TANGENT

ASSESSMENT OF THE TESTING RESULTS IN THE CASE STUDY OF ATHENS

D7.6

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Executive summary

Athens is the capital of Greece and of the Attica region, as well as the largest city of Greece, and is one of the largest economic hubs in Southern Europe. The population of the wider metropolitan area of Athens is approximately four (4) million inhabitants, making Athens the eighth largest urban area in the European Union. The Municipality of Athens (Athens city centre) has a population of more than 600000 inhabitants and a land area of more than 38 km2. Due to the high density of the population, Athens faces severe congestion problems due to the rising demand for car trips and the lack of coordination between modes.

As a Case Study in TANGENT project, Athens focused on identifying the efficiency of network-wide Traffic Management Strategies towards overall better performance of the operation of the network. Three (3) TANGENT services have been applied in the Case Study of Athens. Service 1 deals with demand prediction and Anomaly detection in multi-sourced traffic data. Service 2 deals with optimising the operation of public transport, as well as with investigating the importance of connected vehicles in network wide traffic management. Finally, Service 3 leads to the application of network wide Traffic Management Strategies in predefined scenarios in the Case Study of Athens.

The investigation of the TANGENT Services, and the accompanied subsystems, allows for proving the importance of network wide Traffic Management Strategies in both improving the operational performance of urban transport networks, and mitigating the impacts of planned and unplanned disturbances in the operation of urban transport networks.

The remainder of this Deliverable is structured as follows: Section 1 introduces the present Deliverable. Section 2 acts as a description of the Case Study of Athens. There, the reference network the baseline scenario, the unplanned event, and the planned event are described. Additionally, there is a short description of the TANGENT Services and the accompanied subsystems evaluated in the framework of the Case Study of Athens. In Section 3, the testing of the subsystems is further investigated and described. Finally, Section 4 provides some lessons learned and Section 5 includes the concluding remarks of the present Deliverable.

Keywords

Network wide Traffic Management Strategies, Traffic Simulation, Demand Prediction, Anomaly Detection, Multimodality, Collaboration

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List of abbreviations and acronyms

Acronym	Meaning
API	Application Programming Interface
BPMN	Business Process Model and Notation
CAVs	Connected and Automated Vehicles
COD	Computer Optimised Design
DCP	Dynamic Congestion Pricing
DRT	Demand Responsive Transit
IDM	Intelligent Driver Model
KCONG	Knowledge Catalogue and Governance
KPI	Key Performance Indicator
MAE	Mean Absolute Error
MTGNN	Multi-Temporal Graph Neural Network
NTUA	National Technical University of Athens
OD	Origin-Destination
PPS	Planned and Predicted Scenario
PT	Public Transport
PTTC	Public Transport and Traffic Control
RDF	Resource Description Framework
SCS	Stakeholder Cooperation Survey
SMAPE	Symmetric Mean Absolute Percentage Error
SNLB	Smart Network Load Balance
SVCC	Signal Vehicle Coupled Control
TANGENT	Transport And Next Generation Efficient Network Tools
TBS	Travel Behaviour Survey
TMB	TANGENT Management Board
WP	Work Package

1 Introduction

1.1 Attainment of the objectives and explanation of deviations

The main objective of this deliverable is to present the results of TANGENT for the Case Study of Athens. In line with WP7 “FUTURE TRANSPORT CASE STUDIES,” this document primarily addresses the outcomes of Tasks 7.1 “Definition of Case Studies, stakeholders’ engagement and tests preparation,” and 7.2 “Operation of the tests: testing of subsystems”, as documented in the relevant Deliverables (Deliverable 7.1 “Definition of the Case Studies, testing methodology and stakeholders' & users' engagement campaign” and Deliverable 7.2 “System deployment and testing specifications.”). These documents outlined the Case Study of Athens, including its requirements, testing environment, and the scenarios under which the tests would be conducted.

Specifically, this deliverable presents the results of the simulated experiments conducted in the framework of the Case Study of Athens for the three key Services of TANGENT project, assessed under baseline, unplanned, and planned event scenarios. The selected unplanned and planned event scenarios include a network wide disturbance and a known closure of a major road in the city centre of Athens respectively.

1.2 Intended audience

This deliverable is public. First, it can be retained, reused, and disseminated by the National Technical University of Athens to exploit the results of the TANGENT project. It can also be consulted by local stakeholders involved in the project’s workshops, demonstrations, and tests, even if they are not part of the consortium. More broadly, this deliverable can be accessed by any interested party, including stakeholders involved in traffic and transport management, technology providers, other metropolitan areas or transport operators, researchers, or those engaged in other R&D projects.

1.3 Links with other work packages/deliverables

Deliverable 7.6 is linked to other work packages and deliverables:

- Within Work Package 7, this document relates to Deliverable 7.1 “Definition of the Case Studies, Testing Methodology, and Stakeholders' & Users' Engagement Campaign” and Deliverable 7.2 “System Deployment and Testing Specifications”, which outlined the case study and its requirements. It is also linked to Deliverable 7.3, 7.4, and 7.5, as some methodologies and testing activities were shared across case studies. Additionally, Deliverable 7.7 provides an impact assessment, including the analysis of the KPIs for the Case Study of Athens.
- This document is linked to Work Packages 4 and 5, as the Case Study of Athens has been used as a testbed for applying all the Services developed in the framework of the TANGENT project.

2 Presentation of the Case Study of Athens

Athens is the capital of Greece and of the Attica region, as well as the largest city of Greece. With its urban area's population numbering over three and a quarter million, it is the eighth largest urban area in the European Union. The Municipality of Athens (Athens city centre), which constitutes a small administrative unit of the entire urban area, had a population of 643,452 (according to the 2021 Census) [1] within its official limits, and a land area of 38.96 km2.

In the framework of the Case Study of Athens, the "Athens testbed" has been used, which is developed and maintained by the National Technical University of Athens. Athens testbed includes the inner ring urban transport network of the city of Athens in a custom-made hybrid model as both a macroscopic travel demand model for the larger metropolitan area of Athens, as well as a microscopic traffic simulation model for the Athens inner-ring urban transportation network. Concerning the size of the Athens Testbed, it consists of 1,293 intersections and 2,572 sections. Demand-wise, during the morning peak hour (08:00 – 09:00) approximately 60,000 vehicles are inserted in the network. In Figure *1*, an illustration of the Athens Testbed is presented.

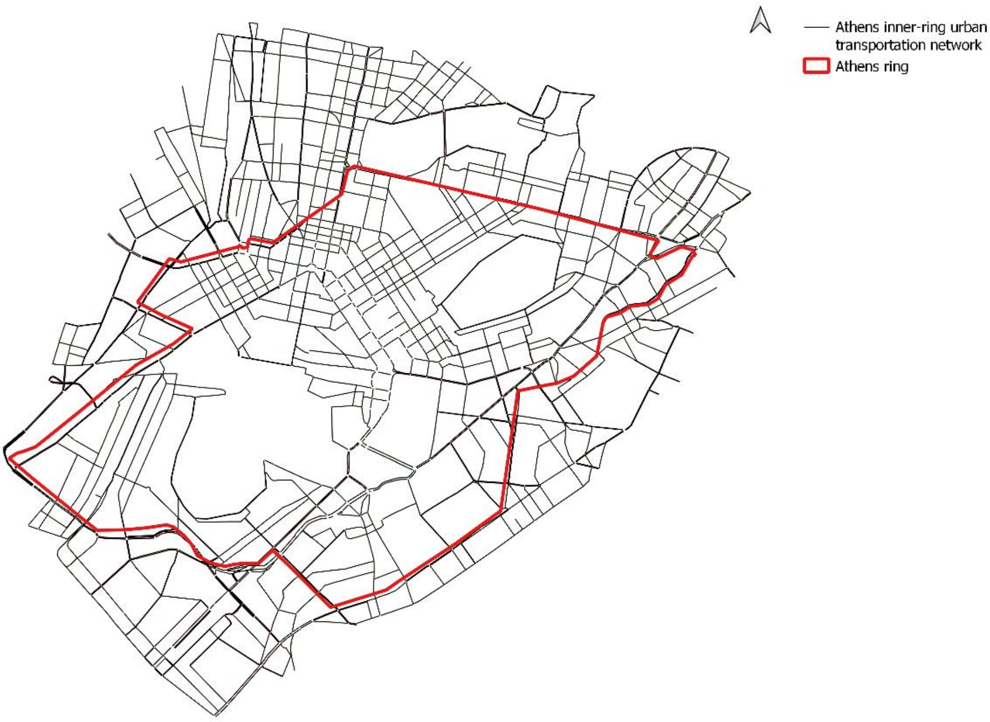


Figure 1: The Athens Testbed

In addition to the above, the major traffic infrastructure of the inner-ring urban transportation network of Athens is incorporated into the Athens Testbed. These include a total of 623 traffic lights that currently operate under a fixed control plan, 256 loop detectors, and 948 bus stops. This is illustrated in Figure 2.

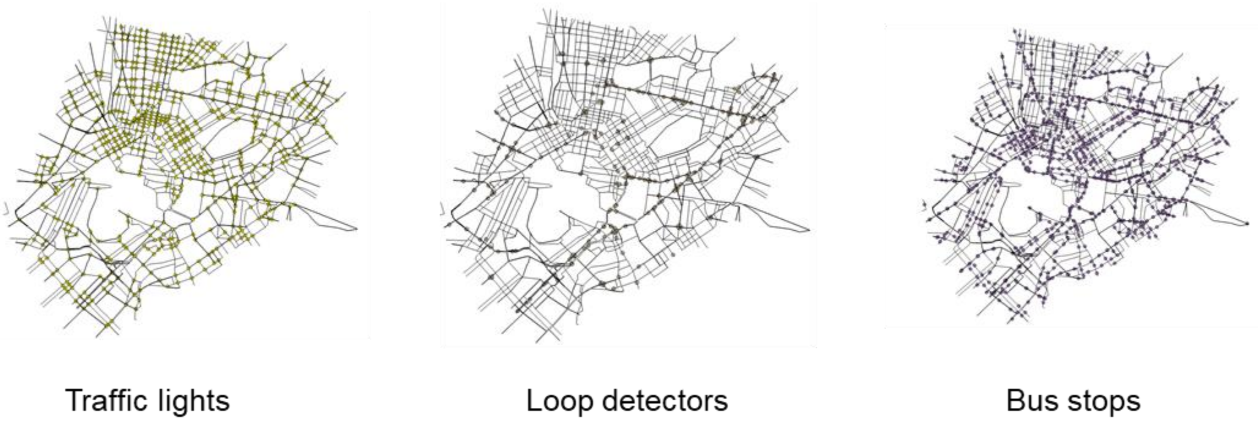


Figure 2: Transport infrastructure included in the Athens Testbed

Said priorities for the Case Study of Athens are: 1) to improve network connectivity, and 2) to reduce congestion. The priorities are to be met after forming the proper scenarios and implementing the subsystems developed in the framework of the TANGENT project. The nature of the Case Study of Athens as a simulated environment allows for selecting scenarios which refer to both planned and/or unplanned events. In the following Sections, the formulated scenarios are defined.

2.1 Baseline scenario

As mentioned in previous Deliverables (Deliverables 7.1 [2] and 7.2 [3]), both morning and afternoon peak hours are to be investigated in the Case Study of Athens. Therefore, two (2) baseline scenarios for morning and afternoon peak hours under normal uninterrupted operation of the network are formed. Additionally, and to be able to examine the efficiency of the methodologies applied in the Case Study of Athens, two (2) more baseline scenarios for morning and afternoon peak hours, in the case of the planned events that were examined, were formed. In order for the realistic conditions occurred in the urban transport network of Athens to be simulated in the framework of the present Task, the Athens testbed is calibrated and validated with 2023 hourly traffic data (counts and speeds) from a network of over 300 loop detectors.

The aforementioned baseline scenarios form the basis in which all the simulated experiments are compared to, proving the efficiency and the importance of the applied network-wide Traffic Management Strategies

2.2 Unplanned Event

For the unplanned event, a time period with a known disturbance, the week of 11/09/2023 - 17/09/2023 has been selected, as heavy rainfalls and flooding events occurred in the wider metropolitan area of Athens. In both cases, morning peak (06:00 – 11:00 A.M.) and afternoon peak (13:00 – 18:00 P.M.) hours loop detectors data have been collected, pre-processed, and analysed. Afterwards, the data have been imported in the Athens testbed and new hourly OD matrices have been adjusted. In Figure 3, the sections affected by the planned event are illustrated.

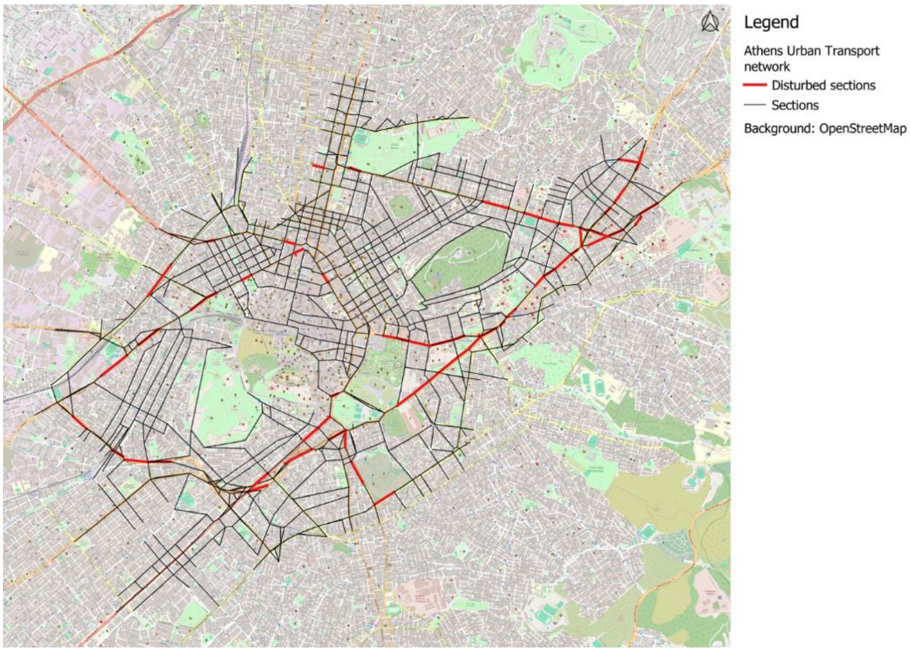


Figure 3: Sections affected in the Athens testbed by the unplanned event (illustration derived from Deliverable 4.6 [4])

2.3 Planned Event

In the framework of the present Task, the closure of a major urban road in the Athens city centre is investigated. This is illustrated in Figure *4*.

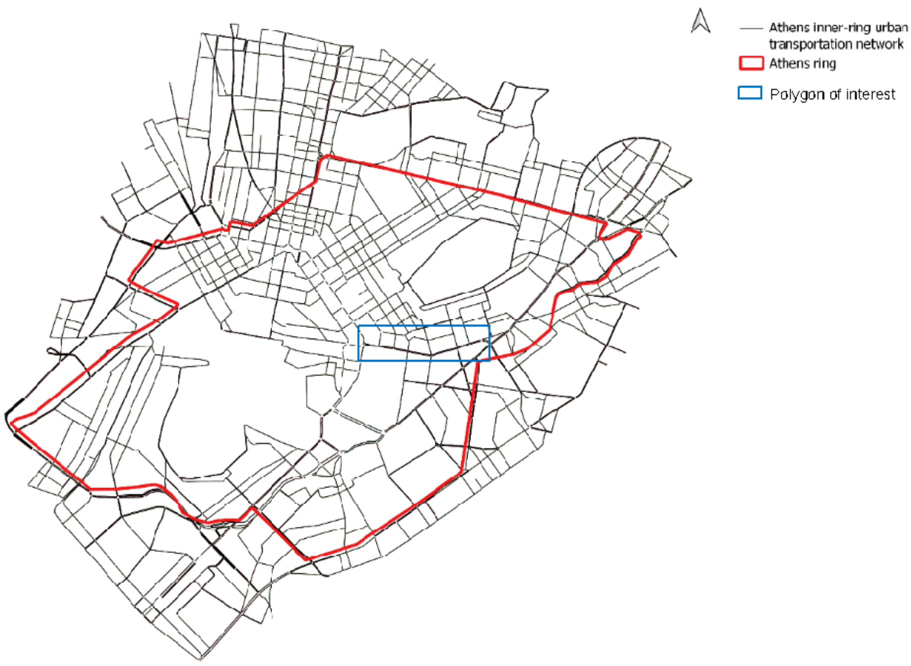


Figure 4: Polygon of interest, which includes the major road of Athens testbed affected by the planned event

Concerning the road closure, Variable Messages Signs were placed in the neighbouring to the event sections. The Variable Messages Signs inform the vehicles that are going to use the affected sections for the event and optimally, through a stochastic route choice process, assign new routes to them to reach their final destinations.

2.4 TANGENT Tools and Services Applied in the Case Study of Athens

Below, the TANGENT Tools and Services examined in the framework of the Case Study of Athens are briefly presented:

Service 1 - Future Status: Service 1 refers to the design and application of both the Demand Prediction and the Anomaly Detection subsystems, developed in the framework of Work Package 4 of the TANGENT project. Service 1 is applied in the case of the unplanned event mentioned above.

Service 2 – Cooperative Incident Management (CIM): For this subservice of Service 2, both the Synchronisation of Demand Responsive Transit with Public Transport (DRT-PT) and the Synchronisation of Public Transport and Traffic Control (PTTC) subsystems developed in the framework of Work Package 5 of the TANGENT project are further investigated.

Service 2 – Smart Network Load Balance (SNLB): The second subservice of Service 2 is investigated in the framework of the Case Study of Athens by applying the Signal Vehicle Coupled Control (SVCC) subsystem, developed in the framework of Work Package 5 of the TANGENT project, in the Athens testbed. This subservice of Service 2 is applied in baseline scenarios, as well as in the case of the planned event.

Service 3 - Simulation of Pre-defined Scenarios: The application of the Dynamic Congestion Pricing (DCP) subsystem is investigated in the framework of this specific system. DCP has been developed in the framework of Work Package 5 of the TANGENT project and is applied only in the case of the normal uninterrupted operation of the network.

The Key Performance Indicators associated with the Case Study of Athens are addressed in Deliverable 7.7.

3 Testing of the subsystems

This section describes the testing activities carried out during Task 7.2 *"Operation of the Tests: Testing of Subsystems"*, in collaboration with the technical partners and the first release of their subsystems. The methodology follows an *"Applied Learning Cycle"*: after the technical partners developed the subsystems, they shared the necessary scripts to be integrated and tested in the Athens testbed.

In the following sections, the process of testing the efficiency of the subsystems mentioned above is described. It is worth noting that these subsections do not necessarily follow the structure of the relevant Deliverables for the other non-virtual case studies. This is due to the nature of the Case Study of Athens as a virtual one, meaning that in the majority of the cases solely simulated experiments have been executed in the Athens testbed.

3.1 Data harmonisation and fusion

The TANGENT Solution for Data Harmonisation and Fusion represents the subsystem developed within WP2 and integrated into the overall TANGENT solution. The first release of the solution is described in D2.3, and the final one, incorporating the feedback received during its testing, is in D2.4. The main components of the TANGENT Solution for Data Harmonisation and Fusion are:

- the TANGENT Data Catalogue: a digital platform enabling data-sharing among different stakeholders;
- the TANGENT Reference Conceptual Model: defining a reference ontology for the transportation-related data handled within TANGENT;
- the Semantic Harmonisation and Fusion Pipelines to fulfil the integration requirements associated with TANGENT data sources;
- the TANGENT Data API: a uniform mechanism to access data sources collected and harmonised by WP2.

The testing of the WP2 subsystem mainly focused on the TANGENT Data Catalogue, which provides a user interface designed to be directly accessible by relevant stakeholders. The testing of the other components has been performed (i) with TANGENT partners from a technical perspective to enable the integration of the different subsystems and (ii) indirectly by stakeholders involved in the testing of other subsystems integrated with the WP2 solution.

The TANGENT Data Catalogue is developed using the Knowledge Catalog and Governance (KCONG) framework by Cefriel. KCONG provides a customizable platform for defining and managing digital asset catalogues, accessible online via a web browser. It supports various digital asset types, each characterized by specific metadata descriptors for user interaction. KCONG allows programmatic access to the list of assets and their metadata, which can be serialized in RDF for advanced querying and automated processing. It also enables the configuration of governance processes for digital assets using the BPMN formalism.

For the TANGENT Data Catalogue, a customized KCONG instance includes:

- organization of digital assets based on TANGENT case studies;
- a Data Source asset type to describe datasets and data services, adhering to the TangentDCAT-AP metadata specification (see D2.2);

- integration of BPMN processes to support TANGENT Data-Sharing Governance rules (see D2.2).

3.1.1 Methodology

The methodology for the TANGENT Data Catalogue considered two distinct types of testing.

The first type involves gathering feedback on the initial version of the TANGENT Data Catalogue. This feedback-driven testing aims to identify areas for improvement to ensure the second and final release of the TANGENT Data Catalogue meets users' requirements. Given that the TANGENT Data Catalogue is a software artefact used uniformly by project partners, the feedback gathered through its testing methodology is not specific to any single use case. Instead, we collected and analysed anonymous data from all participating partners across use cases to obtain a comprehensive assessment of the catalogue's usability and functionality. By analysing this feedback, we identified common issues and areas for improvement that were used to enhance the overall user experience in the final release of the WP2 solution described in D2.4.

The second type of testing focuses on the catalogue's practical usage within the project. This in-project testing evaluates how effectively the TANGENT Data Catalogue serves its intended purpose in real-world scenarios, ensuring its functionality aligns with the users' needs and expectations.

User testing of the TANGENT Data Catalogue

The first version of the TANGENT Data Catalogue, documented in D2.3, was released to partners at M20. To gather opinions and feedback from real users of the catalogue, we designed a set of practical hands-on tasks to be performed by partners on the first version of the Data Catalogue as testing activities within WP7. This testing activity took place from 24th July to 6th September 2023. For the Lisbon case study, CARRIS partners from Lisbon were involved.

Users were introduced to the platform by a short video tutorial explaining the basics of the TANGENT Data Catalogue. Then the users were asked to perform a set of tasks to test the catalogue's intended usage and functionalities. As an immediate follow-up to these tasks, users were asked to respond to a survey to collect explicit and implicit feedback. To improve the quality of the feedback received the survey was made anonymous. Explicit feedback was provided by users in the form of a free text response to an open-ended question. Implicit feedback was collected by asking closed questions related to one of the steps required to complete a task. For instance, if a user provides an incorrect answer to a closed question, it could suggest that the user finds the catalogue’s usage unclear, serving as implicit feedback.

A slightly different set of tasks and accompanying surveys was prepared for case study leaders and other partners taking into account their expected usage of the catalogue. Indeed, case study leaders are expected to use the catalogue to add, edit and browse data sources, while the other users mainly browse available data sources. As such, the tasks and questionnaire were designed to reflect this difference.

As an example, here we discuss a task and the set of associated questions. This task was posed to both case study leaders and technical partners.

Task 1 - Search and analysis of a specific data source

Scenario:

Imagine you need to determine if there was a roadblock in a specific street in Rennes ten days ago. You are invited to check if the "REN_TRAF_11" data source satisfies your needs.

Your assignment is:

Please search the "REN_TRAF_11" data source in the data catalogue and read its metadata description to assess its relevance for addressing the need described in the above scenario.

Answers and follow-up questions:

Did you succeed in finding the REN_TRAF_11 data source?

- *Yes*
  - *Please, describe the steps you did to find the REN_TRAF_11 data source.*
  - *Based on the metadata description, do you think that REN_TRAF_11 data source can be used for addressing the need described in the above scenario? Please, justify your answer.*
- *No*
  - *Please describe any problems you encountered while searching for the data source.*

Through this question, several pieces of information can be gathered. By responding "Yes", we first establish that the user was able to perform the task correctly. The follow-up question then gathers details on how the user performed the task, specifically through which series of steps. This answer is crucial as it reveals whether the user was correctly guided through the intended user experience via the catalogue's user interface. If the user followed an unintended path to complete the task, we can use this information to redesign and improve the user experience. The next follow-up question aims to determine if the adopted metadata profile is clear to the user and if it can be used to solve a task that mirrors a potential real-world use case. The most important information is the one gathered when the user is not able to perform the task. This is crucial, as this information is the main driver for significant changes in the catalogue.

Case study (CS) users and other partners (OP) were assigned various tasks. CS users were given more tasks compared to OP users because they have a more active role in utilizing the catalogue, including adding and editing data sources. In contrast, OP users primarily engage in searching and browsing the catalogue. Feedback from both user groups was collected on the following tasks:

- Searching for a specific data source and analyze its metadata description (CS, OP)
- Searching for a data source that satisfies a specific data requirement (CS, OP)
- Free exploration of the data catalogue and usage of its functionalities (CS)
- Adding and publishing a new data source into the data catalogue (CS)
- Usage of the dashboard functionality to check the status of data sources (CS, OP)

The questions asked to users after these tasks were designed in the same spirit as the previously described task. Similarly, the answers to these questions were used in a similar vein to drive improvements to the catalogue.

In-project testing of the TANGENT Data Catalogue

The TANGENT Data Catalogue is designed to manage the diverse data sources collected from the project's four case studies. This catalogue is not merely a static repository of data and metadata, it is intended to serve as a dynamic, evolving archive that adapts to the project's needs. To facilitate this adaptability and support the project's potential developments, a life cycle has been established for the data sources. Each data source can exist in one of several states, transitioning between them based on specific user actions and conditions set by the TANGENT Data Catalogue Management Board (TMB). The TMB oversees the data quality and governance, ensuring the catalogue remains a robust and responsive tool throughout the project's duration. The list of admissible statuses is the following:

- *Submitted*: When a data source is inserted by a user into the catalogue.
- *Published*: When a data source is reviewed by the TMB and approved for publication.
- *Rejected*: When a data source is rejected after a review by the TMB because it is found to not be useful or applicable to the project.
- *Incomplete*: When a data source lacks certain required metadata fields that have not been filled out by the user. The data source is sent back to the user with a request for further information.
- *Not accessible*: A specific case of incomplete metadata where the data source description lacks the access URL to the actual data it describes.

Regarding the in-project testing activity, we report on the number of data sources collected through the TANGENT Data Catalogue and approved for usage within the TANGENT project for the Lisbon Case Study.

3.1.2 Actions achieved and results

In the following, we report the aggregated results obtained for the user testing of the TANGENT Data Catalogue and the results of the in-project testing for the Lisbon case study.

User testing of the TANGENT Data Catalogue

The user testing activity involved 14 partners acting as case study leaders and 9 other partners. From these groups, the survey aimed at gathering constructive feedback for the TANGENT data catalogue received responses from 9 out of 14 demo leaders and 3 out of 9 other partners. The testing activity was conducted using the first version of the TANGENT Data Catalogue, described in detail in D2.3 and shown in Figure *5*.

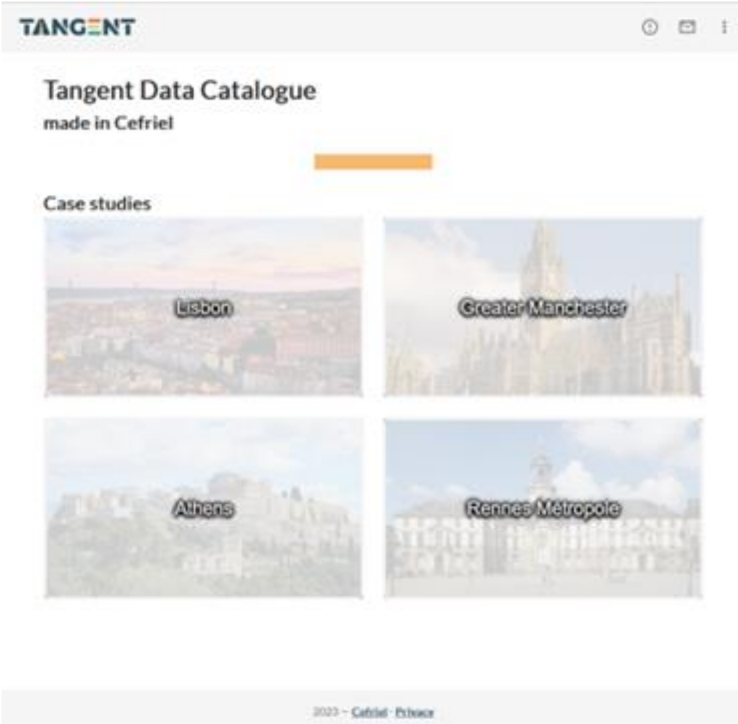


Figure 5: Homepage of the first version of the TANGENT Data Catalogue

After analysing the current survey responses on the testing of the TANGENT data catalogue, the main areas for improvement have been identified as follows:

1. **Search Capabilities and Interface**: Numerous feedbacks indicated the need for enhanced search functionality, specifically the ability to search by metadata attributes that are not currently available as filter options. Additionally, the filtering capabilities offered through the user interface could be made less confusing and more user-friendly.
2. **Dashboard Information and Interactivity**: The information displayed on the dashboard needs to be expanded and made more interactive. Users have expressed a desire for a more detailed and engaging dashboard experience.
3. **Action Feedback**: Certain actions, such as submitting a data source for publication, currently lack feedback mechanisms that inform the user of the action's result. Providing clear and immediate feedback for these actions would improve the overall user experience.

Based on the feedback we gathered, it became evident that a small but notable portion of users experienced difficulty in successfully completing one of the tasks associated with locating a specific data source. This feedback was collected through both quantitative and qualitative methods. Quantitatively, we measured how many users were able to find the data source. Qualitatively, we invited users to provide open-ended feedback detailing the challenges they faced during this task. This dual approach allowed us to capture not only the extent of the issue but also the specific problems encountered, offering a comprehensive understanding of the user experience and the obstacles they encountered. The answers received for task 2 serve as an excellent example of this quantitative aspect, as is shown in Figure 6.

Scenario: A project partner tells you that a data source satisfies the "WEATHER_DATA" data requirement for your case study.

Your assignment is: Try to find the data source in the data catalogue. Read its metadata description carefully.

Figure 6: On the left the percentage of case study leaders who completed task 2; on the right, the percentage for other partners

By addressing these issues, the final version of the TANGENT Data Catalogue improves upon the first release by introducing new functionalities and improving the user experience. For example, the homepage (Figure *7*) has been changed to show the latest uploaded data sources, which helps users know the latest changes in the catalogue. Additionally, because users often access the catalogue to search for a specific asset, a search box and corresponding search functionality have been added to the homepage (Figure *8*).

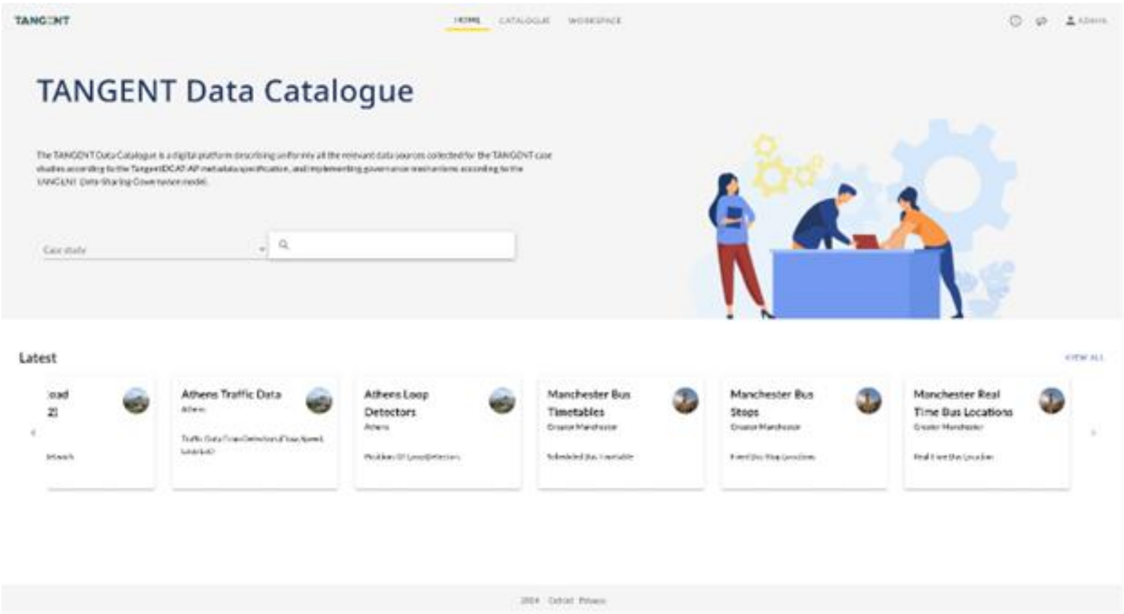


Figure 7: Homepage of the final version of the TANGENT Data Catalogue

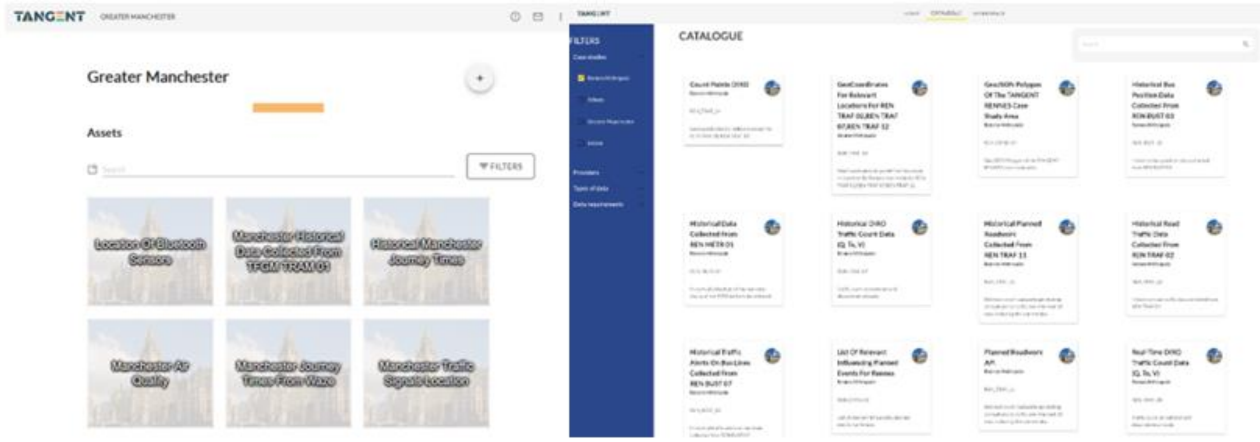


Figure 8: Search functionalities in the different versions of the Tangent Data Catalogue

A site-wide change has been made to separate different functionalities offered by the TANGENT Data Catalogue. As can be seen in the top part of Figure 7Figure 5, the final release of the catalogue is divided into three main areas: the home, the catalogue and the workspace. As previously described, the homepage is designed to bring the user up to date with the latest changes and offer the shortest possible path to one of the most common interactions with the catalogue, i.e., searching. The catalogue area, shown in Figure 8, allows the user to browse all the data sources available in the catalogue and perform more fine-grained searches. Indeed, as searching and filtering were identified as the main areas of interest during the testing of the first release of the data catalogue, the UI and UX for this functionality were particular points of focus. While the previous version of this page was found to be confusing to users, especially because it was not readily apparent what filters were currently active, the new and improved version clearly shows the active filters on the left side of the page and the used keyword in the search box. Additionally, with this layout, more results can be displayed, making it easier for users to manage searches that retrieve an extensive set of results. Lastly, the workspace area is entered when acting on a single data source or to access an overview of the state of the whole catalogue or the state of the data sources owned by the current user.

In-project testing of the TANGENT Data Catalogue

For the Athens use case, a total of 13 data sources were collected and submitted through the TANGENT Data Catalogue. After careful review and discussion with relevant project partners, the TANGENT Data Catalogue Management Board (TMB) determined that 2 of these data sources were not relevant and subsequently rejected them. Of the remaining data sources, 7 met the project's data quality requirements and were approved for use. Three data sources remained inaccessible and were not utilised by any partners.

3.2 Choice model for Synchronisation of Public transport and traffic control & Choice model for Dynamic Congestion Pricing

The principal output of WP3 is the travel choice module, an analytical tool for modelling travel decision-making under various mobility scenarios. The module, the development of which is thoroughly described in D3.2 and schematically described in Figure 9, builds upon input data elicited using the Travel Behavior Survey (TBS), a structured stated-preferences questionnaire that captures commuters' sociodemographic traits, travel patterns, perceptions of system-level attributes, and preferences for different travel options. At its output, the machine learning and econometric models at its core predict mode choice decisions and identify significant factors influencing commuter decisions.

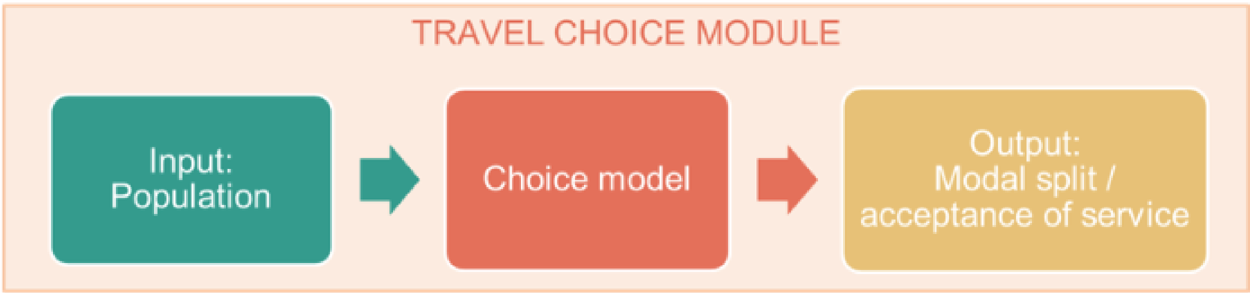


Figure 9: Travel Choice Module inputs & outputs

Given the design of the modelling framework, the testing of the module aims to ensure that all interface points between the module and the population whose behaviour is modelled fulfil expectations.

- Upstream, the survey's ability to effectively capture commuter behaviours must be assessed, best achieved through recipient feedback on its clarity, relevance, and effort needed.
- Downstream, it is necessary to evaluate whether the model's predictions align with common intuitions about travel behaviour in specific cities, with local commuters being again the most qualified evaluators.

As a result, a four-step testing methodology for the WP3 travel behaviour module is developed based on commuter feedback and presented in the sections that follow.

The collected user feedback is critically analysed, offering valuable insights for the development of similar mode choice modules. This methodology is further discussed in the section that follows. Given the consolidated testing process for all case studies, the sections that follow are virtually identical for D7.3/4/5/6.

3.2.1 Methodology

Step A: Testing sample collection

During the initial phase of testing, the Travel Behaviour Survey (TBS) was distributed to commuters from each case study city, including Athens. The objectives of this phase are to:

- Familiarise testers with the questionnaire's content and design by having them take the survey themselves.
- Provide the necessary data for executing the travel behaviour module (Step B).
- Obtain the contact points of testers (email addresses) for the distribution of the feedback survey of Step C.

The TBS questionnaire is included in the Annex of D3.2.

To collect the necessary sample, each case study was asked to identify 10 commuters from various age, gender, profession, and usual transport mode groups who had not taken the survey before. With their contact details, the testers were contacted by NTUA with instructions on how to complete the TBS.

Step B: Execution of the travel behaviour module

Following the collection of testers' responses, the mode choice models in the travel behaviour module were launched, and their predictions about the factors affecting mode choices were converted into simple, non-technical language. The text communicated to the testers is provided below.

One of the key advantages of the models that we have created is that they are able to reveal the factors that affect commuter's travel choices. Specifically, we have found that:

- *The probability to use a private car over public transport is higher among younger commuters and among commuters with higher incomes.*
- *Increased satisfaction with the public transit system correlates with a higher likelihood of choosing public transportation over a private car.*
- *Rising costs and extended travel times, whether for cars or public transport, diminish the appeal of these modes, leading to a shift towards alternative travel options.*

Step C: Feedback Survey

As an immediate follow-up to these tasks, users were asked to complete a second feedback survey to assess the clarity, interpretability, and intuitiveness of the questions, the time and effort necessary to complete the TBS, and opinions on whether the modelling insights are deemed logical and in line with the testers' expectations.

The survey contained 10 questions, with an estimated completion time of 5 minutes. To ensure honesty in the responses, the survey was anonymous. With the contact details from Phase A, NTUA directly disseminated the feedback survey from 14/02/2024 to 19/02/2024.

Tester feedback was collected using closed questions with predetermined, multiple-choice or scale-based answers. The first question of the questionnaire is provided as an example below (Figure *10*).

Figure 10: On a scale of 1 to 5, how easy was it to understand the purpose of the questionnaire?

For specific questions requiring in-depth, qualitative insights that closed-ended questions could not capture, respondents were requested to provide their answers in a free text format to an open-ended question, as illustrated below (Figure *11*).

Can you point out some of the questions that you found confusing or ambiguous?

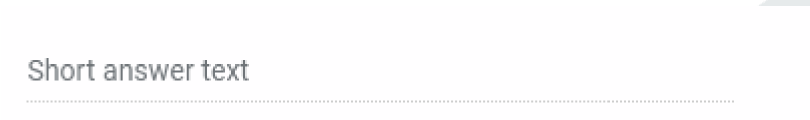


Figure 11: Free text format for open-ended questions

Step D: Reporting on the results

The feedback collected during the testing is presented in the "Results" section that follows. Partial results have also been presented internally to the consortium during the WP7 bi-weekly meetings dedicated to subsystem testing and the consortium's monthly audio meetings.

3.2.2 Actions achieved and results

A total of 42 commuters from all case studies have been contacted by case study leaders and NTUA, out of which 11 have responded to the feedback survey. Their responses are pooled together, translated into English and analysed below on a question-by-question basis.

Initially, respondents were asked to evaluate how easy it was to understand the purpose of the questionnaire (Figure *12*), rating their experience on a scale from 1 (not clear at all) to 5 (very clear). The majority (81.9%) evaluated their understanding as either 4 or 5, suggesting the effectiveness of the introductory materials and instructions provided with the questionnaire.

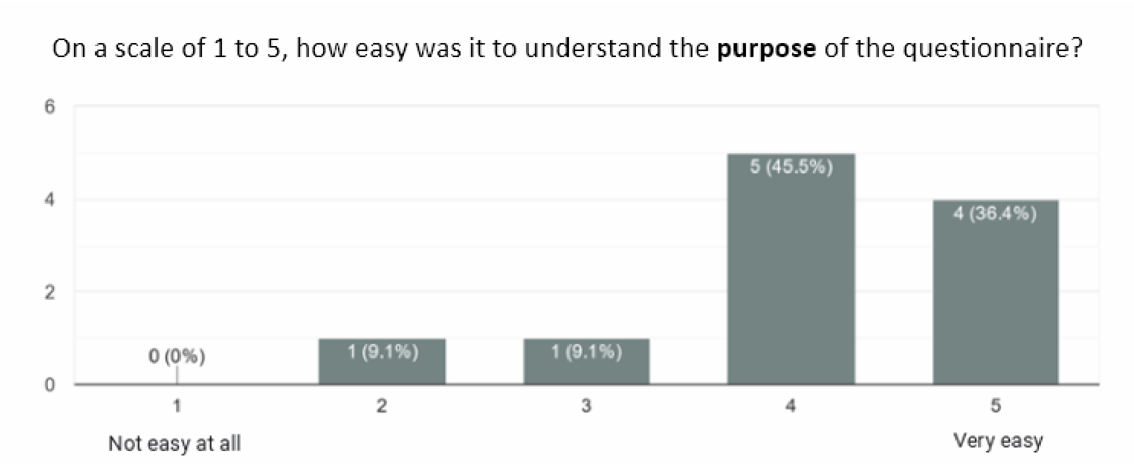


Figure 12: On a scale of 1 to 5, how easy was it to understand the purpose of the questionnaire?

This good understanding of the overall questionnaire can also be attributed to its questions being clear and intuitive. In the relevant question (Figure *13*), where an evaluation of 1 suggests that questions were not clear at all and an evaluation of 5 suggests that questions were very clear, the majority of respondents (63.7%) responded with 4 or 5, while respondents (27.3%) found the questions to be moderately clear by selecting "3".

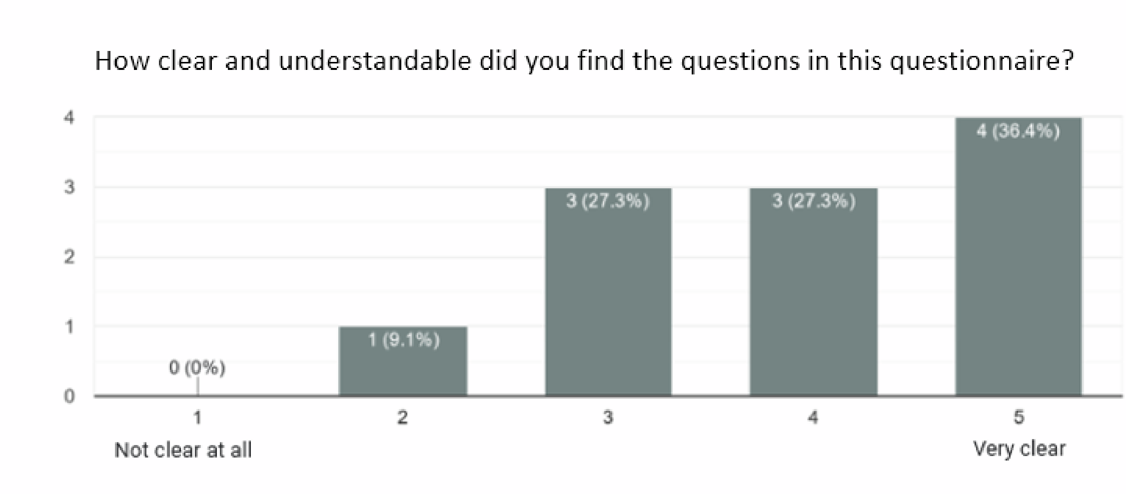


Figure 13: How clear and understandable did you find the questions in this questionnaire?

Two comments were also received in response to the open-ended question on how the overall clarity of the questionnaire can be improved. One respondent suggested the inclusion of a working-from-home option, and a second one suggested that the scale of some questions was somewhat unclear. This feedback can be attributed to Google Forms' practice of providing linguistic interpretations only for the extreme values (1 and 5), leaving the middle scale values as numbers, which can result in some ambiguity.

On a follow-up question of whether the TBS questions were in-context, the vast majority of respondents (81.8%) found all the questions to be relevant, suggesting that the survey was contextually appropriate (Figure *14*).

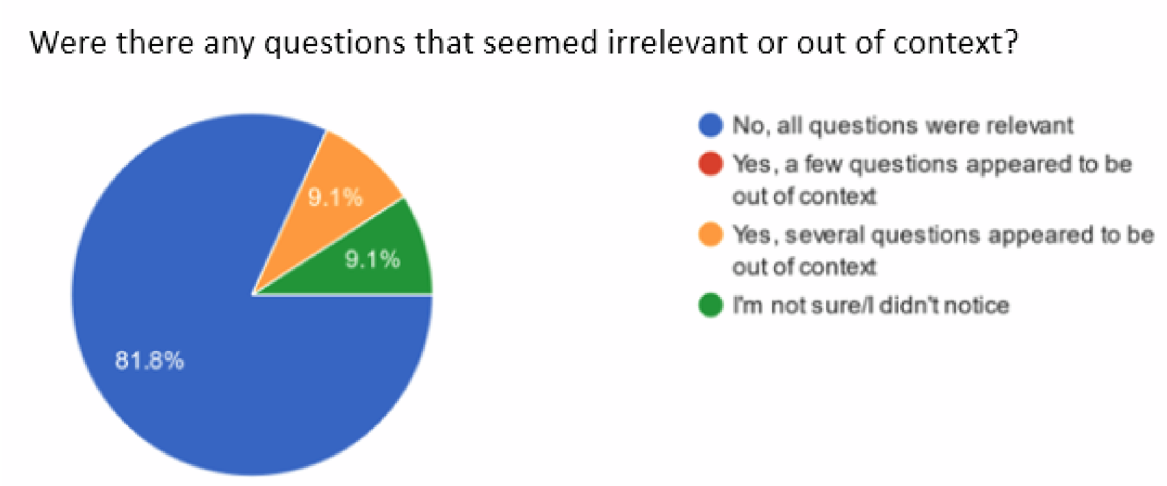


Figure 14: Were there any questions that seemed irrelevant or out of context?

On the overall layout and formatting of the questionnaire (Figure *15*), the majority of respondents (54.6%) rated it as either 4 or 5 (good or excellent). Another 36.4% rated it as satisfactory.

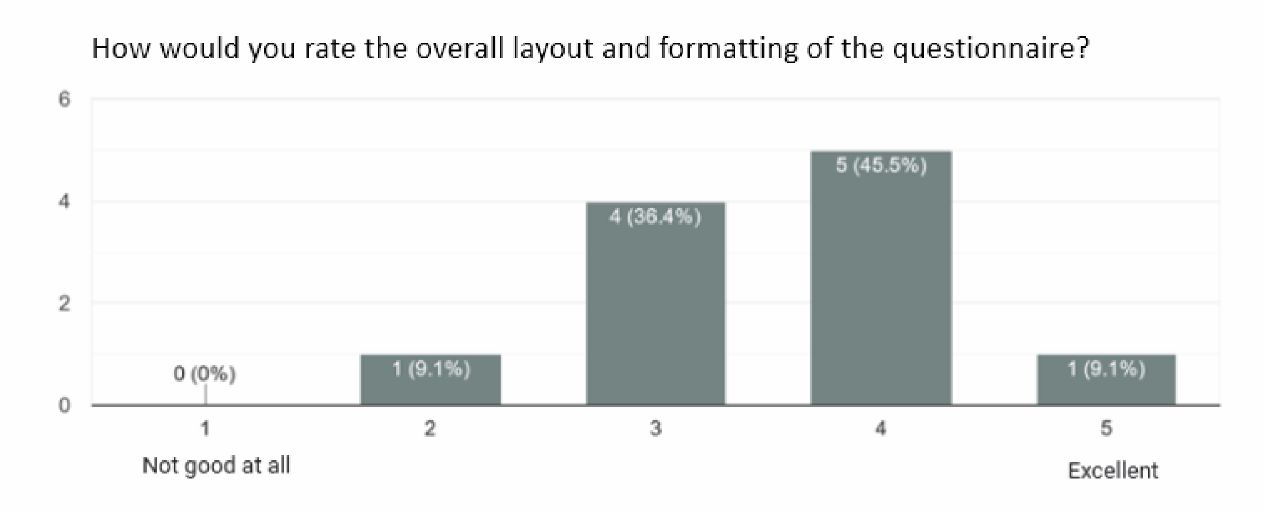


Figure 15: How would you rate the overall layout and formatting of the questionnaire?

Regarding the length and completion time of the questionnaire (Figure *16*), most respondents perceived the survey as either appropriate or somewhat lengthy (chart on the left). While this feedback indicates a potential need to shorten the survey to enhance participant satisfaction, the suggestion must be weighed against the benefit that a longer questionnaire allows for the elicitation of more detailed information concerning commuters' mode choice decisions. Considering that 91% of respondents completed the survey within the estimated 15-minute timeframe deemed necessary by the study team (chart on the right), it can be concluded that the completion time was appropriate for the questionnaire's length.

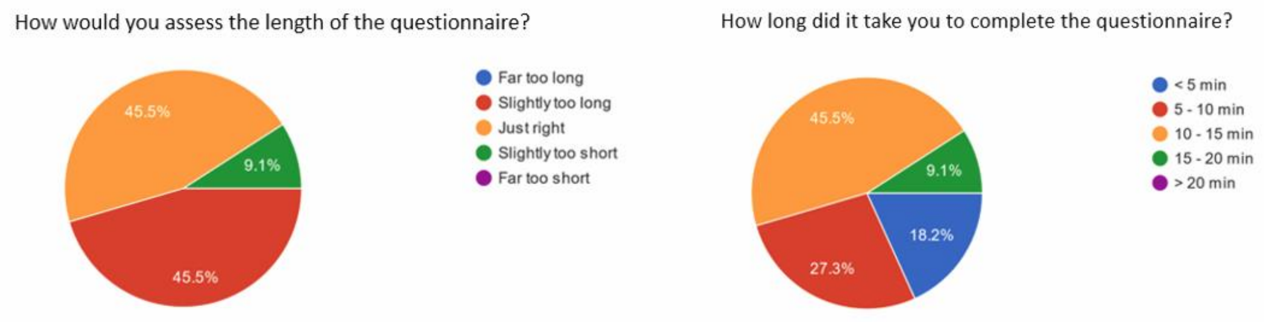


Figure 16: How would you rate the length and completion time of the questionnaire?

Finally, two respondents emphasised the need to revisit and edit previous answers in future questionnaires response to a general open-ended question that elicits overall comments or suggestions on the content and format of the questionnaire. They highlighted that once a page of responses was submitted, it was not possible to return and make corrections, again attributed to Google Forms' functioning.

Modelling insights

In the concluding section of the questionnaire, participants assessed the factors influencing travel choice decisions, as presented in Section B. The overall feedback (Figure *17*) indicates that most respondents found the results logical and consistent with their expectations regarding transportation choices, with 63.7% rating their agreement as 4 or 5 (indicating complete agreement with the analysis). Three respondents (27.3%) rated their agreement as 3, suggesting neutrality while one respondent expressed total disagreement but did not provide an explanation in the follow-up question.

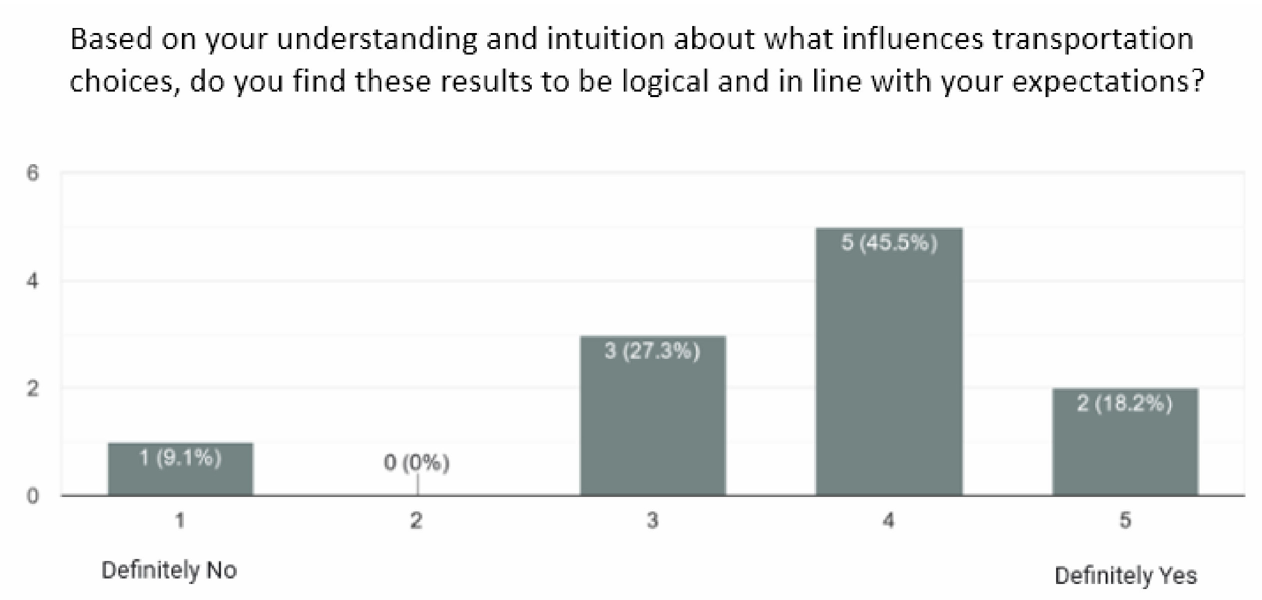


Figure 17: Based on your understanding and intuition about what influences transportation choices, do you find these results to be logical and in line with your expectations?

Concluding, the open-ended question on whether there are additional factors that significantly influence travel choice decisions and could be examined in future models received 5 comments. These comments mentioned the frequency, adherence, reliability, accessibility, and comfort of public transport, as well as the possibility to work from home.

3.3 Demand Prediction and Anomaly Detection

The Demand Prediction and Anomaly Detection subsystems developed in the framework of Work Package 4 of the TANGENT project have been applied to the Athens testbed, with regard to Service 1 mentioned in Section 2.4. Said efforts and results are well-documented, especially in Deliverable 4.6 [4]. Hereinbelow, the testing of both mechanisms is presented.

3.3.1 Data

The application of the framework with respect to supply forecasting for the case study of Athens considers predictions based on traffic counts. The available dataset contains both traffic volume and mean speeds per hour. As mentioned in Deliverables 4.2 [5] and 4.4 [6], data have been collected for two weeks, one week with a normal uninterrupted operation of the network and another week with a known network-wide event. The collected data corresponds on morning peak (06:00 – 12:00) and afternoon peak (13:00 – 19:00) hours. For demonstrating the application of the proposed framework in this deliverable, the week with a known network-wide event is selected for the analysis. The known network-wide event is a heavy rainfall and consequential flooding events that took place in the week of the 11th to 17th of September 2023. The data collection and analysis as well as the procedures for training and validating the models, are described in more detail in the respective deliverables

(Deliverable 4.2 [5] for supply forecasting, Deliverable 4.3 [7] for demand estimation and prediction and Deliverable 4.4 [6] for anomaly detection and duration analysis).

Aligned with the case study needs, data and transport model availability, the demand estimation and prediction methods are also applied to the Athens case study. A calibrated simulation model for the urban network of Athens is already available in Aimsun Next [8]. Hence, a a-priori/historical demand (OD matrix) is available and is used as the base for the generation of adjusted OD matrices to represent new traffic patterns (i.e., the week with heavy rainfall). For the scope of adjusting the historical OD matrices, the existing simulation-based demand adjustment method in the Aimsun Next software is applied, given available historical traffic counts for the city of Athens that represent the select traffic patterns. In particular, a database is first generated with varying adjusted OD matrices that represent identified days with regular traffic patterns as well as days with known historical events. Following, the adjusted OD matrices are used as input to train the data-driven demand prediction model that will interoperate with the Athens simulation model to predict the network-wide traffic conditions. Due to lack of real-time traffic data for Athens, a subset of the historical data is considered as the real-time data for the scope of implementing and assessing the supply forecast and demand prediction methods.

The event detection and duration models use the predictions of the supply forecasting models as well as the deviation of the current traffic values from the expected value (forecasted value) as a trigger criterion for event detection. These models are applied to the virtual case study of Athens and presented in detail in Deliverable 4.4 [6].

3.3.2 Demand Prediction

Simulated experiments using the adjusted demand (as occurred in the framework of Task 4.4 and described in Deliverable 4.3 [7]) took place. As mentioned above, the under-examination disturbance consisted of heavy rainfall and consequential flooding events. To better approach the traffic conditions occurred in the network by the heavy rainfall, speed reduction traffic policies have been implemented for all sections with detectors. The mean speed identified by each detector during event days is compared to the mean speed of the detector under normal operation and the extracted speed drop percentage is used to further simulate the effect of the event in the network. Additionally, to simulate the flooding events, the information for the detected events and their duration is used. By making use of said extracted information, traffic policies for closing the identified road sections for the detected duration are implemented. In Figure 3 above, the affected sections of the network (based on the results of the event detection and congestion duration framework) are illustrated. It is worth noting that the traffic policy for section closure is not applied only in the identified sections, but also on their neighbouring sections as well.

Concerning the event that took place in the week of September 11th – September 17th, 2023, as discussed in Deliverable 4.3, both heavy rainfalls and flooding events occurred in Athens, Greece. The heavy rainfall led to significantly reduced trips in the network (demand disturbance) and the flooding events led to road closures (supply disturbance). To better understand the event occurred in the network due to the event mentioned above, Table 1 quantifies some performance metrics for the Athens inner-ring urban transport network, for a normal date (February 21st, 2023) and an event date (September 12th, 2023) for one hour (08:00 – 09:00) of the morning peak period. From the metrics, two things are obvious.

Metrics	Normal date	Unplanned event date
Delay Time (sec/km)	108.98	53.99
Density (veh/km)	9.95	1.8
Flow (veh/h)	24753.4	2435.4
Input Count (veh)	33093.6	3915.3
Mean Speed (km/h)	27.28	24.15
Travel Time (sec/km)	181.71	169.11
Vehicles Inside (veh)	8340.2	1479.9
Vehicles Waiting to Enter (veh)	190.4	313.7
Served vehicles (veh)	24563	2122

Table 1: Performance metrics for Athens testbed on normal date versus unplanned event data.

It can be observed in Table 1 that the total number of vehicles that have passed through the network (flow) and the number of vehicles that have entered the network during the simulation period are significantly lower on the event day (flow by 90.16% and input count by 88.17%). Hence, significantly lower demand is estimated for that day, as mentioned in Deliverable 4.3 (it is observed in the demand adjustment results), and it is considered as expected. The lower demand can be attributed to the fact that some travels are either cancelled due to the event or performed with another means of transport, even though no data is available to validate travellers' mobility patterns on that day. It can be observed on Table 1 that the performance of the network is affected, despite the lower vehicles counts. The mean speed of all vehicles that have left the network is reduced by 11.47% on the event day.

Interestingly, the average travel time a vehicle needs to travel one kilometre inside the network is slightly reduced (by 6.93%). This is due to the lower number of vehicles entering the network as well as lack of information concerning the overall area affected by the event. Additionally, the number of vehicles that did not manage to enter the network within the simulated period is 64.76% higher in the case of the event, and the percentage of served vehicles (vehicles that entered the simulation and reached their destination) is 74.22% on the case of a normal date and only 54.2% in the case of the event. Those results imply that both the lower speeds in the network due to the heavy rainfall, as well as the closed sections due to the flooding events reduced the performance of the network. Additionally, Figure *18* and Figure *19* illustrate the effect of the event on the network links, color-coded based on the simulated flows and speeds, respectively.

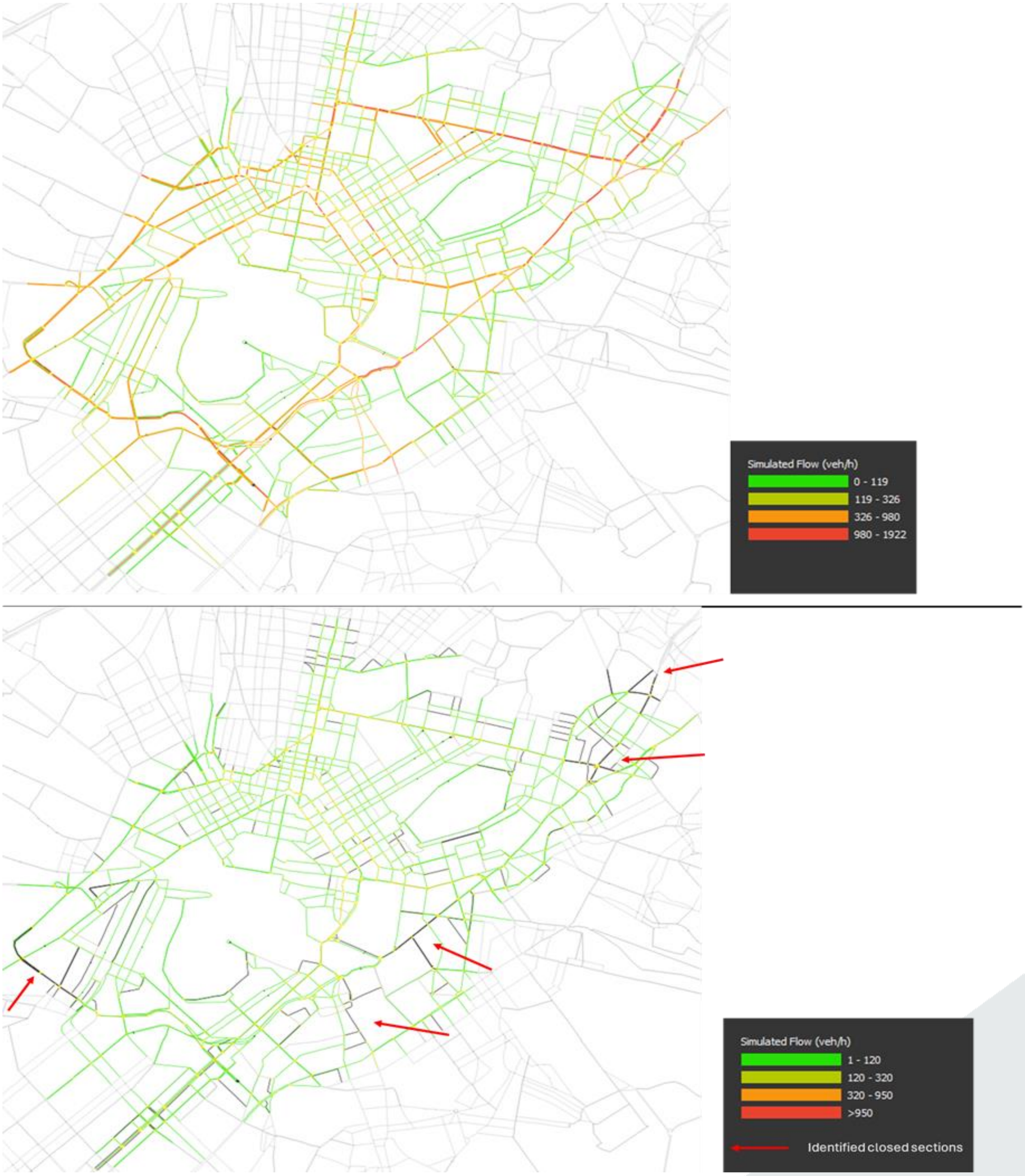


Figure 18: Simulated traffic flow in the Athens inner-ring urban transport network, for morning peak hour, in normal day (up) and in the case of an event (down).

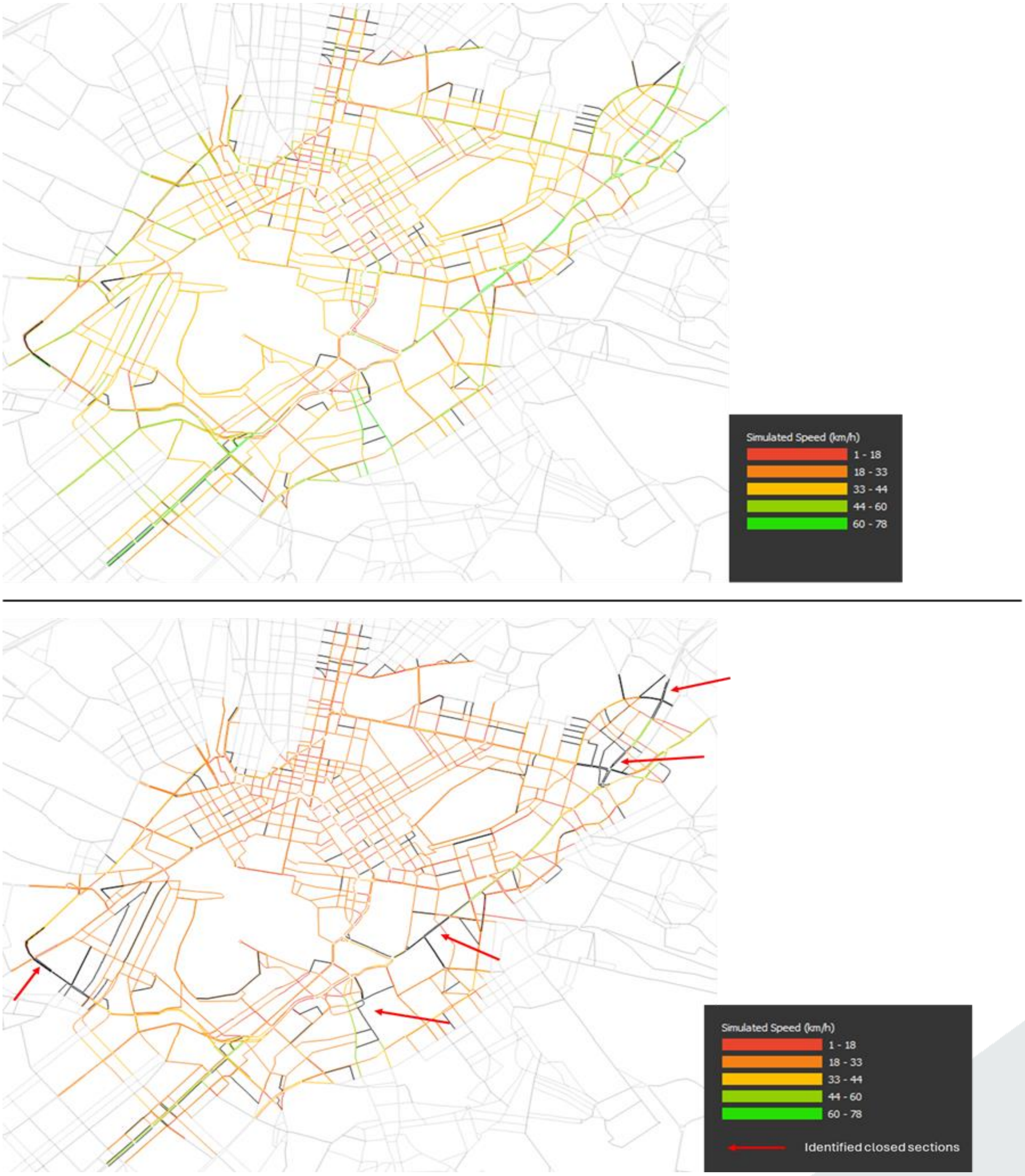


Figure 19: Simulated traffic speed in the Athens inner-ring urban transport network, for morning peak hour, in normal day (up) and in the case of an event (down).

Table 2 presents the results for morning peak and afternoon peak hours for one day with the heavy rainfall event and possible flooding events in the network. The results are expressed in the form of the GEH statistic, which is used to compare traffic volumes and is a wide accepted criterion for travel demand forecasting models. The GEH statistic is defined as

$$GEH = \sqrt{\frac{2(M-C)^2}{M+C}} \qquad (1)$$

where M is the hourly traffic volume as occurred from the simulated experiment, and C is the traffic count as observed from the loop detectors.

To be more specific, in our case the GEH<5 percentages are provided, since a GEH value under 5 is regarded as a good fit between the simulated counts after loading the estimated demand into the simulation model and the observed counts by loop detectors for a certain period of time. In general, 85% of the volumes in a traffic model should have a GEH less than 5.

Time	GEH<5 values (%)
06	88.33
07	86.58
08	86.74
09	86.42
10	87.12
11	86.75
13	87.24
14	87.51
15	86.72
16	86.54
17	86.33
18	86.48

Table 2: GEH<5 percentages for the adjusted demand, for a day with a known network-wide event.

Concerning the predicted demand, as occurred from the methodology described in Deliverable 4.3 [7], the GEH<5 results are presented on Table 3. The results are not considered good compared to those obtained with the base demand (Table 2). This is due to the fact that experiments run with data from Athens included just one sample for each typical pattern and any methodology based on neural networks requires a considerable data to learn from each distribution. In this specific case, the proof of concepts was specifically to investigate next steps with small datasets to further design experiments requirements in follow-up research actions. In this respect, next research actions involve not only having a reasonable amount of well calibrated demands for each typical pattern, but also running enough replications of each pattern to build a dataset of a minimal number of training instances in the order of thousands for each demand pattern. As running simulations for such a big amount of data would be computationally costly, a mixture of simulation and machine learning techniques (such as the demand estimation methodology presented in Deliverable 4.3 [7]) could be used.

Time	GEH<5 values (%)
06	10.08
07	4.20
08	15.13
09	16.81
10	33.61
11	36.97
13	40.34
14	32.50
15	32.50
16	42.50
17	36.67
18	35.00

Table 3: GEH<5 percentages for the predicted demand, for a day with a known network-wide event.

3.3.3 Framework for anomaly detection and duration analysis

The proposed methodology related to supply forecasting and the application to the Case Study of Athens is presented in Deliverable 4.2 [5]. These forecasting results are used in Deliverable 4.4 [6] to detect anomalies, on which duration analysis is performed. The detected duration of the forecasting results with the durations obtained through survival analysis (the proposed methodology) are compared in this deliverable.

The identified events, i.e. non-recurrent congestion detected through comparing predictions with observations as described in Deliverable 4.4 [6], are used. The beginning and end of the event are noted for validation purposes (real_duration). In the most usual case, the beginning and the end are the same timestep, i.e. we have a 1-hour event. This is compared with the survival model, that is used to estimate the duration using as input the traffic volume at the beginning of the event, the number of lanes, day and time (predicted_duration). This model is retrained on hourly data to make it comparable to the hourly prediction results.

A sample of detected events is included on Table 4. This comparison on detected events makes it possible to adjust the threshold used for anomaly detection, e.g., is it too strict, should it detect anomalies sooner or later, etc. We report the mean MAE of 0.12 and the mean GEH of 0.09 between the anomalies detected using supply forecasting methods and the ones using duration analysis.

We can conclude that the duration analysis of events and events detected using data-driven anomaly detection can work side by side by using the duration analysis to fine-tune the data-driven model. Our experiment shows that by fine-tuning the data-driven model, near perfect results can be obtained.

Timestamp_started	Sensor	real_duration	predicted_duration
17/09/2023 19:00	MS108	1	1
12/09/2023 15:00	MS110	1	1
14/09/2023 15:00	MS110	1	1
14/09/2023 17:00	MS110	1	1
15/09/2023 15:00	MS110	1	1
15/09/2023 18:00	MS110	2	2
11/09/2023 14:00	MS111	1	1
12/09/2023 10:00	MS111	1	1
13/09/2023 08:00	MS111	1	1
13/09/2023 13:00	MS111	2	1

Table 4: Sample of detected events with its corresponding real and predicted duration

3.3.4 Supply forecasting including simulation data

This paragraph investigates the potential benefit of using simulated event data on the accuracy of traffic speed forecasting in Athens. It focuses on data provided for the dates of 12th and 13th September 2023.

The simulation data includes speed and count values for morning peak hours (6 AM to 12 PM) and afternoon peak hours (1 PM to 7 PM). To retrieve the relevant information for the detected events and their duration, the associated traffic policies are applied in the Aimsun Next [8] software for closing the identified road sections for the detected duration. This results in the simulation data, that is used in this paragraph. This data is used to re-train the data-driven supply forecasting models. The idea is to simulate the impacts of traffic events and propagate the impact to the neighbouring locations. The simulation output can be used alongside the past values as input of the model to improve the predictions since the simulation model makes this simulative prediction differently than the data-driven forecasting models. We can consider them independent of each other, and independent features can add value to machine learning models' performance. By integrating real-world observations with simulated counts and speeds as external datasets, the objective is to enhance the predictive performance of the supply forecasting model.

The analysis specifically targets common sensor IDs across both real and simulated datasets to ensure a relevant and coherent comparison. The granularity of our dataset is characterized by 117 sensor locations and 12-hourly intervals over two days.

The MTGNN model is used, as described in Deliverable 4.2 [5], with a fine-tuned architecture to align with the data's unique aspects. To evaluate the model's effectiveness, we allocated 40% of the entire dataset for training, 10% for validation, and the remaining 50% (entire 13th September) for testing. The model utilized a 2-hour input window to predict traffic speeds for the upcoming hour.

The findings are included in Table 5. They indicate improvements in prediction accuracy when simulated event data is incorporated. Using external simulated data helped capture the effects of events on traffic speed more accurately. The table below outlines the Mean Absolute Error (MAE) and Symmetric Mean Absolute Percentage Error (SMAPE) metrics for both scenarios, highlighting the impact of integrating simulated event data on prediction accuracy. MAE is the average of the absolute errors, where the absolute error refers to the absolute difference between the prediction and the true value of an observation, while SMAPE is calculated as follows:

$$\frac{100}{n}\sum_{t=1}^{n} \frac{|forecast_i - actual_i|}{\frac{|actual_i + forecast_i|}{2}} \quad (2)$$

Scenario	MAE	SMAPE
Real + Simulated Data	6.28	50.66%
Real data only	6.80	53.12%

Table 5: Comparative Analysis of Model Performance

For a direct visual comparison, we include time series plots for select detectors (Figure 21 and *Figure 21*) of model predictions against ground truth traffic speeds, with and without simulated event data. These illustrate the enhanced accuracy and alignment with real-world data when simulations are integrated. In particular, the standard prediction model (without simulation data considered) was underestimating the speeds, while when simulation data are included in the model, the speeds are overall closer to the actual ones. However, accuracy is still limited as can be seen in the visual comparison. The predictions don't capture the drop in speed as good. The reason is that the model was trained based on a data set that includes mainly days with normal congestion patterns. Therefore, our results in Deliverable 4.2 [5] show more accurate traffic speed forecasting and we can conclude the lack of training data causes the inaccuracies for data-driven model here since the model is only trained on days where simulated data is available (corresponding to seven days with the known disturbance in the network, from which two were selected to train and test the prediction model). This is also the case in the simulated data for the detectors (as illustrated in Figure 8 below). However, this can be justified since no speed data is directly incorporated in the calibration of the simulation model. In particular, in the process of adjusting the demand matrices, only observed traffic counts corresponding to the days of events were used. As mentioned above, one of the limitations of the gradient-based simulation-based approaches for adjusting the demand is usage of only traffic counts in the estimation process, which makes the calibration of congested networks difficult. Speeds are rather used as a validation metric.

Figure 20: Comparative analysis of traffic speed predictions using real data alone versus integrating real data with simulated event data for selected sensor locations.

Figure 21: Comparative analysis of traffic speed predictions using real data alone versus integrating real data with simulated event data for selected sensor locations (cont.)

Figure *22* compares for the event day with heavy rainfall the observed versus simulated speeds for selected sensor locations. For some sensors, the speed is almost constant. This is due to the fact that for said sensors, the traffic counts do not vary. It is worth mentioning here that speed reduction traffic policies have been implemented in the Athens testbed for all sections with detectors. This has been done to better approach the traffic conditions occurred in the network by the heavy rainfall, speed reduction traffic policies have been implemented for all sections with detectors. To be more specific, a comparison between the mean speed identified by each detector during event days and the mean speed of the detectors under normal operation has been made, and the extracted speed drop percentages are further used to simulate the effect of the event in the network.

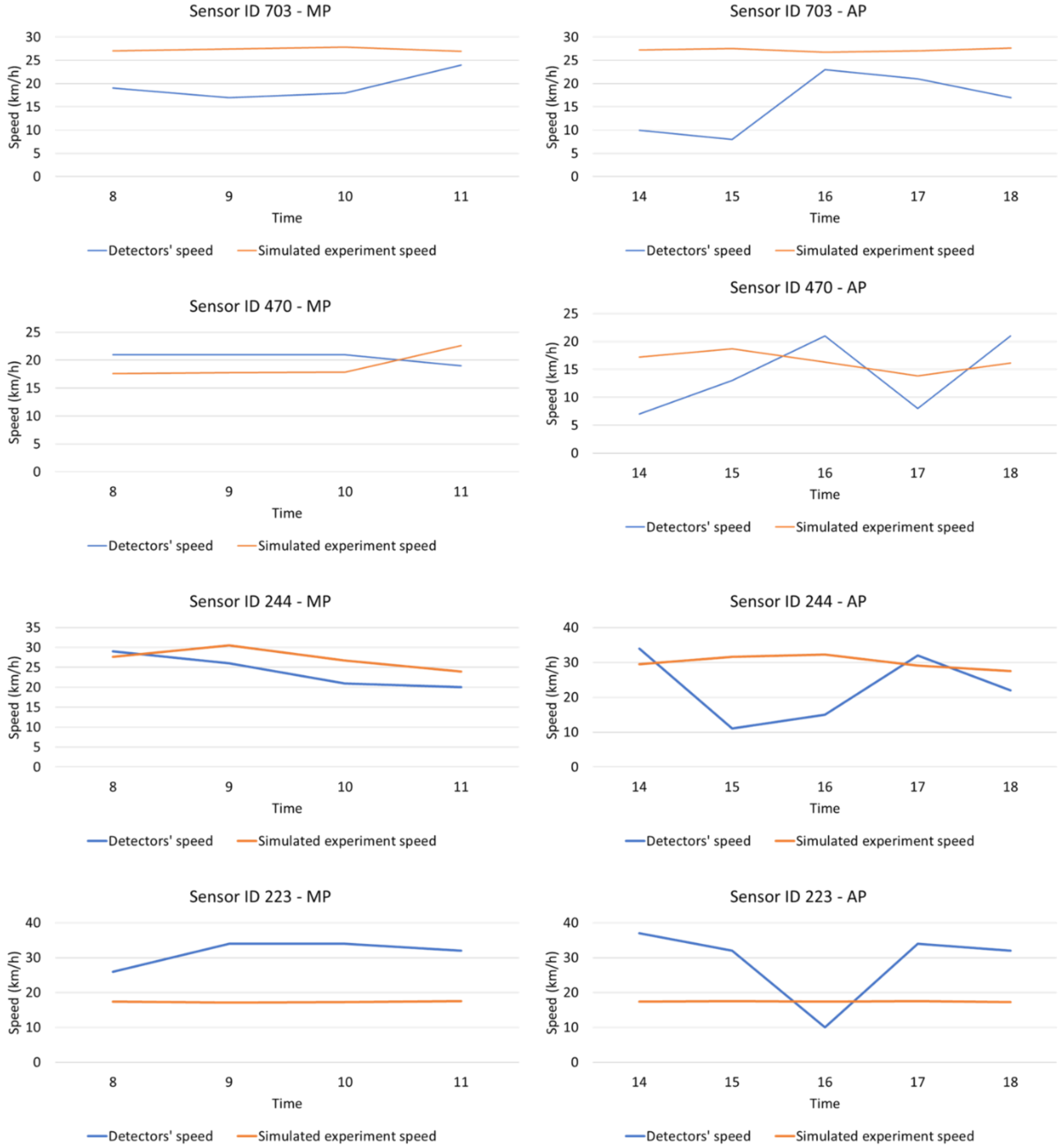


Figure 22: Observed speeds versus simulated speeds for selected sensors' locations.

In addition to the above, Figure *23* below illustrates simulated traffic counts and speeds for the selected sensors' locations. In other cases, when speed increases or decreases, this is accompanied by either a reduction or an increase in traffic counts.

It is worth noting that the selected sensors are not close to an identified event for the selected date. This means that those detectors belong to a part of the network where no flooding event occurred, hence the illustrated results only refer to the effects of the heavy rainfall in those parts of the network. Additionally, the fact that the speed is affected by the traffic counts may demonstrate that the Volume-Capacity ratio is relatively high in the sections that the sensors are located on. In terms of the ability of the simulation to capture the event, it appears that the main dynamics of the disturbance can be derived from the simulation. However, there is the need for more data sources to be incorporated in this process for the total affected area by the event to be defined. Additionally, the use of microscopic simulation may better capture the complex dynamics of a disturbance. It is also worth noting that resilience-related metrics like criticality and efficiency can be used for both identifying the critical parts of the network and performing the necessary Traffic Management Strategies to mitigate the impacts of the disturbance in the network.

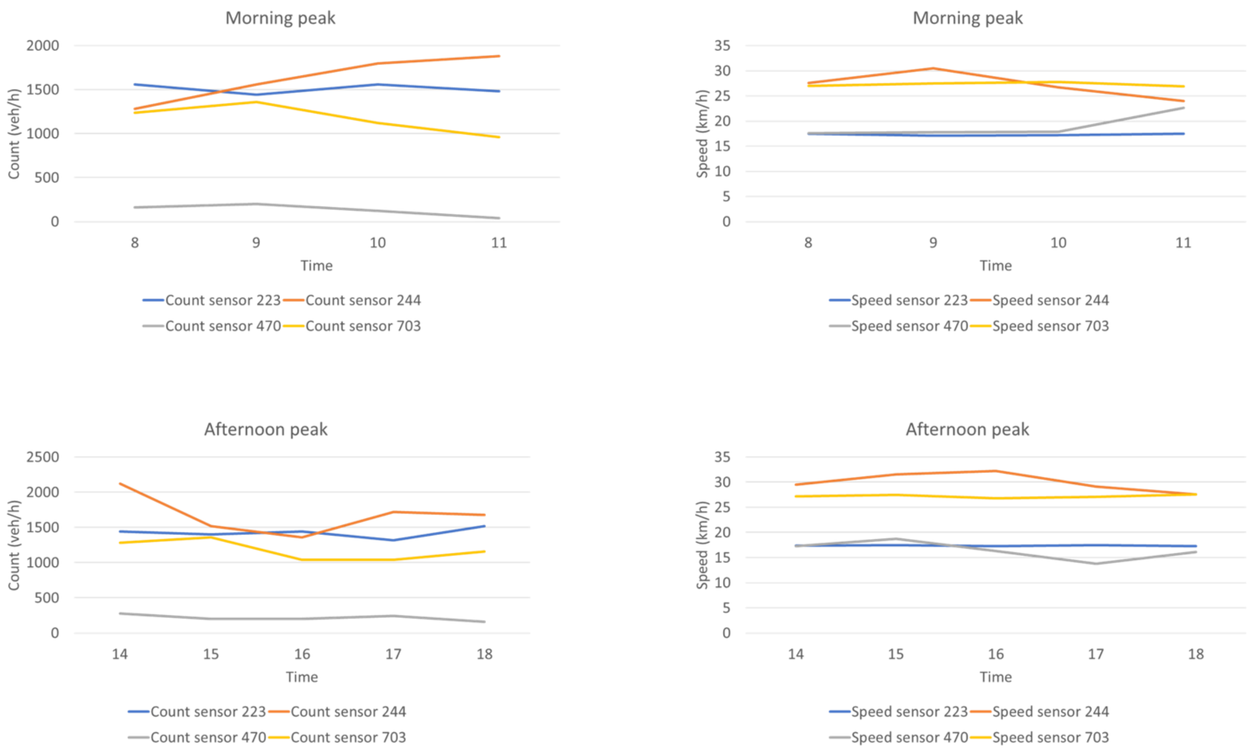


Figure 23: Detectors' counts (veh/h) (left) and simulated speeds (km/h) (right) for morning (up) and afternoon (down) peak hours on event date.

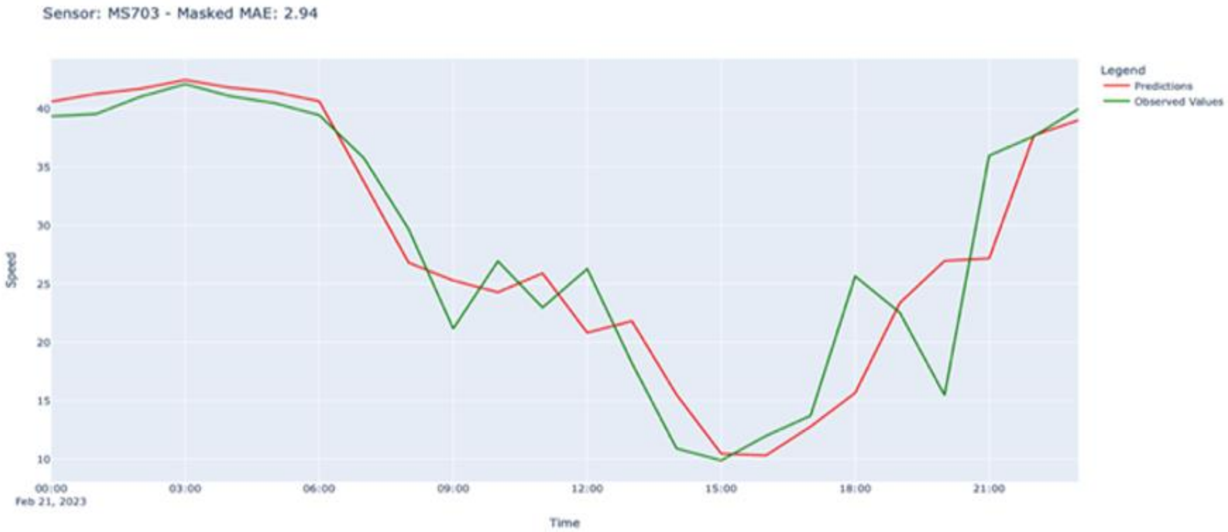
Comparison between observed and predicted speeds on normal days

Given the fact that simulation results are also available on normal days, the comparison between observed and predicted speeds are presented on those days as well. Time series plots are included in the charts below (

Figure 25) for the same sensor IDs on February 21st, 2023. These correspond to the ones presented in Deliverable 4.2, which describes the methodology used to obtain predictions on the test dataset. The prediction horizon is one hour. Besides the comparison graph between predictions and ground truth observations, the charts list masked MAE, which is useful when missing values are present in the dataset. The masking ignores the model's output when the ground truth is missing and bases the error on the remaining output.

In addition to the predicted versus observed values for speeds, the observed versus the simulated speeds are illustrated on Figure *24* and Figure *26*. In general, the simulation manages to sufficiently capture the speed variations. The only exception to that is, for morning peak hour, sensor ID 470. For said sensor, however, not sufficient data have been retrieved for morning peak hour.

We observe that both simulation and data-driven models can capture traffic patterns and make an accurate prediction on normal days. However, the computation cost and expert time needed for simulation in given days is much higher than data-driven models, and it is best to use data-driven models if only predictions are needed and use the simulations when insights into underlying mechanisms of traffic flow and speed are required.



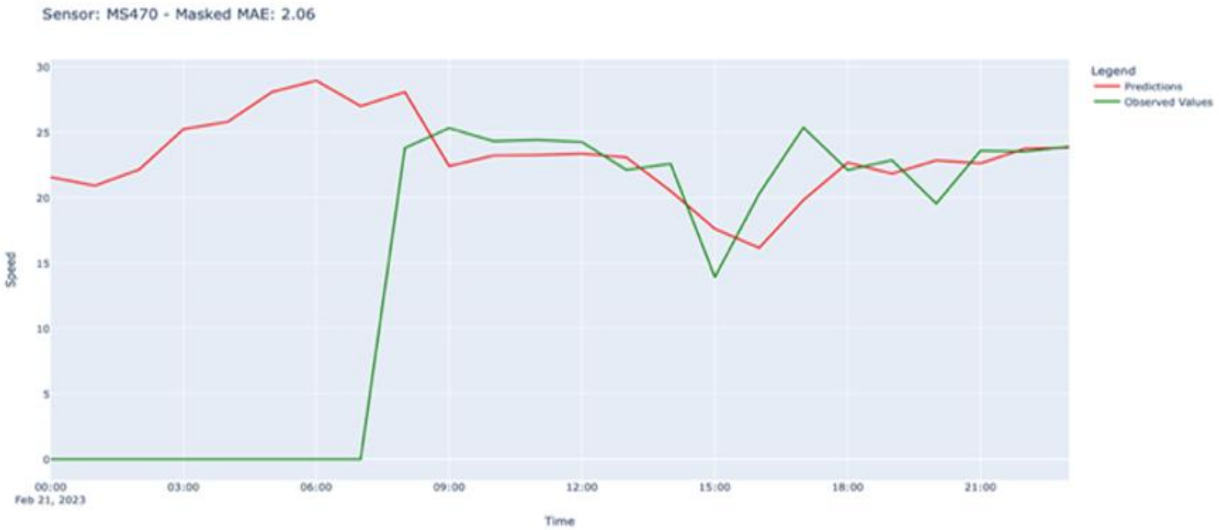
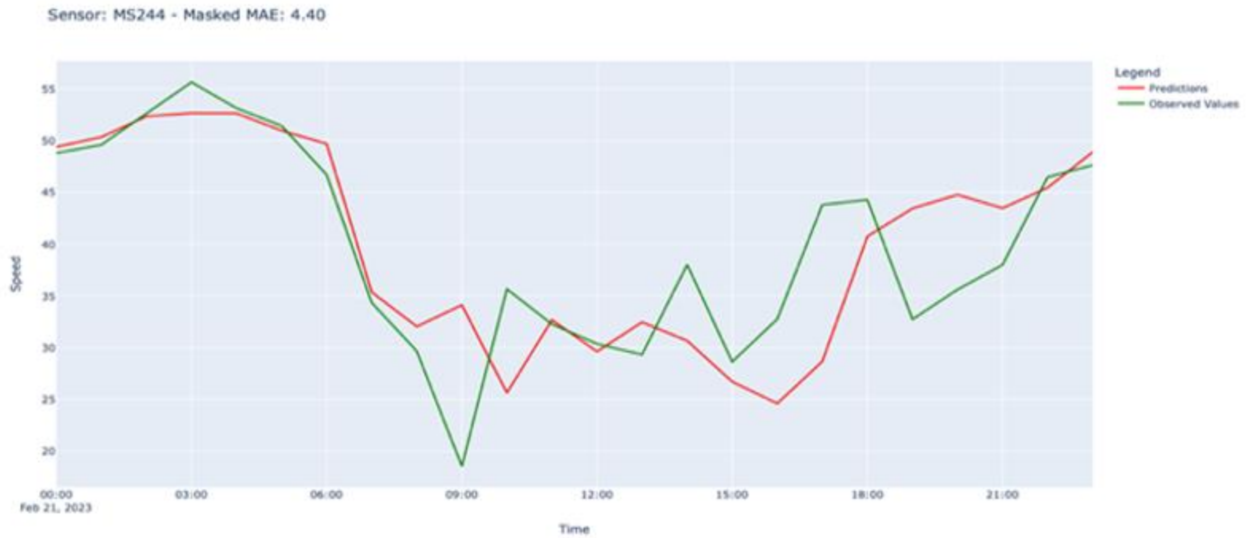


Figure 24: Traffic speed prediction with forecasting period 1 hour ahead for selected sensors' locations on February 21st.



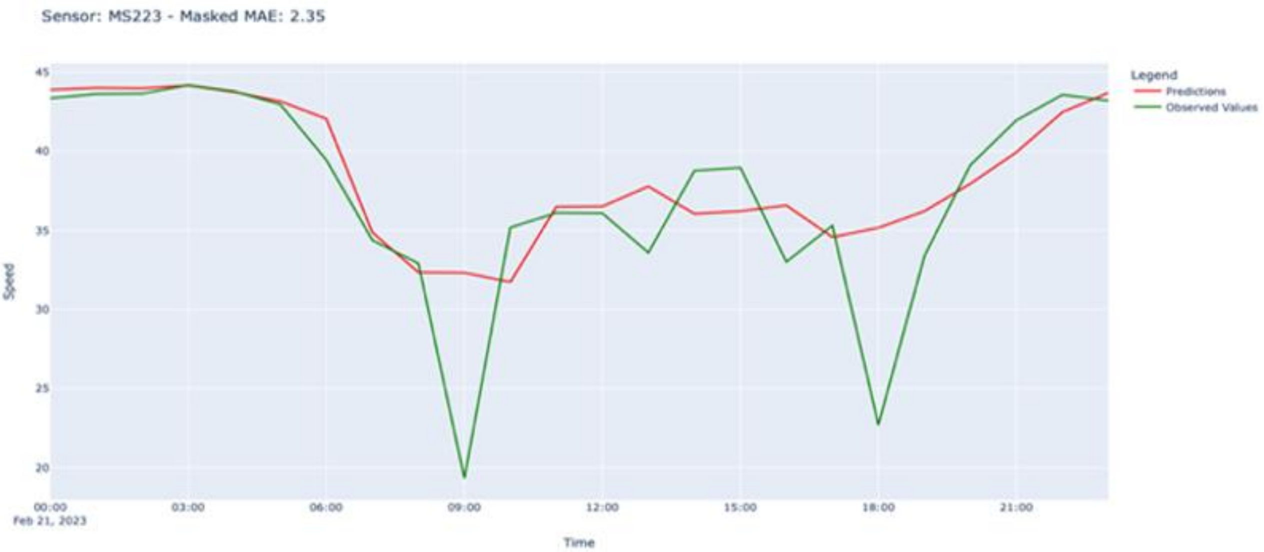


Figure 25: Traffic speed prediction with forecasting period 1 hour ahead for selected sensors' locations on February 21st (cont.).

Figure 26: Counts (veh/h) (left) and speeds (km/h) (right) for morning (up) and afternoon (down) peak hours on normal date.

3.4 Demand Responsive Transit with Public Transport (DRT-PT)

This section aims to discuss the results of the synchronisation of Demand-Responsive Transport and Transit Modes in Athens's case study. First, we will describe the experimental framework defined, and then we will discuss the results obtained.

3.4.1 Methodology

Preparation Phase

A document containing submodule testing specificities was shared with the stakeholder during the initial phase of the testing process. This document had consolidated fields for gathering information like simulation area, PT stop details, DRT pickup and drop point summary. After getting the response from the stakeholder regarding the testing requirement specifications, the testing process commenced. After the testing phase is complete a report is generated with the test result and is sent to the case study stakeholders for their approval and further validation.

Testing Framework

In this subsection, we show the experimental framework designed to test the optimisation module for the Synchronisation of DRT and PT in the Athens case study.

We have considered the implementation of a DRT system that connects a peri-urban area with relatively few transportation options (Paiania) to the closest metro station. Once at this station, individuals can board a train towards the city center, which operates at 30-minute intervals.

The demand to be served by the DRT system was estimated for three specific areas within Paiania: its center, Trigono Lagou and Agia Marina. The demand is represented in Table 6. The origin of the trip requests have been uniformly distributed within the polygons shown in Figure *27* for their respective subareas. Each trip request has associated pick-up and drop-off time windows that represents the preferences of the users for the time interval in which they want to depart or arrive to their destinations. The start time of the departure time windows (T_S^{Oj}) has been randomly generated in the interval 7:30-10:30 (Athens local time) while the end time of the time window has been set 30 minutes later (T_e^{Oj} = T_e^{Oj} + 30mins)). The interval for the arrival time window has been set to[$T_S^{Dj} = T_S^{Oj} + 40 mins$, $T_e^{Dj} = T_S^{Dj} + 35 mins$]. The parameter has been set to 5 minutes, while the parameter λ_{walk} is not applicable in this scenario since the public transport stop is always set to the train station mentioned before and displayed in Figure 2.

Area	DRT calls
Center	356
Trigono Lagou	178
Agia Marina	178

Table 6: DRT demand estimated for each subarea within Paiania

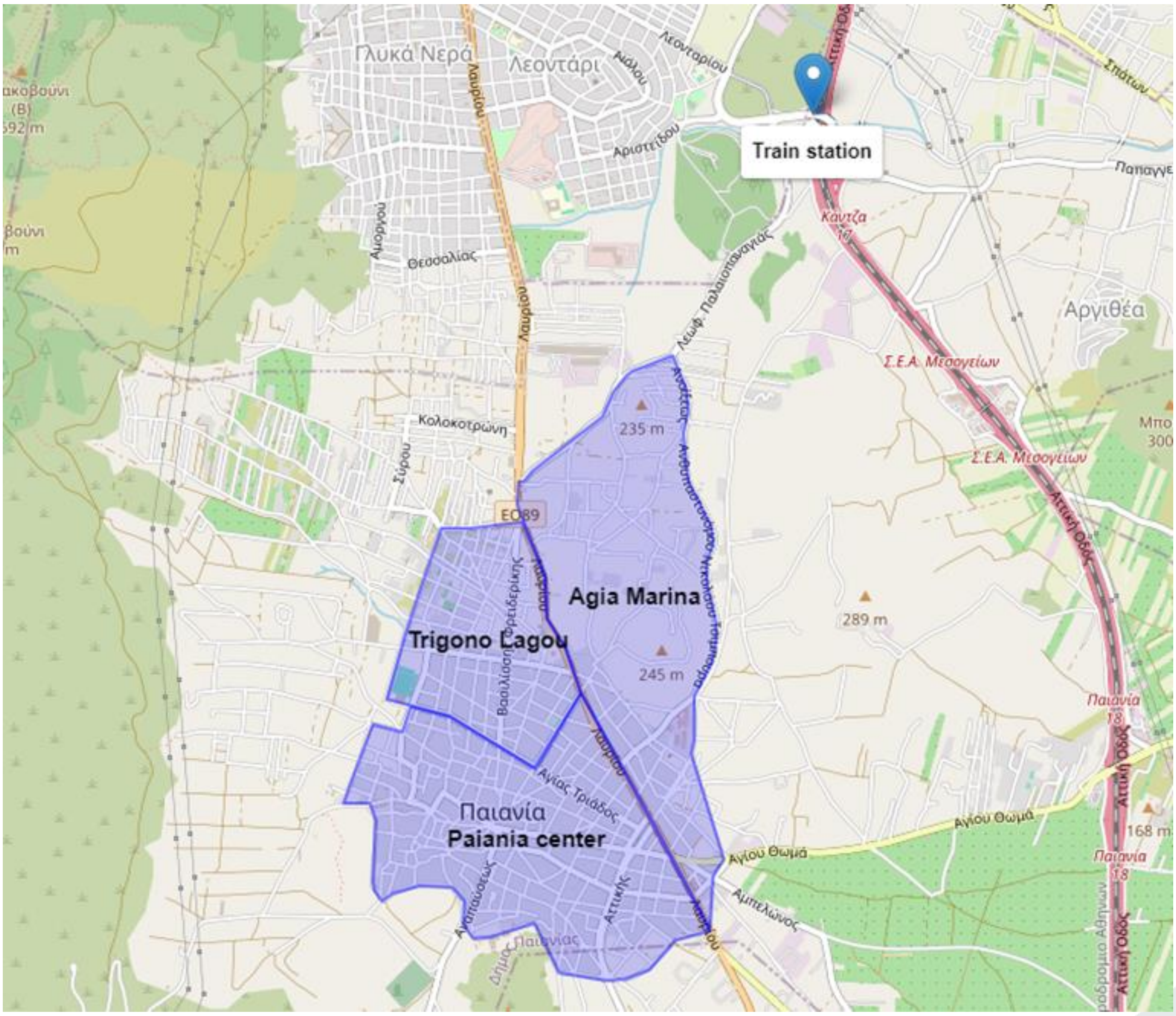


Figure 27: Athens' region considered for the testing of the optimization method for Synchronization of PT and DRT

In addition, two different DRT schemes were considered: one service where the pick-up is at the passenger's own door, and another where the pick-up is at a meeting point no further away than 150 metres. These pick-up points were defined based on existing bus stops and intersections on secondary and tertiary roads, in that order of preference. The selected meeting points are displayed in Figure *28*.

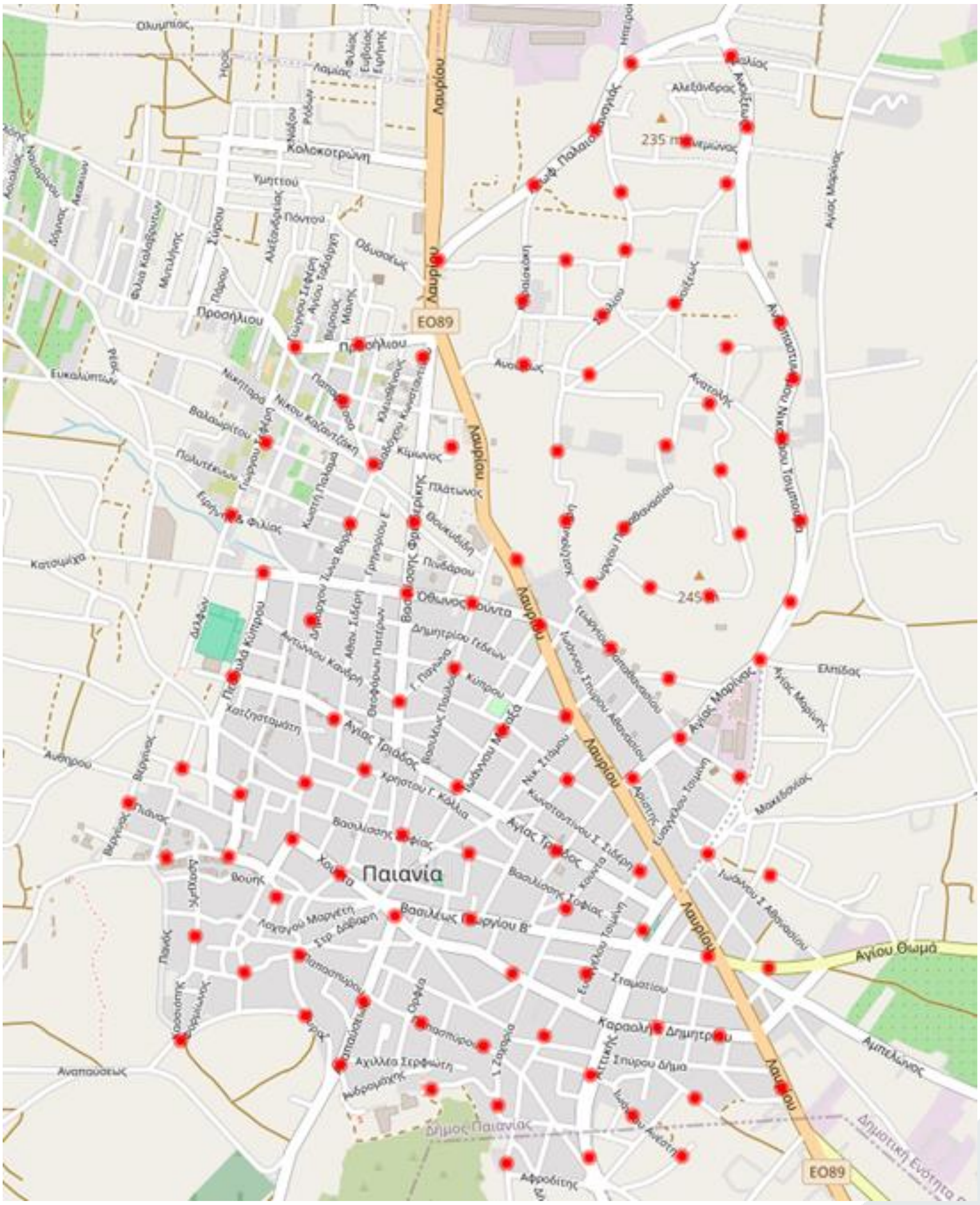


Figure 28: Locations of meeting points for DRT service pick-ups

Apart from that, for both DRT schemes, we have considered different DRT fleet sizes to check the impact of the fleet size in terms of quality of service and operational costs. Concretely, we have tested the following fleet sizes: 6, 12, 18 and 24. Vehicle capacities have been set according to preliminary experimentation. In the case of the DRT scheme door-to-PT stop, the vehicle's capacity was set to 7, whereas for the DRT scheme meeting-point-to-PT stop, this capacity was set to 12. In both cases, increasing the capacity to values higher than 7 and 12, respectively, did not improve service quality, when keeping the fleet size fixed.

Finally, the pick-up times for the DRT service were set to 0.4 seconds per passenger, whereas the drop-off times were set to 0.25 per passenger. The reason for the asymmetric pick-up and drop-off times is due to the higher number of passengers getting off simultaneously at the above-mentioned train stop, which usually results in a lower time per passenger.

For the calculation of the emission indicators for CO, SOx, NOx, NH3, PM10, CO2, CH4 and N2O, we use the estimations of the HBEFA 4.2 database[1]. Estimates were considered for free-flow urban environments at a speed of 40 km/h and with a flat slope.

The operating cost indicators were derived from estimates of both fixed and variable costs. Fixed costs, calculated in euros per hour, primarily included vehicle-related expenses such as depreciation, interest payments, insurance, taxes, fixed maintenance costs, personnel salaries, and overhead allocations. Variable costs, calculated in euros per kilometre, covered fuel or energy expenses and tyre wear. The specific values used were as follows (Table 7).

Vehicle Type	Technology	Fixed Costs (€/hour)	Running Costs (€/Km)
12 places DRT Van	Combustion	24,59	0,18
7 places DRT Van	Combustion	23,99	0,16

Table 7: Fixed and Running costs per DRT vehicle type

Finally, to have a reference whether this combined service of PT and DRT can be competitive with the car and current connections with public transport, we estimated the travel times for these three options to Omonia Square, in the centre of Athens.

3.4.2 Actions achieved and results

The objective of this subsection is to show the results obtained by the optimisation module designed for the DRT and transit modes synchronisation in Deliverable D5.6 using the experimentation framework shown in the previous section.

The main results obtained are shown below. In Table *8* and Table *9*, we can see the results obtained by the Door-to-PT stop DRT services in terms of percentage of demand served, mean travel time for DRT + PT trips between Painaia and Omonia Square, mean travel times for equivalent trips in car use[2], mean travel times for equivalent trip in current public transport options, distance travelled by DRT vehicles in kilometres, travel time of the vehicles in hours, DRT routes total duration (total time including travel time and stops) in hours and the operation costs of the DRT service, as well as the estimated emissions for the pollutants described in previous section.

The equivalent results for the Meeting-point-to-PT stop DRT scheme are displayed in **¡Error! No se encuentra el origen de la referencia.** and in Table 11.

[1] https://www.hbefa.net/e/index.html

[2] Estimated using Google Maps Distance Matrix API to account for typical traffic conditions at the time of the trip request.

Max DRT fleet size	% of demand served	Mean Travel Time DRT+PT (min)	Mean Travel Time Car (min)	Mean Travel Time PT (min)	Percentage of DRT fleet used	Distance travelled by DRT vehicles (km)	Total travel time of DRT vehicles	Total duration of DRT routes (h)	DRT service operation costs, €
6	35,25%	50,24	43.86	73,06	6	880,77	20,03	23,33	696,17
12	66,99%	50,11	43.86	73,06	12	1757,26	39,85	46,67	1.391,67
18	94,10%	50,67	43.86	73,06	18	2594,91	58,67	68,82	2.052,78
24	98,03%	50,51	43.86	73,06	22	2751,31	62,23	76,60	2.263,70

Table 8: Service quality and operational indicators for Door-to-PT stop DRT scheme with different fleet sizes

DRT fleet	CH4 (g)	CO (g)	CO2(g)	FC (g)	FC_MJ (g)	HC (g)	N2O (g)	NH3 (g)	NO2 (g)	NOx (g)	PM (g)	PM (g)	SO2 (g)
6	3,1	81,11	159.648,6	50.682,11	2.105,8	4,47	9,06	2,0	82,99	466,16	34,30	34,30	0,8
12	6,6	171,2	337.078,4	107.009,0	4.446,2	9,44	19,1	4,2	175,2	984,24	72,41	72,41	1,7
18	9,7	249,3	490.850,5	155.825,5	6.474,5	13,7	27,8	6,2	255,1	1.433,2	105,4	105,4	2,4
24	10	260,7	513.253,6	162.937,6	6.770,0	14,3	29,1	6,5	266,7	1.498,6	110,2	110,2	2,6

Table 9: Emissions for meeting Door-to-PT stop DRT scheme with different fleet sizes

Max DRT fleet size	% of demand served	Mean Travel Time DRT+PT (min)	Mean Travel Time Car (min)	Mean Travel Time PT (min)	Percentage of DRT fleet used	Distance travelled by DRT vehicles (km)	Total travel time of DRT vehicles	Total duration of DRT routes (h)	DRT service operation costs, €
6	41,29%	52,34	43.86	73,06	6	823,71	19,22	23,32	721,62
12	73,60%	51,14	43.86	73,06	12	1739,16	38,92	46,65	1.460,17
18	98,17%	50,23	43.86	73,06	18	2532,55	57,83	67,45	2.114,45
24	98,31%	51,37	43.86	73,06	22	2648,14	59,50	74,25	2.302,47

Table 10: Service quality and operational indicators for meeting point-to-PT stop DRT scheme with different fleet sizes

Max DRT fleet size	CH4 (g)	CO (g)	CO2(g)	FC (g)	FC_MJ (g)	HC (g)	N2O (g)	NH3 (g)	NO2 (g)	NOx (g)	PM (g)	PM (g)	SO2 (g)
6	3.17	81.11	159648.6	50682.11	2105.84	4.47	9.06	2.03	82.99	466.16	34.3	34.3	0.81
12	6.69	171.26	337078.4	107009	4446.23	9.44	19.13	4.28	175.22	984.24	72.41	72.41	1.71
18	9.75	249.39	490850.5	155825.6	6474.55	13.75	27.86	6.23	255.15	1433.24	105.45	105.45	2.49
24	10.19	260.77	513253.6	162937.7	6770.06	14.38	29.13	6.52	266.79	1498.66	110.26	110.26	2.61

Table 11: Emissions for meeting point-to-PT stop DRT scheme with different fleet sizes

3.5 Synchronisation of Public Transport and Traffic Control (PTTC)

The objective of this module is to test and validate the effect of changing Public Transport line frequency and corresponding signal timings for intersections of interest to facilitate improved traffic flow and emission conditions.

3.5.1 Methodology

Preparation Phase: Testing schematic and transport model finalisation

A document containing submodule testing specificities was shared with the stakeholder during the initial phase of the testing process. This document had consolidated fields for gathering information like simulation area, traffic node details, simulation scenario details and public transport line of interest. After getting the response from the stakeholder regarding the testing requirement specifications, the transport model is suitably adjusted and the testing process commenced. After the testing phase is complete a report is generated with the test result and will be sent to the case study stakeholders for their approval and further validation.

Testing Framework

The testing framework for the project focuses on the Aimsun model for the Athens test bed area in Athens, Greece.

The simulation area consists of four public transport bus lines and seventy four signal phases. This setup utilises a fixed traffic control plan to evaluate the system's response under various conditions. The testing process involves running a PPS (Planned and Predicted Scenario) to analyse how well the system performs when adapting to different scenarios. The results are compared against a baseline scenario, allowing for a clear evaluation of how interventions, such as adjusting bus frequencies or signal timings, improve traffic flow and public transport efficiency.

In this testing operation we have utilised the relative KPI improvement as the optimization objective, formalised as: KPI_relative_improvement = (KPI_baseline - KPI_optimized) / KPI_baseline

Optimization Phase

In this phase, based on the finalised transport model and stakeholder specified inputs, we have executed the optimization process for predefined KPI specificity. After the optimization process concluded, results were collected from the system for the creation of the report to be shared with the stakeholders and for further validation.

3.5.2 Actions achieved and results

The goal for the optimization process is to improve the congestion in the system along with the system-wide emissions. In the baseline scenario the density was 37.95 veh/km whereas in the optimized scenario it changed to 38.81 veh/km. For over all flow, in baseline scenario it was 20,151.3 veh/h and in optimized scenario it changed to 18,583.9 veh/h. Overall speed was 23.42 km/h in the baseline scenario and when optimised it became 24.32 km/h. The total distance travelled was 88,424 km in the baseline scenario and in the optimized scenario it became 79,897.78 km. Travel time was 312.02 sec/km in the baseline whereas in the optimized scenario it became 289.78 sec/km.

After analysing the raw values of the underlying indicators, we can see that density slightly increased by 1.89% after optimization and traffic flow decreased by 7.41%. In contrast, the travel time decreased by 14.33% than the baseline which suggests that the system is getting more efficient. Passenger experience is improved as their travel time is decreasing but in contrast the system efficiency is not improving as the flow is slightly decreasing and the density is increasing shows the state of the network is after the critical density.

Impact of PTTC on flow and delay-time of the network

The improvement in traffic flow through the optimization of public transport and traffic control reflects a significant enhancement in the efficiency of the transportation network. By optimizing public transport systems by changing the frequency of public transport bus lines, more commuters are likely encouraged to shift from private vehicles to public transit, reducing overall road congestion. Concurrently, the optimization of traffic control plans ensures smoother vehicular movement and minimizes bottlenecks. These combined strategies not only improve flow by balancing demand and capacity but also contribute to reduced travel times as shown in figures below, and enhanced environmental sustainability marking a progressive step toward a more efficient urban mobility system. When delay times are minimized through effective public transport and traffic control optimization, the network operates closer to its optimal capacity and move towards free-flow travel time. The results from the following figures (Figure *29* and Figure *30*) show that the effective management of traffic through PTTC enhanced the overall travel times of the system.

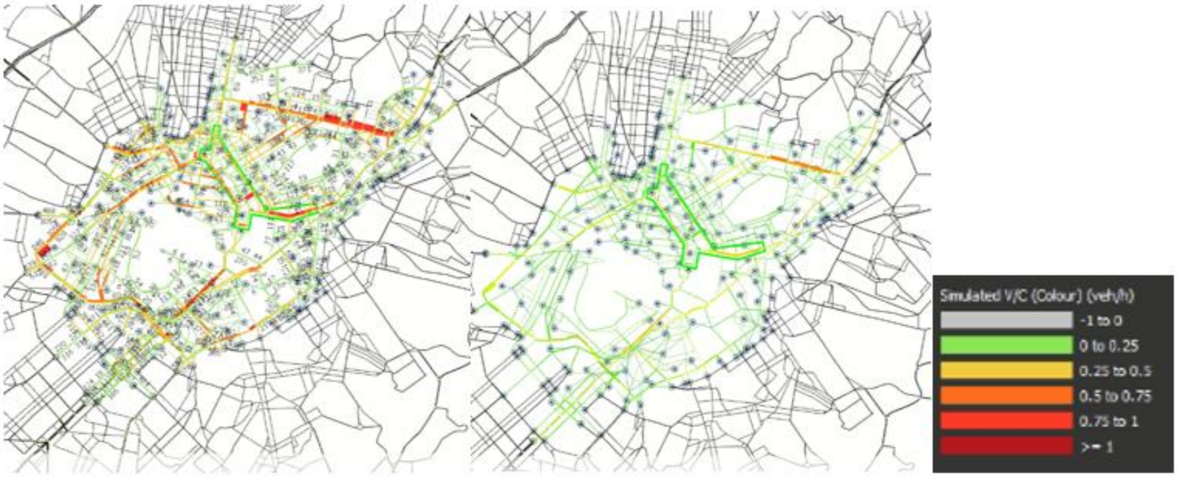


Figure 29: Simulated V/C: Baseline Flow (left) and Optimised flow (right)

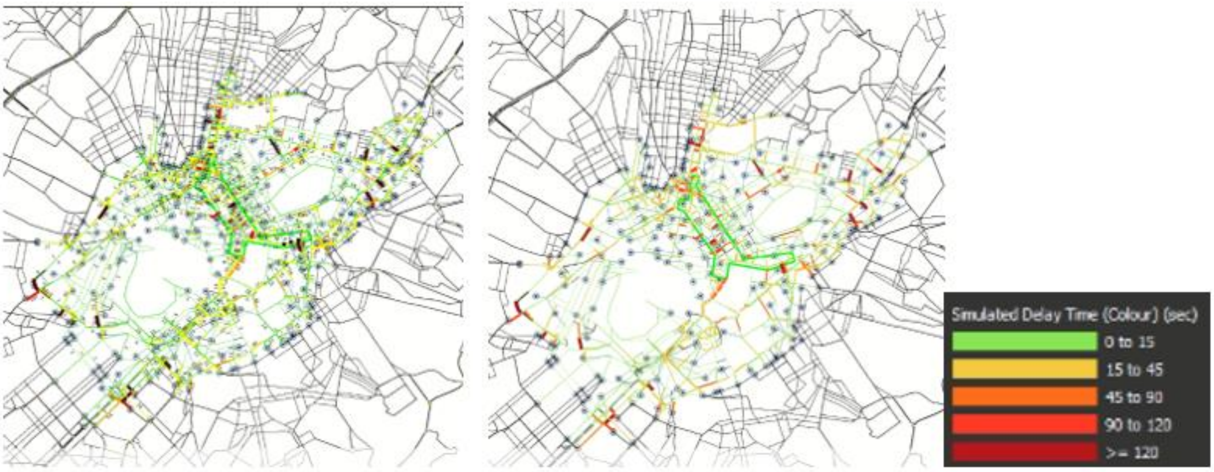


Figure 30: Simulated V/C: Base Delay-time (left) and Optimised Delay-time (right)

Impact of PTTC on Density and speed of the network

The optimization of public transport and traffic control plans play an important role in achieving decreased density and increased speed. The density (Figure *31*) of the network decreased with public transport optimization and optimised traffic control plan ensures smoother vehicle movement, maintaining speeds close to free-flow levels and minimising queues. With the reduced density in an optimised scenario, vehicles can travel closer to free-flow speed (Figure *32*).

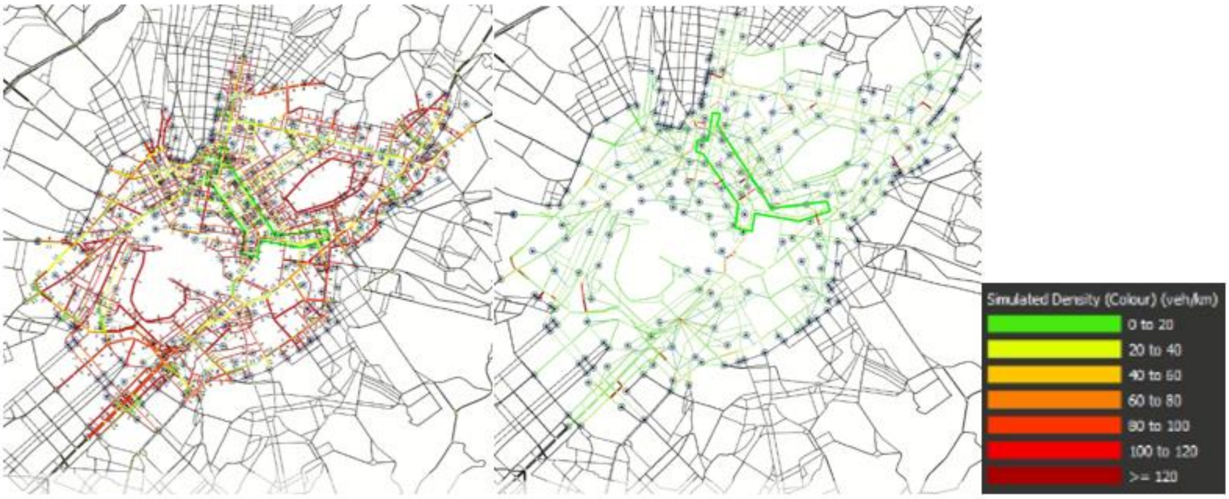


Figure 31: Simulated density: Baseline (left) and Optimised Density (right)

Figure 32: Base speed (left) and optimised speed (right)

3.6 Signal Vehicle Coupled Control with CAVs (SVCC)

3.6.1 Methodology

The Signal Vehicle Coupled Control with CAVs (SVCC) subsystem is applied in the framework of Service 2 - SNLB. It is worth noting that, due to a higher-than-expected technical complexity of this module, no respective subsystem is evaluated. However, in order to investigate the importance of Connected and Automated Vehicles in the network-wide Traffic Management, an alternative approach has been followed by the National Technical University of Athens. To this end, and in order to emulate the anticipated results of the SVCC subsystem, all the throughput movements in the Athens testbed are identified and the penetration rate of CAVs is increased iteratively, with a ten (10) percent step. At first, it is worth noting that this is implemented in both morning and afternoon peak hours, and for both uninterrupted operation of the network and operation of the network under an unplanned event. In total, 44 scenarios are executed with ten (10) replications per scenario to avoid statistical errors in the final retrieved results.

Concerning the simulation of CAVs, the Intelligent Driver Model (IDM) is utilised [9]. IDM is applied in an aggressive manner, in the sense of simulating aggressive behaviour of CAVs which is a specification expected to occur in the network when high penetration rates of CAVs is achieved.

3.6.2 Results

The results occurred showcase the importance of CAVs towards achieving efficient network wide Traffic Management. Starting from morning peak hour and uninterrupted conditions in the network, it seems that the gradually increasing the penetration rate of CAVs allows for a better operation of the network. This is illustrated in the percentage increase of the number of vehicles managed to be inserted in the network during the simulated hour. In high penetration rates, an increase of 4-5% (approximately an increase of 3000 – 4000 vehicles) is achieved. This trend is illustrated in Figure *33*. This increase in vehicles inserted in the network during the simulated time is also accompanied by an increase in the number of served vehicles. Served vehicles are defined as the vehicles that have been inserted in the simulation and reached their destination during the simulated time. This increase is more obvious in the high CAVs penetration rates, reaching a 5% increase (approximately an increase of 4,000 vehicles) for 100% CAVs penetration rate. This is illustrated in Figure *34*.

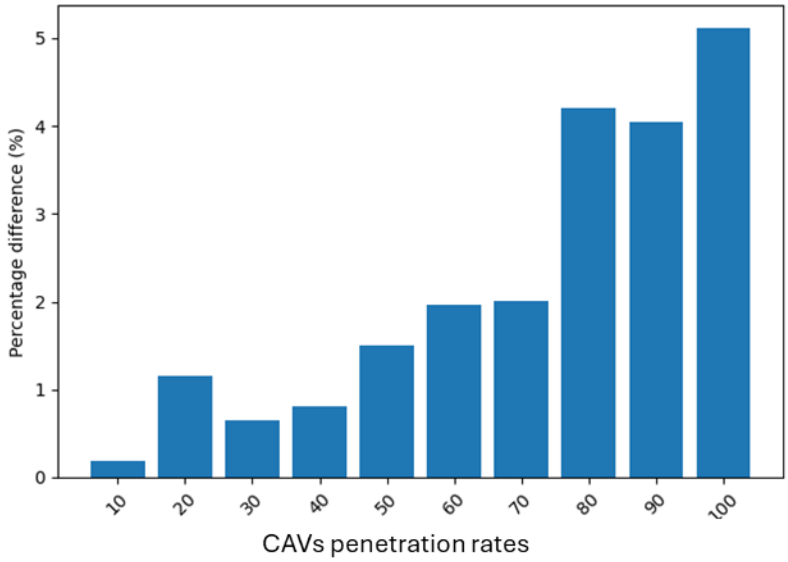


Figure 33: Percentage difference for inserted vehicles, per CAVs penetration rate scenario, compared to the morning peak hour and no planned event baseline scenario.

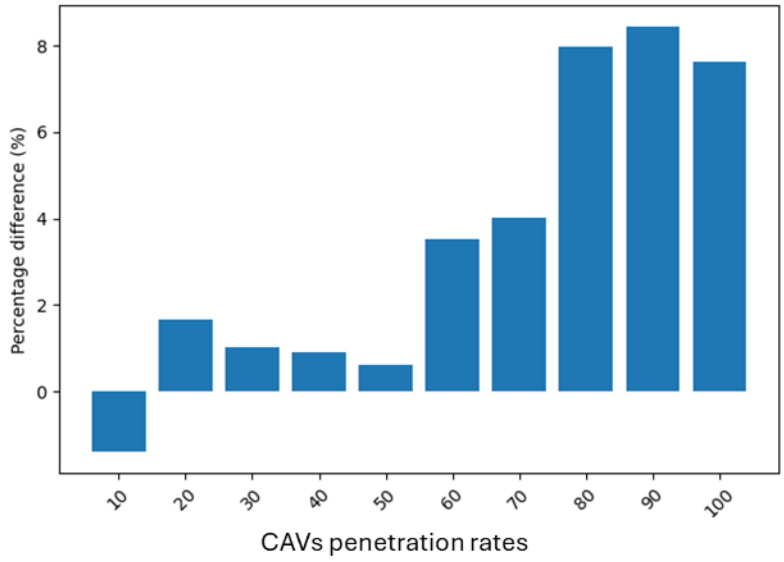


Figure 34: Percentage difference for served vehicles, per CAVs penetration rate scenario, compared to the morning peak hour and no planned event baseline scenario.

Referring to other performance metrics, the mean speed in the network is increased by almost 5%. It is worth noting that, in all CAVs penetration rate scenarios, the mean speed in the Athens testbed is more than 4 metres per second (14.4 kilometres per hour). In addition to all the previously mentioned results, the mean travel time per vehicle is reduced by up to 9%, while the CAVs penetration rate is increased. This is an interesting result which proves the importance of such network wide Traffic Management Strategies. Those results are illustrated in Figure *35* and Figure *36*.

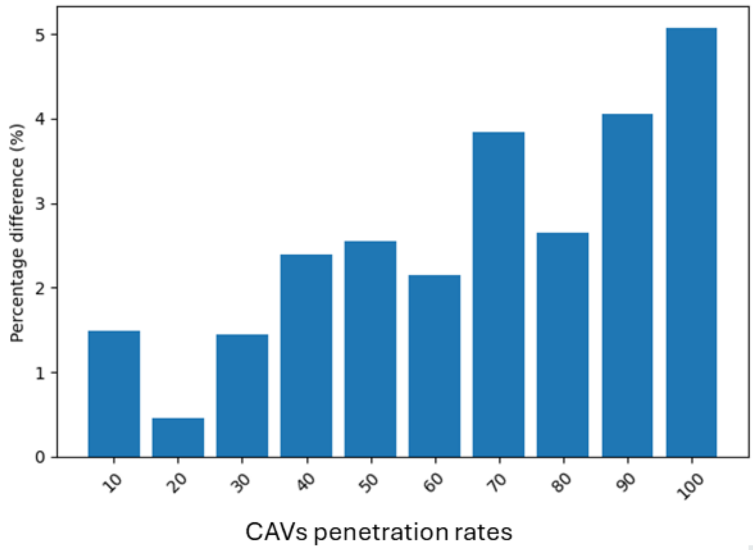


Figure 35: Percentage difference for mean speed, per CAVs penetration rate scenario, compared to the morning peak hour and no planned event baseline scenario.

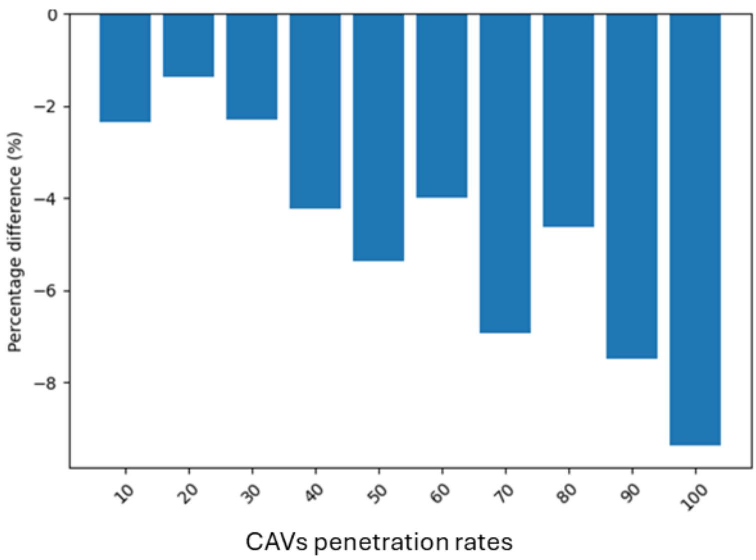


Figure 36: Percentage difference for mean travel time per vehicle, per CAVs penetration rate scenario, compared to the morning peak hour and no planned event baseline scenario.

Following the same approach as above, the scenarios concerning the morning peak hour and the existence of an unplanned event in the network is discussed. Concerning the number of inserted vehicles, the higher the CAVs penetration rate the more vehicles are inserted in the network; the increase is more than 2%, for 100% CAVs penetration rate. It is worth noting that for low CAVs penetration rates of up to 50% the results seem unstable and do not follow in all cases the increasing trend as in the uninterrupted operation of the network during morning peak hour. The same instability in the low CAVs penetration rates appears in the case of served vehicles. What seems as important in the case of served vehicles is that the higher increase appears 70% CAVs penetration rate and not at 100% as in the previous case. Said results are illustrated in Figure *37* and Figure *38* accordingly.

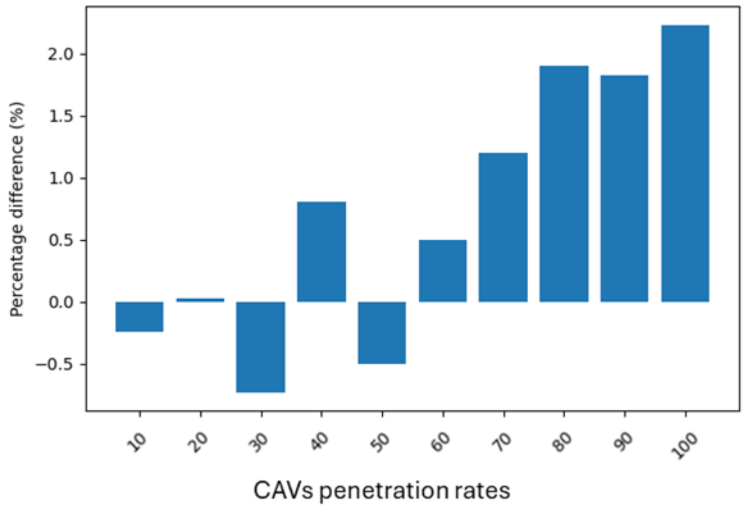


Figure 37: Percentage difference for inserted vehicles, per CAVs penetration rate scenario, compared to the morning peak hour and planned event baseline scenario.

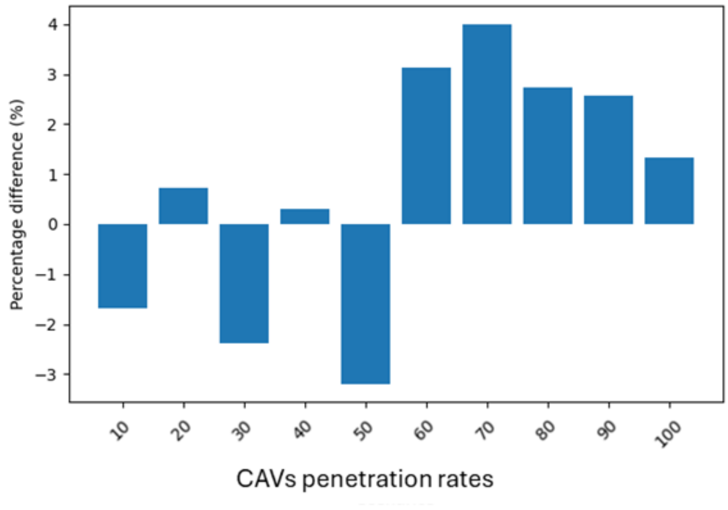


Figure 38: Percentage difference for served vehicles, per CAVs penetration rate scenario, compared to the morning peak hour and planned event baseline scenario.

Concerning the mean speed in the network and the mean travel time per vehicle, it appears that the higher the CAVs penetration rate the best performance gains for the network appear. To be more specific, for 100% CAVs penetration rate, the speed gain is approximately 4% and the mean travel time per vehicle is reduced by approximately 8%. Those results are considered as expected. The way CAVs are modelled in the present Task, in the sense of higher acceleration and less time headway with the leading vehicle, can lead to significant performance gains concerning speed and travel time per vehicle. Said results are illustrated in Figures 18 and 19.

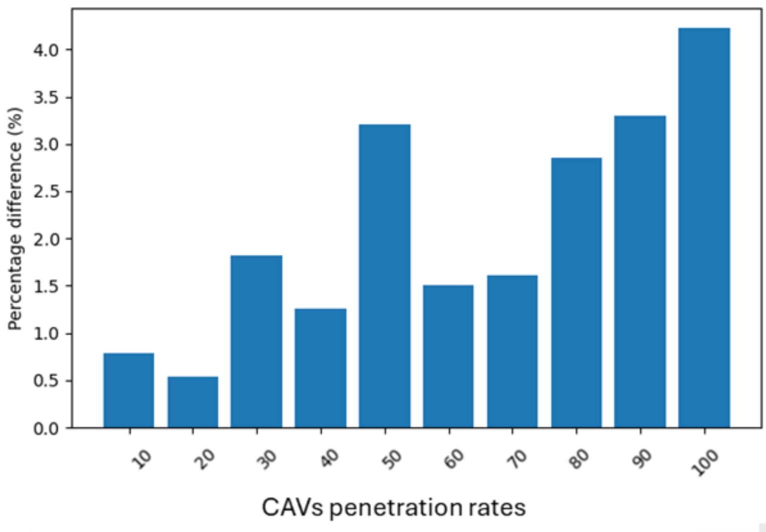


Figure 39: Percentage difference for mean speed, per CAVs penetration rate scenario, compared to the morning peak hour and planned event baseline scenario.

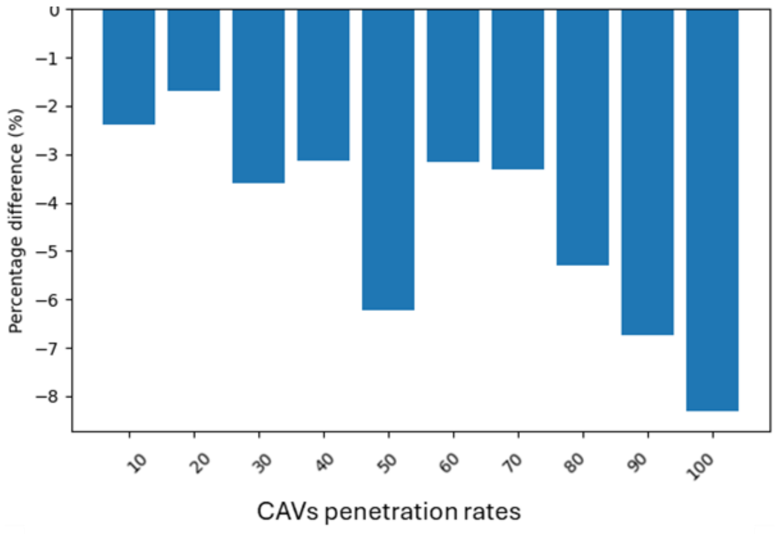


Figure 40: Percentage difference for mean travel time per vehicle, per CAVs penetration rate scenario, compared to the morning peak hour and planned event baseline scenario.

Concerning afternoon peak, the results are more controversial. This was expected however, due to the fact that in afternoon peak the number of throughput movements in the network is reduced and the number of inner movements in the ring road network of Athens is increased. Therefore, since the aTC&CAV subsystem is applied in the throughput movements, its efficiency is expected not be as important as in the cases of morning peak hour. The results for normal uninterrupted operation of the network are illustrated in Figure *41*, Figure *42*, Figure *43* and Figure *44* below.

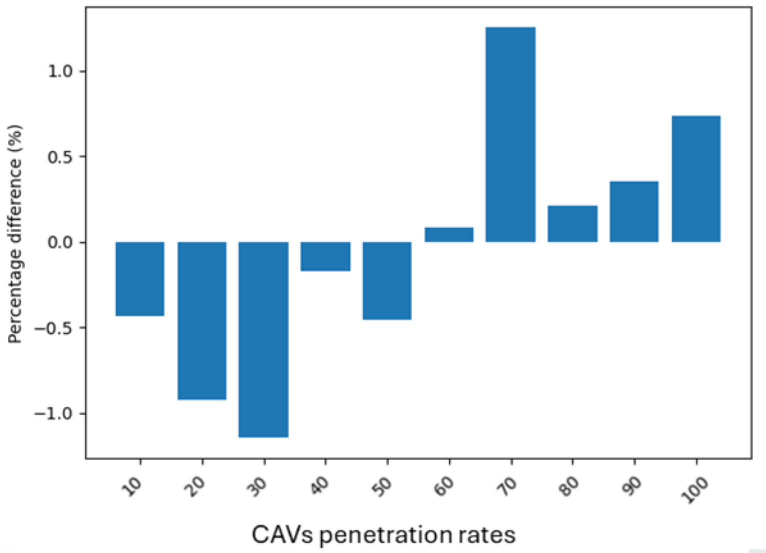


Figure 41: Percentage difference for inserted vehicles, per CAVs penetration rate scenario, compared to the afternoon peak hour and no planned event baseline scenario.

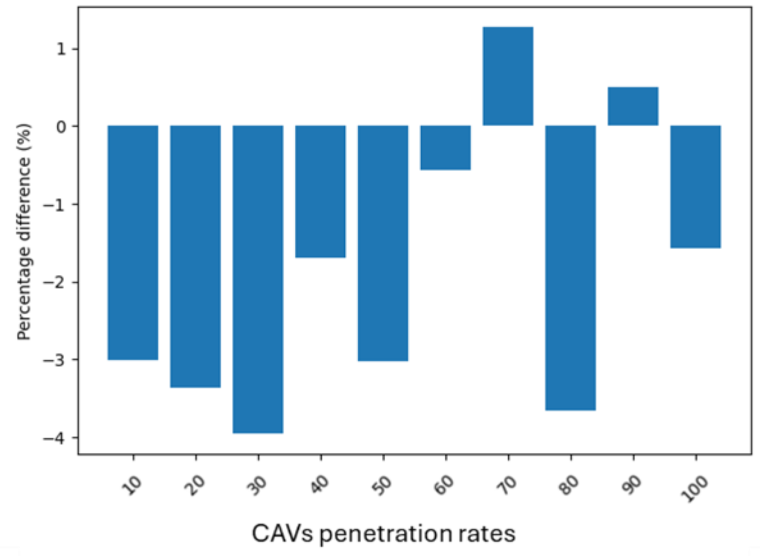


Figure 42: Percentage difference for served vehicles, per CAVs penetration rate scenario, compared to the afternoon peak hour and no planned event baseline scenario.

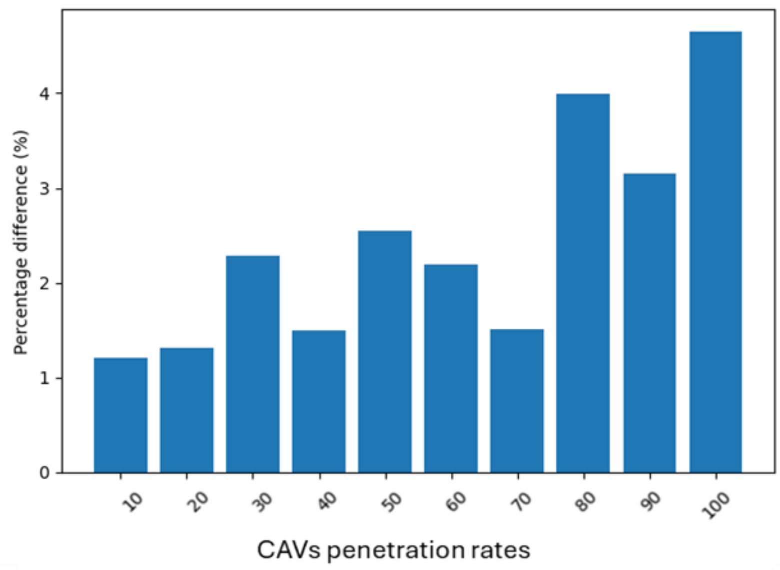


Figure 43: Percentage difference for mean speed, per CAVs penetration rate scenario, compared to the afternoon peak hour and no planned event baseline scenario.

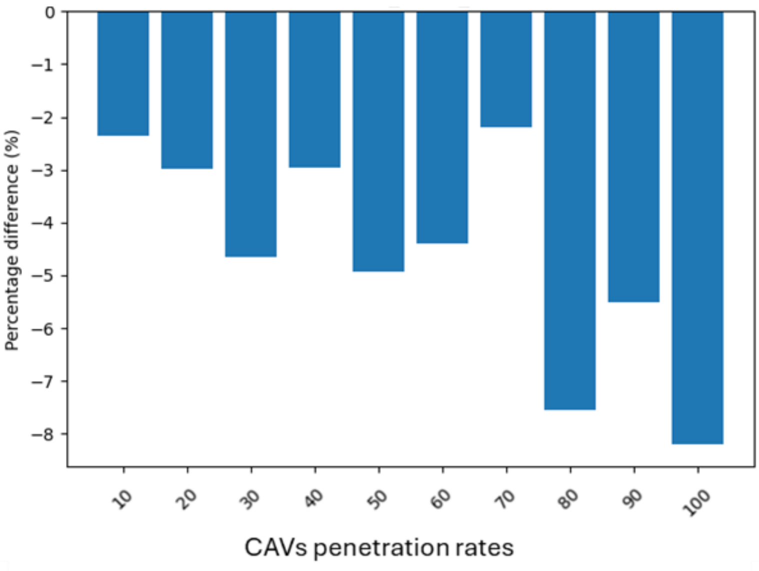


Figure 44: Percentage difference for mean travel time per vehicle, per CAVs penetration rate scenario, compared to the afternoon peak hour and no planned event baseline scenario.

For the vehicles that manage to be inserted in the network during the simulated hour, performance gains are observed for CAVs penetration rates of over 60%; for served vehicles only CAVs penetration rates of 70& and 90% lead to better performance in the network. Especially for 70% CAVs penetration rate, both the number of inserted and the number of served vehicles is increased by approximately 1%.

Concerning mean speed in the network and the mean travel time per vehicle, the results prove the efficiency of the applied subsystem in the network. Mean speed is increased by approximately 5% and mean travel time per vehicle is decreased by more than 8% in 100% CAVs penetration rate.

For afternoon peak hour and the existence of an unplanned event in the network, the results are illustrated in Figure *45*, Figure *46*, Figure *47* and Figure *48*.

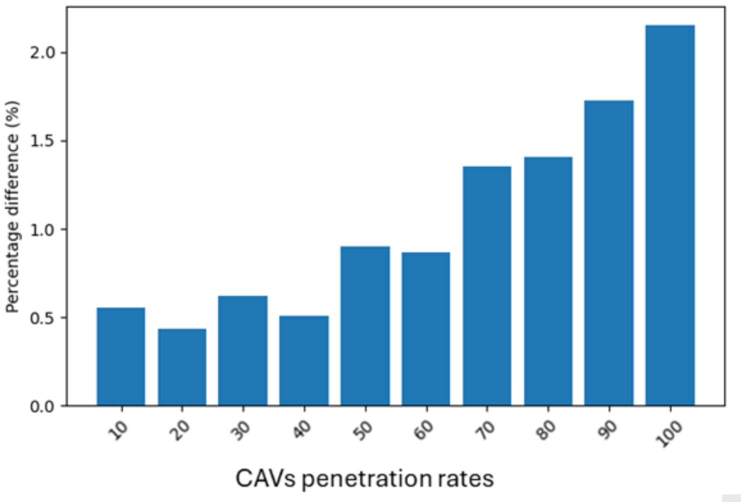


Figure 45: Percentage difference for inserted vehicles, per CAVs penetration rate scenario, compared to the afternoon peak hour and unplanned event baseline scenario.

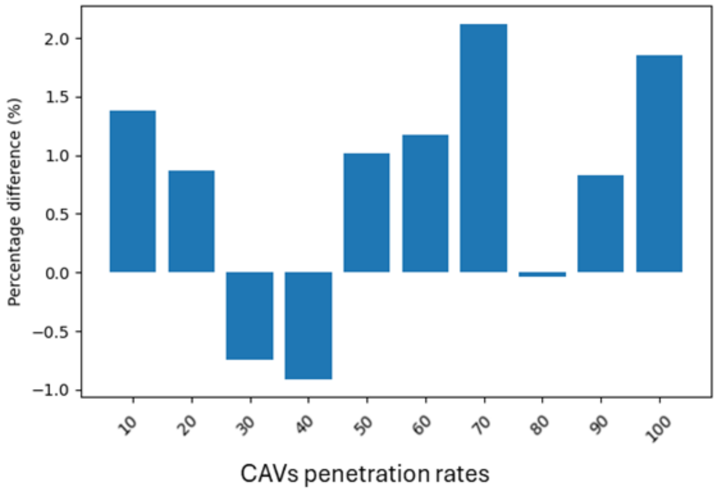


Figure 46: Percentage difference for served vehicles, per CAVs penetration rate scenario, compared to the afternoon peak hour and unplanned event baseline scenario.

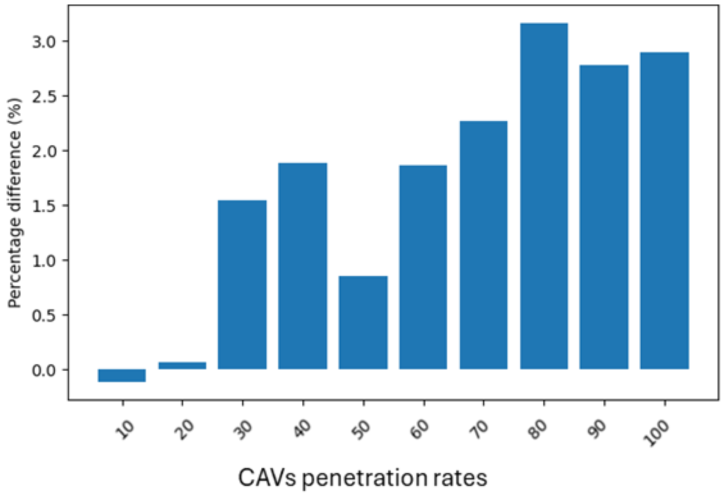


Figure 47: Percentage difference for mean speed, per CAVs penetration rate scenario, compared to the afternoon peak hour and unplanned event baseline scenario.

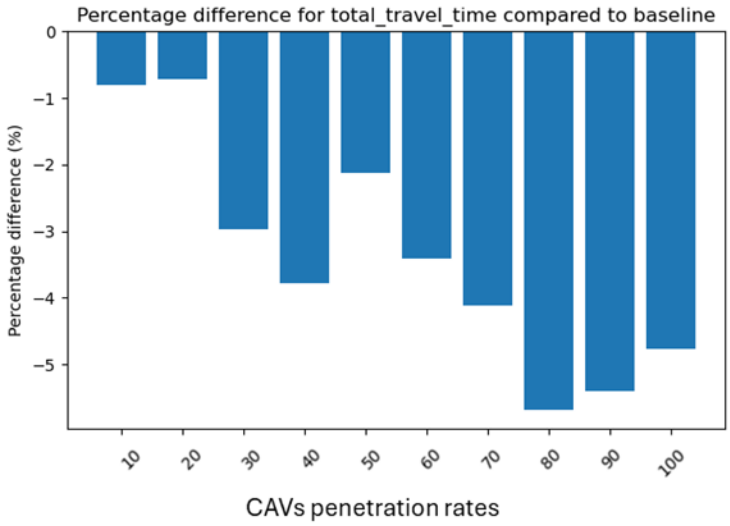


Figure 48: Percentage difference for mean travel time per vehicle, per CAVs penetration rate scenario, compared to the afternoon peak hour and unplanned event baseline scenario.

The results in this case appear more promising compared to the afternoon peak with normal uninterrupted operation of the network. In the majority of the scenarios, the performance gains in the network are significant. Only for served vehicles in low CAVs penetration rates (30% and 40%), results which showcase a worst performance in the network are presented. However, the drop occurred in those cases is below 1% for both CAVs penetration rates.

3.7 Dynamic Congestion Pricing (DCP)

Dynamic Congestion Pricing (DCP) is a traffic management strategy where toll rates are adjusted in real time based on current traffic conditions. The primary goal of DCP is to discourage the use of private cars during peak congestion periods by imposing higher tolls, thus incentivizing drivers to either use public transport (PT) or travel during less congested times. By continually adjusting toll rates, DCP can help distribute traffic more evenly throughout the day, alleviating congestion in high-demand areas and times, and promoting a shift towards more sustainable transportation options like PT. In theory, DCP is an effective way to reduce private car usage and increase the reliance on public transport systems.

However, DCP faces several challenges. One major issue is that while it can reduce private car use, public transport systems may struggle to accommodate the increased demand, particularly during peak hours. Without sufficient coordination between DCP policies and public transport availability, passengers may face overcrowding, delays, or reduced service quality. Another problem is the lack of flexibility in reacting to sudden changes in demand or supply, such as unplanned events, road closures, or disruptions in PT services. Additionally, there can be equity concerns, as DCP might disproportionately affect lower-income drivers who are less able to absorb higher toll costs or shift to public transport.

The TANGENT approach efficiently implements Dynamic Congestion Pricing (DCP) by leveraging Computer Optimised Design (COD) to determine the optimal or near-optimal pricing policy in real time. COD uses advanced simulation and optimization techniques to evaluate traffic conditions and determine toll adjustments that will effectively balance demand between private car use and public transport (PT). By continuously analysing traffic data, TANGENT dynamically adjusts tolls based on current congestion levels, ensuring that toll rates are not only responsive but also strategically aligned with the overall traffic and public transport network.

The key performance indicators (KPIs) for optimising Dynamic Congestion Pricing (DCP) include the level of congestion both inside the DCP zone and in its surrounding areas, total revenue generated by the pricing policy, and the reduction of system-wide emissions. By monitoring and adjusting these KPIs, the DCP aims to balance traffic flow within and around the pricing zone, ensuring that congestion is not simply shifted to other areas. Additionally, the total revenue obtained from the pricing policy can be reinvested into public transport or infrastructure improvements, while emission reductions contribute to environmental sustainability and long-term urban mobility goals.

3.7.1 Methodology

The Dynamic Congestion Pricing (DCP) testing framework for the Athens area is designed to assess the effectiveness of toll adjustments in managing traffic flow during special events. Using the Aimsun traffic simulation model, this framework incorporates real-world traffic conditions of the area. The toll function is modelled using a sixth-degree polynomial, allowing for a flexible and highly responsive toll pricing system that adjusts dynamically based on current traffic conditions within the DCP zone.

On an event day, when traffic demand increases significantly, the framework tests the performance of the DCP by simulating various toll pricing scenarios and comparing them against a baseline where no DCP is applied. This approach evaluates how well the DCP can reduce congestion within the zone and its surrounding areas, control the flow of vehicles, and maintain system efficiency. The simulation also measures total revenue generated by the pricing policy and its impact on system-wide emissions. By comparing the results with the baseline scenario, this testing framework provides insights into the efficiency and environmental benefits of the DCP under real-time, event-driven traffic conditions in a highly congested urban area

3.7.2 Testing of the subsystem

After optimising the Dynamic Congestion Pricing (DCP) system, the results indicate significant improvements in various traffic performance metrics. Within the pricing zone, congestion is reduced by 23.60%, demonstrating the effectiveness of the toll system in managing traffic flow and decreasing congestion on the bottlenecks. Furthermore, congestion outside the pricing zone also improved by 22.69%. These findings suggest that DCP strategy is not only improving traffic performance inside the pricing zone but also improving the immediate area by alleviating the traffic. For evaluating the traffic congestion level, we used volume to the capacity ratio (V/C) as a key indicator. Additionally, system-wide emissions were reduced by 6%, highlighting the environmental benefits of optimising traffic flow through DCP. In terms of financial performance, the DCP system successfully generated a profit of 58 Euros, showcasing its potential for both traffic and revenue management. These results collectively underscore the effectiveness of DCP optimization in improving urban mobility, reducing environmental impacts, and generating economic benefits.

Impact of DCP on Density of the network

The network was not very highly congested initially, so while comparing the results of density of the network, there is only a marginal improvement in the traffic density of the network after the DCP strategy was applied. But the overall performance of the system has improved, which lead to more optimised traffic flow (Figure *49*and Figure *50*).

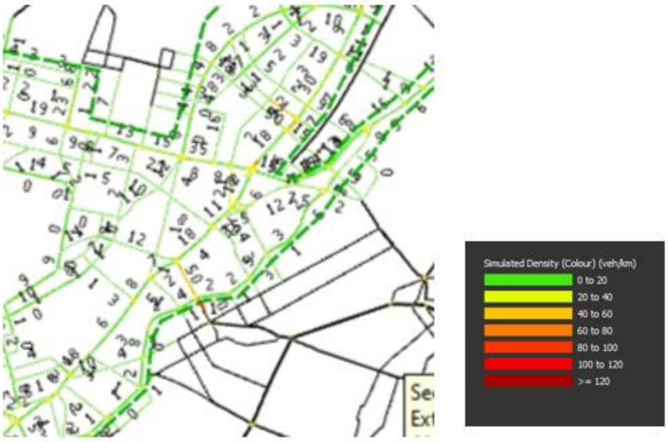


Figure 49: Baseline Density

Figure 50: Optimised Density

Impact of DCP on Delay-time of the Network

The delay time (seconds) of the network is significantly decreased on the road links inside the pricing zone, even if the traffic density is not decreased substantially. Because the pricing strategies don't always lower the density but the main goal is to reduce the congestion by improving the traffic flow. The dynamic congestion pricing focused on reducing the shockwave pattern in traffic by lowering the delay time, and improving the traffic speed, even if the density of the network has not decreased significantly.

The results from the following figures (Figure *51* and Figure *52*) show that the effective management of traffic through DCP enhanced the overall travel times of the system.

Figure 51: Baseline Delay time

Figure 52: Optimised Delay time

3.8 Consensus Mechanism

The goal of Task 5.4, is to develop a comprehensive, automated decision-support tool designed to aid decision-making and foster consensus among stakeholders with divergent opinions. Drawing from actual stakeholder preferences and cooperation patterns obtained through structured surveys, our work, detailed in D5.4 proposes a framework that realistically models the key stages of the consensus-reaching process, until the reach of consensus between stakeholders.

For testing the modelling framework, the same four-step methodology described in section 3.2 used for testing the WP3 module, was followed. The adaptation of this methodology to the specificities of the consensus mechanism is outlined below:

3.8.1 Methodology

Step A: Testing sample collection

During the initial phase of testing, the stakeholder cooperation survey (SCS) was distributed to commuters from each case study city, including Manchester. The SCS questionnaire is included in the Annex of D5.4. To collect the necessary sample, each case study was asked to identify 3 stakeholders. Unlike WP3, case study contact persons directly provided the survey material to stakeholders and collected the completed questionnaires, which were then forwarded to NTUA.

Step B: Execution of the consensus mechanism

The consensus mechanism is applied and its output, in terms of consensual opinions regarding stakeholder priorities when a particular traffic management strategy is implemented, is communicated to participants.

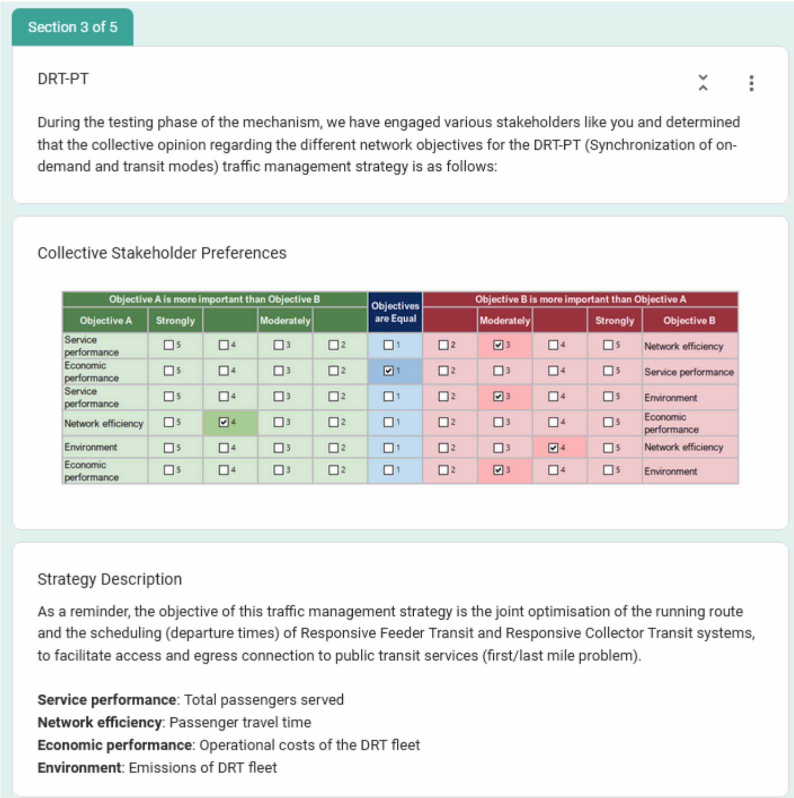
Given that not all strategies are relevant to all stakeholders (since the entity they represent might not be involved in the decision-making process for one or more TMS), the opinions communicated were individualised and determined by their responses to the TBS in Step A. For example, the material communicated to the testers who responded that DRT-PT is relevant for their city and organisations, are provided below (Figure 33)

Step C: Feedback Survey

As with the testing of WP3 modules, stakeholders were contacted again by NTUA to complete a follow up feedback survey to assess both the questionnaire and the results of the opinion modelling. The distribution of the survey occurred from 19/02/2024 to 28/02/2024.

Step D: Reporting on the results

The feedback collected during the testing is presented in the "Results" section that follows. Some interim results have already been presented internally to the consortium during the WP7 bi-weekly meetings dedicated to subsystem testing and the consortium's monthly audio meetings.



Section 3 of 5

DRT-PT

During the testing phase of the mechanism, we have engaged various stakeholders like you and determined that the collective opinion regarding the different network objectives for the DRT-PT (Synchronization of on-demand and transit modes) traffic management strategy is as follows:

Collective Stakeholder Preferences

Objective A is more important than Objective B					Objectives are Equal	Objective B is more important than Objective A				
Objective A	Strongly		Moderately				Moderately		Strongly	Objective B
Service performance	☐ 5	☐ 4	☐ 3	☐ 2	☐ 1	☐ 2	☑ 3	☐ 4	☐ 5	Network efficiency
Economic performance	☐ 5	☐ 4	☐ 3	☐ 2	☑ 1	☐ 2	☐ 3	☐ 4	☐ 5	Service performance
Service performance	☐ 5	☐ 4	☐ 3	☐ 2	☐ 1	☐ 2	☑ 3	☐ 4	☐ 5	Environment
Network efficiency	☐ 5	☑ 4	☐ 3	☐ 2	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	Economic performance
Environment	☐ 5	☐ 4	☐ 3	☐ 2	☐ 1	☐ 2	☐ 3	☑ 4	☐ 5	Network efficiency
Economic performance	☐ 5	☐ 4	☐ 3	☐ 2	☐ 1	☐ 2	☑ 3	☐ 4	☐ 5	Environment

Strategy Description

As a reminder, the objective of this traffic management strategy is the joint optimisation of the running route and the scheduling (departure times) of Responsive Feeder Transit and Responsive Collector Transit systems, to facilitate access and egress connection to public transit services (first/last mile problem).

Service performance: Total passengers served
Network efficiency: Passenger travel time
Economic performance: Operational costs of the DRT fleet
Environment: Emissions of DRT fleet

Figure 53: DRT-PT - Communication of opinion modelling results

3.8.2 Actions achieved and results

A total of 12 stakeholders from all case studies, including 3 from Athens, were contacted by case studies and NTUA. Six stakeholders responded to the feedback survey, and their responses are pooled together and analysed below.

Stakeholders found the questions of the survey to be rather straightforward and understandable (Figure *54*).

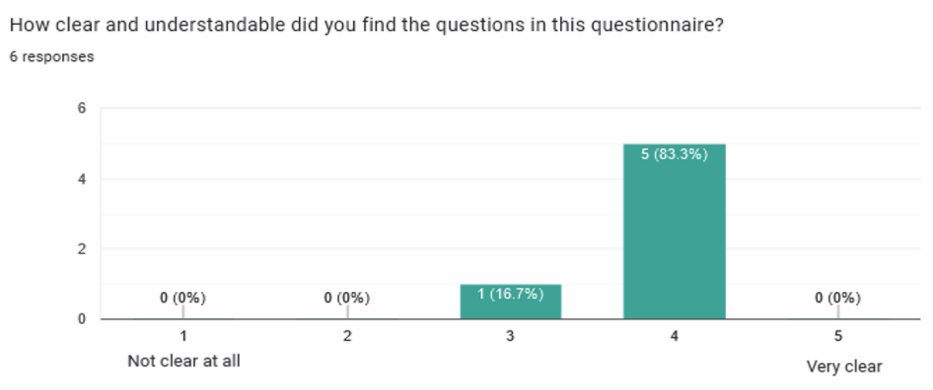


Figure 54: How clear and understandable did you find the questions in this questionnaire?

Perhaps unexpectedly then, 50% of respondents considered that a few questions appeared to be out of context (Figure 55). This issue is attributed to two factors: first, the survey elicited both stakeholder preferences and the institutional relationships between the entities they represent. Although related, these themes are distinct, which is uncommon in similar surveys that are usually highly focused. Additionally, the indicators used for eliciting relationships, such as the frequency of data exchanges between entities, do not directly reveal their relevance to the overall philosophy of the questionnaire.

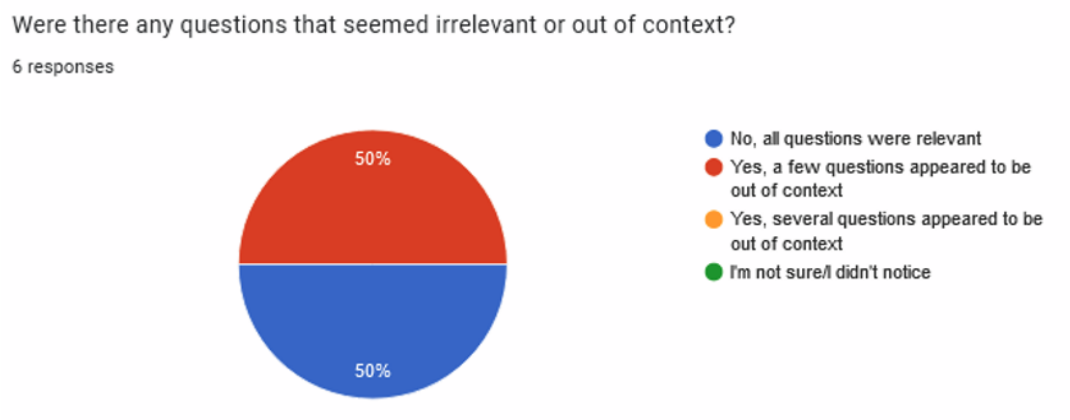


Figure 55: Were there any questions that seemed irrelevant or out of context?

Nevertheless, the instructions provided with the questionnaire were deemed adequate by participants (Figure 56).

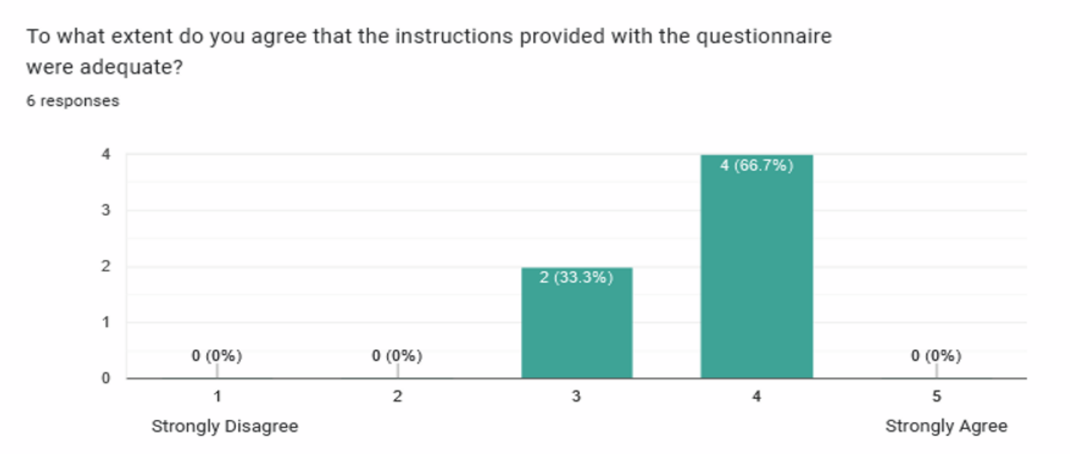


Figure 56: To what extent do you agree that the instructions provided with the questionnaire were adequate?

Opinions were more mixed regarding the overall formatting of the questionnaire. Unlike traditional question design (multiple-choice, open-ended, etc.), the need to provide institutional relationship information by filling a matrix in an Excel format (Figure 57) requires more cognitive effort and may not be immediately intuitive.

Stakeholder Category	Stakeholder Name	**B1**. Communication frequency	**B2**. Integration	**B3**. Data
Government & Authorities				
European Union				
Ministry of transport	Department for Transport	4. 1-2 times/year	2. Partnership: We work together as a formal team with specified responsibilities to achieve common program goals (note: responsibility for each organization is usually outlined in a Memorandum of Understanding or other agreement).	4. Degree 4 – Seamless sharing of information: Universal interpretation of information through data processing based on cooperating applications
Other national ministry				
Regional government				
Local authority				
Neighbouring city	Local councils surrounding Greater Manchester and those across (mainly) North of England	4. 1-2 times/year	3. Collaboration: We work side-by-side and actively pursue opportunities to work together as an informal team (i.e., do not establish a formal agreement; work together "in the spirit of collaboration").	1. Degree 1 – Unstructured data exchange: Exchange of human-interpretable unstructured data such as the text found in operational estimates, analyses and papers
Local transport authority				

Figure 57: Stakeholder relations matrix

The length of the questionnaire was also deemed excessive (Figure *58*), with 67% of respondents finding it too long. This result was anticipated during internal test runs of the survey. The decision to proceed was based on the following: this survey targeted the few stakeholders knowledgeable about the decision-making, cooperation, and communication patterns among stakeholders involved in the transport network's management. For instance, the 14 questionnaires collected in the Stakeholder Cooperation Survey contrast with the 1,859 responses across the four case studies for the TBS, aimed at the general population. To compensate for the few respondents, we opted to demand more cognitive effort from participating stakeholders, facilitated by case study leaders who primarily distributed the questionnaire within their professional circles. Thus, the 14 questionnaires documented 248 cooperation instances and 46 opinion matrices, numbers suitable for the opinion modelling. This cognitive load was significant for some respondents, as noted by two respondents in open-ended questions on general comments or suggestions on the questionnaire content and format.

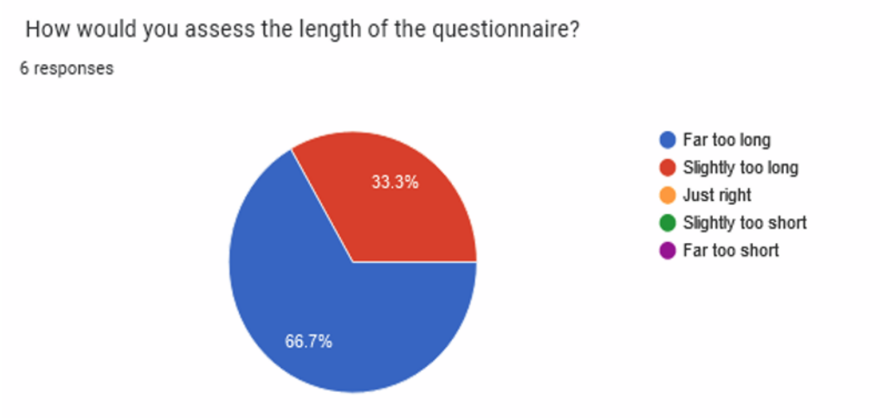


Figure 58: How would you assess the length of the questionnaire?

This cognitive load is also reflected in the fact that most (50%) participants completed the questionnaire in 25 to 30 minutes (Figure 59). For reference, the survey was initially timed at 25 minutes, a duration that most participants did not significantly exceed.

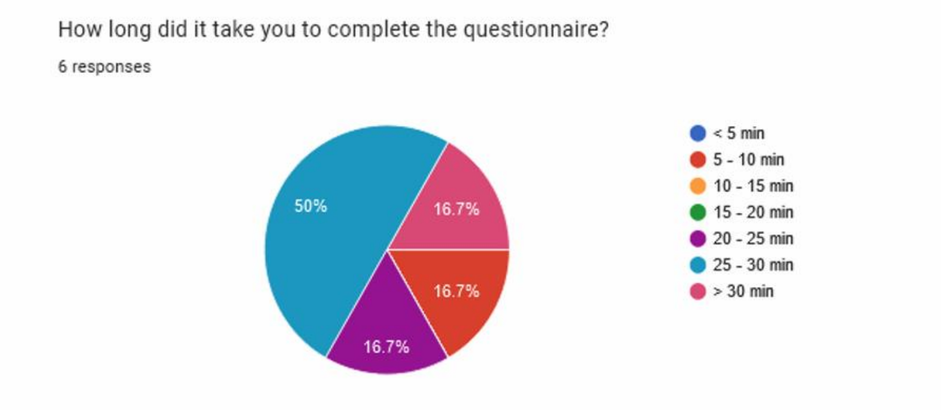


Figure 59: How long did it take you to complete the questionnaire?

Modelling insights

As discussed in D5.4, the opinion modification of the consensual preferences has two main objectives. First, the original opinions of the stakeholders must be preserved to the greatest extent possible, ensuring that each stakeholder's unique perspectives and insights are respected and incorporated into the decision-making process. Second, the consensual collective preference must be accepted by all stakeholders, as this sense of ownership enhances the legitimacy of the decision-making process and ensures that the policies (in this case, traffic management strategies) are more likely to be effectively implemented.

The consensus mechanism successfully achieves both objectives, as stakeholders have explicitly accepted the legitimacy of the consensual opinion (Figure 60) and feel that the consensual opinion is not significantly divergent from their own. This result serves as a robust indicator of the consensus mechanism's capacity to determine the true consensual opinion.

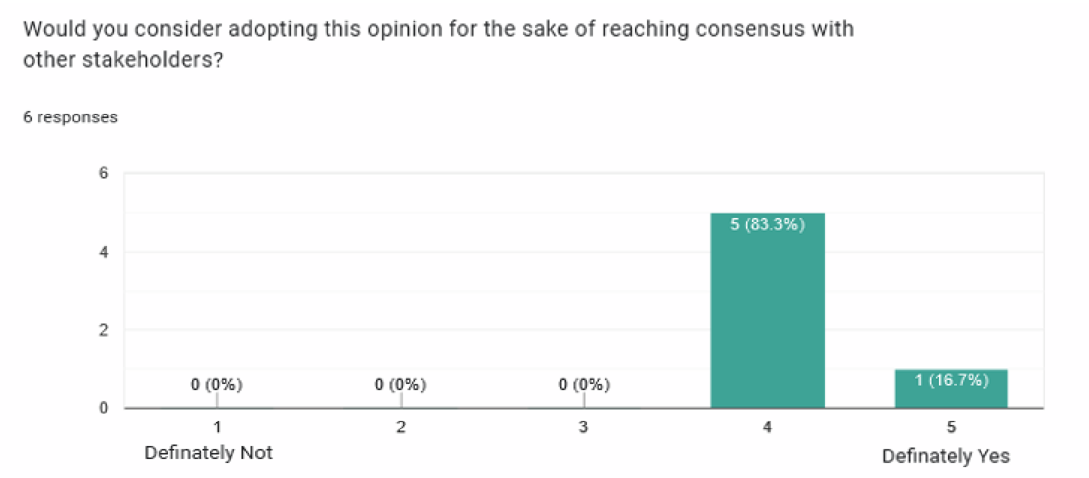


Figure 60: Would you consider adopting this opinion for the sake of reaching consensus with other stakeholders?

4 Lessons learned and next steps

4.1 The lessons learned for the Case Study of Athens

4.1.1 Data sharing / availability / reliability

In the Case Study of Athens, there is a significant lack of data concerning both the traffic conditions in the network and the operation of public transport. Said data is historic and not provided at real-time. Also, the finally provided data is at a one-hour resolution without the application of data cleansing, data fusion, and data harmonisation techniques. To this end, the tools developed in the framework of TANGENT project can assist towards properly analysing and utilising the data provided for the Athens urban transport network.

4.1.2 Local feedback to assess modelling quality

Testing the travel behaviour and consensus mechanism modelling pipelines by eliciting local stakeholder feedback from both experts and the public revealed interesting insights on how to ensure the quality of modelling inputs and outputs.

- The feedback process revealed that surveys and models are more effective when their clarity, relevance, and usability are tested with end users. Clear questions, intuitive formatting, and the ability to revisit answers enhance the user experience and data reliability.
- Detailed questionnaires provide richer insights, their length and complexity should be balanced to maintain participant engagement and satisfaction.
- Testing results against local commuter intuitions ensures the model's applicability and reliability. Engaging commuters in feedback validates whether predictions align with real-world expectations, enhancing trust in the modelling framework.

4.1.3 Functionalities of TANGENT

Future Status

TANGENT’s predictive capabilities can assist towards identifying an event in the urban road network of Athens, predicting its impacts, and selecting the proper network-wide Traffic Management Strategies to mitigate the impact of the identified event.

Cooperative Incident Management

Related to this functionality, the computational resource requirement and algorithmic time complexities were higher than expected. The future way should be to use parallel implementation and asynchronous computing paradigm.

Smart Network Load Balance

Concerning this functionality, and due to a higher-than-expected technical complexity of the SVCC subsystem developed in WP5, this functionality was not developed and tested in the Case Study of Athens as initially expected. To tackle this fragmentation, the National Technical University of Athens proceeded with emulating some expected results of this subsystem, in the sense of identifying the throughput movements in the Athens testbed and gradually increase the percentage rate of CAVs in said movements. The retrieved results prove the significance of CAVs-related network-wide Traffic Management Strategies towards improving the operational performance of urban road networks.

Simulation of Pre-defined Scenarios

For the pre-defined scenarios, the DCP strategy is applied. This application is implemented in the Athens testbed after considering the results of Work Package 3 [10], which revealed the stated preference of drivers moving in the urban road network of Athens is such a strategy is applied. The results are interesting. The implementation of such a network-wide Traffic Management Strategy allows for utilising the capacity of the network in an optimised manner, but the increased number of vehicles entered in the network led to reduced mean speed and increased travel times.

5 Conclusions

The present Deliverable, Deliverable 7.6, aimed to present all the actions related to the Case Study of Athens which are relevant to the testing of the subsystems and Services developed in the framework of the TANGENT project.

The testing activities included the testing of the subsystems developed in the framework of the TANGENT project, in collaboration with the technical partners. The aim of the testing was to assess the efficiency of the developed subsystems. The subsystems provided by the technical partners were imported in the Athens testbed and evaluated based on the outputs of the model.

Key insights were gained in the process of testing the subsystems developed in the framework of TANGENT project. At first, the results prove that network wide Traffic Management Strategies have the potential to improve the operational performance of urban road networks. It is worth noting that for some subsystems, their application was a simple emulation of the expected results. Despite that fragmentation, the results are promising. The lack of data was addressed through multiple steps, combining available data with synthetic, simulation-based inputs. This approach enabled analyses that would not have been possible otherwise. Additionally, algorithmic complexities encountered throughout the process were identified and tackled systematically, while feedback collected from local commuters through surveys has highlighted the importance of user-centric design and the balance between detail and usability in data collection, ensuring the relevance and clarity of inputs and outputs.

The next steps for the Case Study of Athens include the efforts for providing even more efficient network wide Traffic Management Strategies which are going to operate either on their own or as a bundle of services through an innovative Traffic Management Strategies Sandbox. Such a solution shall be able to propose the proper network wide Traffic Management Strategies based on the current and forecasted conditions in the network. Even before the actual implementation of traffic management strategies in Athens though, the current virtual testing phase provides substantial insights and quantifiable data to policymakers about how the transport system will respond during the introduction of these strategies or the occurrence of unexpected events while the TANGENT solution is operational. By addressing multiple dimensions of urban transport challenges, including disruptions like heavy rainfall and flooding, virtual testing provides actionable insights for identifying bottlenecks and critical links, empowering proactive infrastructure adjustments and ensuring safety and congestion control. Insights from the virtual testing of a DRT service in Paiania provide valuable information to local stakeholders about the system's capacity to bridge the service gap between low-density peri-urban areas and the central public transport network, while simulations of various service types and fleet sizes enable the selection of the most appropriate system, considering emerging cost and operational constraints during implementation. Virtual synchronization of PTTC in Athens has resulted in lower emissions and smoother traffic flows, providing compelling evidence for the development of green transport corridors, prioritizing public transit, and initiating discussions about resource allocation for dynamic traffic control and vehicle-to-infrastructure integration. The testing of SVCC testing reveals the potential of CAV fleets to reduce delays, optimize traffic efficiency, and improve speeds in urban corridors, serving as a foundation for a cost-benefit analysis to compare infrastructure investment needs with the long-term gains from CAV penetration. Eventually, the dynamic congestion pricing module testing provides robust insights into how well dynamic pricing can manage traffic demand in Athens centre, a matter already drawing considerable attention from local stakeholders.

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