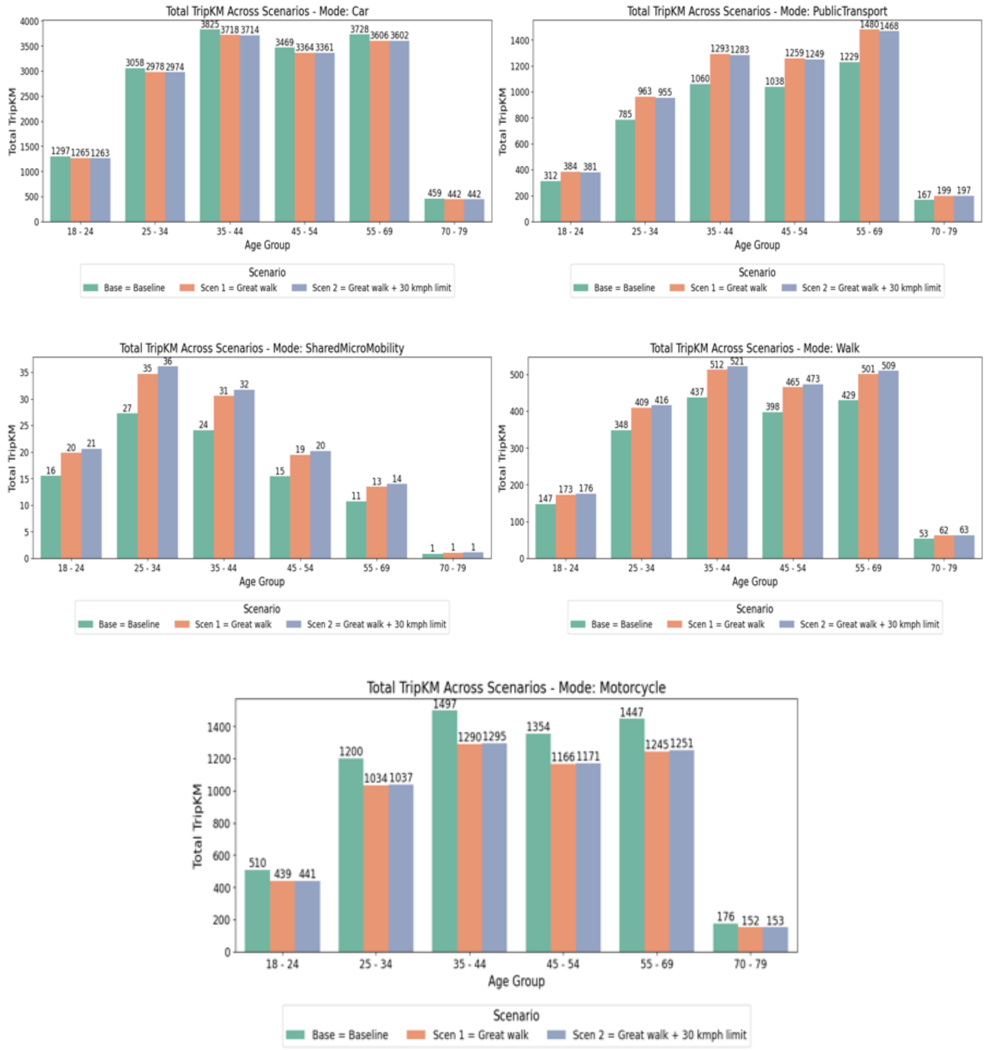

Figure 3-4 Athens Results – Mode shift

Following, the **use of public transport** demonstrates a steady increase across all age groups under both intervention scenarios. The most notable growth is observed in Scenario 2, which demonstrated that combining improved infrastructure and speed management attracts and makes the public transport services more reliable. In terms of **shared micromobility**, referring to bicycles or e-scooters, there is an increase in trip-kilometres, particularly among the 18–44 age groups. The trend shows the positive influence of safer urban conditions and infrastructure that support sustainable modes of transport.

3.1.4 Stakeholder feedback

Stakeholder engagement has been important for the Athens Use Case of the PHOEBE project, ensuring that project interventions and methodologies align with the needs of practitioners and authorities. Through dedicated workshops, consultations, and feedback questionnaires, insights were gathered from experts in transport planning, road safety, technology development, and public administration.

A strong consensus emerged among stakeholders regarding the need to prioritise **road safety and public health**, alongside the promotion of sustainable mobility. As reflected in the survey results (Appendix -Figure A-5), stakeholders ranked 'Road Safety and Public Health' and 'Sustainability & Modal Shift' among the most critical elements for aligning dynamic road safety assessments with overall traffic optimisation.

Participants highlighted the importance of addressing the needs of **VRUs**, such as pedestrians, cyclists, individuals with disabilities, and children. 75% of stakeholders stated that the role of social parameters (age, gender, disability) is as important for behavioural modelling and urban safety planning (Appendix - Figure A-6). This emphasis reflects growing recognition of the need for inclusive street design that protects VRUs. Additionally, the **integration of behavioural models** was highly important for 100% of the participants and more precisely, the integration of pedestrians and VRUs, within traffic simulations and safety assessments. Finally, stakeholders mentioned the **integration of multimodal telematics, artificial intelligence (AI), and predictive risk analysis** as essential for proactive safety management. Specifically, 75% of stakeholders rated this approach as highly important (Appendix -Figure A-7), recognising the role of AI in monitoring, detecting, and mitigating risk factors, especially in complex urban environments.

Additional feedback from the 1st Reflection Workshop and questionnaire strengthen some operational priorities, including the need for **dynamic evaluation of urban interventions**, enabling measurable, real-time feedback on the effectiveness of traffic measures, promoting **evidence-based policies**, using simulation outputs and AI-driven indicators to guide decisions on speed management, pedestrianisation, and public space redesign, and enhancing data sharing and cooperation among authorities, operators, and researchers to support integrated transport and safety planning.

Overall, the Athens Use Case approach in the context of the Phoebe Project is approved by the stakeholders, recognizing the importance of the combination of dynamic traffic modelling with behavioural data and predictive risk assessment (see Appendix - Figure A-8). A powerful tool for improving safety is provided, supporting modal shift, and sustainable urban mobility. The feedback process confirmed that technical solutions must be complemented by inclusive policies and targeted interventions to address the needs of all road users, particularly the most vulnerable.

Following the first reflection workshop, a second one was conducted covering the aspects of the Methodology and Results from the Phoebe Project. The methodology part of the Athens Use Case stakeholders workshop presented the robustness, sufficiency, and integration of modelling tools such as Discrete Choice Analysis, Extreme Value Theory, and Aimsun simulation tools. From the feedback of the participants (Appendix - Figure A-9), only 20% considered the integration to be completely sufficient, while another 20% considered it to be sufficient. However, a significant 40% considered it partially sufficient, indicating a need for improvement in capturing all facets of human activity in cities.

Furthermore, when asked whether the simulated behaviour was representative of real-world urban safety concerns in Athens (see Appendix - Figure A-10), 60% of the stakeholders found the simulations to be partially representative, citing missing behavioural components such as illegal parking and two-wheeler violations. A further 40% acknowledged that principal concerns were represented but with room for enrichment. These findings underscore the necessity for continuous enrichment of behaviour-based modelling through the incorporation of overlooked but significant risk behaviours. In terms of methodological innovation (see Appendix - Figure A-11), the majority of stakeholders (60%) placed the interoperability of observation, modelling, and policy evaluation as the largest contribution of the PHOEBE project. The violation-based method of modelling and the combination of different behavioural models were the other significant mentions.

For the integration quality of data, feedback was positive (Appendix - Figure A-12). Around 50% of participants found the integration to be solid, with good congruence between stated preference surveys, field measurements, and simulation results. 40% still felt that there was space for improvement in terms of more seamless or context-sensitive data fusion.

Stakeholders also examined the degree of API usage and simulation logic (see Appendix -Figure A-13). A promising 40% rated the usage as advanced, citing the incorporation of extended social parameters such as age or urgency into decisions. A further 20% considered it efficient, with logic appropriately tailored to specific behaviours. These findings confirm that the modelling environment is sufficiently sophisticated, even if there is still room for improvement in adaptability and customization of simulations.

The second workshop, also focused on policy relevance and applicability of results, gave precious feedback on the perceived utility of the project results to key stakeholder groups. While 60% of the respondents indicated that the findings have clear potential but require some interpretation before practical application, only 20% envisioned a very clear translation into policy (see Appendix - Figure A-14). This highlights the need for further effort on the part of establishing the models more directly linked to policy frameworks and actionable.

Regarding the most important output of the workshop, 40% of participants specified the integration of empirical and simulation data into a single decision-support tool, and another 40% highlighted the necessity to develop tools that can predict misbehaviour of pedestrians and drivers in city settings. This shows a keen interest in methods extending beyond crash data and actively addressing behavioural risks.

Finally, in evaluating the utility of the findings for different groups, researchers found them very useful (60%) or useful (40%), while urban planners and transport engineers rated them as useful (60%) or adequately useful (20%), and local authorities were more guarded, with 60% choosing adequately useful and 40% useful (see Appendix - Figure A-15).

3.1.5 Performance Indicators results

3.1.5.1 Performance Indicators - Operations

Table 3-3 shows that the microsimulation results for the road network showed a substantial improvement in traffic performance following the interventions. Compared to the baseline, Scenario 1 reduced total network travel time by 34.5% and network distance by 12.84%, indicating more efficient mobility. Network delay decreased by 8.39%, reflecting smoother traffic flows. In Scenario 2, while network delay slightly increased compared to Scenario 1 due to the lower speed limit, overall traffic distance and travel time remained lower than the baseline. These results highlight that the 30 km/h speed limit enhances safety without significantly compromising network efficiency.

Table 3-3 Athens Performance Indicators – Operations

Indicators	Baseline	Scenario 1	Scenario 2
travel time (h)	214.27	140.36	209.68
Network travel distance (km)	23313.85	20320.50	19727.41
Network delay (s)	115.78	106.07	118.69
∆ Network travel time	-	-34.50%	-2.14%
∆ Network travel distance	-	-12.84%	-15.38%
∆ Network delay	-	-8.39%	2.51%

3.1.5.2 Performance Indicators - Environment

Environmental impacts were also evaluated, showing considerable reductions in pollutant emissions as presented in Table 3-4. In Scenario 1, CO2 emissions decreased by 14.6% compared to the baseline, and NOx emissions declined by 6.7%. Scenario 2, which includes the 30 km/h limit, maintained CO2 reductions of 3.7%, although NOx emissions slightly increased compared to Scenario 1. Nevertheless, emissions under Scenario 2 remained lower than baseline levels, demonstrating that safety improvements can be achieved with minimal environmental trade-offs.

Table 3-4 Athens Performance Indicators - Environment

Indicators	Baseline	Scenario 1	Scenario 2
Pollutant Emissions – CO2 (g)	5878436.61	5022144.31	5662815.65
Pollutant Emissions – NOx (g)	8565.59613	7994.80663	9161.73247
∆ CO2	-	-14.57%	-3.67%
∆ NOx	-	-6.66%	6.96%

3.1.5.3 Performance Indicators – Mode Shift

In terms of mode shift, Figure 3-5 shows that car and motorcycle use decreased across all age groups, while walking, public transport, and shared micromobility trips increased substantially, especially among younger users. Non-motorised trip kilometres rose by up to 21%, demonstrating the effectiveness of the interventions in promoting sustainable mobility.

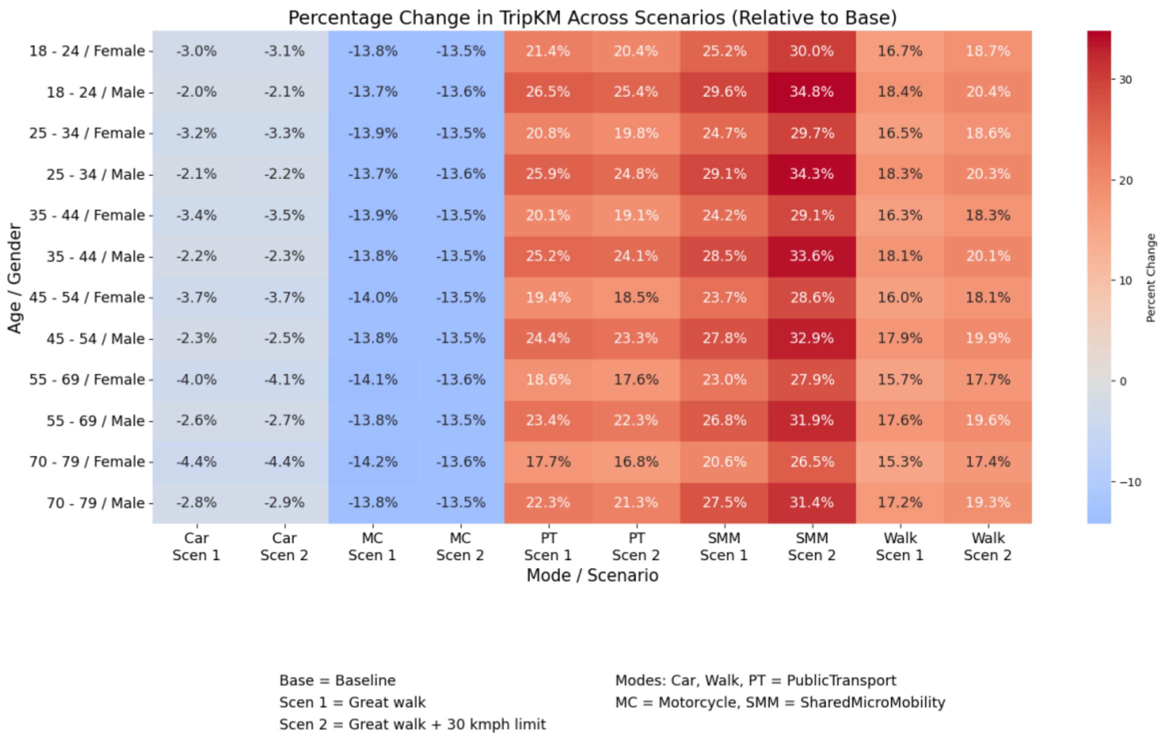

Figure 3-5 Athens Performance indicators – Mode shift

The heatmap presented in Figure 3-6 highlights that motorised travel decreased by up to 1.6%, while non-motorised travel (walking and micromobility) increased by up to 20.8%, with the most substantial gains observed under Scenario 2, which includes the 30 km/h speed limit.

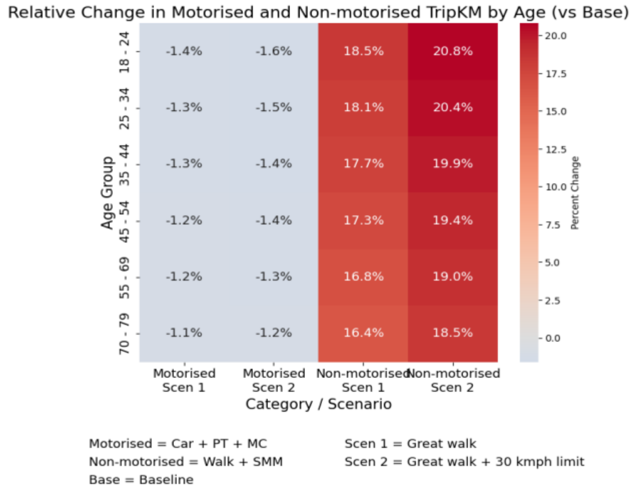

Figure 3-6 Athens Performance indicators – Mode shift

3.1.5.4 Performance Indicators – Health and safety

The safety analysis shows that the Athens interventions significantly improved road safety outcomes. Total fatalities and severe injuries decreased by 50% under Scenario 2. The percentage of the network meeting high safety standards (3 stars or better) increased, especially for pedestrians and cyclists, with pedestrian-safe road sections rising by over 10% and cyclist-safe sections by 18%.

Average road safety risk decreased substantially across all road user groups. For car occupants and motorcyclists, risk reductions exceeded 55%, while pedestrians experienced a remarkable 68% reduction in average risk on road sections. Bicycle user risk also fell by over 60%. Finally, the percentage of the road network where operating speed exceeded safe limits was reduced by nearly 48% under Scenario 2.

The inclusion of behavioural models in the Athens simulations had a positive but limited effect on overall safety outcomes. In all scenarios, the number of fatalities and severe injuries remained unchanged with or without behavioural integration. However, slight improvements were observed when behavioural factors were considered, especially under Scenario 2.

For instance, average road safety risk on nodes for pedestrians decreased from 0.111 to 0.08 under Scenario 2 when behavioural models were integrated, and cyclist risk on nodes decreased from 0.005 to 0.003. Additionally, average road safety risk on sections for pedestrians improved, dropping from 5.901 to 4.494 with behavioural integration.

Table 3-5 Athens Performance Indicators – Health and safety – Part A

Safety KPIs	Baseline	Scenario 1	Scenario 2	∆ Scenario 1	∆ Scenario 2
Number of fatalities and severe injuries in the network	2	2	1	0.00%	-50.00%
Number of severe injuries in the network	63.596	56	38	-11.98%	-39.61%
Number of fatalities and severe injuries in the network - 20 years	1318.18	1160	796	-11.98%	-39.61%
% of network above safety marks (3 stars or better) - Car Occupant	99%	99%	100%	0.00%	1.01%
% of network above safety marks (3 stars or better) - Motorcyclist	97%	98%	99%	1.03%	2.06%
% of network above safety marks (3 stars or better) - Pedestrian	85%	86%	94%	1.18%	10.59%
% of network above safety marks (3 stars or better) - Bicyclist3	76%	77%	90%	1.32%	18.42%
Average road safety risk on nodes - Car Occupant	0.121	0.064	0.039	-47.11%	-67.77%
Average road safety risk on nodes - Motorcyclist	0.121	0.11	0.08	-9.09%	-33.88%
Average road safety risk on nodes - Pedestrian	0.169	0.183	0.111	8.28%	-34.32%
Average road safety risk on nodes - Bicyclist	0.008	0.008	0.005	0.00%	-37.50%

Table 3-6 Athens Performance Indicators – Health and safety – Part B

Safety KPIs	Baseline	Scenario 1	Scenario 2	∆ Scenario 1	∆ Scenario 2
Average road safety risk on sections - Car Occupant	2.009	2.029	0.933	1.00%	-53.56%
Average road safety risk on sections - Motorcyclist	2.034	2.027	0.905	-0.34%	-55.51%
Average road safety risk on sections - Pedestrian	18.795	19.05	5.901	1.36%	-68.60%
Average road safety risk on sections - Bicyclist	24.68	25.489	9.779	3.28%	-60.38%
% of the road network where operating speed (85th) is above speed limit	25.50%	11.20%	37.70%	-56.08%	47.84%
% of road network with inexistent or bad quality sidewalk where operating speed (85th) Is over 30km/h or 20 mph and there is pedestrian walking along flow	0.00%	0.00%	1.00%	0.00%	0.00%

Safety KPIs	Baseline	Scenario 1	Scenario 2	Δ Scenario 1	Δ Scenario 2
% of road network with no crossing facility where operating speed (85th) is over 30km/h or 20 mph and there is pedestrians crossing flow	0.00%	0.00%	0.00%	0.00%	0.00%
% of pedestrian crossings that are not adequately signed or well maintained	0.00%	0.00%	0.00%	0.00%	0.00%
% of road network with no bicycle facility where operating speed (85th) is over 30km/h and there is bicyclists' flow	0.00%	0.00%	0.00%	0.00%	0.00%

The percentage of the road network where operating speeds exceed safe limits also slightly decreased with behavioural integration, particularly under Scenario 2 (from 27.70% to 26.80%).

Table 3-7 Athens Performance Indicators – Comparison between Health and Safety Indicators with and without behaviour models integrated

Safety KPIs	Baseline – With behaviour models integrated	Baseline – Without behaviour models integrated	Scenario 1 – With behaviour models integrated	Scenario 1– Without behaviour models integrated	Scenario 2 – With behaviour models integrated	Scenario 2– Without behaviour models integrated
Number of fatalities and severe injuries in the network	2	2	2	2	1	1
Number of severe injuries in the network	64	64	56	55.906	38	28
Number of fatalities and severe injuries in the network - 20 years	1318	1335	1160	1158.769	796	575
% of network above safety marks (3 stars or better) - Car Occupant	99%	99%	99%	99%	100%	100%
% of network above safety marks (3 stars or better) - Motorcyclist	97%	97%	98%	98%	99%	100%
% of network above safety marks (3 stars or better) - Pedestrian	85%	85%	86%	86%	94%	96%
% of network above safety marks (3 stars or better) - Bicyclist3	76%	76%	77%	77%	90%	98%
Average road safety risk on nodes - Car Occupant	0.121	0.12	0.064	0.064	0.039	0.026
Average road safety risk on nodes - Motorcyclist	0.121	0.12	0.11	0.11	0.08	0.048
Average road safety risk on nodes - Pedestrian	0.169	0.181	0.183	0.17	0.111	0.059
Average road safety risk on nodes - Bicyclist	0.008	0.008	0.008	0.008	0.005	0.003

Safety KPIs	Baseline – With behaviour models integrated	Baseline – Without behaviour models integrated	Scenario 1 – With behaviour models integrated	Scenario 1– Without behaviour models integrated	Scenario 2 – With behaviour models integrated	Scenario 2– Without behaviour models integrated
Average road safety risk on sections - Car Occupant	2.009	2.009	2.029	2.038	0.933	0.825
Average road safety risk on sections - Motorcyclist	2.034	2.037	2.027	2.037	0.905	0.761
Average road safety risk on sections - Pedestrian	18.795	19.036	19.05	19.197	5.901	4.494
Average road safety risk on sections - Bicyclist	24.68	24.697	25.489	25.737	9.779	7.44
% of the road network where operating speed (85th) is above speed limit	25.50%	25.30%	11.20%	26.80%	37.70%	27.70%

The additional analyses performed for the Athens Use Case focused on evaluating the impact of the behavioural model integration on both vehicle dynamics and pedestrian behaviour, particularly under the post-intervention scenario, which includes the 30 km/h speed limit.

Behavioural analysis revealed how traffic conditions and street design influence speeding and red-light violations. In terms of driver behaviour, high traffic volumes and the presence of multi-lane roads were associated with a reduced likelihood of speeding, whereas wider median strips and higher speed limits increased the probability of exceeding speed limits. The presence of speed cameras significantly decreased speeding behaviour, confirming the importance of enforcement mechanisms. For pedestrians, running a red light was more likely when wide crossings were present or when individuals were in a rush, while older age was associated with a lower likelihood of violating red lights. These findings support the design of targeted behavioural interventions alongside infrastructure changes.

For **vehicle behaviour**, the integration of the behavioural model resulted in only limited changes, suggesting the existing traffic dynamics were already aligned with the imposed speed limits. A slight increase in the mean speed was observed after model integration ($t = 2.744$, $p = 0.0081$), but the effect size was small, indicating a negligible practical impact. Interestingly, maximum speeds decreased significantly ($t = -7.474$, $p < 0.0001$), confirming better overall compliance with the 30 km/h limit. Variability in both speed and acceleration remained statistically stable, with distributional plots showing minimal changes in the spread or volatility of these parameters. Despite the stricter speed environment, a modest increase in the rate of speeding behaviour was recorded ($t = 4.692$, $p < 0.0001$), though again with a small effect size.

For **pedestrian behaviour**, the results indicated minimal to no measurable impact from the integration of the behavioural model. Key indicators such as mean walking speed, maximum walking speed, and speed variability remained statistically unchanged across scenarios. Furthermore, the crossing presence rate—reflecting the exposure of pedestrians to vehicular conflict—showed no meaningful variation, confirming the stability of pedestrian movement patterns. Visual inspection of kernel density estimates and violin plots further reinforced these findings, revealing high overlap between pre- and post-integration distributions for both pedestrians and vehicles.

Overall, these findings suggest that the applied 30 km/h speed limit creates a relatively stable and predictable traffic environment, where vehicle kinematics exhibit only marginal adaptations after behavioural model integration, while pedestrian dynamics remain virtually unaffected. This implies that under such uniform speed regimes, behavioural adjustments are minimal, and safety benefits are primarily achieved through infrastructure and regulatory measures rather than spontaneous behavioural shifts.

3.1.6 Socio-economic and network level extrapolation

The mode choice model is the precursor to socio-economic analysis. Here we present a brief summary of the mode choice model outputs which will act as a strong basis for socio-economic analysis.

1. MNL utilities:

$$V_{car} = \beta_{TC}.TC_{Car} + \beta_{IVT}.\frac{IVT_{Car}^{Min}}{60} + \beta_{AWET}.\frac{AWET_{Car}^{Min}}{60.TD_{OD}} + \beta_{RISK}.RISK_{Car}.TD_{OD}$$

$$V_{PT} = \alpha_{PT} + \beta_{TC}.TC_{PT} + \beta_{IVT}.\frac{IVT_{PT}^{Min}}{60} + \beta_{AWET}.\frac{AWET_{PT}^{Min}}{60.TD_{OD}} + \beta_{RISK}.RISK_{PT}.TD_{OD} + \beta_{TD}.TD_{OD} + \beta_{PT}^{AGEMP}.AGEMP + \beta_{GEN}^{PT}.GEN(Female == 1)$$

$$V_{MC} = \beta_{TC}.TC_{MC} + \beta_{IVT}.\frac{IVT_{MC}^{Min}}{60} + \beta_{AWET}.\frac{AWET_{MC}^{Min}}{60.TD_{OD}} + \beta_{RISK}.RISK_{MC}.TD_{OD} + \beta_{TD}.TD_{OD} + \beta_{MC}^{AGEMP}.AGEMP + \beta_{GEN}^{MC}.GEN(Female == 1)$$

$$V_{MM} = \alpha_{MM} + \beta_{TC}.TC_{MM} + \beta_{IVT}.\frac{IVT_{MM}^{Min}}{60} + \beta_{AWET}.\frac{AWET_{MM}^{Min}}{60.TD_{OD}} + \beta_{RISK}.RISK_{MM}.TD_{OD} + \beta_{MM}^{AGEMP}.AGEMP + \beta_{GEN}^{MM}.GEN(Female == 1)$$

$$V_{WK} = \alpha_{WK} + \beta_{IVT}.\frac{IVT_{WK}^{Min}}{60} + \beta_{RISK}.RISK_{WK}.TD_{OD} + \beta_{TD}.TD_{OD}$$

where:

- **Model type: MNL with α being alternative specific constant and β being the sensitivity parameter of the predictors.**
- Car is Car, PT is Public transport, MC is motorcycle, MM is shared micro-mobility/bike, WK is walk
- TC is the travel cost (monetary), IVT is the in-vehicle-time (Min), $RISK$ is the risk associated with the mode wrt. PT, $AWET$ is access-wait-egress time (Min)
- TD_{OD} is the trip distance of the OD pair (skim matrix)
- $AGEMP$ is the midpoint of the age interval, GEN is the gender dummy (for $Female == 1$)

Table 3-8 Athens Choice model parameters estimated

Parameters	Estimate	Std errors	T-Ratios	Significance
α_{PT}	-0.591	0.196	-3.015	***
α_{MM}	-0.842	0.363	-2.320	**
α_{WK}	-0.289	0.164	-1.762	*
β_{TC}	-0.051	0.026	-1.962	**
β_{IVT}	-0.877	0.158	-5.551	***
β_{AWET}	-7.315	1.893	-3.864	***
β_{RISK}	-0.003	0.001	-3.000	***
β_{TD}	-0.135	0.027	-5.000	***
β_{PT}^{AGEMP}	0.008	0.003	2.667	***
β_{MC}^{AGEMP}	-0.014	0.004	-3.500	***
β_{MM}^{AGEMP}	-0.035	0.008	-4.375	***
β_{GEN}^{PT}	0.522	0.087	6.000	***
β_{GEN}^{MC}	-0.594	0.128	-4.641	***
β_{GEN}^{MM}	-0.405	0.220	-1.841	*

The car serves as the reference mode of transport, so every estimate of the alternative specific constants (α) tells us how rival modes stack up against driving in Athens.

3.1.6.1 System-wide effects:

- **Value of Time:** A one-euro rise in cost lowers utility by 0.051, whereas one extra hour inside the vehicle cuts utility by 0.877. The implied value-of-time is about €17 h^{-1} (0.877 / 0.051).
- **Access, waiting and transfer time:** β_{AWET} = -7.315 is eight times larger than the in-vehicle penalty, underlining unreliable headways and transfers in Athenian public transport.

- **Perceived risk and trip length deter non-car travel:** Though small in magnitude, the risk coefficient (-0.003) is highly significant, and the distance effect (-0.135) systematically drags down the attractiveness of PT, motorcycles and micro-mobility as trips get longer.

3.1.6.2 Mode-specific effects:

- **Strong car bias:** All three alternative-specific constants are negative and significant (-0.591 for PT, -0.842 for shared micro-mobility, -0.289 for walk), showing an intrinsic preference for the car after controlling for time and cost.
- **Age reshapes two-wheeler use.** Each additional year of age *raises* PT utility slightly (+0.008) but *cuts* enthusiasm for motorcycles (-0.014) and shared bikes/scooters (-0.035). Athens' older travellers gravitate toward the bus or car, shunning riskier or more physically demanding options.
- **Pronounced gender gap.** Being female boosts the utility of public transport by 0.522 yet slashes that of motorcycles (-0.594) and micro-mobility (-0.405). Safety perceptions and cultural norms likely play a role.

Virtually all coefficients carry t-ratios beyond ±2, so these patterns are statistically robust: Athenians penalise waiting severely, dislike risky or tiring modes as trips lengthen, and women and older adults in particular rely more on conventional public transport.

3.2 Valencia

3.2.1 Baseline and intervention scenarios

The baseline scenario represents pre-intervention conditions, reflecting the existing infrastructure, modal split, and user behaviors. Each intervention was modelled as a distinct scenario, modifying the baseline network to simulate the specific change (e.g., new bike infrastructure, speed limit adjustments, increased micromobility demand, or parking reallocation).

The PHOEBE project tested four main interventions in Valencia to assess their impact on urban mobility and safety:

- Scenario 1: Extension of the off-road bike path along Avenguda Hermanos Machado by reprioritizing the bus lane to accommodate the cycle path. Figure 3-7 shows the before and after in the sections of the corridors where the solution is already implemented.

Before (2022) After (2023)

Figure 3-7 Valencia example of the intervention 1 already present in Avenguda Hermano Machados

- Scenario 2: Implementation of variable speed limits on different road lanes, with a focus on reducing speed near bike lanes.
- Scenario 3: Simulate the increase in micromobility (bicycles and e-scooters) usage by 30% because of an implementation of a new sharing system.

- Scenario 4: Addition of aiparking lane next to the median, reducing the number of lanes for motor vehicles. Figure 3-8 show the intervention implemented.

Figure 3-8 Valencia Intervention 2 already implemented

Simulation periods covered four daily time bands: AM (5:00–10:00), Interpeak (10:00–14:00), PM (15:00–19:00), and Night (20:00–24:00), with outputs aggregated in 15-minute intervals. The modelled network included 289 nodes, 1,765 road segments, and 125 km of roads, encompassing private cars, micromobility, and buses.

3.2.2 Performance indicators

3.2.2.1 Health and Safety

The safety impacts of the four interventions in Valencia were tracked using a set of key performance indicators (KPIs) that focus on both health outcomes and infrastructure risk. The Table 3-9 below summarizes the percentage change in safety KPIs for each scenario compared to the baseline.

The analysis of safety outcomes across the four intervention scenarios reveals a complex interplay between infrastructure changes and user risk. Scenarios 1 and 2, which involve extending the off-road bike path and implementing variable speed limits, yield a modest 1% reduction in fatalities and severe injuries—indicating a slight but positive safety benefit. In contrast, Scenario 3, which models a 30% increase in micromobility usage, results in a sharp 16% rise in serious incidents, underscoring the risks of rapid micromobility growth without adequate safety infrastructure. Interestingly, Scenario 4, which reallocates road space to add a parking lane, achieves the most substantial reduction in fatalities and severe injuries (5%), probably related to the speed impacts of reducing a traffic lane. These results can suggest that strategic reallocation of road space can enhance overall network safety. However, this benefit is tempered by a dramatic 2909% increase in average pedestrian risk because of the increased number of mid-block crossings, highlighting the potential for unintended consequences when pedestrian needs are not fully integrated into design changes.

Infrastructure star ratings and average road safety risk metrics further illustrate the trade-offs inherent in these interventions. While all scenarios improve the percentage of the network rated three stars or better for car occupants and motorcyclists—particularly Scenario 2 with a 4% gain—pedestrian infrastructure quality declines significantly, with ratings dropping by 18–19% in Scenarios 1 through 3. Bicyclist infrastructure sees only marginal improvements in Scenarios 2 and 3 and remains unchanged elsewhere. Risk assessments show that variable speed limits (Scenario 2) are highly effective for motorised users, reducing average node risk by 96%, whereas Scenario 1 unexpectedly increases this risk by 51%. Meanwhile, pedestrian and bicyclist risks rise sharply in several scenarios, especially Scenario 1 for cyclists (+148%), reinforcing the need for balanced, mode-inclusive planning. Overall, the findings stress the importance of holistic safety strategies that consider all road users to avoid shifting risk from one group to another.

Table 3-9 Valencia Health and Safety Indicator by Scenario

Performance Indicators	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Number of fatalities and severe injuries in the network	-1%	-1%	+16%	-5%
Number of severe injuries in the network	-1%	-1%	+16%	-5%
Number of fatalities and severe injuries (20 years)	-1%	-1%	+16%	-5%
% network ≥3 stars (Car Occupant)	+2%	+4%	+1%	+1%
% network ≥3 stars (Motorcyclist)	+2%	+4%	+1%	+1%
% network ≥3 stars (Pedestrian)	-19%	-18%	-19%	-13%
% network ≥3 stars (Bicyclist)	0%	+1%	+1%	0%
Avg. road safety risk on nodes (Car Occupant)	+51%	-96%	-14%	-16%
Avg. road safety risk on nodes (Motorcyclist)	+51%	-96%	-7%	-10%
Avg. road safety risk on nodes (Pedestrian)	+193%	+37%	+36%	+2909%
Avg. road safety risk on nodes (Bicyclist)	+148%	-3%	-4%	+1%

3.2.2.2 Mode Shift

Interventions aimed at promoting micromobility—such as cycling, walking, and shared e-scooter use—led to a noticeable modal shift, increasing both the number of trips and total distance travelled by non-motorised modes, while slightly reducing car usage. The model, which incorporated demographic segmentation by age and gender, revealed that across all age groups, motorised trip-kilometres remained largely unchanged in most scenarios, with variations typically between 0.0% and 0.3%. In Scenario 4, which included reallocating parking lanes, a reduction of 4.3% to 4.4% in non-motorised travel was observed, suggesting a consistent decrease in non-motorised modes when parking spaces are prioritised. Notably, Scenario 3 demonstrated a substantial 25.7% increase in non-motorised trip-kilometres across all age groups, highlighting the effectiveness of these interventions in encouraging active travel and reshaping mobility patterns (see Figure 3-9).

Interventions that promote active travel and micromobility have led to substantial shifts in travel behaviour, particularly among younger age groups. Bicycle trip-kilometres surged by up to 28.8% in scenarios that enhanced cycling infrastructure or encouraged micromobility, while shared micromobility usage rose by as much as 38.3%, reflecting strong induced demand when these modes are prioritised (see Figure 3-10). Car travel saw marginal reductions—up to 0.8%—especially in scenarios that reduced road space for vehicles or promoted alternative modes. Public transport usage remained relatively stable, with only minor fluctuations depending on the scenario and demographic. Walking also experienced moderate growth, with trip-kilometres increasing by up to 9.9%, particularly among elderly groups. Scenario 4 on the other hand present reduction of people walking due to the increase in risk.

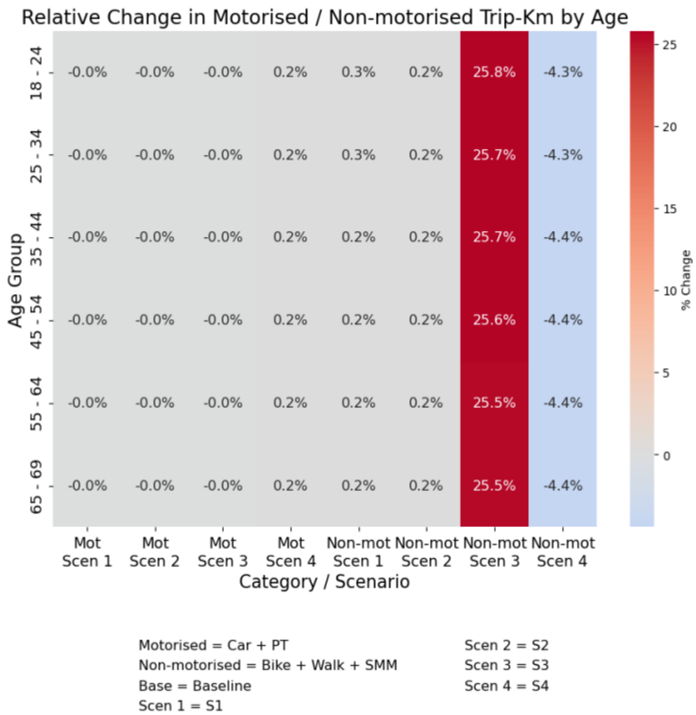

Figure 3-9 Valencia Mode shift between motorised and non-motorised modes

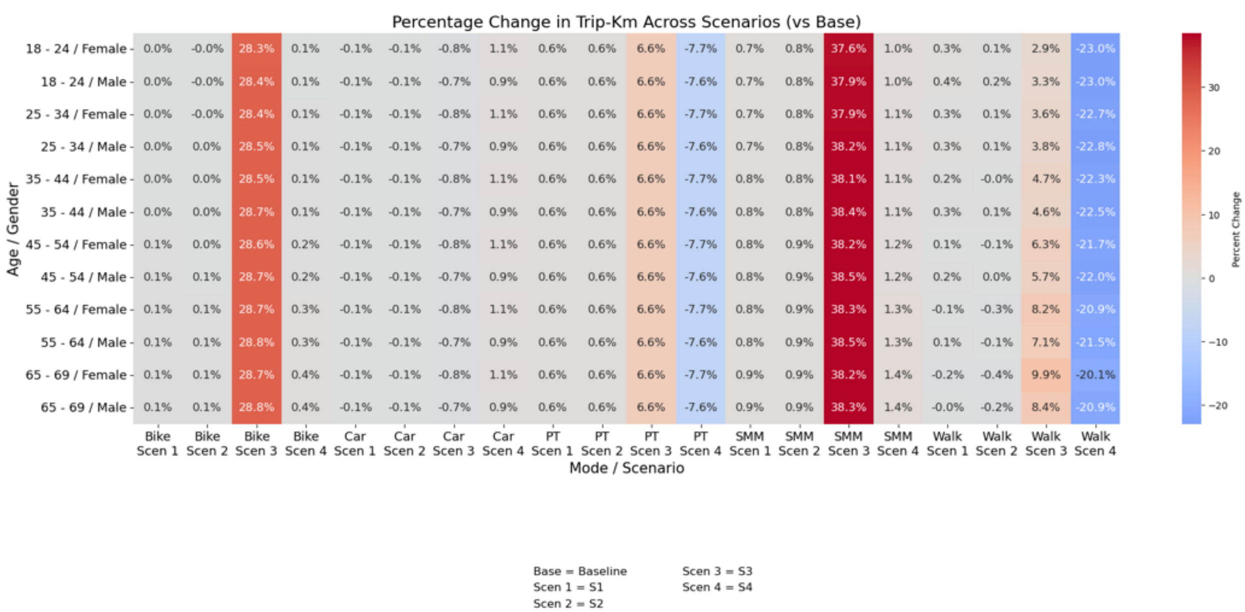

Figure 3-10 Valencia Use Case changes in trip-km

3.2.2.3 Traffic

Most interventions led to only modest increases in network travel time and delay, suggesting limited operational impact on overall network performance. However, Intervention 4—introducing a parking lane—stood out, causing a notable rise in travel time by over 7% and delay by 7.6%, likely due to reduced lane availability for motor vehicles. In contrast, travel distance remained largely unchanged across all scenarios, with variations under 1%, indicating that route choices and trip lengths were minimally affected.

3.2.2.4 Environment

The analysis of pollutant emissions across the four intervention scenarios reveals varying environmental impacts. Carbon dioxide (CO_2) emissions saw modest fluctuations, with Scenario 3 achieving a slight reduction of 0.23% compared to the baseline, while the other scenarios resulted in increases from 0.57% to 3.80%. Similarly, nitrogen oxides (NO_x) emissions followed a comparable trend, with Scenario 3 showing a minor decrease of 0.22%, and other scenarios again recording a rise from 0.59% to 3.51%. These results suggest that while some interventions may offer marginal environmental benefits, others—particularly those involving added road infrastructure—could lead to increased emissions, underscoring the importance of aligning transport strategies with sustainability goals.

3.2.3 Stakeholder Feedback

In Valencia, the first reflection workshop with local stakeholders took place on 26 February, 2025. The goal was to introduce the overall goals of the Use Case and the methodology, present the study areas and the baseline results for the 4 corridors. Finally, we gave an overview of the 4 future scenarios and collected input both in the live sessions and through a questionnaire that was disseminated within the organisations involved.

The Final Presentation and 2nd Reflection Workshop took place on 24 July 2025, with the aim of presenting the results of the Valencia Use Case and receiving feedback from the involved stakeholders. During the workshop, the project team presented the Use Case and the outcomes, starting with an overview of the methodology used for scenario generation and simulation results drawn from road safety analysis and traffic modelling.

At the end of the event, participants of the workshop contributed with various important comments to the topics. As Scenario 4 revealed a surprising and concerning level of pedestrian risk, especially in relation to movements from sidewalks to car doors, the nature of this risk was explained, while one stakeholder confirmed that corrective actions - such as adding pedestrian crossings and vertical signage - are already underway. The recognition of the importance of digitalisation for local law enforcement was highlighted, with the Valencian police now planning to incorporate digitalised data into their operations. Stakeholders also emphasised that the increased use of micromobility options, such as cycling and e-scooters, does not lead to reduced usage of public transport, indicating no cannibalisation between sustainable transport modes. One stakeholder reiterated that while traffic management data remains important, insights into road safety performance - both current and projected - are particularly valuable for shaping future infrastructure and mobility decisions.

3.2.4 Socio-economic and network level extrapolation

As delineated in Athens Use Case, in the Valencia Use Case, the mode choice model acts as a cornerstone for the socio-economic analysis. Here we present a brief description of the estimated mode choice model.

1. MNL utilities:

$$V_{car} = \beta_{TC}.TC_{Car} + \beta_{IVT}.\frac{IVT_{Car}^{Min}}{60} + \beta_{AWET}.\frac{AWET_{Car}^{Min}}{60.TD_{OD}} + \beta_{RISK}.\log(RISK_{Car}).TD_{OD}$$

$$V_{PT} = \beta_{TC}.TC_{PT} + \beta_{IVT}.\frac{IVT_{PT}^{Min}}{60} + \beta_{AWET}.\frac{AWET_{PT}^{Min}}{60.TD_{OD}} + \beta_{RISK}.\log(RISK_{PT}).TD_{OD} + \beta_{TD}^{PT}.TD_{OD} + \beta_{GEN}^{PT}.GEN(Female == 1)$$

$$V_{SMM} = \beta_{TC}.TC_{SMM} + \beta_{IVT}.\frac{IVT_{SMM}^{Min}}{60} + \beta_{AWET}.\frac{AWET_{SMM}^{Min}}{60.TD_{OD}} + \beta_{RISK}.\log(RISK_{SM}).TD_{OD} + \beta_{SMM}^{AGEMP}.AGEMP + \beta_{GEN}^{SMM}.GEN(Female == 1)$$

$$V_{PMM} = \beta_{TC}.TC_{PMM} + \beta_{IVT}.\frac{IVT_{PMM}^{Min}}{60} + \beta_{AWET}.\frac{AWET_{PMM}^{Min}}{60.TD_{OD}} + \beta_{RISK}.\log(RISK_{BK}).TD_{OD} + \beta_{PMM}^{AGEMP}.AGEMP + \beta_{GEN}^{PMM}.GEN(Female == 1)$$

$$V_{WK} = \alpha_{WK} + \beta_{IVT}.\frac{IVT_{WK}^{Min}}{60} + \beta_{RISK}.\log(RISK_{WK}).TD_{OD} + \beta_{TD}^{WK}.TD_{OD} + \beta_{GEN}^{WK}.GEN(Female == 1)$$

where:

- **Model type: MNL with α being alternative specific constant and β being the sensitivity parameter of the predictors.**
- Car is Car, PT is Public transport, SMM is shared micro-mobility, PMM is private micro-mobility/bike, WK is walk
- TC is the travel cost (monetary), IVT is the in-vehicle-time (Min), $RISK$ is the risk associated with the mode wrt. PT, $AWET$ is access-wait-egress time (Min)
- TD_{OD} is the trip distance of the OD pair (skim matrix)
- $AGEMP$ is the midpoint of the age interval, GEN is the gender dummy (for $Female == 1$)

Table 3-10 Valenica Mode shift parameters

Parameters	Estimate	Std errors	T-Ratios	Significance
α_{WK}	1.149	0.178	6.455	***
β_{TC}	-0.040	0.017	-2.353	**
β_{IVT}	-0.549	0.192	-2.859	***
β_{AWET}	-3.189	1.487	-2.145	**
β_{RISK}	-0.027	0.012	-2.250	**
β_{TD}^{PT}	-0.144	0.026	-5.538	***
β_{TD}^{WK}	-0.467	0.051	-9.157	***
β_{SMM}^{AGEMP}	-0.052	0.004	-13.00	***
β_{PMM}^{AGEMP}	-0.036	0.003	-12.00	***
β_{GEN}^{PT}	0.245	0.083	2.952	***
β_{GEN}^{SMM}	-0.296	0.131	-2.259	**
β_{GEN}^{PMM}	-0.425	0.187	-2.273	**
β_{GEN}^{WK}	-0.408	0.100	-4.080	***

In Valencia, the car serves as the reference mode of transport, providing a baseline against which other travel modes are evaluated. The model reveals that travellers place a high value on their time, with each additional euro reducing utility by 0.040 and each extra hour in a vehicle decreasing it by 0.549—implying a value of time around €14 per hour. Off-board time, such as walking to stops or waiting, is heavily penalised—six times more than in-vehicle time—discouraging public transport use when access is inconvenient or headways are long. Perceived risk also plays a role: routes perceived as twice as risky lose about 2.7% of their utility per kilometre.

Walking is generally favoured,especially for short distances, but its appeal drops sharply with longer trips. Public transport performs well for short to medium distances, though its effectiveness is limited in outer areas with high car ownership and sparse rail coverage. Micromobility options like e-scooters and bikes are popular among younger users, with utility declining steadily with age. Every extra year of age knocks 0.052 off shared-device utility and 0.036 off private-bike utility, signalling that e-scooters and bikes remain the playground of students and young professionals. Gender differences are also evident: women show a preference for buses and metros but tend to avoid micromobility and walking, likely due to safety concerns or caregiving responsibilities. Women lean toward the bus or metro (β_{PTGEN} = +0.245) yet shy away from all forms of micro-mobility (-0.296 shared, -0.425 private) and even walking (-0.408). Safety perceptions or childcare logistics likely suppress their use of exposed or effort-intensive modes. Virtually all coefficients exceed the ±2 t-ratio threshold, so these behavioural tendencies are statistically solid for Valencian commuters.

3.3 West Midlands

3.3.1 Scenarios

Four scenarios were explored in the West Midlands Use Case. Our selection focused on interventions that aimed to produce positive outcomes for VRUs. The West Midlands used two Aimsun models, which together form a geographically contiguous area. These regions are referred to as Aimsun 1, which is a 50 km^2 area that stretches from Birmingham city centre to the eastern extent of the city, and Aimsun 2, which is a 5 km^2 region to the south of the centre.

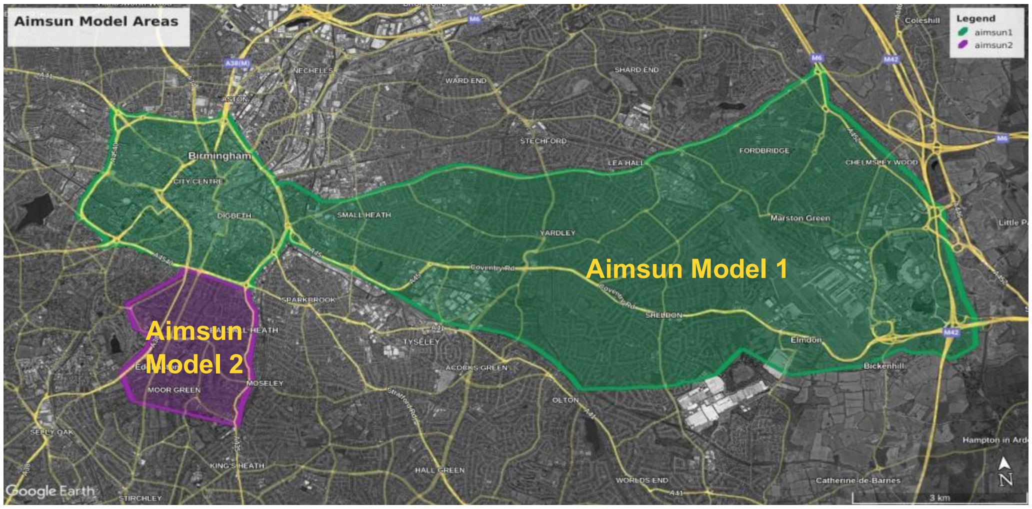

Figure 3-11 West Midlands Study Area

The first scenario concerned active travel, where we studied the effects of introducing new cycle infrastructure to arterial routes into the centre of Birmingham. This scenario utilised the Aimsun 2 model.

The second scenario explored the effects of reducing speed limits over large portions of the road network. In recent years, many districts have reduced the speed limits to 30 mph from 40 mph. There are currently plans to reduce the speed limits on all remaining 40 mph roads. This scenario utilised the Aimsun 1 model.

Local stakeholders also have plans for increasing the proportion of journeys carried out by public transport. Part of this strategy involves the creation of new transport-specific routes that allow for these modes to be prioritised in the network. We explored the effects of introducing additional bus-specific infrastructure. This scenario utilised the Aimsun 1 model.

Finally, we sought to measure the changes that could occur as a result of new or emerging transport solutions. Specifically, we chose to examine the effect of introducing a significant population of autonomous vehicles into the transport network. This experiment did not aim to understand the complex and vehicle-specific effects of a particular CAV technology, but rather to understand how the traffic responds when part of the population is restricted to a particular operational design domain (ODD). This experiment, if repeated, has potential exploitation for understanding active travel projects such as low traffic neighbourhoods or school streets, where the car traffic is reduced or eliminated on certain roads and traffic planners seek to understand the effects as felt by the wider road network. This scenario utilised the Aimsun 1 model.

3.3.1.1 Active Travel

In June 2019, Birmingham City Council opened a new cycle lane that ran parallel to the A38 (Bristol Road), which is the main arterial route into the city centre from the south. This route connected the centre to both the University of Birmingham and Edgbaston Cricket ground, one of the city's four major sports stadia. This cycle route marked a step change in quality compared to existing cycle infrastructure. Whereas existing cycle lanes involved the painting of new, narrow lanes onto the surface of the road, this cycle route mimicked the style that can be found in many continental European cities, with a substantial physical separation from the carriageway for motorists. The new infrastructure can be seen in the Figure 3-12 below, which compares the same section of road between two epochs.

Figure 3-12 West Midlands Intervention 1

We chose to assess how the current cycling infrastructure has changed the road risk and traffic flow by comparing a version of the Aimsun model with and without the cycle lane. This approach means that the base scenario is when the cycle route exists, and the intervention scenario considers what would happen if the cycle route were to be removed. This comparison is of interest to stakeholders, who intend to create additional cycle routes throughout the West Midlands. The intention is that local planners can obtain evidence to support future projects that characterises the possible change in mode shift and the reduction in risk faced by cyclists.

We carried out a Cycle RAP survey along the route to augment our analysis and demonstrate a novel approach for measuring both pre-and post-intervention scenarios even after an intervention has taken place.

3.3.1.2 Speed Limit Changes

In late 2024, Birmingham City Council carried out a statutory consultation to reduce the speed limit to 30 mph on most roads that had speed limits of 40 mph. The council presented a three-fold motivation for implementing this change, reducing speed, improving safety, and to encourage more walking and cycling. The consultation determined that two roads should be exempted from the proposed change, the Quinton Expressway and the A38 (M) Aston Expressway, both of which are outside of the Aimsun 1 region.

3.3.2 Performance Indicators

3.3.2.1 Mode shift

The focus on mode shift to active travel led us to choose to assess the following performance indicators for this scenario.

1. Percentage decrease in bicycle or e-scooter trips
2. Percentage change in motorised vehicle flows
3. Percentage increase in pedestrian trips.

After performing the full suite of simulations, we find that there is no significant difference between the volume of motorised journeys along the route, however, the removal of the cycle lane led to a significant reduction in the total number of trips made by bike across the Aimsun 2 model region. Perhaps against expectations, we also found a slight increase in the number of journeys made by foot, which could be the result of those people who would otherwise cycle choosing to walk when safer infrastructure is not present (see Figure 3-13 and Figure 3-14).

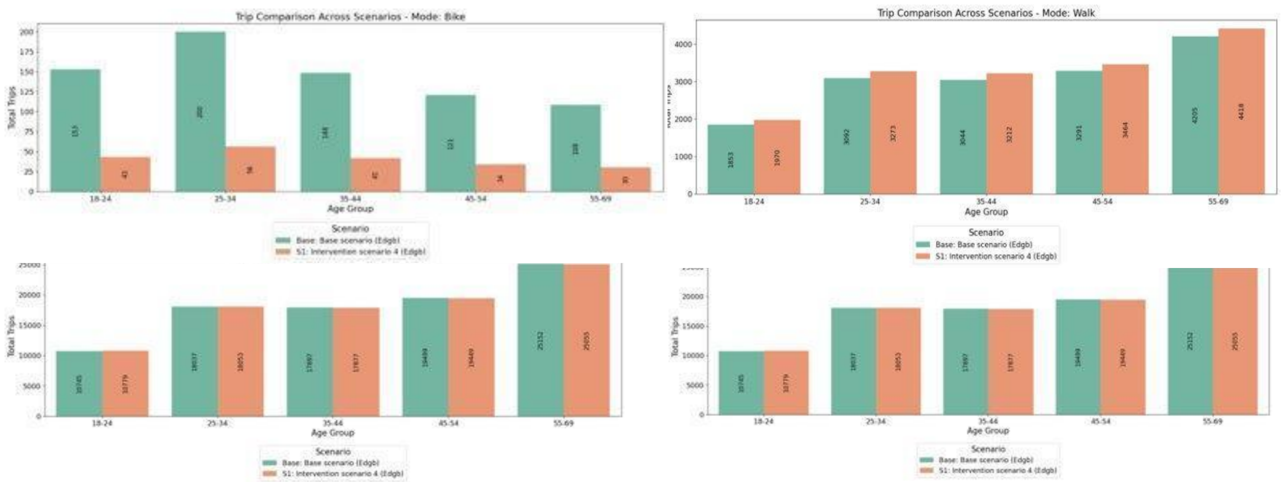

Figure 3-13 West Midlands Mode choice indicators – Scenario 1

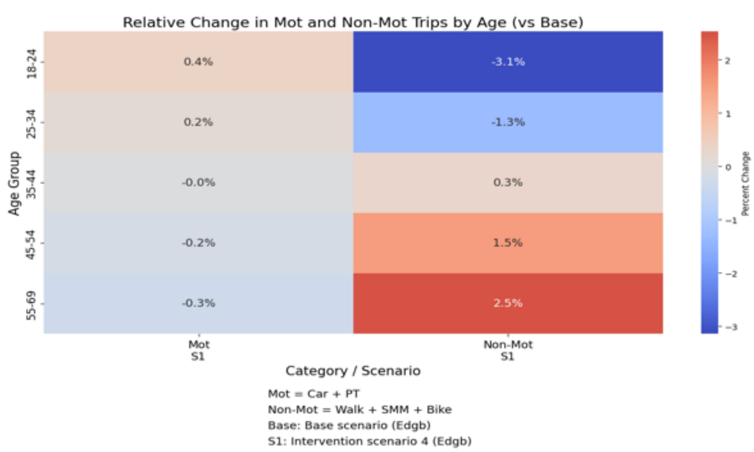

Figure 3-14 West Midlands Relative change in Motorised and Non-motorised trips – Scenario 1

For Scenario 2, we chose to examine the following indicators as they most closely align with the stated objectives of the scheme.

1. Proportion change in travel time per mode
2. The change in delay parameters for motorised vehicles
3. Change in the difference between the speed limit and the 85th speed.

After changing the speed limit on all 40 mph roads to 30 mph our results suggest a significant increase in the number of journeys carried out on foot, by around 50%. We see a slight reduction in the number of journeys carried out by car, while the number of cycle trips remains unchanged. Figure 3-15 and Figure *3-16* present these results.

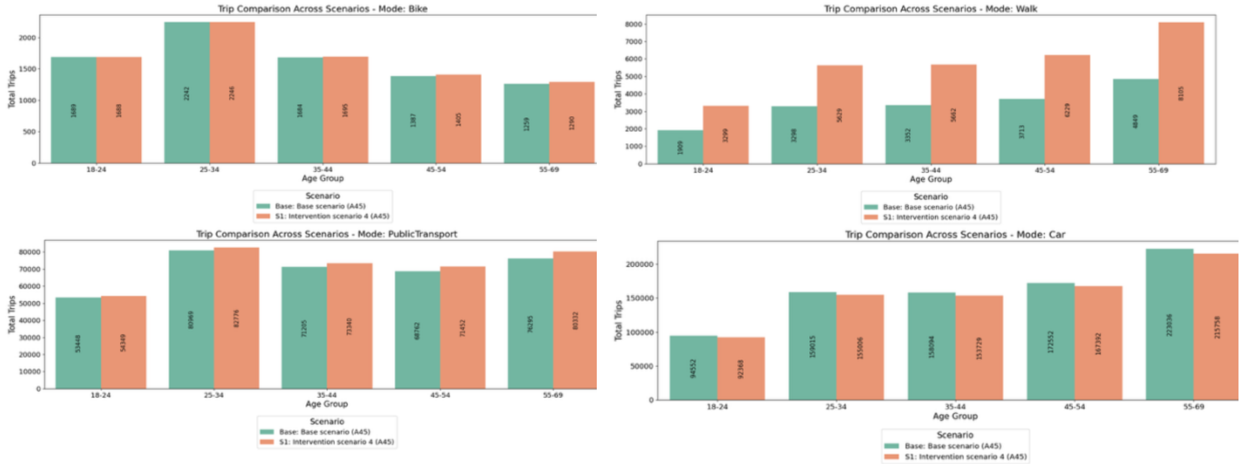

Figure 3-15 West Midlands Mode choice indicators – Scenario 2

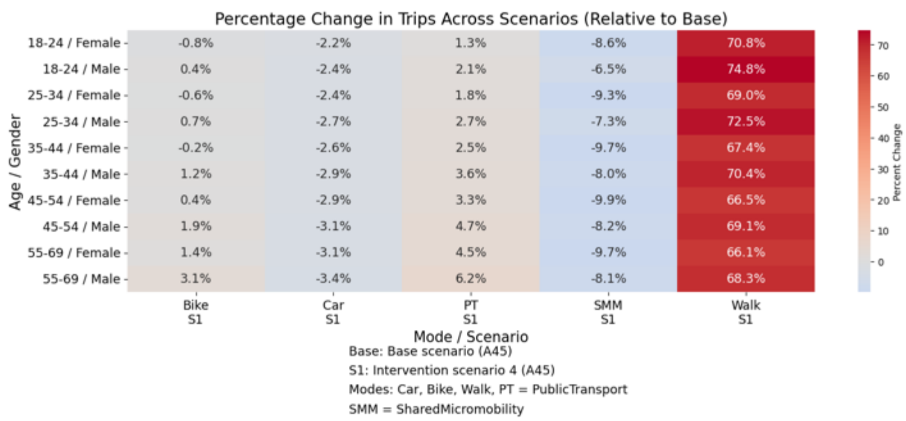

Figure 3-16 West Midlands Relative change in Motorised and Non-motorised trips – Scenaio 2

3.3.2.2 Road Risk

The road safety KPIs are assessed using the standard iRAP survey results, which change in light of mode shift, volume shift, speed changes, and considering new infrastructure. Using the established iRAP methodology, we find the network-wide expectation of fatalities and severe injuries increases by 40% when the cycle lane is removed. The proportion of the network that reaches 3 stars or better, for different road users, is unchanged for vehicle occupants and motorcyclists, with a 5% decrease for pedestrians. Crucially, we find that the proportion of the network that scores three stars or better goes from 59% to 35% when the cycle lane is removed, with the average risk faced by cyclists almost doubling in magnitude.

A CycleRAP survey was also carried out over key routes in the Aimsun2 region. Ordinarily, a survey considers a single pass down a particular road, the footage from which is then analysed to understand potential hazards over the full carriageway. However, we adopted a two-survey approach for this route.

The first pass, in which the cyclist remained on the pavement (sidewalk) adjacent to the southbound lane and a second pass where the cyclist traversed the new cycle lane. The two surveys allowed for the carriageway and the cycle lane to be encoded as separate independent routes. The southbound survey thus became equivalent to the 'after' scenario, when the cycle lane is removed, and the northbound survey used to evaluate the risk faced by cyclists on the new cycle lane. Figure 3-18 and Figure 3-17 show differences in scores and in the estimated cyclists fatalities and severe injuries considering Intervention 1.

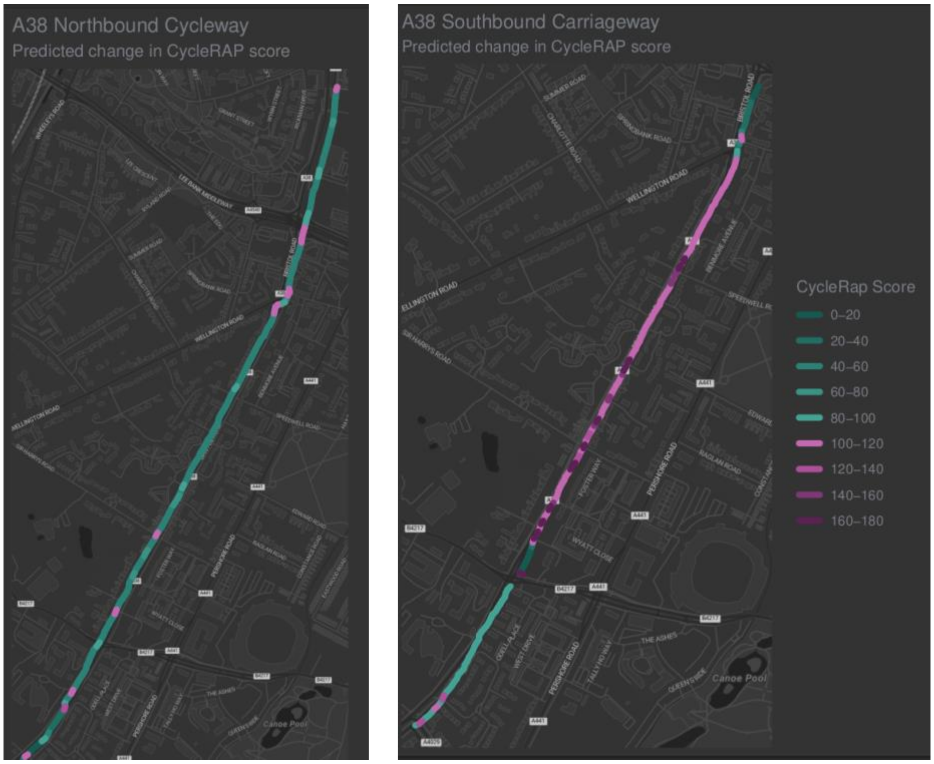

Figure 3-17 West Midlands estimated change in risk score in scenario 1

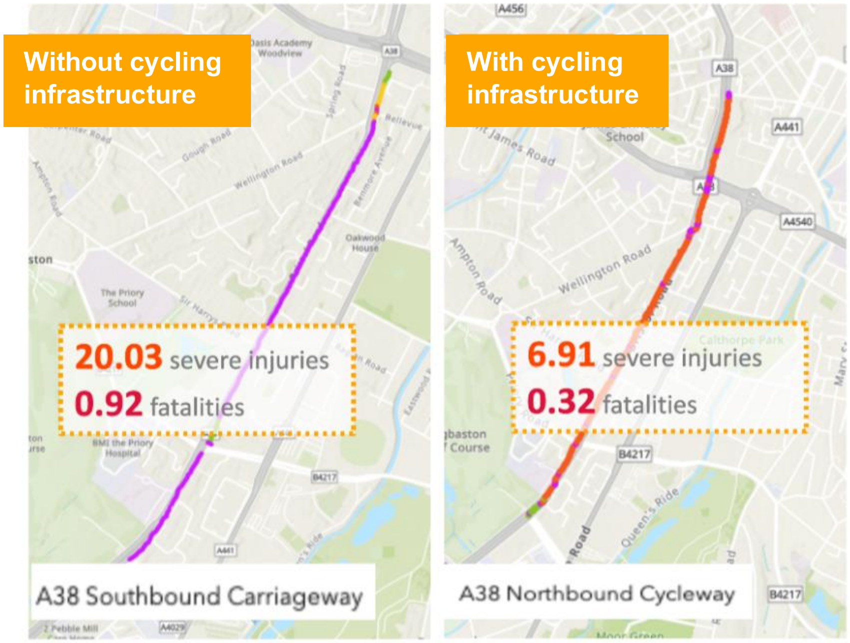

Figure 3-18 West Midlands estimated cyclists' fatalities and severe injuries for Scenario 1

As part of this exercise, we utilised the prediction features in the Lane Patrol software that shows how the risk scores would improve in the event that a particular set of mitigations is enacted. In the following Figure 3-19, we show the distribution of scores per km for the southbound carriageway before and after mitigations are introduced.

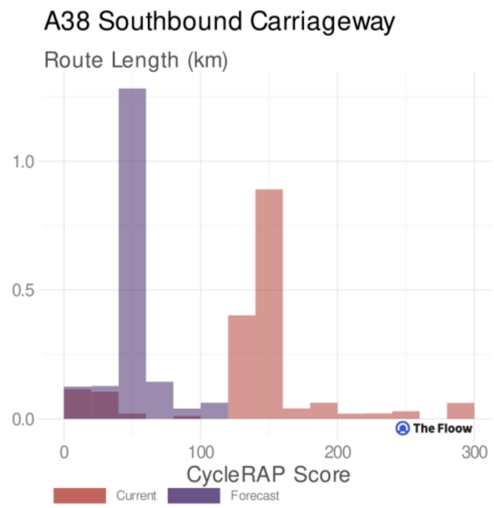

Figure 3-19 West Midlands Simulation of mitigation measures for Scenario 1

In Scenario 2, road risk was assessed only on roads with an iRAP survey. Figure 3-20 shows these corridors and sample results for vehicle occupant safety: green indicates 5-star segments, yellow is 4-star, orange is 3-star, and red signifies 2-star segments. No 1-star segments were found in this analysis.

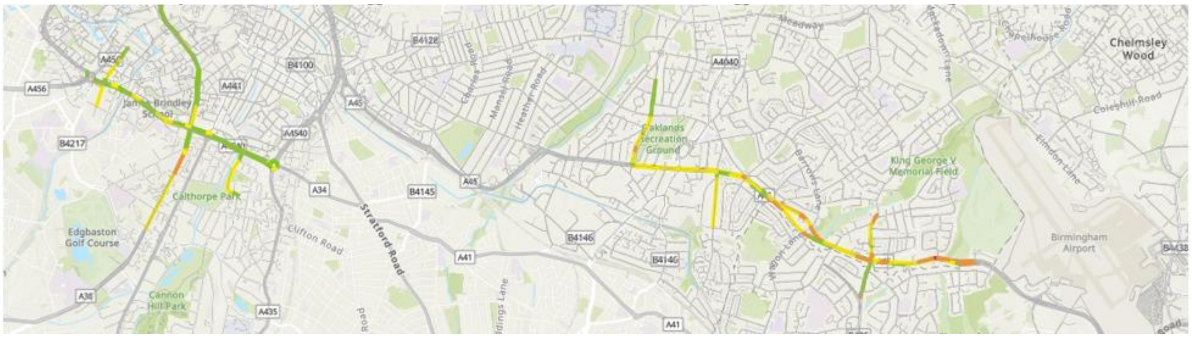

Figure 3-20 West Midlands safety assessed corridor for Scenario 2

The simulations suggest that reducing the speed limit will lead to a 45% reduction in the number of FSI, with the average reduction of safety risk on mid-block sections of at least 24%. The results show some increase in the overall risk due to the increase of traffic; however, the results need to be interpret with careful since the corridors assessed in the WM region are localized and not represent the complete network.

3.3.3 Socioeconomic and network-level extrapolation

The basis of the socio-economic analysis starts with the estimation of the mode-choice model. A brief interpretation of the mode choice model is presented below.

1. MNL utilities:

$$V_{car} = \beta_{TC}.TC_{Car} + \beta_{IVT}.\frac{IVT_{Car}^{Min}}{60} + \beta_{AWET}.\frac{AWET_{Car}^{Min}}{60.TD_{OD}} + \beta_{RISK}.RISK_{Car}$$

$$V_{PT} = \alpha_{PT} + \beta_{TC}.TC_{PT} + \beta_{IVT}.\frac{IVT_{PT}^{Min}}{60} + \beta_{AWET}.\frac{AWET_{PT}^{Min}}{60.TD_{OD}} + \beta_{RISK}.RISK_{PT} + \beta_{TD}.TD_{OD} + \beta_{PT}^{AGEMP}.AGEMP$$

$$V_{SM} = \beta_{TC}.TC_{SM} + \beta_{IVT}.\frac{IVT_{SM}^{Min}}{60} + \beta_{AWET}.\frac{AWET_{SM}^{Min}}{60.TD_{OD}} + \beta_{RISK}.RISK_{SM} + \beta_{SM}^{AGEMP}.AGEMP + \beta_{GEN}^{Female}.GEN(Female == 1)$$

$$V_{BK} = \beta_{TC}.TC_{BK} + \beta_{IVT}.\frac{IVT_{BK}^{Min}}{60} + \beta_{AWET}.\frac{AWET_{BK}^{Min}}{60.TD_{OD}} + \beta_{RISK}.RISK_{BK} + \beta_{BK}^{AGEMP}.AGEMP + \beta_{GEN}^{Female}.GEN(Female == 1)$$

$$V_{WK} = \beta_{IVT}.\frac{IVT_{WK}^{Min}}{60} + \beta_{RISK}.RISK_{WK} + \beta_{TD}.TD_{OD}$$

where:

- **Model type: MNL with α being alternative specific constant and β being the sensitivity parameter of the predictors.**
- Car is Car, PT is Public transport, SM is shared micro-mobility, BK is private micro-mobility/bike, WK is walk
- TC is the travel cost (monetary), IVT is the in-vehicle-time (Min), $RISK$ is the risk associated with the mode wrt. PT, $AWET$ is access-wait-egress time (Min)
- TD_{OD} is the trip distance of the OD pair (skim matrix)
- $AGEMP$ is the midpoint of the age interval, GEN is the gender dummy (for $Female == 1$)

Table 3-11 West Midlands mode shift parameters

Parameters	Estimate	Std errors	T-Ratios	Significance
α_{PT}	0.717	0.189	3.794	***
β_{TC}	-0.049	0.022	-2.227	**
β_{IVT}	-0.887	0.156	-5.686	***
β_{AWET}	-4.148	0.955	-4.343	***
β_{RISK}	-0.012	0.005	-2.400	**
β_{TD}	-0.234	0.048	-4.875	***
β_{PT}^{AGEMP}	-0.013	0.003	-4.333	***
β_{SM}^{AGEMP}	-0.047	0.004	-11.75	***
β_{BK}^{AGEMP}	-0.029	0.003	-9.667	***
β_{GEN}^{Female}	-0.455	0.111	-4.099	***

In this case, the car alternative is the reference (its constant is normalised to 0), so every alternative specific coefficient should be read as the extra "push" or "penalty" that makes the other modes more- or less-attractive relative to driving. For example, the alternative specific coefficient of Public Transport is 0.717, which is positive (the reference here is car with an alternative specific coefficient of 0), therefore people in the West Midlands exhibit a built-in predisposition toward public transport strong enough to tolerate nearly ¾ hour of extra ride time (or, equivalently, about £15 of extra out-of-pocket cost).

The value-of-time analysis indicates that each additional £1 in travel cost reduces utility by 0.049, while an extra hour spent inside a vehicle lowers it by 0.887. This translates to an implied value-of-time of approximately £18 per hour, aligning with UK transport appraisal standards. However, this figures should be interpreted as a regional average, as the model does not differentiate by trip purpose. Perceived risk also plays a role in travel behaviour: each unit increase in the risk index reduces utility by 0.012—a statistically significant effect, even if modest in magnitude.

Mode-specific findings reveal nuanced preferences. Public transport benefits from a positive intrinsic appeal, with an alternative-specific constant of 0.717, suggesting that even after accounting for time, cost, and risk, it remains a preferred option—likely due to convenience, multitasking opportunities, or reduced parking stress. However, distance negatively affects non-car modes, with a coefficient of -0.234 for both public transport and walking, reflecting the West Midlands' limited public transport connectivity in peripheral areas. Age influences mode choice as well: each additional year reduces utility for public transport by 0.013, and even more steeply for shared micromobility (-0.047) and private bikes (-0.029), indicating a shift toward private transport among older residents. Gender disparities are also evident, with women showing significantly lower utility for shared and private micromobility (-0.455), likely due to concerns around safety, comfort, or cultural norms that discourage their use of these modes.

3.3.4 Stakeholder Feedback

3.3.4.1 West Midlands Road Safety Workshop

TfWM are the key stakeholder in the West Midlands. They make strategic transport decisions for the region, which comprises seven local authorities (towns and cities). In November 2024, TfWM hosted a workshop for PHOEBE that engaged with several of the constituent local authorities. This workshop was presented with the results of the iRAP and CycleRAP surveys and spent time in focus groups discussing key problems relating to the implementation of road safety infrastructural projects. This session highlighted the great difficulty faced by transport planners in trying to achieve or maintain widespread public support for changes that aim to save lives, particularly when those changes inhibit or restrict the movement of motorised vehicles.

3.3.4.2 Stakeholder Feedback Sessions

The TfWM project contacts are the Regional Road Safety Manager and an associate Senior Research Analyst. They took part in three stakeholder meetings in the first half of 2025, with a final review meeting scheduled for August 2025. These meetings took the form of 1 hour workshops where the project results were presented, discussed and interrogated.

Initial stakeholder feedback session - 28/02/2025

Stakeholders were provided with initial road risk results from iRAP before the meeting took place. During the session a questionnaire served as a guide to the discussion. The objective of the session was to determine if these results were broadly in line with expectations given local knowledge and context. These results were considered in terms of the star rating for each type of road user. The stakeholders expressed agreement with the findings for a majority of routes. We chose to then focus on the most extreme, lowest-scoring road sections for much of the subsequent discussion. The stakeholders were able to explain why they agreed with these findings, however, they were also able to highlight how the star rating might be revised in light of factors unknown to the encoders. One such example involved a section of an on-ramp to the A38 in the vicinity of the Aston expressway. The iRAP survey identified a high risk to pedestrians crossing at this location and assumed a particular level of crossing traffic, however, TfWM were able to show that this crossing traffic is actually zero because pedestrians can utilise subterranean walkways that would not have been identified during the encoding process for the iRAP survey.

Second stakeholder feedback session - 02/05/2025

Stakeholders provided subsequent feedback to the initial iRAP results, which they had been able to analyse in more detail since the previous meeting. They highlighted some locations where the predicted FSI is unaccountably high, particularly along the Eastern extent of A454.

Stakeholders were presented with preliminary results of simulations of before and after scenarios, which had been carried out without consideration of induced demand. These results included the modified road risk factors and FSIs as well as the adjusted traffic properties. The KPIs for each scenario were reviewed and results were presented when available. This meeting served to familiarise the stakeholders with the format of the results and helped them to understand what measurements were likely to be present in the final evaluation of each experiment.

Final stakeholder feedback session - 12/06/2025

The stakeholders were presented with the first portfolio of completed simulation results, which included consideration of induced demand. Several results were queried, particularly some of the traffic findings, which they believed to be counter-intuitive in places. The stakeholders expressed enthusiasm for the majority of the work and explained that they had started the process of determining how insights from PHOEBE can be distributed to the relevant working groups within TfWM. A final session is scheduled which will answer outstanding questions from the stakeholders and provide them with a finalised set of results as per deliverable 3.2.

This session and the final session are being used to determine whether appropriate KPIs have been selected for the Use Cases experiments. Stakeholders have made several suggestions for a shift in focus for some of the experiments to pinpoint the information that actually matters for decision makers. This information will be used to refine the KPIs for the activities planned under WP5.

4 Cross-Use Case Synthesis

4.1 Observed behavioural and systemic patterns

The evaluation of the three Use Cases revealed consistent patterns in both user behaviour and system-level responses to the proposed interventions. These patterns were derived from the interpretation of model outputs, cross-case comparison of indicators, and structured stakeholder feedback.

Across all cities, interventions aimed at reallocating road space or reducing vehicle speeds led to projected increases in walking and cycling. In Valencia, micromobility infrastructure measures were associated with increased cycling volumes in central corridors. In the West Midlands, active travel scenarios resulted in moderate growth in cycling mode share, especially in areas with improved connectivity. These changes were consistent with the expected effects of infrastructure improvements and were supported by stakeholder feedback during validation sessions.

In Athens, behavioural outcomes were primarily linked to compliance with speed limits and changes in pedestrian risk levels. The modelling results suggested improved safety in areas with reduced speeds, although local experts noted that additional enforcement and infrastructure elements would be required to achieve such changes in practice. Similar concerns were raised in Valencia, where informal behaviour such as pedestrian crossings outside designated areas and two-wheeler filtering were not fully reflected in modelled scenarios.

System-level effects included spatial redistribution of traffic and risk exposure. In Valencia, certain pedestrian-focused scenarios reduced conflict in the core zone but shifted motorised traffic to adjacent links, increasing safety risks at network edges. In the West Midlands, changes in route choice were observed around key corridors, leading to increased demand and potential congestion on secondary roads. These effects highlight the importance of assessing interventions beyond their immediate location, as secondary impacts can offset local benefits.

The analysis also confirmed that behavioural outcomes and systemic patterns were shaped by baseline network conditions and data availability, as discussed in the Use Case Evaluation Chapter. Differences in input resolution, such as the availability of detailed pedestrian flows or modal segmentation, affected the sensitivity of model outputs. In some cases, assumptions were applied to estimate compliance rates or exposure for vulnerable users, which introduced additional uncertainty in the interpretation of results.

Model calibration also influenced observed patterns. While common modelling components were applied across the three pilots, local adjustments were made to better reflect city-specific conditions. These included modifications to speed profiles, trip generation rates, and mode shift coefficients. The ability to adjust model logic based on stakeholder input was identified as a strength of the framework, allowing each city to align assumptions with observed local behaviour.

Stakeholder feedback also highlighted behavioural patterns not captured by the core indicators, including user discomfort, informal infrastructure use, and differences in response by gender and age. These issues were particularly noted in Athens and the West Midlands and suggest the need to expand behavioural inputs and performance indicators in future applications.

The PHOEBE applications had also identified some common side effects of the interventions:

Table 4-1Interventions side effects

Side Effect	Evidence in PHOEBE Use Cases	Measurement Approach	City Example
Traffic Diversion	Redistribution of traffic flows was noted in Athens after pedestrianisation and bus lane expansion.	Traffic flow maps and simulation outputs showed changes in volume across corridors.	Athens
Increased Travel Time	In Valencia, some interventions (e.g. parking lane addition) led to a 7% increase in travel time and 7.6% delay.	Network travel time and delay KPIs.	Valencia
Risk Redistribution	Safety improved in intervention zones but worsened in others. For example, Valencia saw a big increase in pedestrian node risk in Scenario 4.	Disaggregated safety KPIs and risk maps.	Valencia
Behavioural Adaptation	Slight increase in speeding behaviour was observed when reducing speed limits.	Behavioural model integration and statistical analysis.	Athens and West Midlands
Equity Impacts	Gender and age differences in mode choice were evident. Older users and women showed lower uptake of micromobility.	Mode choice model outputs segmented by age and gender.	Athens, Valencia, West Midlands
Perceived Inconvenience	Stakeholders in West Midlands expressed concern over public resistance to interventions that restrict motor vehicle movement.	Stakeholder feedback sessions and workshops.	West Midlands

While it is clear that any intervention may lead to unforeseen impacts, the ability to capture these side effects demonstrates the robustness of the evaluation framework. This capability empowers decision-makers to measure and understand potential consequences before committing resources. It enables them to determine whether an intervention should be implemented as planned, adjusted to mitigate risks, or replaced with an alternative approach.

4.2 Replicability and transferability

4.2.1 Inspiration on interventions

The interventions implemented in Athens, Valencia, and the West Midlands showcase a diverse spectrum of urban mobility strategies, each offering varying degrees of replicability and transferability. Under the PHOEBE framework, all three cities selected pilot interventions that directly address urgent and widely shared mobility challenges, like the increasing safety risks faced by VRUs. These are common challenges in many urban areas, making the core interventions, such as speed limit reductions, pedestrianisation, and micromobility infrastructure, broadly applicable. These initiatives also reflect a strong commitment to advancing sustainable transport modes and implementing robust speed management measures.

Moreover, the selected measures demonstrate responsiveness to emerging urban mobility trends. For instance, the growing presence of micromobility users, characterised by diverse vehicle types and operating speeds, prompted innovative responses such as Valencia's trial of differential speed limits by lane. Such forward-looking solutions underscore the adaptability of the PHOEBE framework and its potential to inspire other cities seeking to modernise their transport systems while prioritising safety, inclusivity, and sustainability.

With the three cities we have learned:

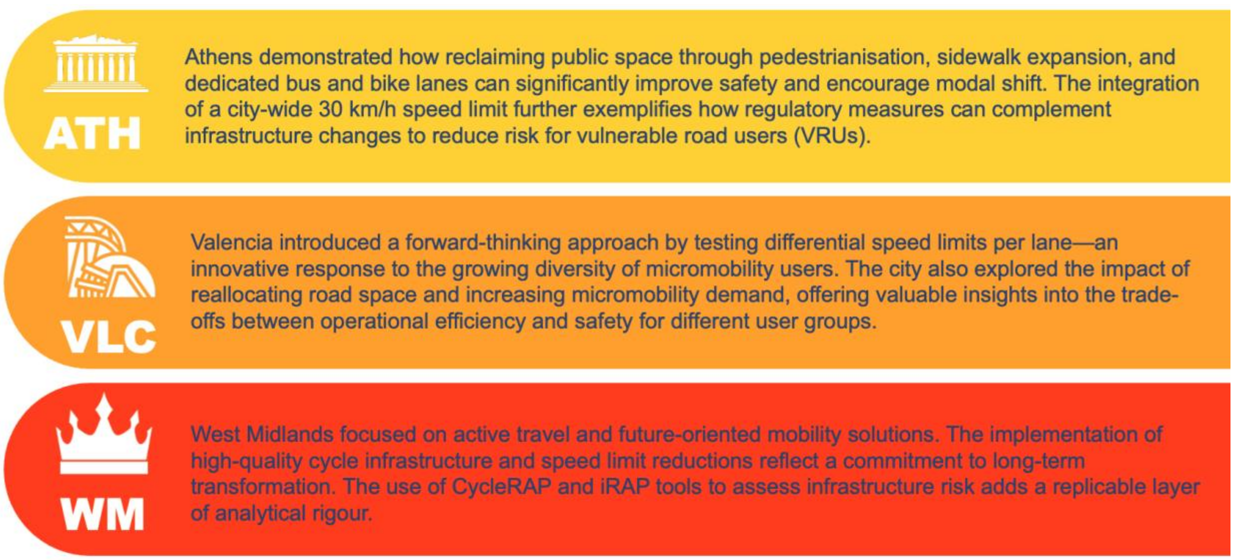

Figure 4-1 Use case learnings

4.2.2 Transferability of results

The results derived from these interventions are firmly grounded in a rigorous, evidence-based methodology. By integrating advanced and enhanced simulations, alongside behavioural and mode shift models, the evaluation framework delivers a comprehensive and credible assessment of impact. This data-driven approach not only reinforces the validity of the findings but also strengthens the adaptability of the strategies, empowering other cities to confidently tailor and implement similar approaches to test interventions within their own urban contexts.

However, the transferability of these results is not without limitations. Differences in urban form, such as city layout, density, and the maturity of transport infrastructure, can significantly constrain direct replication. For instance, the compact and historic core of Athens with a great number of tourists downtown presents spatial and operational characteristics that may not align with those of newer or more sprawling cities.

Moreover, variations in travel behaviour, risk perception, and modal preferences influence how interventions are received and adopted. The uptake of micromobility in Valencia, for example, may not be mirrored in cities with older populations, steeper topographies, or less favourable climate conditions. As such, behavioural and demand models must be developed to reflect local socio-demographic, cultural and environmental contexts.

The success of these interventions often hinges on the presence of supportive regulatory frameworks and enforcement mechanisms. The implementation of a 30 km/h speed limit in Athens and the West Midlands, for example, required legislative backing and institutional coordination. These conditions may not be readily available or politically feasible in all jurisdictions.

Finally, although the PHOEBE project focused on the technical development of the framework, we aim to add guidelines also on how to ensure an active involvement of local stakeholders. In all three cities, the stakeholders' engagement was vital to ensure that interventions were context-sensitive and aligned with public needs. This participatory model should be replicated to improve acceptance and effectiveness elsewhere and to ensure the framework brings value to the city and citizens.

4.2.3 Adaptation Strategies

To enhance transferability, cities should tailor interventions to local conditions while maintaining the core principles of safety, sustainability, and inclusivity. This includes conducting localised simulations, engaging stakeholders early, and integrating behavioural insights into planning. Moreover, modular implementation—starting with pilot projects—can help test and refine strategies before full-scale deployment.

In conclusion, while local contexts shape the specific interventions in Athens, Valencia, and West Midlands, the PHOEBE underlying methodologies and goals offer valuable templates for other cities aiming to improve urban mobility and safety. Additionally, although in the replication of the PHOEBE framework, the human behaviours and the demand models need to be developed for each contact and intervention tested, the framework on the path to integration remains the same, with minor tweaks to adjust objectives. On the other hand, the traffic simulation and the risk assessment models used (AIMSUN Next and iRAP Star Ratings in the case of the three pilots) are designed to be located independently and can be applied globally. This means the PHOEBE enhancements on these two modules are ready to use in any European cities.

One of the key takeaways from the PHOEBE framework demonstrations is its modularity. This means, the framework could be divided into different modules for its replication There is, although the framework was originally designed to operate as a comprehensive end-to-end system, cities can still derive substantial value by implementing selected components. This flexible approach can significantly reduce the effort required for model development, data processing, and computational resources, making it more accessible for cities with limited capacity.

Naturally, omitting parts of the framework may reduce the depth of insights gained. However, by strategically selecting which modules to apply, cities can maximise the relevance and impact of their analysis based on specific goals. For example:

- A city aiming to evaluate how a new shared mobility system combined with a comprehensive bicycle infrastructure might increase cycling uptake can focus on demand modelling, simulation, and risk assessment, without needing full behavioural integration.

- If the goal is to assess the benefits of increasing green light time for pedestrians, combining behavioural models with simulation can provide targeted insights into pedestrian compliance and safety.
- For projects involving pedestrianisation of a downtown street, risk assessment paired with simulation can generate all the necessary metrics to evaluate safety and operational impact.
- In cases where shared spaces for cyclists and vehicles are being considered, behavioural models aligned with risk assessment can offer valuable insights into potential conflicts and mitigation strategies. Simulation can be added to further enrich the analysis.

This modular application of the PHOEBE framework empowers cities to customize their evaluation approach, aligning it with local priorities, available resources, and policy objectives, while still benefiting from the framework's robust analytical foundation.

4.3 Integration with the broader PHOEBE framework

WP4 applied the PHOEBE methodology across three Use Cases to test whether the core components developed in WPs 1 to 3 can function together as a structured framework. The Use Cases followed the **SELECT–SIMULATE–EVALUATE–EXTRAPOLATE** sequence and assessed its applicability under different policy, data and governance settings. The results confirm that the PHOEBE framework can be implemented as intended, using a combination of behavioural modelling, simulation, risk estimation and structured evaluation.

The broader PHOEBE framework is defined by a combination of analytical components and procedural steps. It integrates behaviourally informed transport demand modelling, scenario-based intervention logic, road safety risk profiling and network-wide impact extrapolation. The Use Cases confirmed that these components can be connected through shared data flows, common indicators and aligned modelling assumptions. They also demonstrated that outputs can be interpreted consistently, even when input data or intervention types vary.

WP4 supported the technical and procedural alignment of the framework. It tested how input data is transferred across components, how simulation outputs feed into safety and behavioural models, and how KPIs can be interpreted in relation to planning objectives. It also confirmed that the framework structure can support scenario comparison and policy evaluation, including assessments of safety outcomes, behavioural changes and modal shifts.

The activities in WP4 link the conceptual structure of the PHOEBE framework with its operational application. They confirm that the framework can support multi-criteria evaluation of interventions in realistic planning environments. The Use Cases demonstrated how the framework can be applied in cities with different planning approaches, institutional capacities and data conditions.

The integration achieved in WP4 reinforces the internal consistency of the PHOEBE framework and provides evidence that it can be scaled and transferred. The structure tested here supports the broader project objectives of developing a flexible, evidence-based approach to predictive safety assessment that is applicable across a range of urban contexts.

4.4 Insights for future Use Case design or policy

The results of WP4 highlight several considerations for designing future Use Cases and applying the PHOEBE framework in policy and planning contexts. These insights reflect both technical requirements and procedural conditions that influence the successful deployment of the methodology.

Future Use Cases should begin with a structured assessment of data availability and compatibility. The framework relies on behavioural, network, and safety-related inputs that must be calibrated to the local context while remaining consistent with PHOEBE model assumptions. Where primary behavioural data is not available, proxy variables or regionally transferable defaults should be clearly documented. Consistency in input structure supports cross-case comparability and improves the reliability of extrapolated results.

Intervention design should follow a logic that aligns with the **SELECT–SIMULATE–EVALUATE–EXTRAPOLATE** structure. Scenarios must be clearly defined in terms of physical measures, behavioural assumptions and expected modal impacts. Interventions that combine infrastructure changes with behavioural incentives (e.g. speed reduction and compliance monitoring) are well suited to the PHOEBE modelling architecture.

From a policy perspective, the framework is most effective when used to support multi-criteria evaluation across safety, mobility and environmental indicators. The cases demonstrated that the same intervention can produce different patterns of safety and modal outcomes depending on local context. Future applications should emphasise this interdependence and use the framework to test trade-offs between policy goals.

Stakeholder engagement should be embedded throughout the Use Case process. Input from local authorities and relevant user groups improves the realism of behavioural assumptions and helps interpret model outputs in terms of practical implementation. Feedback collected in WP4 also shows that early communication of the modelling structure and indicator logic improves confidence in results and supports local uptake.

In future rollouts, Use Cases may also serve as reference configurations for cities with similar profiles. A repository of standardised intervention types, input templates and example outputs could support this function. This would allow cities to adopt the framework more rapidly by building on previously tested structures.

Finally, future applications should account for institutional and procedural timelines. The PHOEBE framework can be aligned with existing planning cycles, but requires coordinated access to data, expert interpretation of results and capacity to integrate findings into decision-making. Use Cases should be selected not only for technical relevance but also for readiness to engage with the framework through the full evaluation cycle.

5 Conclusions and Recommendations

The PHOEBE framework demonstrations across Athens, Valencia, and the West Midlands have provided valuable insights into the design, implementation, and evaluation of the urban mobility interventions selected to pilot the framework in the three Use Cases.

Overall, the PHOEBE framework offers a replicable and scalable approach to improving urban mobility, safety, and sustainability, with the flexibility to adapt to diverse urban environments.

Summary of framework validation success

The PHOEBE framework was validated through the evaluation of Use Case results and structured feedback collected from local stakeholders. The validation process focused on the applicability of the methodology in real planning contexts, the consistency of model outputs, and the relevance of indicators used for assessing intervention impacts.

Results were reviewed with partners in each city to confirm the interpretability and usefulness of the outputs. Feedback from these sessions was used to assess the strengths and limitations of the approach and to identify aspects requiring further refinement.

The outcomes confirm that the framework is methodologically sound, adaptable to different local conditions, and suitable for further development.

Identified challenges and mitigation strategies

Several challenges were identified during the Use Case activities. These included differences in data availability and structure, limitations in the compatibility of local datasets with model requirements, and variations in institutional capacity to engage with model assumptions and outputs.

In cases where detailed behavioural or mode choice data were not available, proxy inputs or adjusted parameters were used in coordination with local partners. Differences in modelling capacity were addressed through iterative support and simplified reporting formats. Stakeholder feedback highlighted the need for clearer communication of assumptions, particularly in relation to output interpretation and policy relevance.

These challenges were addressed through local calibration, joint review sessions, and adjustments to indicator presentation. The experience will inform the preparation of technical guidelines and user support materials in the next phase of the project.

Recommendations for WP5 integration and future rollout

The experience from the three Use Cases provides a clear basis for the integration and system development activities planned in WP5. Several elements confirmed in WP4 should be carried forward and formalised, with attention to internal consistency, usability and transferability.

The structure of the framework should be further refined under Task 5.1. The Use Cases showed that the components can be combined in a consistent way, but that their interaction depends on clear input definitions and control parameters. WP5 should document the operational logic linking behavioural modelling, demand estimation, safety assessment and simulation, and define how these components are configured under different conditions.

Task 5.2 should expand the extrapolation methods used in WP4. The West Midlands case demonstrated how disaggregated model outputs can inform city-level impact estimates, including changes in FSIs and mode share. This approach should be developed further to support comparisons across intervention types and to produce socio-economic indicators relevant for policy and funding decisions.

Task 5.3 should ensure that the framework can be used in a modular form. The pilots showed that some cities focused on specific components depending on local needs and capacity. The final tool should allow users to apply selected elements of the framework without running the full process. This requires clear guidance on minimum data inputs, configuration dependencies and output limitations.

Task 5.4 should address the variability in input data observed across the pilots. Standardised input formats, variable definitions and quality checks are needed to ensure consistent outputs. Documentation should include data preparation instructions and validation steps that reflect the challenges reported in the Use Cases.

Task 5.5 should incorporate feedback on usability and result interpretation. Stakeholders across the Use Cases asked for clearer presentation of model results and indicators. The final version of the framework should include reporting templates, visualisation tools and user instructions that support both technical and non-technical users.

In preparation for wider rollout, WP5 will be preparing a set of transferability indicators based on the Use Cases in WP4. These can serve as starting points for new applications and provide tested configurations that support consistent implementation in other cities were no or few data are available, albeit with the limitations that arise when scaling and generalizing results.

Suggestions for additional Performance Indicators or evaluation methods

The existing Performance Indicators set includes changes in FSIs, iRAP star ratings, mode share shifts, delay metrics, travel time and exposure-based safety outcomes. These provided a strong technical baseline for evaluation in WP4. However, feedback from stakeholders during the Use Cases workshops, and the cross-Use Case comparison, highlighted specific limitations and areas for enrichment.

- Behavioural violation indicators

In Athens, 60% of stakeholders found the simulated behaviour only partially representative of real-world safety risks. Missing elements included illegal parking, two-wheeler filtering, and red-light violations. Future KPIs should include proxy indicators of risky behaviour, such as frequency of lateral conflicts, illegal manoeuvres, or near-miss events derived from video analytics or enhanced simulation logic.

- Perceived safety metrics

Athens and West Midlands workshops also pointed to a gap between measured safety and perceived safety, particularly among vulnerable road users. Participants suggested including qualitative metrics, such as post-intervention user confidence scores or perceived danger ratings from surveys. These could be integrated through optional survey modules or stated-preference proxies and would complement the predictive focus of the framework.

- Zone-level impact differentiation

Valencia and West Midlands reported contrasting effects across network segments, including improvements in intervention zones and deterioration in neighbouring ones (e.g. pedestrian node risk increased in Scenario 4 in Valencia). Disaggregated KPIs by corridor or administrative area are needed to detect localized trade-offs, and should be integrated in the default output structure.

- Equity-sensitive KPIs

In all three cities, stakeholder feedback noted that aggregated results often obscure differences by user group. In Athens and West Midlands, lower micromobility uptake among older users and women was highlighted. Mode shift and safety indicators disaggregated by age and gender should be included as standard, using demographic segmentation already available in the modelling structure.

- Policy-aligned socio-economic indicators

While FSIs are a central metric, stakeholders also requested output formats better suited to policy translation. These include FSIs avoided per 100,000 trips, monetised safety benefits using standard values of statistical life (VSL), and comparisons with regulatory thresholds. These formats would support project appraisal and alignment with EU and national funding frameworks.

- Dynamic KPIs for implementation tracking

Stakeholders in West Midlands expressed interest in using PHOEBE outputs to support adaptive planning and ongoing intervention monitoring. KPIs based on short-term projections or real-time inputs (e.g. weekly forecast of speed violations, dynamic pedestrian exposure) could extend the use of the framework beyond scenario evaluation towards implementation support. These additions should be considered in WP5 as optional modules, with clear input requirements and output formats. Templates, thresholds, and reference values will be needed to ensure comparability and clarity across Use Cases.

A. Annex

Athens Location of interventions

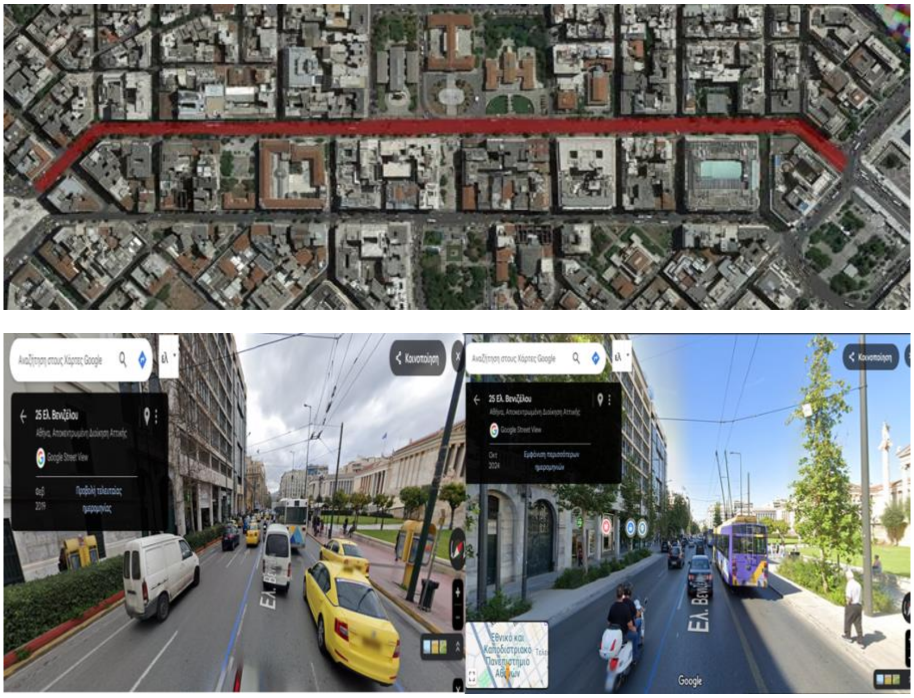

Figure A-1 Athens Interventions: Panepistimou Street (Before and after)

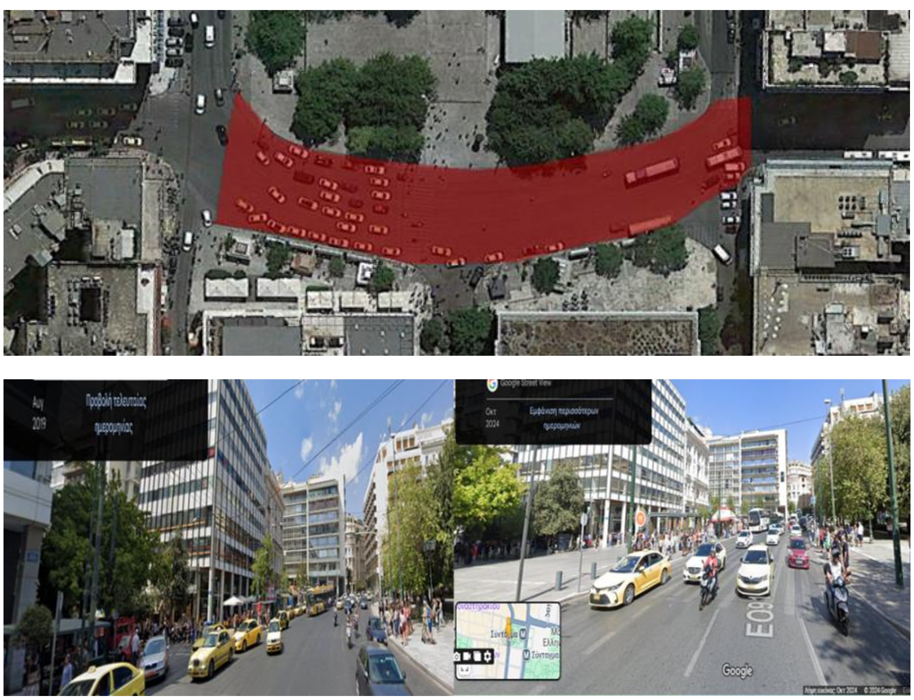

Figure A-2 Athens Interventions: Syntagma Square (Before and after)

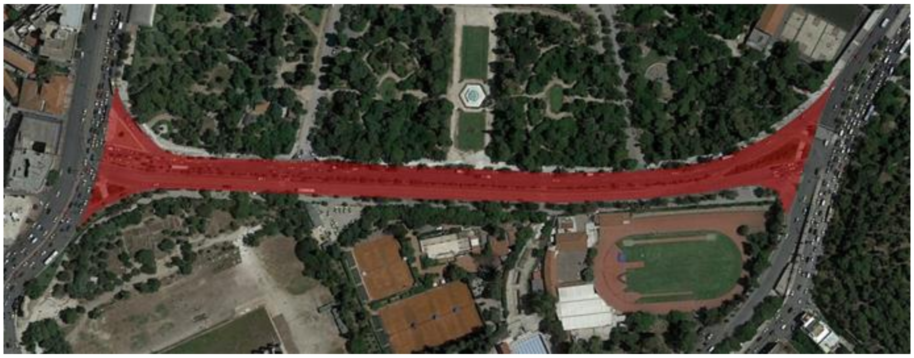

Figure A-3 Athens Interventions: Vasilissis Olgas Avenue

Figure A-4 Athens Interventions: Ermou Street

Athens Feedback Results

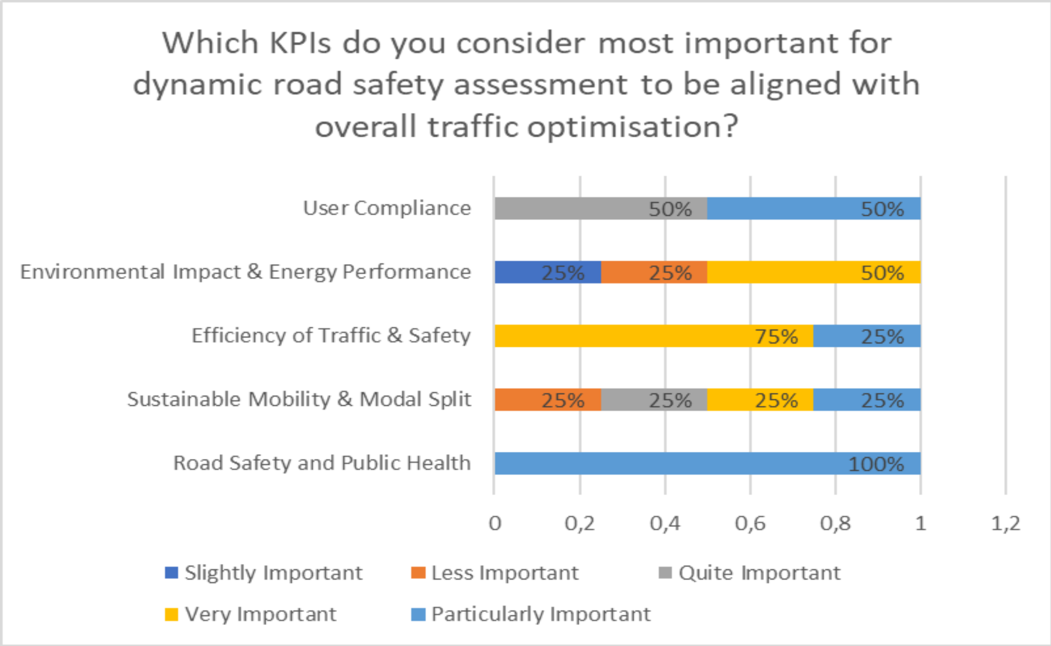

Figure A-5 Athens stakeholders 'feedback on balancing road safety and traffic optimisation

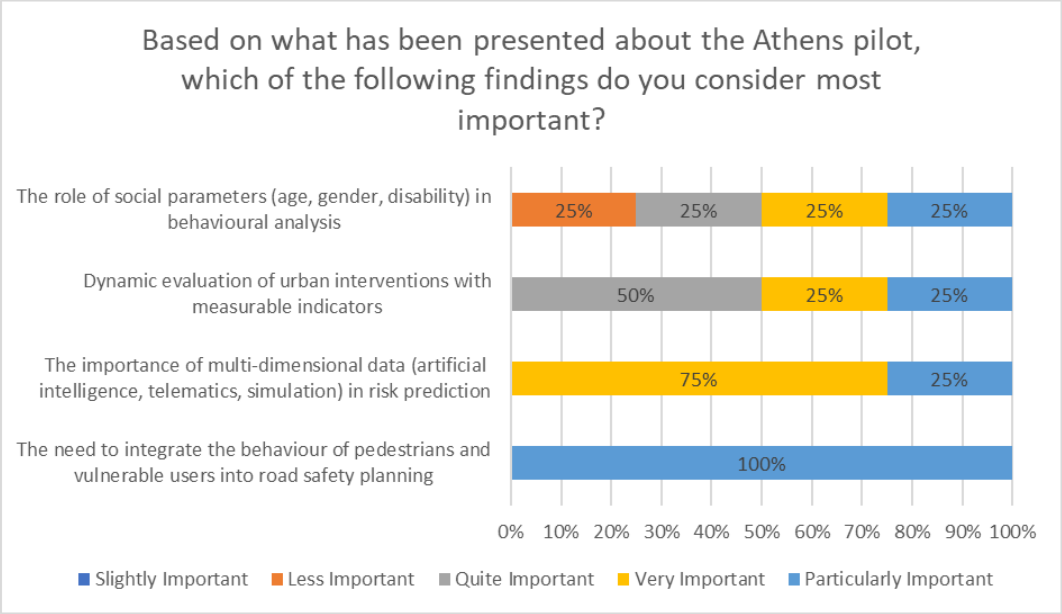

Figure A-6 Athens stakeholders 'feedback on most important findings

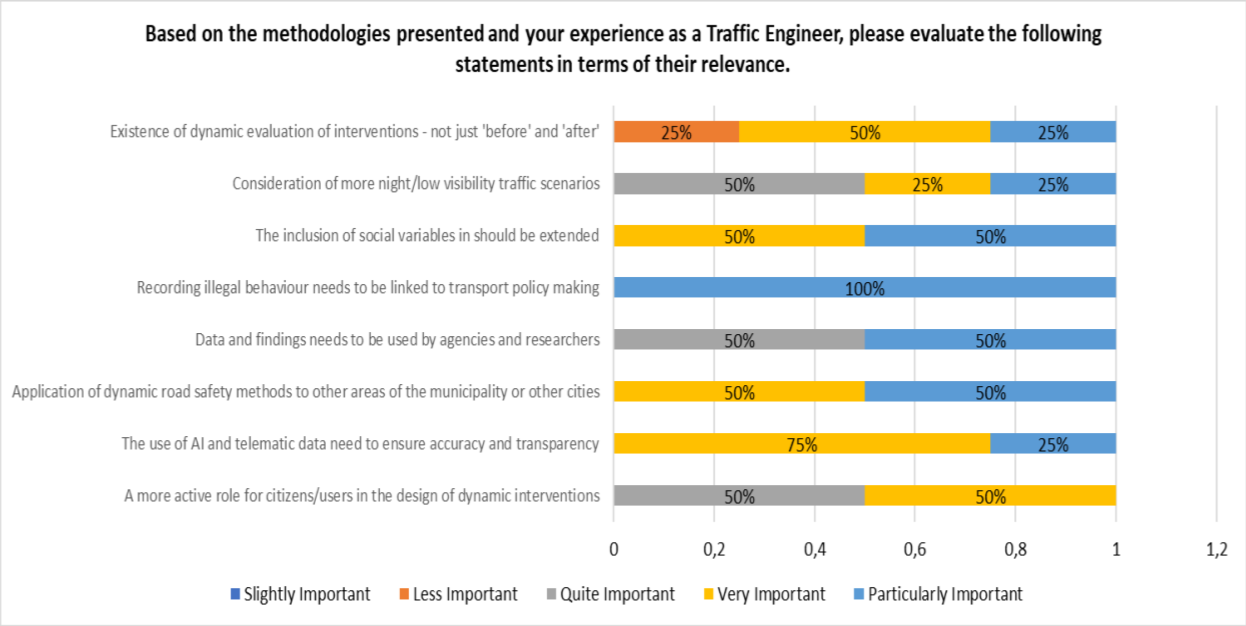

Figure A-7 Athens stakeholders' feedback on importance of PHOEBE elements

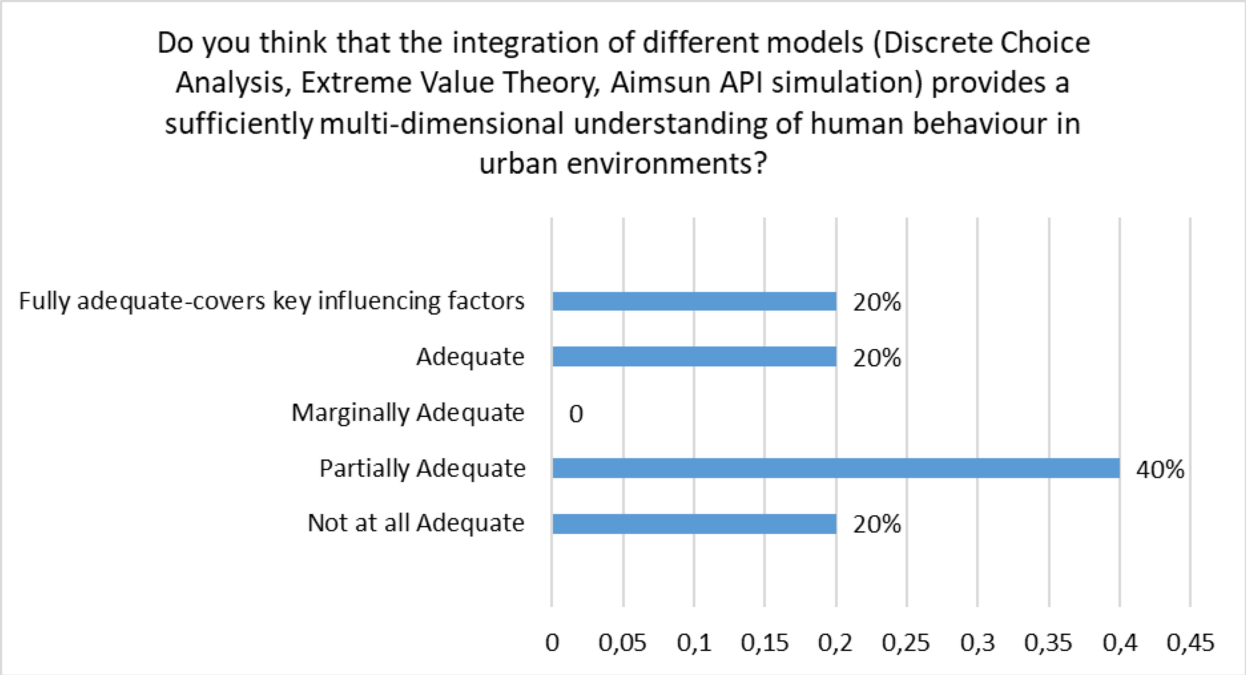

Figure A-8 Athens stakeholders 'feedback on multi-dimensional understanding of human behaviour

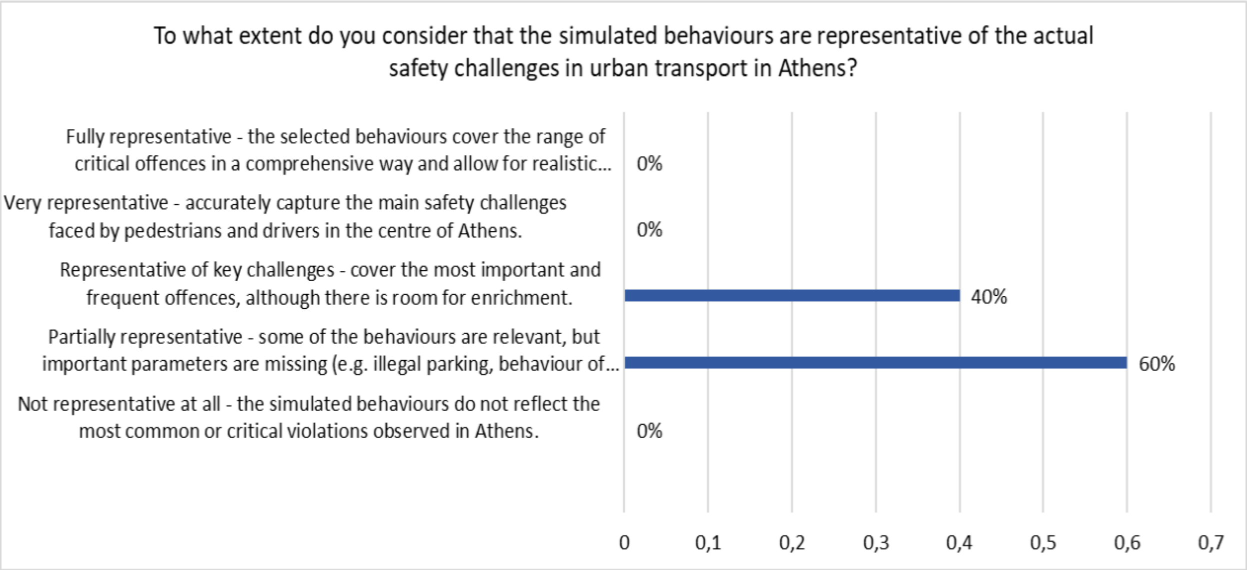

Figure A-9 Athens stakeholders' feedback on simulated behaviours

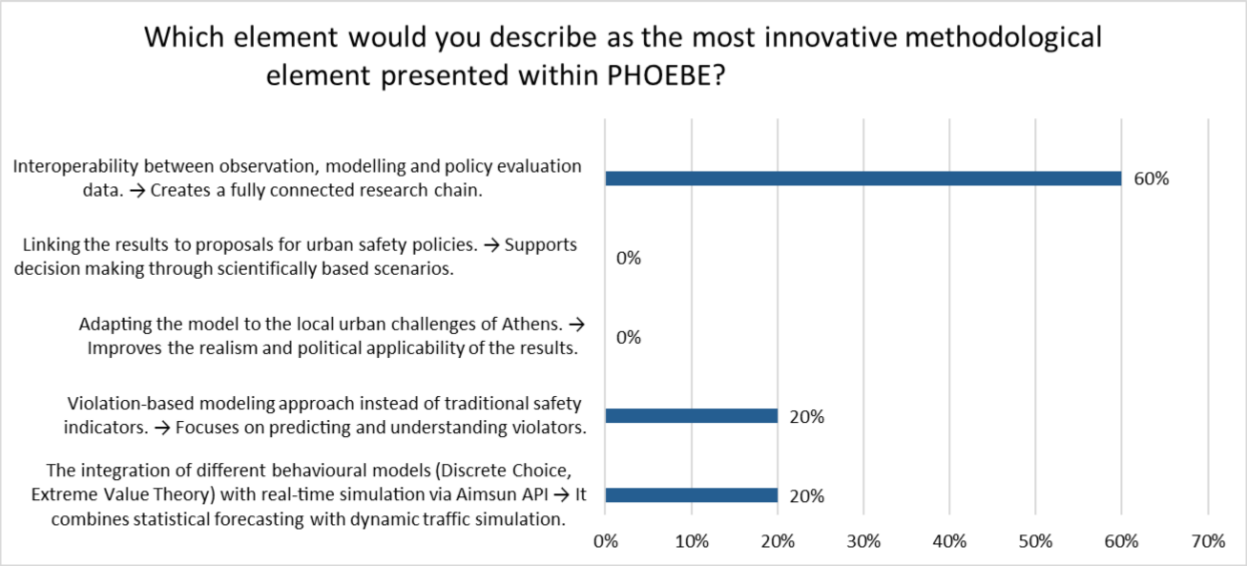

Figure A-10 Athens stakeholders 'feedback on innovation

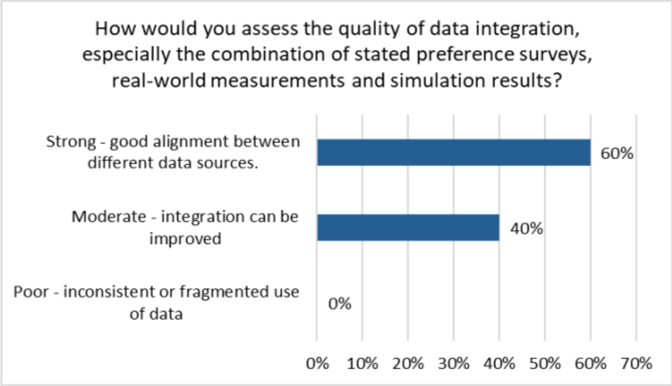

Figure A-11 Athens stakeholders 'feedback on integration

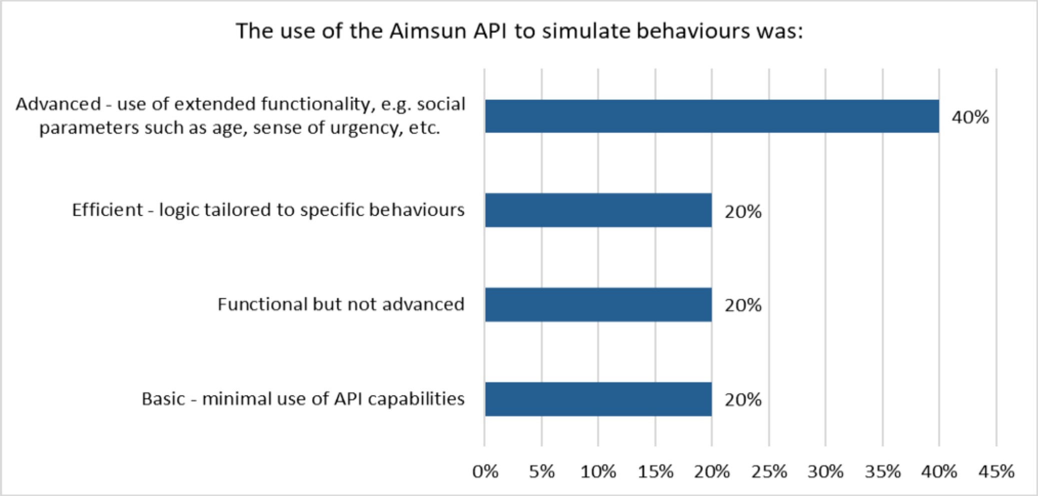

Figure A-12 Athens stkaholders' feedback on integration

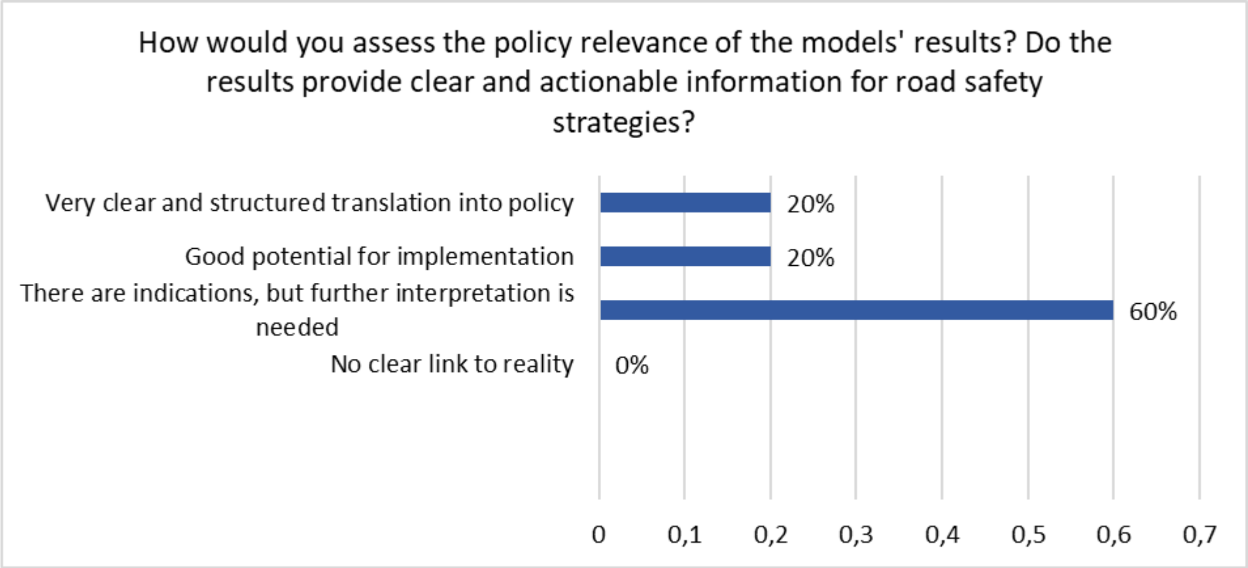

Figure A-13 Athens stakeholders' feedback on relevance of model results

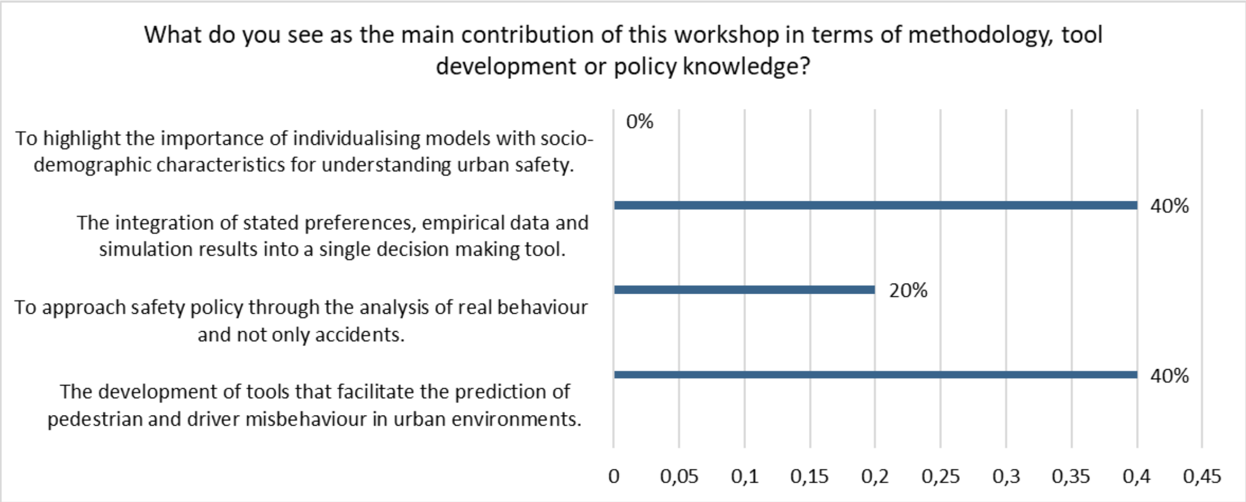

Figure A-14 Athens stakeholders' feedback on workshop contributions

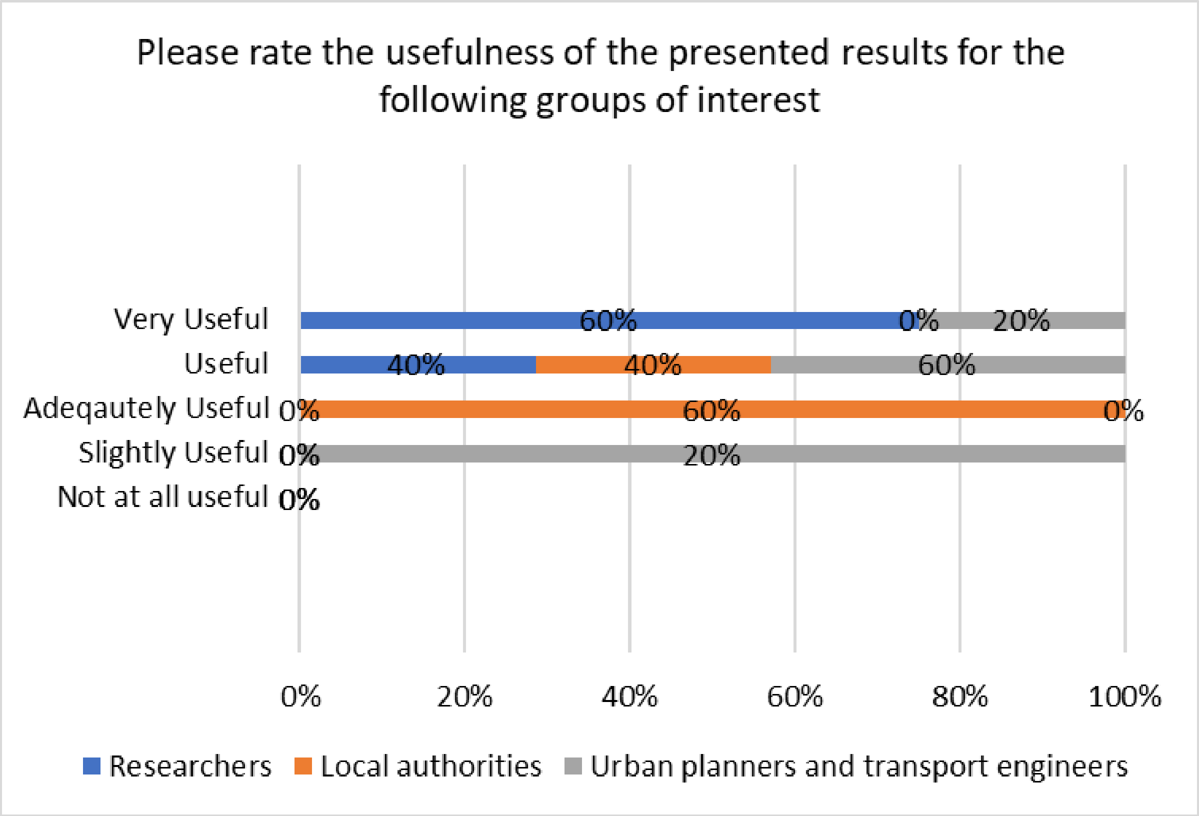

Figure A-15 Athens stakeholders' feedback on usefulness of presented results