Fleet and traffic management systems
for conducting future cooperative mobility

D1.3 Detailed use-case specifications and their KPIs

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Primary Author(s)	Oskar Eikenbroek, Zakir Farahmand, Eric van Berkum | University of Twente
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Project Coordinator	Flavien Massi | Flavien.MASSI@netcompany-intrasoft.com
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CONTRIBUTORS

Name	Organization	Name	Organization
Oskar Eikenbroek	University of Twente	Miha Cimperman	JSI
Zakir Farahmand	University of Twente	Rok Stauber	GoOpti
Eric van Berkum	University of Twente	Luka Bradesko	JSI
Raquel Sánchez	Nommon	Athina Tympakianaki	AIMSUN
Emmanouil Nisyrios	NTUA	Athanasios Grigoropoulos	Netcompany Intrasoft
Konstantinos Gkiotsalitis	NTUA	Jaime Pizarroso	Nommon
Anotnio Pellicer	AIMSUN	Leirre Serrano	Deusto
Arka Ghosh	Deusto		

FORMAL REVIEWERS

Name	Organization	Date
Paola Lanzi, Elisa Spiller	DeepBlue	2023-04-21
Konstantinos Gkiotsalitis, Emmanouil Nisyrios	NTUA	2023-04-21

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1 EXECUTIVE SUMMARY

The goal of the CONDUCTOR project is to design, integrate and demonstrate advanced, high-level traffic and fleet management for the efficient and optimal transport of both passengers and goods. For this, existing models will be upgraded, and the developed technologies will be integrated and validated through three use cases (UCs). This report, as a result of Task 1.5 of the project, presents the detailed use case specifications as well as the key performance indicators (KPIs) that will be used in the pilot projects which will be conducted to test the CONDUCTOR innovations.

Since the to-be-tested functionalities differ per pilot, the deliverable presents pilot-specific use case specifications and KPIs. The UC1 Athens pilot project focuses on the synchronisation of schedules of conventional services including metro, bus, and trams to allow for a reduction in door-to-door travel times. The UC1 Madrid pilot project considers the integration of connected and autonomous vehicles into traffic management services to improve traffic network recovery after planned and unplanned events. For this pilot, the impact of various penetration levels of CAVs on the road is considered in a simulation environment of the M-30 ring road of Madrid, including the adjacent urban road network. UC1 Almelo considers conditional freight signal priority combined with green light optimised speed advice along a corridor to improve the fuel consumption of heavy-duty vehicles through a reduction of the number of stops. UC2 focuses on demand-responsive airport shuttle services from (to) Slovenian cities to (from) Italian airports. Specifically, predictive analytics are integrated in the planning processes to improve the service quality for users. The simulation-based Madrid pilot project for UC3 on urban logistics integrates freight and passenger transport through the allocation of capacity of on-demand transport vehicles for the delivery of goods.

Use case models describe the functional requirements of a system, specifying how the system under consideration is supposed to interact with the user and other actors. Such specifications benefit further development activities and elicit and simulate discussion between stakeholders since use cases are easy to understand and follow without in-detailed knowledge. An iterative approach has been adopted in close collaboration with stakeholders to establish the use cases. Per pilot project, various scenarios have been identified, and for each scenario, among other things, the trigger conditions, main process flow and termination conditions are reported in this deliverable.

Key performance indicators are used for monitoring and evaluation purposes, measuring progress towards the defined goals. Such indicators are typically part of a larger assessment framework. In the context of measuring progress, a transition is happening - and recent (European) research and reports highlight the relevance of assessing the positive and negative impact not only for the economy but also for the environment and society, including a differentiation between user groups. In the light of this trend, this report presents a comprehensive multi-dimensional framework to monitor and evaluate the impact of the CONDUCTOR functionalities in the pilots. The framework considers four groups or dimensions of KPIs: technical, economic, environmental, and social KPIs. By allowing for use case and site-specific indicators, local challenges are additionally included and although they do not directly transfer to other sites, the included groups assure assessment along the dimensions of sustainable development.

Chapter 8 of this report provides an overview of the defined KPIs, identifying impact domains of CCAM beyond the individual pilots. In fact, CCAM may impact the efficiency, quality and reliability of passenger transport and freight transport services as well the network-wide traffic conditions. From a business perspective, CCAM is expected to impact business performance and flexibility. On an environmental level, the defined KPIs cover substance emissions and noise. The CONDUCTOR social KPIs consider both the safety impacts of the functionalities as well as the acceptance of different user groups, essential for the larger-scale implementation and adoption of the innovations.

These KPIs will particularly be used for the tasks that are part of work package 5, focusing on validation and impact assessment.

Keywords: CCAM, Impact assessment, Use case, System requirements, Key performance indicators

2 INTRODUCTION

2.1 Objectives of the deliverable

The CONDUCTOR project's goal is to design, integrate and demonstrate advanced, high-level traffic and fleet management that will allow efficient and globally optimal transport of passengers and goods while ensuring seamless multimodality and interoperability[1]. Within CONDUCTOR, existing technologies and models are upgraded, allowing for a future in which autonomous vehicles are at the centre of cities and where transport authorities and operators can coordinate traffic and fleets in a flexible, responsive, and centralized manner. As such, urban traffic congestion and the corresponding negative externalities will decrease, and the quality of life will improve.

The developed technologies will be integrated and validated through three use cases (UCs). This deliverable D1.3, resulting from the activities employed as part of Task 1.5 – "Detailed specifications of use cases and their KPIs", introduces the UCs and provides an in-detailed description of each use case, including a specification of the functional requirements, the research objectives, the scenarios to be considered, datasets to be used and key performance indicators (KPIs) to be analysed.

This document was developed in the context of WP1 ("Specifications and needs for future CCAM"). The work package has the objective to gather stakeholder recommendations and user requirements, specifying the use cases and KPIs, and specifying the future mobility system architecture and required data sources. In this deliverable, a detailed specification of the functional requirements of the use cases is included as well as an overview of how to measure progress regarding the success conditions. In fact, the results of this deliverable will be used to upgrade technologies and for validation purposes, i.e., to verify whether the following specific objectives of CONDUCTOR are met [1]:

- O1: To demonstrate traffic and fleet management to integrate CCAM for people and goods
- O2: To address intermodal interfaces and interoperability between traffic management systems
- O3: To test and demonstrate advanced simulation models in real-life traffic conditions considering different priorities
- O4: To demonstrate optimised mobility network load balancing
- O5: To consider governance of the traffic management system considering user needs

The deliverable builds upon the results of the other deliverables produced in the context of WP1. Deliverable D1.1 – "Report on user needs and social innovations", resulting from the activities employed in Tasks 1.1 and 1.2, establishes an understanding of the *context* in which each use case will take place. This context includes the regulatory and social requirements and an overview of the key stakeholders and users, including their requirements and needs. Deliverable D1.2 – "Specification of the future mobility system and data sources" presents the results of Tasks 1.3 and 1.4, specifying the data sources that are used for each use case including a description of the to-be-used and upgraded components and scenarios to be considered. Deliverable D1.3, on the other hand, establishes the context-dependent system requirements by providing an in-detail description

[1] https://conductor-project.eu/?show=about

of the functionalities of the system, understandable even for stakeholders without deep knowledge about the system under consideration [2]. Further, based on the available data sources, this deliverable lists the KPIs that will be used for impact assessment, i.e., to monitor and evaluate progress with respect to the CONDUCTOR objectives and the identification and quantification of the potential effects of innovations beyond the defined objectives.

The results presented in this deliverable will be used throughout the CONDUCTOR project. Specifically, the KPIs will be incorporated in the extended models (WP2 – "Models for adaptation to CCAM" and WP3 – "Methods for supporting CCAM"). WP2 is concerned with the adaptation and implementation of traffic management, fleet management, multi-modality, simulation and governance models. WP3 focuses on the selection and implementation of techniques for data analyses, dynamic optimisation, network load balancing and anomaly detection. The results of this deliverable benefit the activities that will be conducted in the context of WP2 and WP3, for example, by using the assessment framework in an ex-ante simulation setting for the *a priori* refinement of models. Further, the use case specifications can be used as input for the development activities related to WP2 and WP3. Apart from WP2 and WP3, the results of this deliverable will be particularly used for validation and impact assessment in the following deliverables:

- D5.1 – "Validation Strategy and Plan", providing a consistent validation strategy and plan, in which KPIs and overall validation objectives and hypotheses of CONDUCTOR are addressed (related to task T5.4).
- D5.2 – "Impact evaluation framework and dedicated KPIs", providing the impact evaluation framework to be applied to the different solutions and use cases – including the impact assessment strategy which will be used in WP5 (related to task T5.5)
- D5.3 – "Report on Use cases execution and their validation", providing the documentation with respect to the three use cases including implementation of the validation strategy and plan (related to tasks T5.1, T5.2, T5.3 and T5.4).
- D5.4 – "Report on impact assessment of Use cases", discussing the Impact evaluation framework of deliverable D5.2 will be implemented by making use of the data associated with each of the three use cases (related to tasks T5.1, T5.2, T5.3 and T5.5)

2.2 Use Cases

The developed functionalities of CONDUCTOR as a result of model integration will be validated through use case pilots. The role of the use case is to demonstrate and evaluate future mobility system functionalities. Each use case covers multiple aspects of the interoperability of traffic management systems and integration of various transport modes, considering the transport of both people and goods. Use case UC1 integrates traffic management with inter-modality, UC2 considers demand-responsive transport, and UC3 is on urban logistics.

Figure 1 Map of CONDUCTOR pilots

Use cases are demonstrated in five pilot projects throughout Europe, with each pilot project testing specific functionalities using real-world data. Figure 1 provides an overview of the pilot project locations. Based on their functionalities, the pilot projects are categorised based on umbrella use cases as follows:

- UC1: Integrated Traffic Management with Inter-Modality
    - *UC1 – Athens pilot project* (Greece) involves the optimal synchronization of buses and light rail (tram), metro, and trolley buses services by adjusting schedules to reduce door-to-door travel times and using traffic management and journey planning platforms to improve the reliability and flexibility of multi-modal journeys.
    - *UC1 – Madrid pilot project* (Spain) considers traffic management to accelerate network recovery after planned and unplanned events in the context of the transition towards a traffic composition with a larger share of connected and automated vehicles that can communicate with their surroundings and with a traffic management centre directly.
    - *UC1 – Almelo pilot project* (The Netherlands) deals with conditional priority for freight traffic along a major logistics corridor to reduce the number of stops at traffic lights and thereby improve traffic circulation throughout the network.
- UC2: Demand-responsive transport
    - *UC2 – Slovenia / Italy pilot project* (Slovenia and Italy) deals with the long-term optimisation and continuous refinement of route plans for demand-responsive transport services in the context of shuttle operations between Slovenian cities and Italian airports.
- UC3: Urban Logistics
    - *UC3 – Madrid pilot project* (Spain) considers solutions for last-mile parcel delivery based on the integration of the urban distribution of goods with public transport

services, thereby improving utilization of under-utilized services during off-peak hours.

2.3 Methodology

2.3.1 Use case specifications

Use cases are a popular tool for eliciting and analysing the functional requirements of a system under consideration or development [2]. The interactions of the user with a system can be described or modelled by use cases, specifying how the system is supposed to respond to a possible request from a user with a certain goal ([3], [4], [5]). It includes the sequences of the interactions of the system – triggered by a request – with the actors. A use case can be seen as a form of writing system requirements using natural language [3] and benefit describing or documenting processes. Thereby, a use case allows and stimulates discussion between stakeholders (without in-depth knowledge) and can serve as the input for further modelling and development steps [3] [4] [5]. However, since natural language is used which lacks formal expressions, use cases can introduce ambiguity and are therefore only used as an input for defining the actual technical requirements. In fact, there is a typical trade-off between precision and accuracy on the one hand and readability on the other hand [6]. Hence, although use cases are constructed to improve understanding considering the system and operational requirements, at the same time it can introduce ambiguity that is potentially transferred to the development stage and the drafting process should therefore be carefully and systematically executed to assure that the system under development matches the requirements and expectations of the users and other stakeholders involved.

Within CONDUCTOR, an iterative approach has been adopted in close collaboration with stakeholders to assure that the developed functionalities match their requirements and objectives (as formulated in deliverable D1.1). First, the goal was to establish a shared but high-level understanding of the requirements. Therefore, each pilot project was assigned a key 'leading' actor, typically the technology provider, within CONDUCTOR. The lead partners already presented an initial description of the pilot projects and the to-be-validated functionalities in the proposal phase. An updated description was presented during a consortium meeting with all project partners, allowing for further refinement or even redefinition of the systems under consideration. Based on the feedback, pilot leaders presented their project, and identified the risks, key stakeholders, and users during an initial workshop. Project stakeholders were asked to reflect upon the initial description of the pilot projects by expressing their expectations of the system, including potential benefits. The main results from the bottom-up approach identifying stakeholders' and users' needs and requirements are presented in deliverable D1.1.

After an initial description of the pilot projects and the accompanying functionalities was available, detailed information on the available data sources and to-be-used and to-be-upgraded components was collected in the context of deliverable D1.2. Concurrent with these activities, a high-level overview of each pilot project, and thereby of the umbrella use cases, was established. For each pilot site, the rationale, the main stakeholders, the research objectives, potential side-effects and the to-be-tested functionalities were identified either during bilateral meetings or through pilot-specific workshops with involved stakeholders and users.

The high-level overview of the functionalities was used as input to capture the requirements for each system. Following the typical approach for modelling use cases (see, for example, [3] and [7]), a template was made to identify the functional requirements for each use case. A template is helpful to systematically identify the elements of the use cases [2] but also allows for a comparison across use cases. In contrast to the approach oftentimes adopted in other projects, in CONDUCTOR use cases are identified on a pilot level rather than having a series of use cases corresponding to the different requests. In fact, within a single pilot, the identified scenarios cover the various possible requests from the main actors. This approach is adopted since the functionalities of a system are implemented, monitored, and evaluated as a whole by means of a pilot. The use cases were documented based on feedback from relevant project partners and stakeholders.

The filled-out use case templates served as input for the use case pilot-specific chapters of this deliverable. Key stakeholders were asked to identify per pilot the research objectives and questions as well as the potential benefits. The process flow component of the template focused on the actors, the pre-conditions for the use case, the trigger conditions, the basic process flows related to the various scenarios that can trigger the use case and the termination conditions. The impact assessment part of the template covers the performance indicators that will be used for monitoring and evaluating the progress of the pilot project, including a description of the scenarios that will be considered.

2.3.2 Key performance indicators

Performance indicators are used to monitor and evaluate progress towards targets and goals in a quantitative manner. Such indicators are typically part of a performance measurement system, and "…enable us to gain an understanding of the complex systems around us" [8, p. 105]. An indicator summarizes the current state of a system and thereby allows stakeholders to identify appropriate actions since options can be assessed relative to their progress with respect to the objectives [8], [9], [10]. However, decision-makers typically have a range of potentially conflicting goals, and whereas decision-makers partly base their actions on the information provided by the key performance indicators (KPIs), the selection of these indicators is a delicate task. In general, it is increasingly recognized that the selection of a single KPI or a set of narrowly focused KPIs does not or only partly address the potential trade-offs [9], [11] , particularly since indicators may overlap or be interrelated. To prevent biased decisions, KPIs should be objective, simple and transparent enough to allow for rapid feedback on actions and to stimulate discussions with the involved stakeholders [8], [12], [13]. In fact, a comprehensive and balanced set of KPIs allows for the continuous refinement of actions, e.g., by adopting these metrics in an optimisation framework.

Based on the review of the literature above, the impact of actions should not only be assessed with respect to the defined objectives and targets, but the monitoring and evaluation activities should additionally address the impact beyond (economic) efficiency. Decisions may potentially lead to several (unintended) side-effects, so-called externalities, particularly since mobility is a cause of the creation of greenhouse gas emissions and air and noise pollution (see, e.g., [14] and the European Green Deal [15]). According to the Sustainable and Smart Mobility Strategy (SSMS) [16], these societal costs have not been sufficiently addressed in previous projects. Concurrently, on a more macroscopic level, it is increasingly recognized since the release of the report of the French "Commission on the Measurement of Economic Performance and Social Progress" [17], that the typically used socio-economic metrics fail to address the (perception of) social progress or societal well-being. Various statistical reports such as the Dutch "Monitor Brede Welvaart" [18] try to sketch a more comprehensive picture of development over multiple scales. In fact, a range of indicators addressing wellbeing aspects has been developed [19].

The SSMS underlines the need for a comprehensive multi-faceted impact assessment framework, since mobility does not only provide benefits for users, it also is the cause for problematic side-effects affecting health and wellbeing. It is indicated that these costs for society should be addressed in conjunction with the possible benefits, particularly since society expects improved air quality, less noise, improved road safety, etc. The Strategic Research and Innovation Agenda (SRIA) for CCAM [20] mentions that CCAM will contribute the Sustainable Development Goals (SDGs) as defined by the United Nations by improved safety, reduced emissions, increased equitability and adoption and higher economic impact. Nonetheless, the report stresses that the direct and indirect costs of CCAM should be considered over various timescales. Consequently, in the context of CONDUCTOR, assessment occurs using a balanced set of indicators addressing impact beyond efficiency but also considers sustainable development goals, safety [21], wellbeing, and the impacts on different user and socio-economic groups, in both the short and long run.

In the context of fleet and traffic management, numerous indicators have been defined to evaluate impact. Traditionally, most performance metrics measure economic progress or efficiency benefits [13], [22]. In recent years, however, a paradigm shift is occurring and performance beyond efficiency is increasingly considered [12]. For example, the review of Tian et al. [11] identified that metrics measuring the impact of connected and automated vehicles can be categorized using the five themes safety, traffic efficiency, environmental impacts, social inclusion and land use, and user experience. In the context of logistics, in [23] it is indicated that in the light of corporate social responsibility, almost all logistics service providers nowadays consider their impact on society. They note, however, that there is no consistent set of indicators to measure social and environmental impact, and that even for the same metrics different data collection and analysis approaches are used. As Cai et al. [24] highlighted, KPIs are typically defined according to the situation-specific requirements and the manager's experiences. Notwithstanding the need to tailor the KPIs to the situation at hand, the variety of seemingly arbitrary indicators used hampers the comparison of solutions across scenarios or geographical sites, and thereby can obstruct the potential transferability of success stories [22]. In this context, the EU Urban Mobility Framework [14] stresses the need for EU-wide common indicators that allow for sharing best practices. For example, the World Business Council for Sustainable Development proposes in SMP2.0 a set of indicators for standardized evaluation of mobility systems, spanning the four dimensions Global environment, Economic success, Quality of life, Performance of the mobility system [25]. Within the European project LEVITATE, short, medium, and long-term impacts of connected and automated transport systems are categorized using the dimensions society, environment, economy and safety [26]. However, the comparison of two example city strategies within LEVITATE reveals that the development is difficult to compare directly, but that on a higher level the goals can be structured according to groups mentioned afore.

A multi-dimensional KPI framework has been developed to monitor and evaluate the performance of the CONDUCTOR functionalities in the pilots. The included KPIs measure not only the progress towards reaching the objective and whether the technical requirements of the use cases are met, but also specifically address the three dimensions of sustainable development (economic, environment and social) [27]. Hence, use case and site-specific indicators are classified using the following impact dimensions or groups, spanning both technical and sustainable development ([28], [29]):

- **Technical KPIs** reflect the impact of the technical functionalities on service performance. Technical KPIs include mobility and transportation system metrics on travel time, travel distance, punctuality, etc.
- **Economic KPIs:** metrics measuring the performance in economic terms – typically expressed using monetary indicators, e.g., shipping costs per parcel delivered.
- **Environmental KPIs:** KPIs considering the impact on energy consumption and environmental footprints such as air pollutants, noise pollution and greenhouse gas emissions. For example, KPIs are related CO2 and NOx emissions.
- **Social KPIs:** include metrics on acceptance, fairness (equity), and safety, including end-user satisfaction and perception.

The introduced framework allows for a coherent evaluation across multiple dimensions of the pilots and the project, including the comparison of effects across various user groups, scenarios, and sites.

It should be noted, however, that pilot and use-case-specific KPIs are included since local (e.g., national) challenges are to be addressed that may not directly transfer to other sites. For example, the Netherlands aims for an improvement in air quality, particularly a reduction of nitrogen emissions.

The pilot-specific KPIs were identified concurrently with the use-case specifications using an iterative approach. After an initial description of each pilot project was available, key stakeholders were identified in collaboration with the involved partners. Based on this discussion, an in-depth discussion with lead partners led to the identification of system-level policy objectives on a global, European, national and local level, including objectives beyond efficiency, for example with respect to the sustainable development goals, wellbeing and emissions. Further, the objectives of the involved stakeholders and user groups were identified, including the corresponding KPIs. It should be noted that data availability and quality led to a refinement of the initial list of indicators. The results from this process, particularly the extracted KPIs, were summarized and reflected upon during a consortium meeting where partners had the opportunity to provide in-depth feedback. A final consultation round with involved partners was executed to select the final list of indicators as presented in this deliverable (see also [30]). Nonetheless, the established KPIs in the remainder of this report should not be considered fixed but are subject to change over the course of the pilots due to potentially changing circumstances and conditions.

2.4 Contents of the document

The results of the process as discussed in Section 2.3 are presented in the upcoming chapter. Each chapter covers a single pilot project: Chapter 3 discusses the UC1–Athens pilot, Chapter 4 the UC1-Madrid pilot, Chapter 5 considers UC1-Almelo pilot, Chapter 6 UC2-Demand responsive transport (Slovenia/Italy pilot), and Chapter 7 UC3-Urban Logistics (and the corresponding Madrid pilot). Each chapter contains the following sections:

- Introduction with general information on the use case and the pilot project context, including research objective(s).
- Use case description: rationale of the pilot project, key requirements, and potential benefits of the use case.
- Process flow: overview of tasks that are considered, conditions that should be met before use case can be executed (*pre-conditions*), identification of actors, overview of how tasks are executed (sequentially) within the system (*main flow*), and under which conditions the system will be activated (*trigger conditions*).
- Impact assessment framework and KPIs: overview of indicators that are used to measure progress over time towards reaching objectives.
- Pilot deployment and testing: description of how the functionalities will be implemented in the pilot.

3 UC1 – ATHENS PILOT

Use case 1 focuses on integrated traffic management with inter-modality. The Athens pilot project specifically considers conditional synchronisation for multi-modal travel.

3.1 Introduction

Athens, Greece, is one of the largest economic hubs in Southern Europe and faces severe network-wide congestion issues from day to day. After the outbreak of the COVID-19 pandemic, the Municipality of Athens decided to increase public space, as to allow social distancing measures to be adhered to during the pandemic, but also in prospect of prioritising pedestrians and soft modes at the cost of road traffic. The re-allocation of urban space, the so-called Athens 'Great Walk' project, is anticipated to introduce a new traffic situation in the longer term. Travels are expected to have a stronger multimodal character compared to the situation before the pandemic.

Multimodal transportation systems are typically more complex to manage. In fact, to allow passengers having a seamless trip from door to door while using various modes requires that systems with different scales, typically operating in isolation, are synchronised. Coordination and partnerships are necessary to resolve the inefficiencies of the network and to prevent disturbances from propagating throughout the network. However, the partial or full cooperation of stakeholders is not trivial, since, for example, parties may have conflicting objectives and access to different sources of information. Currently, there is momentum to shift towards an inter-connected system in which different services such as metro, bus and tram systems exchange information and adapt their operations to serve the expected increase in demand. In fact, with the relatively recent introduction of connected vehicles, on-demand transport services and personalised information services, multi-modal trips can be tailored to the individual's needs.

3.2 Use case description

In the current situation, there is limited collaboration among actors managing the various systems in the multimodal transport network in Athens. To assure that response plans can be incorporated on various scales and to enable optimised mobility and accessibility solutions for people by tailoring multi-modal trips to the individual requirements, the solutions introduced by the CONDUCTOR project need to consider the needs and objectives of the different actors involved. UC1 – Athens pilot project focuses on technical and organisational interfaces for multimodal network management. The research objective of the pilot project is to enable optimised mobility of people through the synchronization of various forms of transport, including conventional public transport services such as light rail (tram), metro, buses, and trolley buses.

The use case pilot specifically focuses on the synchronisation of schedules of conventional service lines. Metro, bus and trams will be connected and can exchange information. Rather than having sub-systems that are optimised in isolation solely considering the passenger demand for each service line, the introduction of connected vehicles allows for a reduction in door-to-door travel times through the synchronization of service frequencies and timetables. Benefits can even be further increased if, in addition to the synchronization of services, other dynamic supply-side and control measures, such as prioritizing public transit at signalized intersections and the deployment of on-demand services, are implemented alongside.

3.2.1 Benefits

The potential benefits of multi-modal network management include:

- Reduction in passengers' door-to-door travel times
- Reduction in emissions (CO2, NOx)
- Enhancement of collaboration among transport authorities
- Improved service reliability
- Improvement in traffic safety
- Improved accessibility for vulnerable groups

3.2.2 Use case objectives

The objectives of the use case are to enable the network-wide management of a multi-modal transportation system by the synchronization of buses and on-demand services with metro and tram by means of adjusting their schedules to reduce the door-to-door travel times of passengers while using traffic management centres by

- updating schedules of public transport service lines to synchronize multimodal trips in real time
- integrating services in the city of Athens
- updating estimated time of arrival after disruptions
- improving traffic management, dynamic bus allocation combined with signal priority
- multimodal planning using personalized travel information
- early anomaly detection in the network and predict traffic state in future time-window intervals

3.2.3 Key requirements

Based on the user needs and requirements as further elaborated upon in deliverable D1.1, the key categories of stakeholders are the transport operators, public transit passengers, traffic managers and operators and local public administrations. For the successful execution of the pilot project, the resistance of communities to these innovations should be considered, as well as the potential loss of consensus among the various managers and operators deploying management services. The potential complexity involved in the management of multi-modal networks is a concern for traffic managers and operators.

3.3 Process flow

The typical situations in which actors interact with the system are described.

3.3.1 Actors

Identified actors are the user travel information service, traffic data centre, traffic management centre, fleet management centre, vehicle scheduling service, multimodal journey planner, simulation service, situation detection service, intelligent traffic light controller (iTLC), and connected vehicles.

3.3.2 Pre-conditions

The pre-conditions for the actors identified in Section 3.3.1 are as follows.

User Travel Information service

- Can periodically inform travellers on route plans

Traffic data centre

- Can receive information on current traffic conditions

Traffic management centre

- Can receive information on timetables, vehicle positions
- Can determine optimal traffic management strategies (signal planning, bus lane allocation) based on anticipated traffic conditions
- Can send traffic management priority conditions to intelligent traffic light controller
- Can send information on vehicle schedules and timetables to multimodal journey planner

Fleet management centre

- Can receive real-time information on vehicle positions and passenger demand from connected vehicles
- Can visualize the status of the operations in a GUI
- Can send operations data to API

Vehicle scheduling service

- Can periodically send information regarding the schedule and timetables to the connected vehicles
- Can determine optimal timetables and schedules based on journey requests, anticipated traffic conditions and traffic management strategies

Multimodal journey planner

- Can receive information on detected anomalies from the situation detection service
- Can receive information on traffic management strategies from traffic management service
- Can send information on suggested routes and provide travel information to the traffic management service

Simulation service

- Can receive information on current traffic data conditions, traffic management strategies and vehicle schedules
- Can predict near-future traffic conditions, and send information on near-future traffic conditions to the traffic management centre

Situation detection service

- Can detect anomalies in the (future) network conditions
- Can send anomaly information to multimodal journey planner, fleet management centre and traffic management centre

Intelligent traffic light controller

- Conditions for priority are determined

- Can receive information from nearby connected vehicles, including position and lane
- Can optimise signal timings in real time
- Connected vehicles
- Can send information to the fleet management centre, including information on position, direction, and speed
- Can send information to nearby intelligent traffic light controllers on position and lane
- Can periodically inform the driver of the vehicle on time-of-departure, next stop and route

3.3.3 Trigger conditions

There are typically two scenarios that can occur:

i) Incident in public transport operations

ii) Significant deviation in time of arrival is predicted

3.3.4 Main process flow

Scenario i: Incident in public transport operations

1. Traffic data centre collects traffic network data and broadcasts information to the traffic management centre
2. Traffic management centre receives information on traffic conditions from the traffic data centre and constructs an operational picture, sends the operational picture to the multimodal traffic management centre.
3. Data regarding public transport fleet operations, including route and vehicle position, and public transit demand is collected continuously and broadcasted to the fleet management platform and situation detection service
4. The situation detection service collects data from public transport operations and detects that an incident occurred.
5. Situation detection service sends a message to the fleet management platform, multimodal journey planner, and traffic management service
6. The fleet management platform receives information on fleet operations
7. Fleet management platform visualizes operations and location of the incident and broadcasts data to APIs
8. Multimodal journey planner receives incident data and periodically sends information on the suggested routes and disruptions to user travel information service and multimodal management centre
9. Multimodal management centre receives information on the incident from the incident detection service, and suggested routes from the multimodal journey planner.
10. Multimodal management centre receives information on traffic conditions from the traffic management centre and receives public transport schedules from the public transport operator.
11. Traffic management centre allocates bus lanes with signal priority, sends priority requests to iTLC

12. Multimodal management centre feeds simulation service, with information on vehicle schedules, incidents, travel advice, traffic management strategies and traffic conditions, and receives prediction of traffic conditions.
13. Multimodal management centre sends a request for re-optimisation to the vehicle scheduling service.
14. Vehicle scheduling receives periodically telematics on public transport operations, including schedule, passenger counts and vehicle locations.
15. Vehicle scheduling service receives a request for re-optimisation
16. Vehicle scheduling service determines updated schedule (timetable, service lines) based on iterative interaction with multimodal traffic management centre
17. Multimodal traffic management centre sends information on traffic management strategies and vehicle schedules to multimodal journey planner
18. User travel information service periodically receives information from multimodal route planner and shows personalised information messages (upon request) to the traveller
19. Intelligent traffic light controller receives priority requests and shows lane allocation message

Scenario ii can be considered to be an alternative flow, i.e., the process flow in case of a change in the estimated time of arrival is similar to the process flow corresponding to Scenario i.

3.3.5 Termination conditions

Interruption may occur in case the traffic conditions significantly change during the re-optimisation, e.g., if an incident or accident occurs, and initial re-optimisation is triggered based on outdated information. Technical failure of one of the services may cause termination.

3.4 Impact assessment framework and KPIs

The pilot project will be conducted in a simulation environment of the central part of Athens, based on real-world data collected from loop detectors, ticket validation data, and telematics from busses. Tables 1-3 provide an overview of the defined KPIs.

Table 1: Technical KPIs UC1 Athens

ID	Technical KPI
UC1_T01	Average door-to-door travel time of passengers
UC1_T02	Average travel distance per passenger
UC1_T03	Punctuality of public transport, arrivals/departures within 5min of scheduled arrival/departure time.
UC1_T04	Waiting time and delay at public transport-prioritized signalized intersections
UC1_T05	Public transport ridership

Table 2: Economic KPIs UC1 Athens

KPI	Economic KPI
UC1_B01	Running costs per passenger

Table 3: Environmental/Social KPIs UC1 Athens

KPI	Environmental / Social KPI
UC1_E01	Acceptance of governance model

3.5 Pilot deployment and testing

The components will be developed, trained, and tested in the context of simulation and pilot. The simulation model is calibrated so that it represents the traffic conditions as close as possible to the real-world conditions. The same applies for the passenger demand and the positions of public transport vehicles, including their arrival times at stops. The model output will feed the services to be examined and the results will be compared against the base scenario. The base scenario represents regular traffic patterns and public transport schedules without interventions related to traffic management and rescheduling of bus/trolley bus services.

Various scenarios will be considered in the use case. In fact, different days of the year with varying traffic and passenger demand patterns will be simulated, and the effect on the KPIs will be tested. The assessment, therefore, occurs by comparing scenarios assuming all other settings are kept constant. The application of the model will be also tested in real life to explore the potential reduction of door-to-door travel times for passengers using multiple modes.

4 UC1 – MADRID PILOT

Use case 1 focuses on integrated traffic management with inter-modality. The Madrid pilot project specifically considers traffic network recovery after planned and unplanned events.

4.1 Introduction

Non-recurrent disruptions, such as those caused by traffic incidents or unfavourable weather conditions, have an increasing impact on traffic network operations. In fact, a significant and growing share of traffic congestion can be traced back to planned and unplanned events. Since, typically, the time and location of occurrence of such events are difficult to predict, traffic management strategies focus on rapidly recovering the 'normal' network operations after events occurred. The uptake of connected and automated vehicles (CAVs) introduces opportunities in this context. Traffic management strategies have increased flexibility to mitigate or relieve the impact whereas direct and continuous communication between traffic management and vehicles becomes possible. For example, individually tailored rerouting directions can be communicated to CAVs and refined in real-time, thereby not only allowing for a reduction in travel time of individuals but also improving societal objectives alongside.

The UC1-Madrid pilot considers traffic management for network recovery after recurrent and non-recurrent events in the context of the transition towards road traffic mainly consisting of CAVs. The use case focuses on both planned (e.g., roadworks and demonstrations) and unplanned events (e.g., accidents and incidents). During the transition towards a fully automated future, the fleet composition of road traffic will be mixed, consisting of both conventional vehicles and CAVs. The research objective of this use case is to develop and validate network recovery strategies by means of traffic management in a situation in which direct communication with vehicles is only possible for a portion of the vehicles.

Even under an increasing penetration level of CAVs on the road, network recovery after disruptive events by means of individually tailored suggestions or directions is challenging since functionalities including lane indication, and rerouting and travel suggestions need to balance both individual needs and objectives as well as system-wide objectives. In fact, simulation analyses are necessary to identify and evaluate the adequate response plans and strategies to be deployed, such that they can mitigate the impacts due to the emerging congestion. The challenge is to deploy management strategies in a dynamic fashion in which there is only limited time before information becomes obsolete.

4.2 Use case description

The UC1 Madrid pilot considers the integration of connected and autonomous vehicles into traffic management services. The M-30 ring road of Madrid, Spain, is selected as the network for the pilot project. The adjacent urban road network is also planned to be modelled to enable the analysis of impacts on the wider area. Whereas in the near future, the market penetration of CAVs is still expected to be low, the potential of traffic management services in a setting with increasing levels of connectivity and automation is considered in a simulation context. The use case considers both mixed traffic (CAVs and conventional vehicles) and fully autonomous scenarios (high CAVs penetration level), under various levels of demand. In this setting, CAVs can communicate with their surroundings and are receptive for directions or instructions from a traffic manager since they are equipped with an onboard unit or a smart device. The CONDUCTOR innovations to be tested focus on the optimal deployment of individually tailored travel advice for the benefit of network recovery.

4.2.1 Key requirements

Five main stakeholder categories were identified for this use case (deliverable D1.1): conventional vehicle passengers, CAVs passengers, network managers, vehicles involved in the disruption and other users. The goal of the use case is to recover network operations after planned and unplanned events using tailored suggestions and directions. Individual and societal or network-wide objectives should be balanced, in that the travel advice to CAVs passengers could be sub-optimal but should be acceptable. In fact, compliance with advice is key for the success of the functionality. Further, it is key that the network management systems allow for the implementation of the developed systems, this may require, however, future hardware and software adaptations.

4.2.2 Benefits

The objective of the use case is to mitigate the impact of planned and unplanned events on the network-wide traffic conditions, leading to optimal travel decisions of CAVs, and allowing for a rapid recovery of the network to ‘normal’ conditions. The benefits of rerouting and rescheduling in case of events include:

- Reduction of traffic-related emissions
- Improvement in road capacity utilization
- Improvement in network performance
- Improved network resilience by reduction in recovery time
- Reduction in travel times and delays
- Better and timely informed decisions
- Less incidents
- Reduction of economic losses due to travel delays

4.2.3 Use case objectives

The focus of this use case is on the management of planned or unplanned events as to ensure a rapid recovery of network operations by including strategies such as

- setting optimal departure times for CAVs in case of events
- setting optimal routes for CAVs in case of events
- anticipating lane selection for CAVs when approaching a lane closure
- adapting speeds for CAVs, from the reception of the ITS message until the position of the event

4.3 Process flow

The typical situations in which actors interact with the system are described.

4.3.1 Actors

Identified actors are the CAVs, traffic data centre, traffic management centre, and vehicle re-scheduling service.

4.3.2 Pre-conditions

The pre-conditions are as follows:

CAVs

- Can receive travel routes and departure times directions from the traffic management centre
- Can periodically send information regarding location, route and destination to the traffic management centre
- Can receive the location of the incident and the number of closed lanes from the traffic management centre

Traffic data centre

- Can periodically broadcast information on the traffic situation, including vehicle counts, speeds, event data, and CAVs in the system

Traffic management centre

- Can receive directions on routes and departure times for CAVs
- Can detect anomalies using incident detection service
- Can send directions and suggestions to CAVs

Vehicle re-scheduling service

- Can determine optimal routes and departure times based on traffic management strategy
- Can receive information on traffic demand, traffic conditions and CAVs in the network
- Can send routes and departure time directions to the traffic management centre

4.3.3 Trigger conditions

There are typically three scenarios that can occur:

- Scenario i: An unexpected event is detected
- Scenario ii: A planned event is scheduled
- Scenario iii: A CAV announces or schedules a trip

4.3.4 Main process flow

<u>Scenario i: An unexpected event is detected</u>

1. Data from the traffic network is collected and periodically broadcasted to the management centre by the traffic data centre
2. The traffic management centre identifies an unexpected event based on real-time traffic data
3. Traffic management service sends information on current traffic conditions including origin-destination traffic demand, traffic status, event lists, and CAVs to the vehicle re-scheduling service
4. Traffic management centre sends a request for CAVs re-scheduling to the vehicle re-scheduling service
5. The vehicle re-scheduling service determines the departure time and routes of CAVs, anticipating emergent traffic conditions.

6. The optimal routes and departure times are communicated to the traffic management centre
7. The traffic management centre sends routes and departure times to the CAVs and also provides the location of the incident to the CAVs
8. CAVs receive routes and/or departure times and the location of the incident from the traffic management centre

In Scenario ii, an event is scheduled and added to the list of events, and the main flow is similar to the flow outlined in Scenario i.

Scenario iii: A CAV announces or schedules a trip

1. CAV announces or schedules a trip, and sends trip information to the traffic management centre
2. Traffic management centre adds a trip to the list of CAVs
3. Traffic management centre sends information about the CAVs trips, including (expected) traffic demand, status and events lists, to vehicle re-scheduling service
4. The vehicle-rescheduling service calculates and determines the departure time and routes of CAVs, anticipating the emergent traffic conditions as a result of the CAVs' schedules and routes.
5. The optimal routes and departure times are communicated to the traffic management centre
6. The traffic management centre sends routes and departure times to the CAV
7. CAV receives routes and/or departure times from the traffic management centre

4.3.5 Termination conditions

Interruption may occur in case the traffic conditions significantly change during the re-optimisation, e.g., if an incident or accident occurs, and initial re-optimisation is triggered based on outdated information. Termination can also occur if a trip is recalled by the CAV.

4.4 Impact assessment framework and KPIs

The pilot project will be conducted in a simulation context, necessary to test various scenarios regarding CCAM market penetration. Data from both virtual roadside sensors, as well as individual vehicles' trajectory data, will be used to monitor and evaluate progress regarding the formulated objectives, using the following technical, business, and environmental social KPIs. Network characteristics and demand levels required as input by the simulation software need to be defined. The specifications of the Madrid network are already available, and traffic demand data can be obtained from the components defined in deliverable D1.2.

Table 4: Technical KPIs UC1 Madrid

KPI	Technical KPI
UC1_T06	Average travel time per connected vehicle
UC1_T07	Average travel distance per connected vehicle

UC1_T08	Average recovery time after events/disruptions
UC1_T09	Average travel time per vehicle
UC1_T10	Average travel distance per vehicle

Table 5: Economic KPIs UC1 Madrid

KPI	Economic KPI
UC1_B02	Economic losses due to travel delays

Table 6: Environmental/Social KPIs UC1 Madrid

KPI	Environmental / Social KPI
UC1_E02	Total vehicle emissions of CO2 and NOx

4.5 Pilot deployment and testing

The components will be developed, trained, and tested in the context of simulation. The simulation model is calibrated so that it represents the traffic conditions as close as possible to real-life. The model output will feed the services to be examined and the results will be compared against the base scenario. The base scenario represents regular traffic patterns without planned or unplanned events.

Various scenarios will be considered in the use case. In fact, different events will be simulated in the simulation environment, and the effect on the KPIs will be tested under varying levels with respect to the market penetration of CAVs, and the traffic demand including conventional vehicles. The assessment, therefore, occurs by comparing scenarios assuming all other settings are kept constant (i.e., ceteris paribus).

5 UC1 – ALMELO PILOT

Use case 1 focuses on integrated traffic management with inter-modality. The Almelo pilot project specifically considers conditional freight signal priority.

5.1 Introduction

Logistics service providers suffer from the delays induced by traffic lights in urban areas. In fact, every time a truck (or: heavy duty vehicle) comes to a standstill due to a red signal faced at a traffic light, the additional fuel consumption because of the acceleration imposes an extra cost of approximately one euro to the operator compared to an uninterrupted pass. Apart from the additional costs, accumulated local delays may be manifested in the route plan and impact the reliability of the operation, and, therefore, it may be necessary to introduce significant slack in the route plan – further increasing operational costs. The standstill of trucks not only negatively influences the efficiency of logistics operations, but also has an impact on the network-wide traffic conditions due to a decreased road capacity. In addition, the interrupted circulation of freight traffic directly impacts a range of societal objectives, e.g., with increased emissions due to the fuel used and decreased safety due to the additional manoeuvres.

The city of Almelo, the Netherlands, is part of the Twente region and is a central city for over 230,000 residents in the region. The city is well known for its high-tech production industry, and, consequently, a substantial share of the traffic volume is freight traffic. In the context of Almelo's pathway towards zero-emission logistics while freight traffic is expected to increase in the upcoming years, the UC1 pilot project in Almelo aims for reduced emissions from heavy-duty vehicles through prioritizing trucks in a mixed traffic environment along a major logistics corridor connecting the highway with a logistics hub in the city.

Prioritization occurs by means of a green wave in the corridor, i.e., a sequence of coordinated traffic signals that allow an uninterrupted progression of freight transport, in combination with ad-hoc platoon forming and green light optimised speed advice (GLOSA). Intelligent traffic light controllers (iTLCs) can communicate with trucks and thereby provide early green or extended green signals based on vehicle positions, speeds, etc. In this case, a platoon of trucks will be given conditional priority, and truck drivers will be provided with speed advice to prevent a standstill. Uninterrupted truck journeys increase the reliability of the logistics operation, improve road capacity, reduce truck maintenance costs, reduce emissions (CO2, particulate matter (PM), and noise), improve citizens' well-being, improve road capacity, and, potentially, improve general traffic flow. The research objective of the Almelo pilot project is to establish an understanding of governance issues related to the prioritization of specific transport modes for the benefit of society, potentially at the additional cost of a portion of other road users. The results of the pilot enable governments to balance various users' needs and objectives in traffic management strategies.

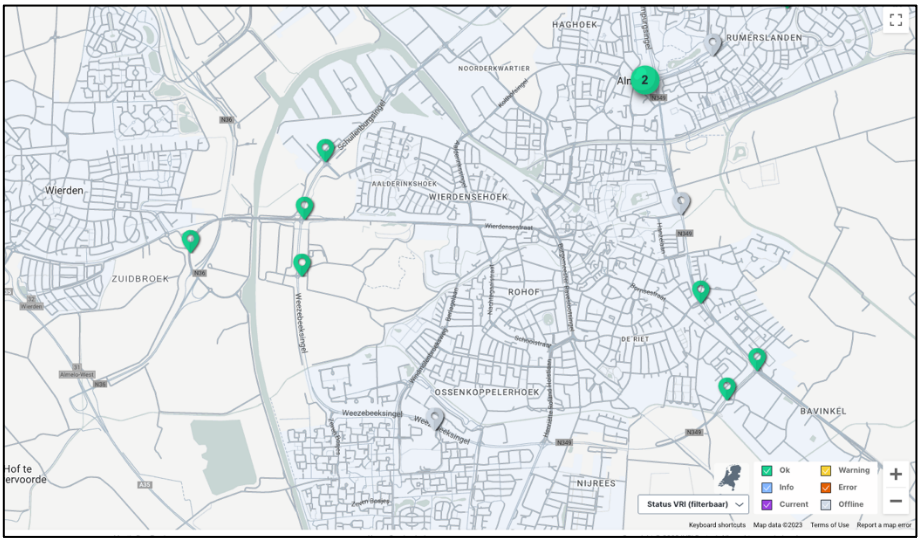

Figure 2 Almelo Corridor with operational iTLCs early 2023 (source: ivriportaal.nl)

5.2 Use case description

In the current situation, most of the traffic light control systems in the Netherlands are vehicle actuated. Typically, no priority for specific vehicle types apart from emergency services and public transport vehicles is given. In general, green waves currently exist along corridors with a sequence of signalized intersections based on infrastructure-to-infrastructure communication, aiming to prevent stops at intersections for traffic travelling along with the green wave.

The goal of the use case is to reduce the frequency of stops of heavy-duty vehicles, by giving priority to such vehicles approaching a traffic light, provided that the benefits outweigh the disadvantages, as perceived by the traffic manager. Priority can be given by green extension, early green, phase insertion and/or phase rotation. The vehicle approaching the traffic light will be provided with the (estimated) phase schedule upon arrival at the intersection, as well as speed advice.

Conditional freight signal priority can be implemented for a single intersection or in combination with a (freight) green wave, where the benefits increase in case a platoon of trucks does not have to stop when travelling along with the green wave. In this context, a single heavy-duty vehicle approaching a traffic light may not be given priority, as to form a platoon of trucks at the approaching lane. In a mixed traffic environment without dedicated lanes for heavy-duty vehicles, a platoon, however, may be mixed, with light, medium and heavy-duty vehicles.

5.2.1 Benefits

The potential benefits of conditional freight signal priority along a corridor include:

- Less acceleration and breaking (less maintenance)
- Reduction in frequency of truck stops
- Reduction of noise production
- Reduction of greenhouse gas emitted
- Improvement of air quality
- Reduction of fuel consumption

- Improved road safety (direct): reduction of travel time and manoeuvres of vehicles transporting hazardous substances
- Improved road safety (indirect): reduction of truck red light crossings, and less manoeuvres
- Increased road capacity

5.2.2 Use case objectives

The objectives of the use case are to minimize the frequency of stops of heavy-duty vehicles, and to facilitate a smooth progression along the corridor, by implementing and testing the following functionalities:

- extension or insertion of green phase to assure that (a mixed platoon including) trucks can pass a signalized intersection without interruption.
- introduction of a green wave for trucks, allowing a mixed platoon travelling along with the green wave to pass signalized intersections without interruption.
- coordination of traffic signals with freight signal prioritization
- heavy-duty vehicles adjusting their speed causing the vehicle to reach the intersection when the light has turned green.
- extension or introduction of red phases to form platoons of heavy-duty vehicles

5.2.3 Key requirements

Based on the user needs and requirements as further elaborated upon in deliverable D1.1, the key categories of stakeholders are logistics operators, road authorities and road users (including emergency services, cyclists, and public transport vehicles). To assure that the objectives of the use case are met, the potential drawbacks regarding the entrance barrier for (digitally excluded) fleet companies, the privacy and safety concerns of truck drivers, the acceptance for road users in the sense of potential increased or unreliable waiting times at the traffic lights should be explicitly considered.

5.3 Process flow

The typical situations in which actors interact with the system are described, partly based on relevant projects ([31], [32]).

5.3.1 Actors

Identified actors include the road traffic manager and operator, cloud service provider, connected heavy-duty vehicles, road users (drivers) and intelligent traffic light controllers (iTLCs).

5.3.2 Pre-conditions

Use case 1 focuses on integrated traffic Management with inter-modality. The Almelo pilot project considers conditional freight signal priority. The pre-conditions for the actors identified in Section 5.3.1 are as follows:

iTLC

- Conditions for priority are incorporated in the signal control system, based on near-future traffic predictions including weather conditions
- Can receive vehicle information, including position, direction, load, and speed.
- Can send information to cloud services, including information on the green phases
- Can receive information from cloud services, including information on predicted traffic conditions, weather conditions and green wave status.
- Can calculate near-future signal status and timing based on traffic
- Can optimise signal timings in real time
- If part of the green wave corridor: can receive and send information on recently departed vehicles

Connected heavy-duty vehicle

- Can periodically receive information including priority and signal status and speed advice from iTLCs using cloud services
- Can periodically send information to cloud services, including information on position, load, speed, and direction.
- Can periodically inform the driver of the vehicle on suggested speed and priority status

Road traffic manager and operator

- Conditions under which priority for freight traffic is given are determined
- Conditions under which green wave occurs are determined

Cloud Services

- Can receive priority status and signal timings from iTLC
- Can send priority requests to iTLC

5.3.3 Trigger conditions

There are typically three scenarios that can occur:

- Scenario i: A connected heavy-duty vehicle approaches an intersection
- Scenario ii: A connected heavy-duty vehicle is part of a (mixed) platoon, and travels along with the green wave.
- Scenario iii: A connected heavy-duty vehicle is in a queue in front of a traffic light, and potentially part of a (mixed) platoon.

5.3.4 Main process flow

<u>Scenario i: A connected heavy-duty vehicle approaches an intersection:</u>

1. A heavy-duty vehicle periodically broadcasts its position, speed, and direction to the cloud services
2. Heavy-duty vehicle in the vicinity of the iTLC sends a ‘priority request message’ and state information to the cloud service
3. Cloud services forward request to iTLC

4. iTLC receives the request and determines that priority can be given by green extension, early green, or phase rotation/insertion based on current and future traffic conditions, including the potential near-future arrival of trucks.
5. iTLC creates green wave requests based on the conditions as formulated by the traffic manager.
6. iTLC periodically sends priority request replies including status, signal timings and phases, to cloud services.
7. iTLC sends green wave requests to other iTLCs part of the green wave corridor.
8. Cloud services forward near-future signal status to vehicles, including speed advice
9. Connected vehicle receives signal status and speed advice and informs the driver

Scenario ii: A connected heavy-duty vehicle is part of a (mixed) platoon, and travels along with the green wave.

1. A heavy-duty vehicle periodically broadcasts its position, speed, and direction to the cloud services
2. At departure at an upstream intersection, upstream iTLC sends a green wave request to downstream iTLC
3. iTLCs receives the request and determines whether the green wave can be realized. iTLCs send a reply to upstream iTLC.
4. iTLC receives green wave replies and periodically sends signal status messages, including signal timings and phases, to cloud services.
5. iTLC sends green wave status including signal timings to iTLCs part of the green wave corridor.
6. Cloud services forward near-future signal status to vehicles, including speed advice
7. Vehicle receives signal status and speed advice and informs the driver

Scenario iii (alternative process flow of Scenario i and ii):

- A connected heavy-duty vehicle is in a queue in front of a traffic light, and potentially part of a (mixed) platoon. In this case, priority in the scenario i has been rejected since priority cannot be given or it is terminated, or the green wave in scenario ii could not be realized or is terminated.

5.3.5 Termination conditions

Priority will not be given in case the (near-future) traffic conditions on the corridor do not allow for a green extension, early green or phase rotation. It is also possible that the flow is terminated if the priority cannot be granted since a conflicting (higher or absolute) priority request is received from emergency services or public transport, depending on the priority hierarchy as determined by the traffic manager. Further, termination occurs if priority is overruled or green is aborted due to suddenly changing traffic conditions, e.g., in case of an incident or accident.

5.4 Impact assessment framework and KPIs

The pilot project is based on a real-world test in Almelo. Data will be collected in real-time using roadside and vehicle-based sensors. Roadside sensors include inductive loop detectors, CCTV, radar, and GPS. Realized and planned signal timings are logged. Requests for green signals are logged via the vehicle-to-infrastructure cloud services. Vehicle-based sensor data including GPS locations and loads are logged in the onboard computer. Historical roadside and vehicle-based sensor data are available for analysis, including origin-destination matrices. Acceptance of services will be evaluated using in-depth interviews and surveys with road users and truck drivers.

Table 7: Technical KPIs UC1 Almelo

KPI	Technical KPI
UC1_T11	Average travel time along the corridor per connected heavy-duty vehicle
UC1_T12	Average waiting time per user group (car drivers, cyclists, pedestrians, heavy-duty vehicles, public transport)
UC1_T13	Average queue length per approaching lane
UC1_T14	Frequency of stops per connected heavy-duty vehicle per trip along the corridor

Table 8: Economic KPIs UC1 Almelo

KPI	Economic KPI
UC1_B03	Average fuel consumption per heavy-duty vehicle trip along the corridor
UC1_B04	Average shipping costs

Table 9: Environmental/Social KPIs UC1 Almelo

KPI	Environmental / Social KPI
UC1_E03	Total vehicle emissions (CO_2, PM10, NOx)
UC1_E04	Average sound power level along the corridor
UC1_E05	Number of red-light violations
UC1_E06	Logistics service providers' acceptance
UC1_E07	Heavy-duty vehicle drivers' acceptance
UC1_E08	Average time-to-collision

5.5 Pilot deployment and testing

The pilot project is intended to consist of two test periods (pilot 1 and 2). During the first pilot period, two scenarios will be compared. Therefore, every other week the conditional freight signal priority system will be activated, thereby allowing priority for freight traffic. In this case, truck drivers will be provided with real-time information regarding the next traffic signal, as well as speed advice. The real-time communication aims for a speed adaptation of the truck drivers, as to assure that they will face a green signal upon arrival at the intersections – and thereby trucks do not have to come to a standstill. The speed advice is combined with real-time signal adaptation, prioritizing trucks over other vehicle types (if possible) along the corridor. By prioritizing freight traffic, since the number of stops is reduced, travel time can be improved, and fuel consumption is reduced, and intersection capacity can be increased, thereby reducing waiting times and queue lengths for the general traffic. Here, real-time communication between infrastructure and freight traffic is required, and cloud services will therefore be utilized.

Based on the evaluation of the first tests, the prioritization and GLOSA system will be updated – explicitly balancing user and societal requirements. In fact, rather than providing priority to individual trucks, prioritization is particularly beneficial for a platoon of trucks along a corridor ('green wave'). In this case, such platoons will be formed en-route in an ad-hoc manner by means of adaptation of signals, e.g., by holding the red light to wait for another truck to arrive. To prevent unintended (side-)effects, the behavioural responses of all road users need to be anticipated, e.g., in case users and societal objectives conflict, the losses for individuals should be kept to an 'acceptable' level. In this case, real-time predictions on travel times and waiting times (delays) for all road users including cyclists and pedestrians are necessary. The optimisation routine determining the signal timings and speed advice should run in real-time.

Apart from project partners, relevant stakeholders such as local, regional and national road authorities and logistics service providers will be involved by means of various workshops, including a kick-off session with involved logistics service providers. Regular meetings and in-depth interviews will be organized to discuss implementation issues, data gathering, and to collect feedback on the various results – as well as to evaluate user acceptance during and after implementation.

Evaluation will take place on a continuous basis by means of direct observations (using roadside and vehicle sensors), and user surveys and interviews before and during the pilots, in between pilot periods 1 and 2, and after pilot period 2. Additional data sources based on diaries, including event (e.g., football matches) data and weather conditions, will be used to assess impacts.

6 UC2 – DEMAND-RESPONSIVE TRANSPORT

Use case 2 focuses on demand-responsive transport services. The Slovenia/Italy pilot project specifically considers shuttle services from (to) Slovenian cities to (from) Italian airports.

6.1 Introduction

Slovenia experiences poor accessibility by planes. In fact, only a limited number of flights are offered at Slovenian airports, and tickets are typically expensive. As to reach a range of international destinations directly, many travellers prefer to travel through a nearby international airport, particularly in Italy or Croatia, and use shuttle services connecting Slovenia with the desired airport. To facilitate these cross-border trips, demand-responsive shuttle services – synchronized with the arrival and departure times of flights – to and from the airport are offered by GoOpti. The Conductor UC2 pilot project focuses particularly on trips between Slovenia (Ljubljana) and airports in Italy (Trieste, Venice Treviso, Venice Marco Polo). Compared to more conventional forms of demand-responsive transport, cross-border airport shuttle services are characterized by one-off demand requests, highly variable demand in space and time, and a high degree of personal requirements.

In the current system, travellers can choose among various services offered by GoOpti. The 'shared transfer' service groups passengers sharing a vehicle, as requests are similar in the sense of the desired time of departure and/or time of arrival. These services operate on fixed routes, and the exact departure time is fixed one day before departure. The 'private transfer' service also operates on fixed routes but has increased flexibility since the departure or arrival time is chosen by the customer. A customized service option is available as well, further increasing flexibility in that routes are not fixed a priori.

UC 2 focuses on demand-responsive transport facilitating cross-border airport shuttle trips from Slovenia to Italian airports and vice versa. Currently, route plans involving pickup/drop-off orders as well as a vehicle assignment, are constructed in an offline setting using rough projections of travel times and a set of realized requests as inputs. Estimated pick-up and drop-off times are communicated to the customer a day in advance. The research objective of this pilot is to improve customer satisfaction, vehicle occupancy and schedule quality in general under uncertainty. In fact, demand is realized over time and future travel conditions become increasingly unpredictable and incidents and accidents can significantly travel times and routes. Therefore, services should be optimised a priori based on a prediction of the demand and traffic conditions and re-evaluated and refined in real time not only based on the realized ad-hoc requests and changing conditions but also in anticipation of the future demand and the emergent traffic situation. The goal of the use case is to include predictive analytics and dynamic routing to enable future demand planning while accounting for the evolution of network states and optimising the occupancy of vehicles while considering people's needs.

6.2 Use case description

In the current situation, customers can choose between various services. The resulting planning occurs offline and is a one-time event. The result is a list of vehicles with detailed route and pickup and drop-off events that in principle remains fixed. In the current services, ad-hoc (i.e., same-day) requests cannot be granted. That is, only realized requests are taken into consideration while constructing the route plan, and the route plan is based on rough estimates of the travel time. The route remains fixed even if the underlying traffic situation changes, e.g., due to events and incidents.

The service is not fully resilient to cope with changes in the demand and/or traffic state. In fact, adaptations only occur after the intervention of a human planner.

The goal of the use case is to incorporate predictive analytics in the route planning process. That is, future requests on different resolutions ranging from within-day to several days ahead can be anticipated while constructing route plans. This allows for higher flexibility and thereby improves the service, e.g., expressed in improved vehicle occupancy. The goal of the use case is further to allow for real-time adjustments of the service (e.g., re-routing) considering the same-day requests. The inclusion of a new request into existing or new route plans requires automated re-optimisation of initial schedules. Re-optimisation of route plans can also occur if the actual traffic conditions differ from what was expected. In fact, initial route plans may become sub-optimal, infeasible, or vulnerable to future disruptions or disturbances, e.g., due to events, incidents, flight cancellations or changing weather conditions. Considering both the dynamics in the requests as well as in traffic, GoOpti aims for a scenario in which a schedule is optimised a priori based on a prediction of the demand and the future traffic conditions, while schedules and routes are re-optimised in real-time in response to realized traffic conditions and (ad-hoc) requests in anticipation of future dynamics.

6.2.1 Benefits

The benefits of real-time demand-responsive transport in combination with predictive analytics include:

- Enabled cost-effective transfers between airports and cities via optimal route planning while achieving better fleet occupancy
- Communicate fine-tuned and personalized pre-trip advice to customers on various timescales ranging from one week until just before departure
- Increased vehicle occupancy
- Reduced human labour for the construction and refinement of route plans
- Allow customers to make real-time and ad-hoc requests
- Reliable services, including dropped off at the desired time to be on time for air travel
- Well-informed customers regarding their expected time of departure and time of arrival
- Improved service quality: allow real-time trip requests
- Predictable and equally distributed workload among franchises and drivers

6.2.2 Use case objectives

The objectives of the use case are to enable (re-)optimisation of transfers and the management of the fleet on various timescales by the

- real-time pickup and drop-off requests are to be included in the currently valid route plain
- real-time re-optimisation of route plans based on underlying events (changing traffic conditions, within-day requests)
- prediction of demand for various time horizons and geographic zones
- prediction of emergent traffic conditions after incidents and accidents

6.2.3 Key requirements

In deliverable D1.1, four main categories of stakeholders are identified for UC2, namely: passengers, drivers, operators (franchises), and vulnerable road users. The main requirement for passengers is that the implemented services should consider the diverse needs that they might have in the sense that initial and re-optimised routes and schedules should satisfy user requirements. To ensure adoption and sustained effects in the longer term, it is key that the schedules and routes, and management decisions in general, should further satisfy the operators and the drivers' needs, e.g., in that passengers should be fairly distributed among franchises and drivers. In fact, the acceptability of operators and drivers is key for real-world applications.

6.3 Process flow

The typical situations in which actors interact with the system are described.

6.3.1 Actors

Identified actors are the user application, traffic data centre, control centre, prediction services, shuttle vehicles, and demand-responsive transport (DRT) route optimisation services.

6.3.2 Pre-conditions

The pre-conditions for the use case 2 focusing on predictive analytics combined with real-time on-demand responsive transport are as follows:

Control centre

- Can receive information on traffic events, including road restrictions, prediction on spatio-temporal traffic conditions, and non-recurrent events
- Can receive information on customer requests including their departure and arrival location and their booked flight
- Can periodically send information regarding the route plan to the shuttle services
- Can receive route plan information from the DRT optimisation services in real-time
- Can send updated route plan information from the DRT optimisation services

Prediction service

- Can receive detailed information on the route plan and list of orders from the control centre and the route optimisation service
- Can send information including predicted demand and network-wide traffic conditions to the DRT route optimisation service and the control centre

DRT route optimisation service

- Can receive information from the prediction service, including predicted demand, list of orders, and information on network-wide predicted traffic conditions
- Can send detailed information on the route plan to the prediction service Can send an optimised route plan to the control centre

User application

- Can receive personalized information on the route plan in real-time, including the status of a request, and the estimated time of arrival and departure.

Shuttle vehicles

- Can periodically receive information regarding the route plan including the next pickup or drop-off point and time
- Can periodically send information to the control centre, including information on stay points, speed, route and location
- Can periodically inform the driver of the vehicle on the route plan including the next pickup or drop-off point

Traffic data centre

- Can periodically broadcast information on the traffic situation, including vehicle counts, speeds, and event data

6.3.3 Trigger conditions

There are typically four scenarios that can occur:

Scenario i: A change in (future) traffic conditions is monitored or expected, e.g., as a result of an incident or accident

Scenario ii: An ad-hoc, same-day request is made by a customer

Scenario iii: Overnight planning is executed

Scenario iv: A typical longer-term request is made by a customer

Scenario v: A change in the flight's time of arrival or departure

6.3.4 Main process flow

The main flow is distinguished based on the four scenarios as listed in Section 6.3.3.

<u>Scenario i: A change in (future) traffic conditions is monitored or expected</u>

1. Data from the traffic network is collected and periodically broadcasted to the control centre by the traffic data centre
2. Weather conditions data are periodically broadcasted to the central services
3. Fleet periodically broadcasts information including vehicle position, speed, and occupancy to the control centre
4. The (traffic) prediction service indicates that planned operation and communicated time of arrival may be infeasible, sub-optimal, or vulnerable to future disruptions and disturbances
5. Traffic prediction service triggers re-optimisation and sends a request to the DRT route optimisation service
6. The optimisation service receives a 're-optimisation request', including vehicle information and positions, the route plan, a list of potential and received orders and a prediction of future traffic conditions
7. Re-optimisation service determines an updated route plan for the fleet of vehicles, based on the requested delivery demand and constraints and fleet availability.

8. Re-optimisation service sends new route plan including detailed routes and pickup and drop-off events, including estimated times, to the control centre
9. The control centre receives the new route plan and forwards route plan information to the user application
10. User application receives individual information on the route plans and informs the user

Scenario ii: An ad-hoc, same-day request is made

1. A user makes a request for an ad-hoc pick-up and drop-off in the user application
2. User application sends a request to the control centre
3. The control centre receives the request and adds the request to the list of orders.
4. Control centre triggers re-optimisation, sends a request and a list of orders, vehicle information and positions, current route plan, and future traffic conditions to the optimisation service
5. The DRT route optimisation service receives a 'potential re-optimisation request', including vehicle information and positions, the route plan, a list of predicted and realized requests, as well as information on future traffic conditions.
6. Re-optimisation service determines an updated route plan for the fleet of vehicles, based on the requested delivery demand and constraints and fleet availability.
7. Re-optimisation service sends new route plan including detailed routes and pickup and drop-off events, including estimated times, to the control centre
8. The control centre receives the new route plan and forwards route plan information to the user application
9. The user application receives individual information on the route plans and informs the user

Scenario iii: Overnight planning is executed

1. The control centre inserts a list of orders into the optimisation component
2. The DRT optimisation component receives the list of requests, including a list of predicted requests, as well as information on the typical traffic conditions
3. The optimisation service determines a detailed route plan for the fleet of vehicles, based on the requested delivery demand and constraints and fleet availability.
4. The optimisation service sends the route plan including detailed routes and pickup and drop-off events, including estimated times is sent to the control centre
5. The control centre receives the new route plan and forwards route plan information to the user application
6. User application receives individual information on the route plans and informs the user

Scenario iv: A typical longer-term request is made by a customer

1. A user makes a request for a future pick-up and drop-off in the user application
2. The user application sends the order to the control centre
3. The control centre receives the request, and the request is added to the list of orders (Scenario iii)
4. The control centre periodically sends information about the personalized service on the route plan

<u>Scenario v: A change in the flight's time of arrival or departure</u>

1. Control centre receives 'flight information message'
2. Control centre sends flight information to the user application
3. User application receives flight information and informs the user
4. Control centre sends re-optimisation request to DRT route optimisation service

The remaining stages are similar to Scenario i and therefore not repeated here.

6.3.5 Termination conditions

Interruption may occur in case the traffic conditions or set of requests significantly change during the re-optimisation, e.g., if an incident or accident occurs, and initial re-optimisation is triggered based on outdated information. Termination can occur if a request is recalled by the client. Technical failure is also a reason for termination.

6.4 Impact assessment framework and KPIs

The tools for predictive analytics, used for the Slovenia/Italy pilot project in the context of the use case 2, will be fed with real-world data. Specifically, developed functionalities will be evaluated based on real-world user request data, traffic data (including data on dynamic events), realised flight schedules, as well as weather conditions. To evaluate the performance of the developed CONDUCTOR functionalities, a simulation environment will be used. After successful evaluation using the key performance indicators listed below, real-world pilot tests are planned to be conducted. Acceptance of the functionalities for operators will be tested based on scheduled interviews, and objectively compared with metrics such as vehicle occupancy. Similarly, an indicator of passenger perception regarding the innovations can be based on the ratio of accepted and rejected requests. Tables 10-12 provide an overview of the defined KPIs.

Table 10: Technical KPIs UC2

ID	Technical KPI
UC2_T01	Fleet kilometres per daily plan
UC2_T02	Rate of manual interventions for shuttle service route plans
UC2_T03	Vehicle occupancy per daily plan executed
UC2_T04	Planning service reaction time

Table 11: Economic KPIs UC2

ID	Economic KPI
UC2_B01	Average costs per kilometre per passenger dropped off
UC2_B02	Average planning costs per route plan
UC2_B03	Enabled and number of last-minute product sales

Table 12: Environmental/Social KPIs UC2

ID	Environmental / Social KPI
UC2_E01	Fuel consumption per passenger dropped off
UC2_E02	Ratio of accepted and rejected requests

6.5 Pilot deployment and testing

The components will be developed, trained, and tested in a simulation environment, where real-life traffic conditions will be fed to the services and compared to the business-as-usual scenario to allow a fair comparison between the current and new scenarios. The results based on the improved DRT route optimisation engine will be executed in a simulation environment and thereby allows for data collection to evaluate the KPIs as listed in Section 6.3.6.

After satisfactory simulation results, a real-world implementation may occur. The progress regarding the objectives can be difficult to measure directly with exogenous factors influencing operations and demand. The assessment therefore initially occurs by comparing two scenarios assuming all other constraints and settings are kept constant (i.e., *ceteris paribus*).

7 UC3 – URBAN LOGISTICS

Use case 3 focuses on urban logistics services. The Madrid pilot project specifically considers the integration of parcel delivery services with passenger transport services.

7.1 Introduction

The e-commerce industry has shown impressive growth over the last few years, and particularly since the outbreak of the COVID-19 crisis, more and more people use the internet to buy or sell products or services. Although convenient from a customer's perspective, the boost in e-commerce is responsible for a significant rise in the demand for urban goods deliveries. Consequently, urban freight traffic has been growing particularly due to the increase in the number of last-mile delivery vans on the road.

Logistics service providers (LSPs) face difficulties in being a reliable partner in the delivery process. Not only has demand increased, but traffic conditions are also unreliable, and even minor disruptions and disturbances can have a sustained effect on the route plan. Hence, in order to satisfy service agreements, delivery vehicles have low load ratios and drive many empty kilometres. Apart from the impact on customer satisfaction and business efficiency, with an expected increase of 36% in delivery vehicles in inner cities by 2030, societal goals suffer under the boost of e-commerce due to the accompanying increase in both emissions and traffic congestion.

In parallel, new concepts of operations for passenger transport services are emerging, shifting from traditional mass public transport with fixed routes and schedules to a model where high-capacity services (bus, tram, subway, commuter rail…) are complemented with on-demand services that provide a more flexible and tailored solution for certain situations (e.g., low-demand areas, last-mile access to mass transit, etc.). Vehicle automation is expected to lower the costs for these services, and thus facilitate their expansion.

At a time when vehicle concepts for these services (i.e., shared autonomous vehicles) are still in an early stage of development, this is the right time to explore whether solutions combining parcel delivery and passenger trip requests would be successful in achieving a better multimodal transport network optimisation through load-balancing strategies. The integration of freight and passenger transport, known as 'freight-on-transit' [33] or 'ride-parcel-pooling' (RPP) [34], requires and understanding not only of its positive impacts on the efficiency of the urban distribution of goods and of mobility services for passengers but also the effects on the quality of both services and the consequences for stakeholders' individual costs (e.g., LSPs operating costs). The simulation of different strategies in the context of the CONDUCTOR project can shed light on their effectiveness to face the challenges posed by the growth of e-commerce.

7.2 Use case description

UC3 – Urban logistics investigates and proposes solutions for last-mile parcel delivery based on the integration of urban goods delivery with on-demand transport services. The objective of the use case and the pilot project conducted in Madrid is to propose and simulate different passenger and goods coordination strategies that reduce last-mile parcel delivery-related traffic, taking advantage of the synergies with on-demand passenger transport services.

If the vehicular concepts behind these services allow for the transportation of parcels along with passengers (e.g., with a dedicated locker inside the vehicle), there may be room for an integrated use for passenger and freight transportation. Parcel delivery requests and passenger trip requests can be combined in the service optimisation algorithms: routes that would already take place to attend passenger demand may add stops to deal with parcels, time windows when the vehicle would stay without use considering only passenger trip requests can be used for parcel delivery, etc. A comprehensive understanding of passenger demand patterns is key, in order to identify off-peak time windows. The strategies allocating capacity of on-demand transport vehicles should anticipate and react to temporary but abrupt changes in passenger demand, e.g., due to events or disruptions in other services or modes.

The main challenge of this UC is that the interests of the main actors involved (i.e., compliance with the delivery time window for logistics operators, and adhesion to the people transport schedules for on-demand transport services) may come into conflict, thus the UC may find a balance that meet the requirements of both parts in order to ensure adoption.

This UC will be developed purely in a simulation environment and will focus on the definition of optimisation and coordination strategies of both services. The results of the simulations in the UC should help understand if there are solutions that are able to significantly reduce the transport-related externalities of e-commerce, while at the same time being attractive enough for logistics stakeholders, service providers and transport authorities in terms of quality of service, operating costs and/or required subsidies.

7.2.1 Benefits

The benefits of integrating delivery processes with on-demand passenger's transport services include:

- reduction of average travel times of all vehicles
- reduction of total distance travelled by delivery vans
- reduction of vehicles used for delivery processes
- reduction in vehicle emissions from general traffic
- establishment of cooperation between on-demand passenger's transport and parcel delivery services

7.2.2 Use case objectives

The overall objective of the use case is to anticipate the impacts of solutions that integrate on-demand passenger's transport services with last-mile freight delivery. The specific objectives are the following:

- Identify and describe a set of alternative concepts of operations for the integrated on-demand passenger and parcel delivery services: minimum requirements from service providers and transport authorities, how passengers and LSPs would interact with the service, required characteristics for the vehicles, etc.
- Demonstrate solutions for the identification of time-windows during which on-demand transport services would have overcapacity suitable for the transportation of goods.
- Demonstrate solutions for optimising the services that integrate passenger trip and parcel delivery requests, anticipating the impacts of these services both at societal/network level (e.g., congestion, emissions) and at operation level (e.g., changes in operation costs for mobility service providers and LSPs).

7.2.3 Key requirements

Based on the user needs and requirements as further elaborated upon in the deliverable D1.1, the key categories of stakeholders are the passengers, LSPs, on-demand passenger's transport service operators, residents, and parcel receivers. On the one hand, the main requirement of the on-demand transport service operators is that the new service may not impact on the regular operations, i.e., it may ensure adherence of people's transport schedule. On the other hand, the main requirements of the logistics companies are that the new service ensures the security of the goods, the adhesion to the delivery time window, and the compliance with current transport regulation.

As identified by both logistics companies and on-demand transport operators, the fact of traveling with unknown goods may cause insecurity or stress to passengers, which may affect the demand for the service. So, a further key requirement is to ensure the security and tranquillity of the passengers.

To ensure adoption, normative or incentives for the logistics services are required to reduce the number of delivery vans of the road. Potentially, also adaptations to the passenger transport vehicles for mixed transportation of passengers and parcels are necessary.

As already mentioned in Section 1.2, the compliance with the requirements of the two main actors (logistic operators and on-demand transport services) is a challenge for this UC, as they can conflict with each other, however, it is essential to ensure adoption.

Finally, the main requirement of the passengers is to maintain the normal use of the service, while the one of the parcels receivers is to receive their parcels in time and in good conditions.

7.3 Process flow

The typical situations in which actors interact with the system are described.

7.3.1 Actors

Identified actors are the fleet management centre, the on-demand transport control centre, the route optimisation service, the last-mile delivery service, the connected passenger transport vehicle, and the user application.

7.3.2 Pre-conditions

Fleet management centre

- Established a governance structure for coordination of logistics and on-demand passenger's transport services
- Can send information on the parcel demand, including parcel-dependent time of arrival and destination to the on-demand transport control centre
- Can receive real-time information on the announced parcel delivery requests
- Can send real-time information on the parcel's location, location of arrival
- Can send information on the last-mile process to the last-mile delivery process

On-demand transport control centre

- Established a governance structure for coordination of logistics and on-demand passenger's transport services

- Can send information on the demand to the route optimisation service
- Can send information on the vehicle route to the connected passenger transport vehicle
- Can receive information on on-demand trips

Route optimisation service

- Can receive information on the predicted on-demand transport demand
- Can receive information on the parcel delivery requests
- Can determine and send optimal integrated plans for the transportation of goods and people

Traffic management centre

- Can predict future network states based on vehicle locations and routes
- Can send information on network states to route optimisation service

User application

- Can receive real-time information on the parcel
- Can send real-time requests for on-demand transit to on-demand transport control centre
- Can receive real-time on-demand transit request from user

Logistics service provider

- Can receive information on updated routes from fleet management
- Existence of normative of incentives to adopt the service

Connected passenger transport vehicle

- Can receive information on updated routes from on-demand transport control centre
- Are authorized for the mixed transportation of both passengers and parcels

Last-mile delivery service

- Can periodically receive information regarding the route plan including the next pickup or drop-off point and time

7.3.3 Trigger conditions

Two optimisation approaches will be considered:

- Scenario i: passengers' route optimisation without constraints in the parcel delivery time, i.e., low priority parcel with flexible delivery window, and
- Scenario ii: passengers' route optimisation, constrained to parcel delivery time windows, i.e., high priority parcel with little flexible delivery window.

These two approaches will have a different impact in the selected KPIs (see Section 1.4). Specifically, the first one will allow higher flexibility for adhesion to the passenger optimal schedule, while the second one will deviate from the optimal passenger schedule but will also ensure higher predictability of the delivery.

As already mentioned, the interests of the end users of this UC can sometimes conflict. Even though the objective of the UC is to prioritize the transport of passengers, the possible negative effect on the delivery service must be minimized, since for this UC to be successful both end users (mobility providers and delivery companies) must be willing to implement and adopt it. Therefore, finding a trade-off with the parameters of these two approaches will allow us to find a Pareto solution, that meets the preferences of the decision-makers.

Finally, the approaches considered in this UC will be developed, integrated and tested in a simulation environment. Currently, the available Aimsun Next traffic model only covers the M-30 ring road area, at a microscopic level of detail. However, in order to properly understand the impact of these solutions, it is necessary to have a model that covers not only the M-30 but also the urban area of Madrid. An existing macroscopic Aimsun traffic model, which is owned by Madrid City Council, covers the whole urban area. However, this macroscopic model is not suitable for simulating in detail the traffic conditions and road congestions. If this model is used, the comparison criteria should be relaxed as it does not allow for such a detailed comparison. Further discussions will raise the possibility of developing a mesoscopic model of the urban area, which will provide a higher level of detail of traffic conditions. This mesoscopic traffic simulation model would allow the comparison of both optimisation approaches in much more detail, with a more accurate simulation of travel times of all vehicles as congestion impacts are better modelled

7.3.4 Main process flow

This section describes the flow implementation of the UC. The main flow is distinguished based on the two optimisation scenarios listed in Section 7.3.3.

Scneario i: passengers' route optimisation without constraints in the parcel delivery time

- The passengers' mobility patterns obtained from big data sources (in particular, mobile network data and shared mobility service data) are analysed to generate on-demand transport service demand and identify windows of low demand for specific routes.
- The last-mile delivery routes are characterised, and the logistics and delivery hubs are identified.
- Route optimisation strategies without constraints are applied.
- The segmented general private mobility matrix is generated.
- The 'background' traffic, in terms of aggregated origin-destination trips, is simulated using Aimsun Next and the simulation of on-demand transport service demand (individual requests) is enabled using Aimsun Ride.
- The results of the simulation are analysed and the KPIs computed to assess the impact of the solution.

Scenario ii: passengers' route optimisation, constrained to parcel delivery time windows

- The passengers' mobility patterns obtained from big data sources (in particular, mobile network data and shared mobility service data) are analysed to generate on-demand transport service demand and identify windows of low demand for specific routes.
- The last-mile delivery routes are characterised, and the logistics and delivery hubs are identified.
- Route optimisation strategies without constraints are applied. In this case, a preference-based categorisation (high and low priority) of the parcel request is needed. Nevertheless, in this scenario passengers' demand will still be the priority.
- The segmented general private mobility matrix is generated.

- The ‘background’ traffic, in terms of aggregated origin-destination trips, is simulated using Aimsun Next and the simulation of on-demand transport service demand (individual requests) is enabled using Aimsun Ride.
- The results of the simulation are analysed and the KPIs computed to assess the impact of the solution.

7.3.5 Termination conditions

Interruption may occur in case the traffic conditions or set of requests significantly change during the re-optimisation, e.g., if an incident or accident occurs, and initial re-optimisation is triggered based on outdated information. Technical failure can also induce termination.

7.4 Impact assessment framework and KPIs

The following KPIs will be used to assess impact and compliance with user’s requirements. They are divided in three categories: technical KPIs, business KPIs, and environmental KPIs. As mentioned in Section 7.3.3, in case the macroscopic model is used, the KPIs related to the network and environmental performance may be relaxed.

Table 13: Technical KPIs UC3

ID	Technical KPI
UC3_T01	Total distance travelled by delivery vehicles
UC3_T02	Total travel time of the delivery vehicles
UC3_T03	Number of vehicles used for goods delivery
UC3_T04	Average travel times of road traffic
UC3_T05	Total distance travelled by passenger transport vehicles
UC3_T06	Total travel time of the passenger transport vehicles
UC3_T07	Uncertainty of time of delivery of parcels
UC3_T08	Passenger demand served
UC3_T09	Total number of parcels delivered
UC3_T10	Adherence to passenger travel schedules

Table 14: Economic KPIs UC3

ID	Economic KPI
UC3_B01	Average shipping costs per parcel delivered
UC3_B02	Average costs per passenger

Table 15: Environmental/Social KPIs UC3

ID	Environmental / Social KPI
UC3_E01	Total vehicle emissions of CO2 and NOx
UC3_E02	Acceptance of ride-parcel-pooling

7.5 Pilot deployment and testing

The solutions and scenarios considered in UC3 will be developed and evaluated purely in a simulation environment, that allow us to get as close as possible to real-life operations. Based on the simulation results and the interaction with stakeholders, requirements for the implementation in real-world conditions will be determined. Therefore, stakeholders' engagement is of paramount importance for the UC development.

An initial workshop with the stakeholders was already organized in March 2023 to present UC3 and to gather their initial impressions and expectations. It is planned to keep regular contact with key stakeholders during UC implementation and testing to discuss the interest and feasibility of the solutions proposed, their compliance with the requirements, and gather their feedback on the results obtained.

In the assessment of the use case, specific attention will be paid to (i) the impact on passenger's demand, (ii) adhesion to people's transport schedule (desired departure/arrival times), and (iii) adhesion to parcel delivery time window.

8 KEY PERFORMANCE INDICATORS

This chapter reviews the potential impacts of the CCAM functionalities that are identified in the context of the CONDUCTOR pilot projects. For each pilot, the KPIs are defined and categorised according to the following groups or dimensions: technical, business, environment and social (see Chapter 2). In the taxonomy presented in this chapter these CONDUCTOR KPIs are further categorised based on their impact domain. Tables 16-19 provide a mapping of the dimension specific KPIs (including the KPI IDs) to the impact domain. It should be underlined, however, that some of the impacts are related (a reduction of fuel consumption is expected to reduce shipping costs), see, e.g., [29].

The technical KPIs reflect the progress regarding the technical functionalities' impacts on the services. The identified KPIs address the potential higher-level impact domains of CCAM:

- *efficiency, quality and reliability of passenger transport services*: CCAM functionalities are expected to impact the journey of travelers, for example by the synchronization of various transport modes but also the deployment of flexible on-demand services. In turn, this may lead to increased demand for passenger transport services. KPIs reflecting the impact on the service performance include metrics on travel time, travel distance and punctuality of public transport service.
- *efficiency, quality and reliability of freight transport services:* CCAM developments and functionalities are likely to have an effect on the operational performance of freight service. CONDUCTOR innovations on this aspect focus on improved travel times or travel distances.
- *network-wide traffic conditions:* a large-scale adoption of CCAM functionalities may have impact beyond individual users and influence the level of service of the road network. CONDUCTOR KPIs on network-wide traffic conditions reflect both the conditions on a more local scale (i.e., at signalized intersections) as well as on a journey and network level.

Table 16 provides an overview of the technical KPIs defined for the CONDUCTOR project.

Table 16: Overview CONDUCTOR Technical KPIs

Domain	Related Technical KPIs	KPI IDs
Efficiency, quality, and reliability of passenger transport services	Door-to-door travel time per passenger	UC1_T01
	Travel distance per passenger	UC1_T02
	Punctuality of public transport services	UC1_T03
	Fleet kilometres per daily plan	UC2_T01
	Total travel time	UC3_T06
	Total travel distance	UC3_T05
	Rate of manual interventions per route plan	UC2_T02
	Vehicle occupancy	UC2_T03
	Planning service reaction time	UC2_T04
	Ridership	UC1_T05, UC3_T08
	Adherence to passenger travel schedules	UC3_T10

Efficiency, quality, and reliability of freight transport services	Travel time per vehicle Total travel distance Total travel time Frequency of stops per vehicle per trip Number of vehicles used Uncertainty in time-of-delivery Number of parcels delivered	UC1_T11 UC3_T01 UC3_T02 UC1_T14 UC3_T03 UC3_T07 UC3_T09
Network-wide traffic conditions	Average waiting time at signalized intersections per user group Average travel time per vehicle Average travel distance per vehicle Average recovery time after events/disruptions Average queue length at signalized intersections	UC1_T04, UC1_T12 UC1_T06, UC1_T09, UC3_T04 UC1_T07, UC1_T10 UC1_T08 UC1_T13

The uptake of CCAM by various groups including businesses and individuals is crucial in the transition towards improved passenger and fleet operations and network-wide traffic conditions. Typically, organisations monitor business performance or continuity, for which economic or monetary metrics are still predominantly used. On a macroscopic scale, economic metrics are oftentimes adopted to measure development. In the context of CONDUCTOR, the following impact domains of economic KPIs have been identified:

- *Business performance and efficiency:* CCAM functionalities may allow for reaching economic goals. KPIs in this domain reflect the economic impact from an operator or service provider point of view, e.g., the costs per passenger, per parcel or per trip (or a part thereof).
- *Business flexibility:* beyond impact on the performance of the existing business operations, CCAM also provides opportunities for the introduction of new types of services.
- *Economic performance:* this domain includes KPIs that reflect economic progress on a macroscopic scale.

Table 17 provides an overview of the economic KPIs defined for the CONDUCTOR project.

Table 17: Overview CONDUCTOR Economic KPIs

Domain	Related Economic KPIs	KPI IDs
Business performance and efficiency	Costs per passenger Average shipping costs Average planning costs per route plan Average fuel consumption per vehicle trip	UC1_B01, UC2_B01, UC3_B02 UC1_B04, UC3_B01 UC2_B02 UC1_B03
Business flexibility	Enabled and number of last-minute product sales	UC2_B03

Economic performance	Economic losses due to travel delays	UC1_B02

Developed functionalities may have side-effects. Particularly externalities with respect to air quality, greenhouse gas emissions and noise pollution have gained increasing attention, particularly due to EU and UN targets [35]. In the wider spectrum of impacts of traffic and logistics, KPIs on the domain substance emissions and noise are included.

- *Substance missions*: this domain considers the impact of the functionalities on air pollutant and quality, greenhouse gas emissions and the (related) fuel consumption.
- *Noise:* with transport a major source of noise pollution, this domain considers sound production by traffic.

Table 18 provides an overview of the environmental KPIs defined for the CONDUCTOR project.

Table 18: Overview CONDUCTOR Environmental KPIs

Domain	Related Environmental KPIs	KPI IDs
Substance emissions	Vehicle emissions Fuel consumption per passenger dropped off	UC1_E02, UC1_E03, UC3_E01 UC2_E01
Noise	Average sound power level	UC1_E04

The CONDUCTOR social KPIs consider both the safety of the services as well as the acceptance of different user groups, including logistics and transport operators, governmental agencies, heavy-duty vehicle drivers and passengers. Table 19 provides an overview of the social KPIs defined for the CONDUCTOR project distinguishing the following domains:

- *Safety:* the KPIs in this domain consider the impact on road safety using real-world and surrogate metrics.
- *Acceptance:* the uptake of CCAM, and thereby the impact on a larger scale, highly depends on the acceptance of its users. A set of KPIs has been defined reflecting the acceptance of (end) users including travellers, operators, service providers and drivers.

Table 19: Overview CONDUCTOR Social KPIs

Domain	Related Social/Environmental KPIs	KPI IDs
Safety	Number of red-light violations Average time-to-collision	UC1_E05 UC1_E08

Acceptance	Acceptance of governance models Logistics service providers' acceptance Drivers' acceptance Ratio of accepted and rejected requests Acceptance of ride-parcel-pooling	UC1_E01 UC1_E06 EC1_E07 UC2_E02 UC3_E02

9 CONCLUSIONS

The developed and upgraded functionalities part of the CONDUCTOR project will be validated through three use cases and tested in five pilot projects throughout Europe. UC1 on integrating traffic management with inter-modality will be tested in Athens, Madrid and Almelo. UC2 considers demand-responsive transport, evaluated in the context of shuttle services between Slovenian cities and Italian airports. UC3 focuses on the integration of freight and passenger transport, tested in Madrid. This deliverable presented the specifications of the use case per pilot since site-specific requirements should be considered during further development activities. Per pilot, the research questions, functional requirements, potential benefits, and impact assessment are discussed.

The textual use case specifications presented in this deliverable were defined through an iterative approach in close collaboration with the stakeholders. The potential benefits of the systems under consideration include an improvement in the efficiency of both passenger and freight transport operations, e.g., expressed by a reduction in travel time and travel distance. In addition, with transport being a major source of various health and environment-related issues, successful adoption of the CCAM functionalities in passenger and freight transportation services can lead to a positive impact beyond efficiency, including a reduction of fuel consumption, an improvement of air quality and increased road safety.

A comprehensive multi-dimensional KPI framework has been established, used to measure the impact of the innovations in the pilot projects. The indicators are clustered using the four dimensions technical, environment, economy and society. The categorization allows for an assessment that is applicable beyond the individual pilot projects, while at the same time considers the effects across user groups and stakeholders, scenarios, and sites.

The KPIs from the pilot projects are further classified within each dimension, identifying the domain for which impact is anticipated and monitored. These domains, and the corresponding KPIs, can be incorporated during the future development tasks of CONDUCTOR, specifically the modelling activities part of WP2 and WP3, and the validation and impact assessment of WP5.

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A. ABBREVIATIONS AND DEFINITIONS

Term	**Definition**
API	Application programming interface
CAV	Connected and automated vehicle
CCAM	Connected, cooperative and automated mobility
CCTV	Closed-circuit television
DRT	Demand-responsive transport
EU	European Union
iTLC	Intelligent traffic light controller
GLOSA	Green light optimised speed advice
GPS	Global positioning system
KPI	Key performance indicator
LSP	Logistics service provider
RPP	Ride parcel pooling
SDG	Sustainable Development Goal
SSMS	Sustainable and Smart Mobility Strategy
UC	Use case
UN	United Nations
WP	Work package