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ORCHESTRA Project Deliverable: D6.1

Evaluation Handbook

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Deliverable Identification

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Release History

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0.1	2021-10-27	PCOS proposed	The table of contents of the deliverable has been defined, showing the planned overall structure of the document.
0.2	2021-11-08	PCOS approved	Approved if updated – no new review needed
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0.5	2022-06-15	External proposed	Deliverable complete and ready for release. Last internal review to identify remaining deficiencies.
1.0	2022-06-30	Released	Formal approval of Project Coordinator and partners has been obtained.

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About ORCHESTRA

The problem addressed by ORCHESTRA is that traffic caused by transport has many negative effects. There are congestions, delays, emissions, and negative impacts on urban environments, and in case of disruptions, there may be huge consequences on the efficiency and timeliness. These challenges are hard to handle due to lack of coordination between the different transport modes.

The long-term vision of ORCHESTRA is a future where it is easy to coordinate and synchronise the traffic management of all modes to cope with diverse demands and situations. The overall objective of ORCHESTRA is to provide European policy makers, public authorities, transport providers and citizens with new knowledge and technical and organisational solutions to enhance collaboration and synchronising of operations within and across transport modes.

The project will:

- Establish a common understanding of multimodal traffic management concepts and solutions, within and across different modes, for various stakeholders and multiple contexts
- Define a Multimodal Traffic Management Ecosystem (MTME) where traffic managements in different modes and areas (rural and urban) are coordinated to contribute to a more balanced and resilient transport system, bridging current barriers and silos
- Support MTME realisation and deployments, through the provision of tools, models, and guidelines – including the integration of connected and automated vehicles and vessels (CAVs)
- Validate and adjust MTME for organisational issues, functionality, capability, and usability
- Maximise outreach and uptake of project results through strong stakeholder involvement

ORCHESTRA's main advancements beyond state-of-the-art are related to four focus areas:

- MTME facilitated by: 1) a Polycentric Multimodal Architecture (PMA) specifying how systems collaborate. 2) Flexible organizational and business models. 3) Simulation and training tools. 4) Policy and regulatory recommendations. 5) data governance and sharing framework
- Traffic orchestration supporting optimal traffic flows, adapted to current and foreseen situations and societal aspects. Data on ongoing and planned transports as well as other issues that may affect the traffic will be monitored and used in decision support and to facilitate resilience
- Coordination across modes and networks bridging current silos, ensuring best possible utilisation of transport system as a whole
- Traffic management supporting more optimal multimodal transport services and fleet operations, those carried out by CAVs included. Transport operations will be guided and controlled according to pre-defined rules and trade-offs between different optimisation targets.

The project will validate and evaluate the multimodal traffic management concept and related tools in its two Living Labs, both in Norway and Italy, covering freight and person transports across road, rail, water and air.

Legal disclaimer

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Executive Summary

This document presents an impact assessment framework for the evaluation studies to be conducted in the ORCHESTRA project. The main results include:

- A stepwise description of the evaluation process
- Development of the program theory for the multimodal traffic management ecosystem (MTME), explaining the underlying logic of how the system in expected to operate to achieve improvements in traffic management and societal impacts
- Key performance areas to be addressed in evaluation studies with corresponding research questions and a suggestion of key performance indicators
- An overview of data collection methods and analysis
- A guideline for reporting of results from the evaluation studies, to ease the comparison of results between studies and ensure a common basis for knowledge development and lessons learned

The final list of KPIs and details in data collection and analysis will be further elaborated as part of task 6.2 in collaboration with WP4 and WP5 when developing the enabling tools and planning the simulation studies and living lab experiments in details.

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List of Abbreviations

Table 1: List of abbreviations

Abbreviation	Explanation
CAV	Connected and automated vehicle/vessel
C-ITS	Cooperative Intelligent Transport Systems
CoP	Community of Practitioners
GHG	Greenhouse Gas
ITS	Intelligent Transport Systems
KPA	Key Performance Area
KPI	Key Performance Indicator
MAAS	Mobility as a service
MTM	Multimodal Traffic Management
MTME	Multimodal Traffic Management Ecosystem
PMA	Polycentric Multimodal Architecture
TO	Traffic Orchestrator
TRL	Technology Readiness Level

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List of Definitions

Table 2: List of definitions

Definition	Explanation
Acceptability	Focus on people's opinions about performances of a future or possible technology (acceptability process).
Acceptance	Focus more on people's opinions and experience during and after the introduction of ICT (technology acceptance process).
Effects	A change that is a result or consequence of an intervention/project. May be intended or not.
Impacts	The influence of the result/effect of an intervention or project.
Mode	Road, sea, rail, or air. Within some modes, there might be sub-modes. In general, the traffic orchestrator addresses one mode, which may include sub-modes (e.g., bike, bus, car, etc. for road). If a sub-mode (e.g., light rail) is managed as a separate network, the sub-mode is itself considered as a mode (as defined in D3.1).
MTM	Multimodal traffic management system, including the system tools and functionality.
MTME	Multimodal traffic management ecosystem, including the context and relationships between actors and environment in which the MTM is operating.
Network	A transport network has a mode and the traffic in the network is managed in one or more governance areas (as defined in D3.1).
Outcomes	The result or consequence of the intervention or project.
Program theory	A program theory explains how an intervention is understood to contribute to a chain of results that produce the intended or actual impacts[1].
Resilience	The definition we use in this report is "A system is resilient if it can adjust its functioning prior to, during, or following events (changes, disturbances, and opportunities), and thereby sustain required operations under both expected and unexpected conditions" (as defined in D3.1 and Hollnagel, 2019).

[1] www.betterevaluation.org

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1 About this Deliverable

1.1 Why would I want to read this deliverable?

The Evaluation Handbook presents the scientific framework for the impact assessment of the MTME within the ORCHESTRA project. An overall description of the evaluation methodology is provided, along with a stepwise explanation of the different stages of the impact assessment process. This document gives guidance for the individual evaluation studies that will be conducted as part of the ORCHESTRA project, including definitions of KPIs as well as data collection methods and plans for data analysis.

1.2 Intended readership/users

In addition to provide guidelines for the evaluation studies within the ORCHESTRA project, the Evaluation Handbook will present a methodological framework for impact assessment of innovative transport and mobility services with a high degree of complexity. Therefore, the document should be of interest for research scientists performing the evaluation of the MTM ecosystem and other research scientists and stakeholders involved in evaluation of intelligent transport systems.

1.3 Structure

This document provides an overview of the evaluation approach and research methods that will be utilised in the evaluation of the multimodal traffic management ecosystem (MTME).

Chapter 2 presents the overall evaluation methodology, explaining the research and innovation process of ORCHESTRA and the scientific basis for the evaluation approach for impact assessment of the MTME.

In Chapter 3 the impact assessment framework is described in detail, with assessment of technology readiness levels, a problem analysis, and the development of the program theory of the MTME, resulting in a list of key performance areas (KPAs) of the MTME.

Chapter 4 presents the operational evaluation plan, including research questions, key performance indicators (KPIs), research and data collection methods, analysis and guidelines for reporting of results.

Chapter 5 presents a short summary of conclusions and comments on how the results will be utilised and elaborated in other parts of the project.

1.4 Other project deliverables that may be of interest

This deliverable has relations to other ORCHESTRA deliverables. Inputs are used from:

- D2.1 Initial target vision
- D2.2 Pre-Studies on environment analysis and drivers
- D2.3 Initial scenarios for multimodal traffic management
- D3.1 Initial use cases for multimodal traffic management
- D3.2 Intermediate Polycentric Multimodal Architecture (PMA) for multimodal traffic management
- D3.3 Final Polycentric Multimodal Architecture (PMA) for multimodal traffic management
- D4.1 Initial version of technical tools
- D5.1 Simulation Architecture
- D5.3 Plan for ORCHESTRA Living labs

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The conceptual model based on Program Theory in WP6 has been reciprocally used in D2.3 and outputs will be utilized in Task 6.2 Evaluation, for performing the evaluation assessment based on qualitative and quantitative analysis and data collected from the simulations and real-life experimental studies carried out in the two Living labs.

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2 The ORCHESTRA evaluation methodology

2.1 Research and innovation process

The overall research and innovation process of ORCHESTRA is based on the principles of the design science framework for evaluating information system research (Hevner, 2007). This iterative innovation approach embodies three research cycles as a way to ensure an efficient evolution of the project to gain knowledge for future deployment.

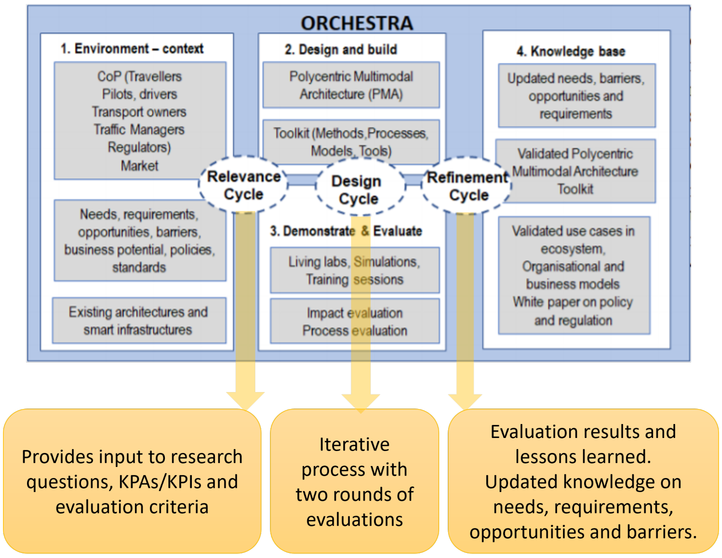

Figure 1: Design science framework adapted to multimodal traffic management and providing input to the evaluation process

Figure 1 illustrates how the ORCHESTRA activities are connected to provide project results and outcome, and how the research cycles involved will contribute to the evaluation process.

The aim of the **relevance cycle** is to link the project to its contextual environment and to ensure the relevance of the multimodal traffic management system.

The aim of the **design cycle** is to design and establish the multimodal traffic management system through an iterative process where two rounds of evaluation facilitate learning and improvements.

The aim of the **refinement cycle** is to use and refine existing knowledge based on the results and lessons learned during the project.

Several evaluation studies related to the different key performance areas will be conducted with the aim of 1) verifying that the multimodal traffic management ecosystem (MTME) will meet stakeholder needs and requirements, 2) validating the relevance of the system, and 3) building knowledge on potential effects and impacts of the implementation process. The main purpose of the evaluation activities is to increase the understanding on how the MTME should be developed and implemented in the future transport system to obtain beneficial impacts for stakeholders and the society.

2.2 A theory-driven evaluation approach

The ORCHESTRA project will utilize a theory-driven evaluation approach for the impact assessment and process evaluation of the multimodal traffic management ecosystem (MTME). The methodological framework is built on previous research works related to the evaluation of intelligent transport systems (Lervåg, 2021). This scientific approach will provide a structured way of addressing the different factors intervening in the implementation process of a multimodal traffic management system and evaluating the positive and negative outcomes.

The theory-driven evaluation approach is applicable throughout the whole innovation and decision-making process, ranging from early concept development phase until the MTME is applied and

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ready for market deployment. This approach is based on an iterative methodology that allows adding and combining multiple evaluation designs and methods.

The theory-driven evaluation approach is suggested to be beneficial when the purpose of the evaluation is to serve interdisciplinary knowledge development, and when the intervention has a high complexity level or involvement of multiple stakeholders (Weiss, 1995; Blamey & Mackenzie, 2007; Funnel and Rogers, 2011; Chen, 2012; Pawson & Tilley, 1997; Hills & Junge, 2010; Bredgard et al., 2016). The approach is often applied when the empirical evidence on cause-and effect relationships cannot be proven (e.g., programmes and interventions in the health sector). The theory-based evaluation methods are therefore less likely to provide quantitative evidence with the same scientific power that is attended with the experimental model (before- and after-studies). The main reasons for choosing the theory-driven evaluation approach as an overall scientific approach in ORCHESTRA are:

- The MTME encompasses a variety of technological solutions and services, and complex causal mechanisms and substantial contextual factors influencing the outcomes.
- The MTME is subject to accelerating technology development. Hence, measures and services undergo incremental improvements throughout its lifetime, making it rather difficult to compare the outcomes over time or between different implementation phases.

Research and evaluation studies within the transport sector commonly follow the (quasi-) experimental model for estimating the causal impact of interventions or measures. This approach is, however, developed for and adapted to conventional road and traffic management measures, and can be in some cases considered inadequate when it comes to highly innovative and complex systems; facing methodological challenges related to limited empirical evidence, complex causal mechanisms, baseline issues and contextual effects among other factors (Böhm, Flechl, Aigner og Visser, 2016; Mitsakis et al., 2016; Newman-Askins, Ferreira, & Bunker, 2003).

The main differences between the theory-driven approach and conventional quasi-experimental research designs are twofold: The theory-driven evaluation provides a mechanistic interpretation rather than a counterfactual approach to determining causality, and the influence of contextual factors on direct and indirect outcomes is included in the evaluation design. This approach proposes an explanation of how and why an intervention, or a measure, will provide/provides a specific result, or otherwise in case of failure, it makes it possible to identify the circumstances and conditions that have caused the failure and the ones that would lead to a successful implementation.

2.2.1 The program theory as a conceptual framework for defining the research questions and the evaluation design

The evaluation process in ORCHESTRA is based on the *program theory* of the MTME concept, which is an abstract representation of how the MTME is intended to operate. The program theory facilitates the understanding of how and why the MTME would produce a set of predefined effects and impact, by explaining the relationships between the key elements of the MTME concept.

The relationships between the different innovations developed in the project and the expected outcomes are described in terms of a) how the MTME is expected to result in changes, b) why and in what context changes are expected to occur, and c) the impacts (influence of the changes) and effects (consequences of the changes) in short, medium and/or long term (Chen, 2012; Funnel and Rogers, 2011; Hills and Junge, 2010). The program theory will contribute to expose the underlying logic of the ORCHESTRA concept, describing the stakeholders' expectations of how the planned

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inputs and efforts should lead to the desired outcomes, involving assumptions, risks, causal mechanisms, and external conditions.

Once the program theory of ORCHESTRA is established, the first step is to define the key performance areas and formulate the corresponding research questions. The next step is to identify the qualitative and quantitative KPIs and decide the appropriate evaluation methods.

2.2.2 Contextual aspects

To be able to efficiently develop and deploy a new multimodal traffic management system in a way that generates beneficial direct and indirect impacts for users and society, we need to identify the drivers and barriers to the successful implementation of the system. In addition, the contextual factors, requirements (e.g., legal, political, safety) and enablers (e.g., technologies) should be included in the whole picture of change.

It is acknowledged that some contextual or external aspects intervening in the implementation process (areas of application) may inhibit or enhance the outcomes of a new system. Examples of determining factors include among others, the policies, governance, laws and regulations, the use of smart infrastructure, and the data sharing and governance practices. Furthermore, the program theory approach will also identify the underlying mechanisms of change that can help to realise the expected outcomes, such as the usability of the MTM developed in ORCHESTRA and the acceptance of the MTME concept, the use of more autonomy in the transport sector, and new operational practices and decision-making support system.

New elements or inputs can be later incorporated in the program theory framework throughout the life cycle of the MTME, for generating new informed decisions or new system functionality adjustments. This option is useful before the implementation in real traffic since the proposed technologies of the MTME in this project are in different phases of the innovation process (with various technology readiness levels).

2.2.3 Determination of causality

The wide range of evaluation designs available are based on different scientific assessment methods of the various effects and impacts. The reliability and validity of these methods influence to what degree the assessment approach is valid and well designed. Experimental designs are associated with inherent methodical stringency emphasizing internal validity (Shadish, Cook, & Campbell, 2002). Such comparative before-and-after studies generate scientific evidence-based knowledge on whether a measure works or not. It cannot however explain why the measure provides a specific result, or otherwise why it fails to do it, without a thoroughly investigation of the different contextual factors. This requires available data on system performance and outcome. The causality is usually determined with a counterfactual analysis comparing the observed results with what the situation would have been if the system was not implemented (the baseline option).

Determining the cause-effect relationships is fundamental for all research studies. The generative and mechanistic approaches involve the consideration of causality as a latent variable, that can be activated under certain circumstances where the causal mechanisms increase the likelihood of a change (or an effect) to occur but depend on the contextual and situational conditions (Pawson and Tilley, 1997; Bhaskar, 2008). The same measure might also trigger different effects in different situations and for different user groups. Hence, causality is determined by a logic-based model assessment of cause-and-effect relationships in order to identify the contribution of multiple causes to the observed or desired outcomes. This will provide evidence on how, when and under what circumstances a system will generate the most beneficial effects.

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The overall theory-driven evaluation approach of ORCHESTRA will determine the relevant decisive factors for the implementation of the MTME. This approach will propose appropriate evaluation methods in accordance with the research questions for the different key performance areas. Multiple types of evaluation designs will be combined to obtain a complete understanding of the full potential of the MTME.

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3 The impact assessment framework

The evaluation methodology of ORCHESTRA follows a theory-driven impact assessment process as illustrated in Figure 2. A stepwise description of the evaluation framework and process are presented in chapter 3 and 4.

Chapter 3 describes the development of the assessment framework, addressing the technology readiness of the MTME, a short summary of the problem analysis and development of the program theory as a conceptual framework for the following evaluation studies.

Chapter 4 describes the evaluation process in terms of the research questions, research methods, data collection methods and analysis, as well as some guidelines for the presentation of results.

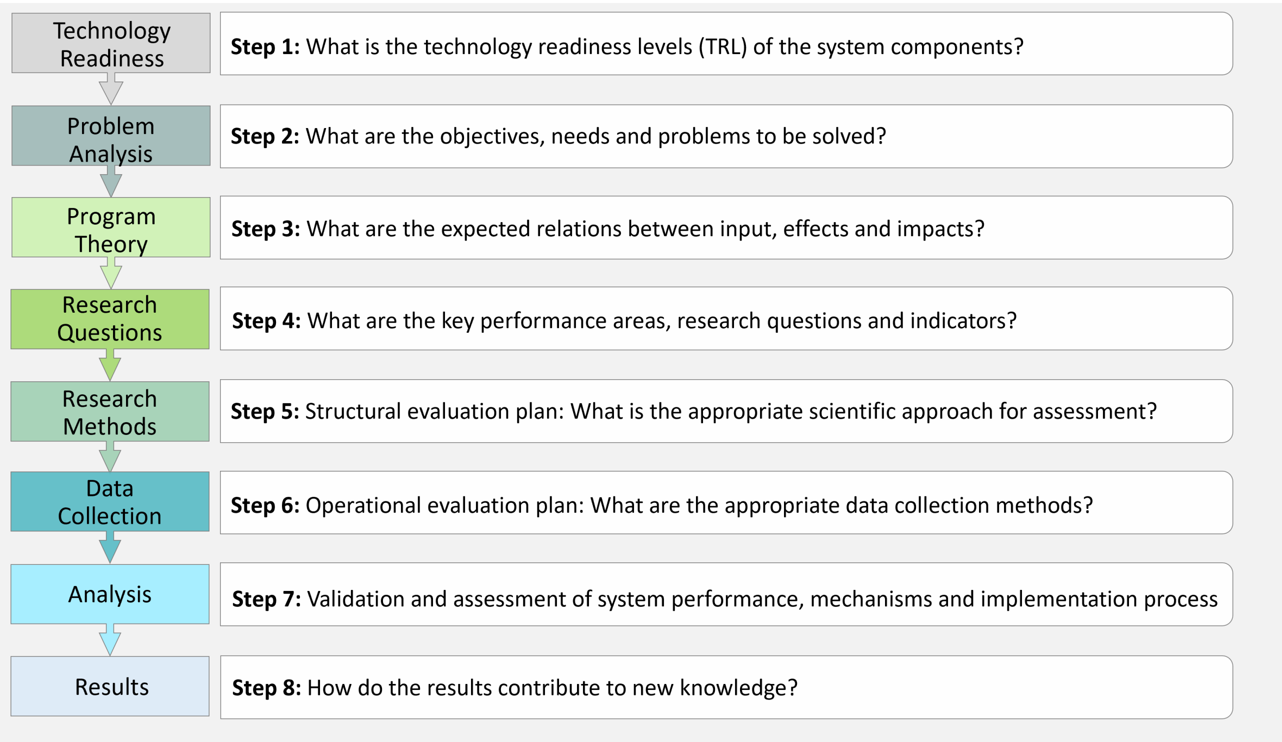

Figure 2: A theory-driven framework for impact assessment

3.1 Technology readiness

3.1.1 Description of TRL scale

Technology readiness levels (TRLs) are scales used to evaluate the maturity of a technology or a system. During these last 30 years, the original TRL scale developed by the American National Aeronautics and Space Administration (NASA) in 1995 for the aeronautics and space programs has changed significantly and has been applied in different technology research contexts.

The primary objective of the NASA seven-level TRL scale was to identify what the engineers still had to do to reach the maturity level of components necessary for the implementation in space hardware systems. In 2013, the TRL scale finally became an ISO standard, ISO 16290:2013 standard, *Space systems – definitions of the Technology Readiness Levels (TRLs) and their criteria of assessment* (International Organization for Standardization).

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The TRL scale is also an innovation policy tool, implemented in the Horizon 2020 European framework program, and used for the evaluation of the maturity level of various technologies (e.g., finance, nanoscience, electronics, energy, robotics, transport).

The High-Level Expert Group on Key Enabling Technologies (HLG-KET) of the European Commission (EC) presented in 2015 a final version of the scale to be used in European projects with the aim of supporting the innovation and industrialisation process of technologies from the formulation of a promising concept to a practical market product. The expert group recommended that the commission provides funding for new technologies of TRLs 2-3 up to deployment and large-scale demonstrations (TRL 5-8) to accelerate the commercialisation of innovative technologies. The NASA scale[2] and the HLG-KET scale[3] (2015) are quite similar and now composed of nine levels.

The first 1-3 TRL levels represent the technological research part of the scale, whereas the 4-7 levels concern the technology development and levels 8-9, the market deployment. At the lowest level, TRL 1, a new idea regarding a technology generally arises, and the scientific basic properties of the technology are described in either articles or documents. At TRL 2, the technology concept and practical applications are formulated for further active research at the next level. TRL 3 is the level where the analytical research and laboratory studies are expected to reveal the feasibility of the concept (proof of concept) and validate the eventual theories by measuring relevant parameters in a laboratory. At this level, the practical potential of the technology is verified with results from the laboratory tests (TRL 4), and the development process starts with the preparation of a plan for the next level. The results show that the expected performances can be achieved. TRL 5 continues the validation of the technology under simulated operating conditions in relevant environments to provide the construction basis for prototyping the technology. A TRL 6 technology becomes a prototype, to be tested at a pilot scale under realistic operating conditions (including safety requirements). TRL 7 requires demonstrating the prototype at a market scale under real operating conditions. A TRL 8 technology is ready to be implemented, but still required to be tested before the final successful implementation at level 9 (deployment and manufacturing).

Table 3 shows the TRLs as presented in 2015 by the HLG-KET in their final European Commission report. The scale is useful to compare maturity levels of different system components. The TRL level of a system is the lowest TRL of its components. In addition, when a level is reached, the next level of development is not necessarily a higher level. The time scale from level 1 to level 9, often takes decades of research and engineering investigations. This means that higher technology maturity levels generally reached in the framework of European projects are not expected to be more than 2-3 levels.

Table 3: Technology Readiness levels as defined by the HLG-KET of the European commission (2015).

TRL	Definitions
1	Basic principles observed and reported
2	Technology concept and/or application formulated

2 Technology Readiness Levels Demystified. Accessed December 01, 2021: https://www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level

3 HLG-KET (2015). Final Report. European Commission https://www.kowi.de/Portaldata/2/Resources/fp7/hlg_kets_final_report_en.pdf

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3	Analytical and experimental critical function and/or characteristic proof of concept
4	Technology validation in laboratory environment
5	Technology validation in relevant environment
6	Prototype demonstrated in relevant environment
7	Prototype demonstrated in operational environment
8	Technology completed through test and demonstration
9	Technology qualified through successful operations

3.1.2 Evaluation of technology readiness levels

The utilisation of the TRL scale as part of an assessment framework can represent a challenge, for example, when the components of a system are at different levels or when different applications have to be considered. The linear TRL evaluation scale may be found not adapted and new measuring methods have been proposed in the past to evaluate particular technologies (e.g., EU project ALISE[4]). These matrices associated to the TRL scale the economic competitiveness and the technology performances. Time, cost and performance requirements often generate deviations from the linear TRL analysis.

Table 4 presents the technologies and tools developed in the ORCHESTRA project, as described in the Description of the Action (DoA) document. The TRLs before and expected at the end of the project have been evaluated by the project experts responsible for the development of the different technologies and tools. These technologies will be tested and validated in connection with the living labs, training modules or the simulations, and the TRLs attained at the end of project will be examined again.

Table 4: Technology readiness levels for the technologies and tools developed in the framework of the ORCHESTRA projects.

Key technologies		**TRL before**	**Expected TRL after**
1	Multimodal traffic management ecosystem	NA	**3**
2	Polycentric multimodal architecture	2	**3-5**
3	Simulator	4	**6**
4	Data governance tool	4	**6**
5	Distributed ledger tech. for credentials sharing supporting transport demand management	3	**5**
6	Data fusion tool	3	**6**

4 Advanced Lithium Sulphur battery for xEV (2015-2019). https://cordis.europa.eu/project/id/666157

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7	Transport demand management Access priority (Norway, Living lab)	3	**4**
8	Demand capacity balancing Speed adjustment (Norway, Living lab)	2	**4**
9	Integrated services for traffic data sharing, capacity demand balancing, traffic flow management and (re-) routing, and mobility information (Italy, Living lab)	4	**6**
10	Arbitration models and decisions support (simulations)	2	**4**
11	Smart infrastructure for CAVs (Norway, Living lab)	3	**5**
12	Training modules	3	**5**

In order to provide the necessary framework to evaluate the TRL of the 12 project technologies and tools, Table 5 reproduces the milestones and work to be achieved for the different *elements under consideration for the technology readiness assessment*, as described in the ISO 16290:2013. By *element*, the ISO standard means *a component, a piece of equipment, a subsystem or a system*.

Table 5: TRL – Milestones and work achievement as described in ISO 16290:2013 (permission for copyright required in July 2021).

TRL	Milestones achieved for the element	Work achievement (documented)
1	Potential applications are identified following basic observations but element concept not yet formulated.	Expression of the basic principles intended for use. Identification of potential applications.
2	Formulation of potential applications and preliminary element concept. No proof of concept yet.	Formulation of potential applications. Preliminary conceptual design of the element, providing understanding of how the basic principles would be used.
3	Element concept is elaborated and expected performance is demonstrated through analytical models supported by experimental data/characteristics.	Preliminary performance requirements including definition of functional performance requirements. Conceptual design of the element. Experimental data inputs, laboratory-based experiment definition and results. Element analytical models for the proof-of-concept.

4	Element functional performance is demonstrated with breadboard/physical model tests in laboratory environment.	Preliminary performance requirements with definition of functional performance requirements. Conceptual design of the element. Functional performance test plan. Breadboard/physical model definition for the functional performance verification. Breadboard/physical model test reports
5	Critical functions of the element are identified and the associated relevant environment is defined. Breadboard/physical model not full-scale are built for verifying the performance through testing in the relevant environment, subject to scaling effect.	Preliminary definition of performance requirements and of the relevant environment. Identification and analysis of the element critical functions. Preliminary design of the element supported by appropriate models for the critical functions verification. Critical function test plan. Analysis of scaling effects. Breadboard/physical model definition for the critical function verifications. Breadboard/physical model test reports
6	Critical functions of the element are verified, performance is demonstrated in the relevant environment and representative model(s) or prototype(s) in form, fit and function.	Definition of performance requirements and of the relevant environment. Identification and analysis of the element critical functions. Design of the element, supported by appropriate models for the critical functions verification. Critical function test plan. Model or prototype definition for the critical function verification. Model or prototype test reports.
7	Performance is demonstrated for the operational environment. A representative model (physical or abstract) fully reflecting all aspects of the model design is built and tested with adequate margins for demonstrating the performance in the operational environment.	Definition of performance requirements, including definition of the operational environment. Model definition and realization. Model test plan. Model test results.

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8	Model integrated in the final system ready to be used.	Model is built and integrated into the final system. Acceptance of the final system.
9	Technology is mature. The element is successfully in service for the assigned work in the actual operational environment.	Commissioning in early operation phase. Operation reports

To ease the TRL evaluation process, the following steps are proposed in Figure 3. In step 1, the project partners will assign experts to evaluate the TRLs of technologies and tools developed in the project. These experts will define the different elements to be evaluated in step 2. Developers of the technologies and tools will provide reports about results achieved in the framework of the project and the demonstrated capabilities of the elements (step 3). In step 4, experts will define key questions to address, and evidence required for a rigorous TRL evaluation. In the last step, experts will decide the TRLs of the different elements, technologies and tools.

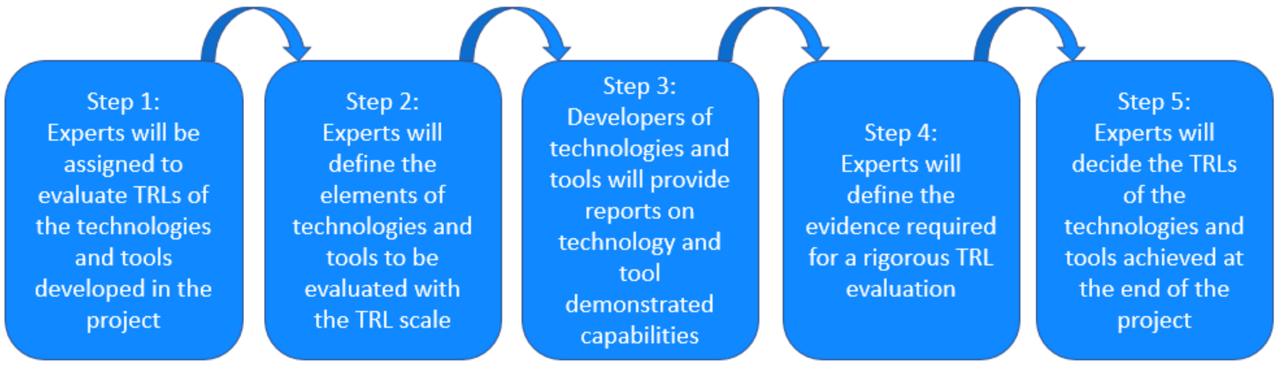

Figure 3: Summary of the five-step approach to evaluating TRLs

3.1.3 Consequences for the impact assessment of the MTME

Key performance indicators are measurable from TRL 4 and repeatable performances demonstrated in either TRL 4 or 5, depending on the technology. No particular difficulties are currently envisaged with regard to the data collection, since the TRLs expected to be reached at the end of the project for all the listed technologies and tools are described in the DoA as level 4 or above.

The robustness of the technologies is proven in relevant simulated environment at TRL 5 and parameters related to economy, environment, and safety are more often available at TRL 6 where the operating conditions are demonstrated in a realistic and relevant environment.

3.2 Problem analysis

Development and implementation of the MTME aim to overcome some of today's traffic and transport challenges by facilitating increased multimodality and resilience in transport operations. Typical challenges include excessive use of private cars and little support for coordination between modes in passenger transport, and lack of flexibility, poor integration across modes and limited use of green modes in freight transport.

Factors that can positively (drivers) or negatively (barriers) influence the implementation and future development of MTME and the achievement of its target vision were analysed in task 2.3 of WP2,

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Target vision and Scenarios. These factors were identified from four different perspectives: economic and market, safety and security, legal and regulatory, and social. The perspectives discussed and presented below are the result of both the review of the relevant academic literature and the interviews conducted by the ORCHESTRA project partners of around twenty project stakeholders (academic and professional experts, public authorities in the transport sector, etc.). The stakeholders highlighted the obstacles to be removed in order to successfully implement the MTME.

Results from the environment analysis in WP2 has shown that **the search for efficiency, sustainability and increased productivity in transport, as well as the reduction of private costs, are key objectives to be achieved in the implementation and development of MTME**. In front of the current "siloed" traffic management and the reluctance of stakeholders to share data and information, **a need for integrated and unified traffic management with real-time data sharing was identified in order to avoid a loss of efficiency that could lead to direct and indirect consequences such as increased congestion and GHG emissions**. This need requires adapted and appropriate technical and governance responses.

Among the proposed technical responses, innovative tools and materials for data collection and standardisation, the guarantee of interoperability of all systems and the reliability of interfaces are prerequisites for any implementation of an integrated management system. In addition, there is a need for tools with the capacity to manage and process huge quantities of information, which requires accompanying software capacities and innovations. These tools will need to integrate data from highly automated vehicles, Real-time vehicle positioning data, and a better ability to predict events that may impact traffic (weather, road works, congestion, etc.). This real-time knowledge of traffic flows will make it possible to anticipate and solve problems as they arise, thus improving traffic flow, reducing private costs and controlling pollution and external costs.

Among the proposed governance responses, an efficient system of data access control will be necessary to implement such a traffic management platform where data can be shared between stakeholders.

There is also **a need to clarify the roles of public and private actors** because their objectives and interests rarely converge.

If barriers can be removed, new mobility services could be offered easily (MaaS), better use of transport capacity would be enabled and the use of environmentally friendly modes of transport would be facilitated. This should also lead to a reduction in pollutant emissions, land use, costs and better returns on investment.

Another objective highlighted by the work of WP2 is the improvement of the safety of the flow of goods and people that could be generated by a faster management of traffic and a better prediction of disruptive effects thanks to the implementation of the MTME. This is reflected in terms of policy and regulation with the realisation of Vision Zero and in terms of certification of standards to increase security with the enforcement of existing standards.

Cyber security requirements are also an objective that emerges from the work of WP2. All stakeholders would like to benefit from the advantages of further digitalisation, but the concerns associated with cyber risks are a considerable brake; all the more so as the costs of investment and maintenance of equipment to protect against these risks are high. Only large companies accept such costs. The aspects of cyber security are confidentiality, integrity, data availability and system availability. According to some of the stakeholders interviewed, the security of digital exchanges should become mandatory.

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If the barriers to achieving these objectives were removed, benefits could be achieved in terms of reduced fatalities and resilience of transport networks.

The work of WP2 shows **the need to offer stakeholders a stable regulatory framework applicable to all for the implementation of multimodal traffic management**. It must provide a legal and contractual guarantee for data (collection, standardisation, types of information that can be shared or not, obligation to share data or not, with which public players, with which private players, etc.), for the subsequent use of the data collected, and guarantee all the legal means necessary for cyber security. It must also ensure the dissemination of the standardisation of exchange tools and protocols, if necessary. In addition, it must alert, prevent and propose solutions to prevent overlapping administrative authorities in charge of transport from hindering the evolution towards multimodal traffic management.

The benefits of such a regulatory framework would be more widespread multimodality through regulatory incentives for data sharing, contractual flexibility, increased collaboration and smoother transhipments.

The need to offer security of tools to be used, simplicity of use, both for network and transport node managers and for end users (passengers, shippers) has been identified, in particular through the social perspective, which concerns the acceptance and acceptability of technical and organisational innovations. Acceptability depends very much on the trust placed in the partners with whom the data will be shared, and in the operators of the data (e.g., for further processing using artificial intelligence). Information sharing may be more difficult to accept depending on the existing competitive environment. It may also generate a significant amount of processing work in view of the large volume of data to be collected and the need to standardise and anonymise it. The stakeholders interviewed express **a very strong need for a regulatory authority that is both effective and trustworthy, in combination with an organising authority.**

If these difficulties were removed, the implementation and dissemination of multimodal practices would be truly effective for the collective benefit of all mobility stakeholders.

The requirements and needs for MTME to work can be summarised as follows:

- Need for investment in
  - ✓ physical infrastructure (possibly smart infrastructure to allow for automation and integration of CAVs),
  - ✓ innovative software, tools and hardware needed to process the data collected, to standardise and protect it,
  - ✓ interoperability devices and interfaces.
- Need for a strong regulatory environment to give all stakeholders the necessary confidence in the processing, exploitation and sharing of data, as well as in the security of transactions and transport of goods and people through guarantees provided by the certification of existing standards
- Need for fair and transparent data sharing, data governance capable of regulating the risks of conflicts of interest and abuses linked to their data sharing (anti-competitive effects, ...)
- Need to clarify the competences and expectations of private and public actors

Accepting multimodal traffic management and the organisational changes that result from it cannot be done without the intervention of and collaboration with public authorities.

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3.3 Development of the program theory and key performance areas

3.3.1 Program theory

The starting point for the evaluation framework is the stakeholders' analysis of how and why the planned MTM ecosystem components will lead to specific outcomes (i.e. measurable short-term effects and impacts defined as long-term effects with a more comprehensive viewpoint). This can be visualized as a program theory similar to a logic model explaining the relations between the inputs, effects, and impacts of the MTME, including the underlying mechanisms of change and contextual aspects. An overall program theory model of the MTME is presented in Figure 4.

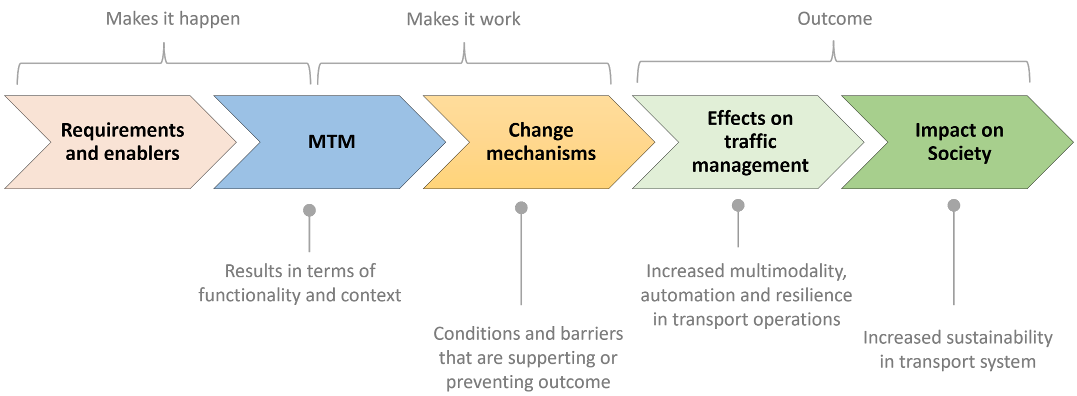

Figure 4: An overall sketch of the MTME Program theory

The program theory is further elaborated on the basis of predefined objectives stated in the project plan, inputs from the stakeholder workshops, and additional work on user needs and requirements in WP2.

Requirements and enablers represent the framework conditions that needs to be in order for the multimodal traffic management system to be developed and deployed in accordance with the specifications:

- Policies, governance, and regulations in terms of standardisation, legislation, ethics, etc.
- Data governance and sharing, e.g., cyber security, privacy, and real-time information sharing
- Smart infrastructure for automation and integration of CAVs
- Safety requirements for prevailing accidents and fatalities

MTM functionalities include:

- Dynamic transport demand management
- Demand-capacity balancing and coordination
- Decision support

These functionalities are expected to facilitate the every-day MTM operations, and to solve issues related to unexpected incidents and expected situations.

Mechanisms of change include specific processes that need to be activated or prevented for the MTM system to work as intended and realise the expected effects on traffic management

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operations. This includes both the enhancement of beneficial factors and to overcome the barriers. The most relevant mechanisms identified in ORCHESTRA include:

- Stakeholders' acceptance of MTME and autonomy
- Operational practices and decision making for orchestrators e.g., skills and training
- Business policy for transport service providers e.g., increased flexibility in contractual framework
- Increased collaboration, coordination, and transhipment between organisations

Effects on traffic management represent the objectives of the development and implementation of the MTME, in terms of increased multimodality, automation and resilience in the transport operations. These aspects are expressed by the following expected outcomes:

- Better utilisation of capacity
- Better handling of disruptions
- Support for multimodal services like mobility-as-a-service (MaaS) and physical internet (PI)
- Support for connected and automated vehicles (CAVs)
- Increased use of green modes

Impact on society represents how the long-term effects on traffic management will improve sustainability with greener and more efficient transport and mobility.

The elaborated program theory of the MTME is presented in Figure 5.

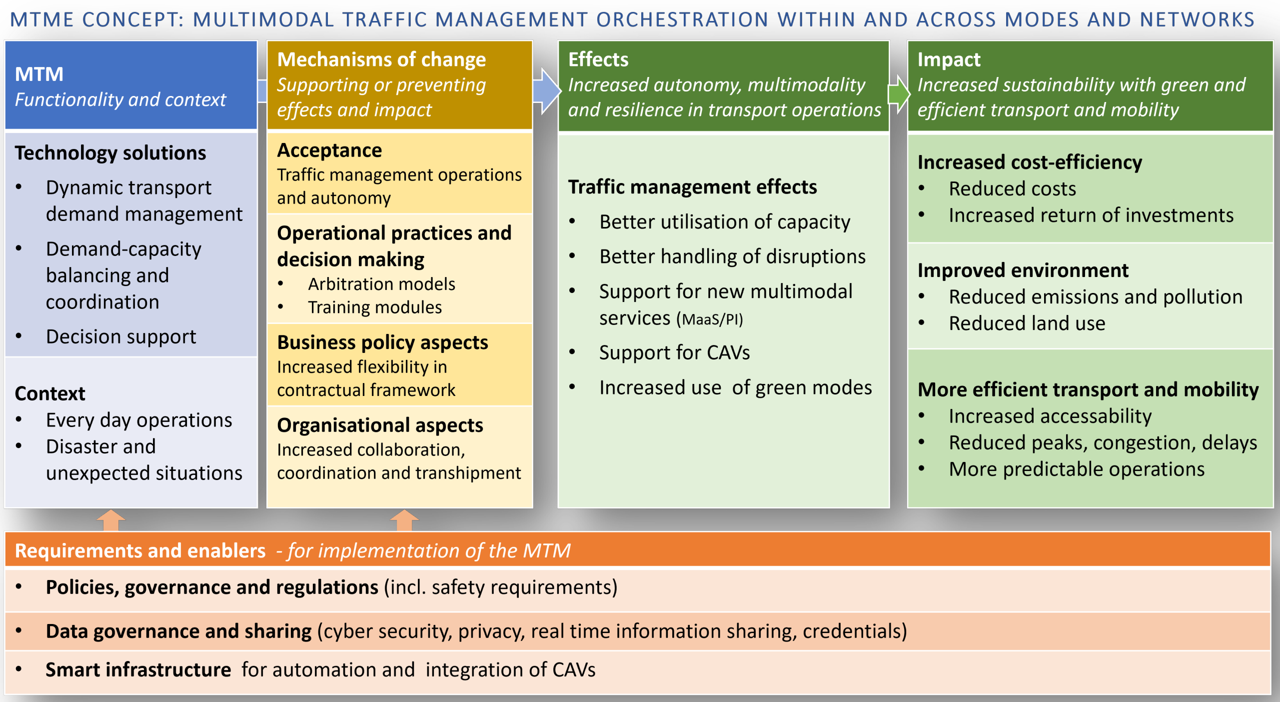

Figure 5: The MTME program theory

The program theory identifies the Key Performance Areas (KPA) of the MTME, that need to be addressed in the consecutive evaluation process of ORCHESTRA.

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3.3.2 Key performance areas

The following Key Performance Areas (KPA) are derived from the program theory of the MTME, as developed and described in section 3.3.1:

1. Policies, governance and regulations
2. Data governance and sharing
3. Smart infrastructure
4. Technological solutions (functionality)
5. Stakeholders' acceptance of traffic management operations and autonomy
6. Operational practices and decision making for traffic orchestrators
7. Business policy aspects
8. Organisational aspects
9. Traffic management effects
10. Economic impact (increased cost-efficiency)
11. Environmental impact
12. Transport and mobility impact

The KPAs represents the partners common understanding of the underlying mechanisms and outcomes expected from the implementation of the MTME.

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4 Evaluation process

The evaluation process explains how the evaluation should be performed (in order to contribute with new knowledge) and how the different measures should be assessed. The evaluation process is based on the program theory presented in chapter 3.3 and expressed in terms of key performance areas (KPAs), which are further derived into a list of research questions, followed by a set of quantitative and qualitative key performance indicators (KPIs). The KPIs are subsequently decisive for the choice of evaluation and data collection methods.

The collected data will be analysed to test the identified hypotheses and provide answer to the related research questions. Both qualitative and quantitative data analysis techniques will be used.

4.1 Research questions

The research questions have been discussed by the Evaluation Task Force group for each key performance area (see section 3.3.2). To facilitate the work process at an early stage of the project, it was decided that the questions should not be too much detailed (to avoid having a large number of questions) and not too broad (to avoid having questions beyond the scope of the project).

The research questions define exactly what the project partners intend to investigate in ORCHESTRA and the results will provide new knowledge on each research topic. The questions are answerable, and they will determine the type of studies to be conducted in this project.

Table 6 shows the research questions for the 12 key performance areas defined by the project partners during the Evaluation Task Force meeting sessions.

Table 6: Research questions for the 12 key performance areas.

KPA	RQ	Research questions
1.	**Policies, governance and regulations**	
	RQ 1.1	Which regulatory actions and policy decisions are needed to implement the MTM? a. To what extent is the MTM compliant with national and European policies and regulations? b. What are the current regulatory barriers and facilitators to MTM? c. How to fill the gap in the current policies?
	RQ 1.2	What new standardisation is needed for the realisation of the MTM? a. What are the gaps with the current standards? b. What are the necessary adjustments in standards?
	RQ 1.3	What new safety requirements are needed for the implementation of MTM?
2.	**Data governance and sharing**	
	RQ 2.1	How to design and implement data quality, accuracy, relevancy, timeliness and validity for MTM? a. How can stakeholders effectively share data and information and how to enable it?
	RQ 2.2	How to design and implement confidentiality agreements, personal rights, data credentials and ownership? a. How to design and implement information security?
	RQ 2.3	How to design and implement necessary legal conditions for the coordination and synchronisation across modes and networks?

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KPA	RQ	Research questions
3.	**Smart infrastructure**	
	RQ 3.1	Which technical requirements for smart infrastructure should be in place to implement MTM?
	RQ 3.2	What smart infrastructure and functionalities are necessary for the implementation of MTM? a. How can MTM be implemented for the different infrastructure classification levels? b. How can MTM be implemented for different automation levels for transport means?
4.	**Technological solutions (functionalities)**	
	RQ 4.1	What is the MTM solution? a. What system functional requirements are needed for transport demand management and capacity balancing? b. What are the relevant types of data and information to be shared? c. What traffic orchestration measures are needed?
	RQ 4.2	How should resilience be implemented?
	RQ 4.3	What kinds of decision support are needed in case of e.g., congestion or disruptions? a. How will the method for forecasting be carried out? b. How should decision be supported? c. How can knowledge be maintained?
	RQ 4.4	How to coordinate traffic across multiple networks and modes, and governance areas?
	RQ 4.5	How can MTM be implemented?
5.	**Stakeholders' acceptance of traffic management operations and autonomy**	
	RQ 5.1	What is the expected acceptance of MTM among relevant stakeholders? a. Traffic managers and policy makers b. Fleet operators and transport service providers
	RQ 5.2	What are the facilitators and barriers for stakeholders to share data and information?
	RQ 5.3	How to facilitate collaboration and data sharing between different networks and modes?
	RQ 5.4	Which factors can most likely contribute to the stakeholders' acceptance of automation solutions?
	RQ 5.5	What are the expected benefits for the society? For different stakeholders?
6.	**Operational practices and decision making for traffic orchestrators**	
	RQ 6.1	What are the skills needed for the traffic orchestrators?
	RQ 6.2	How should traffic orchestraters be trained to develop the required skills?
	RQ 6.3	How is MTM expected to affect safety? a. How can resilience be used to improve safety? b. How can MTM balance traffic management efficiency versus safety?
7.	**Business policy aspects**	

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KPA	RQ	Research questions
	RQ 7.1	What are the values that different stakeholder types can offer each other under a successful MTME operation?
	RQ 7.2	What are the essential elements of business models for successful implementation of MTME? a. What are the barriers and facilitators? b. How can flexibility in contractual framework and increased collaboration be established? c. How can the willingness to share data be supported?
8.	**Organisational aspects**	
	RQ 8.1	How can MTM support flexible and dynamic responsibilities between traffic orchestrators? a. How should the responsibilities be distributed or modified? b. How can the resilience in the organisational models be supported?
9.	**Traffic management effects**	
	RQ 9.1	How and to what degree will the MTM improve the utilisation of capacity?
	RQ 9.2	How and to what degree will the MTM improve the handling of disruptions?
	RQ 9.3	How and to what degree will the MTM provide support to new multimodal services?
	RQ 9.4	How and to what degree will the MTM increase the use of green modes?
	RQ 9.5	How and to what degree will the MTM provide support use of CAVs?
10.	**Economic impact (increased cost efficiency)**	
	RQ 10.1	What is the techno-economic trends (drivers) which lead to new, sustainable and transition positive (CO_2 neutral) business models?
	RQ 10.2	Which added values are monetizable and not monetizable?
11.	**Environmental impact**	
	RQ 11.1	How is MTM expected to reduce negative environmental impacts? a. Reduced greenhouse gas emissions and pollution b. Reduced land use
12.	**Transport and mobility impact**	
	RQ 12.1	How and to what degree will MTM increase accessibility?
	RQ 12.2	How and to what degree will MTM reduce traffic peaks, congestion and delays? a. How can MTM support the service providers and fleet operators? b. How can MTM support modal, route and time shift to reduce traffic peaks, congestion and disruptions?
	RQ 12.3	How and to what degree will MTM support more operations that are predictable?

Research questions will be addressed by the means of qualitative and quantitative KPIs presented in respectively section 4.1.1 and section 4.1.2.

4.1.1 Qualitative key performance indicators

Table 7 shows the qualitative indicators for the evaluation process assigned to the key performance areas. The KPIs are identified by the experts of the Evaluation Task Force group and are to a large degree based on results from workshops and pre-studies carried out in WP2.

Table 7: Qualitative indicators for the 12 key performance areas.

KPA	Qualitative KPIs
1.	**Policies, governance and regulations**

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KPA	Qualitative KPIs
	• International treaties covering multimodal transport (UN Convention on International Multimodal Transport of Goods not in force) • Enforcement issues, European roadmap for sector-specific paths to climate neutrality (acknowledged in the EU Climate law) • NIS2 Directive, Proposed Artificial Intelligence Act • European legal framework for CAVs
2.	**Data governance and sharing**
	• Sharing new dynamic data sets, digitally available local traffic rules for decision-making, • Collaboration between stakeholders via a European Mobility Data Space • Taking into account GDPR requirements to design MTM system • Data quality in terms of reliability, traceability, interoperability, (EU Data Act- first steps for standardisation between sectors), • Contractual agreements on data usage
3.	**Smart infrastructure**
	• Data collection and processing, strategies for handling different levels of network equipment • Standardising and regulating all relevant aspects related to the capabilities of the infrastructure • Capabilities offered by CAVs in line with the traffic orchestration • Facilitating the implementation of CAVs through regulations. • Ensuring that CAVs are connected to all areas of the network, can communicate as required, and are able to handle mixed traffic conditions autonomously
4.	**Technological solutions (functionalities)**
	• Automated measures taken based on prerequisites for transport demand management and capacity balancing • Measures taken to handle imbalance between traffic volumes and network capacities (demand capacity balancing) • Software that supports decisions for transport demand management and demand capacity balancing
5.	**Stakeholders' acceptance of traffic management operations and autonomy**
	• Performance expectancy: time and cost saving, inclusiveness • Effort expectancy: level of ease of use associated with the use of MTM • Facilitating conditions: trainings, data standardisation, understanding of the decision made by the traffic orchestrator (TO) • Acceptance of CAVs: trust, efficiency, ease of use
6.	**Operational practices and decision making for traffic orchestrators**

	• Regular simulated situation exercises (based for example on practices in road safety crisis management)
	• Framework for data exchange (for a common situation awareness)
	• New types of negotiations and trade-offs should be imagined relying on:
	    • clear rules and framework for data exchange (for a common situation awareness)
	    • clear scope of responsibilities and clear hierarchy of communication
	    • relevant context: spatial scale, type of stakeholders, local issues
	• Predefined decision rules (priority requests, arbitration rules)
	• Regular meetings to assess observed situations

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KPA	Qualitative KPIs
7.	**Business policy aspects**
	• Defining the most critical values for the relevant stakeholders which correspond to possible business models that use the identified drivers to overcome barriers. • Definition of a flexible contractual framework allowing for collaboration between stakeholders.
8.	**Organisational aspects**
	• Showing through examples of scenarios how the distribution of responsibilities and integration of MTME leads to improved network resilience and reduces traffic interruptions.
9.	**Traffic management effects**
	• Support for new multimodal services (MAAS/PI) • Support for CAVs • Increased use of green modes
10.	**Economic impact (increased cost efficiency)**
	• Reduced costs • Increased return of investments
11.	**Environmental impact**
	• Reduced emissions and pollution • Reduced land use
12.	**Transport and mobility impact**
	• Increased accessibility • Reduced peaks, congestion and delays • More predictable operations

4.1.2 Quantitative key performance indicators

Table 8 shows the key performance indicators suggested by the experts of the Evaluation Task Force group. The list of quantitative KPIs will be further elaborated as part of the development of the scenarios for the simulations and Living Lab experiments in task 5.3. These adjustments will be presented and explained in D6.2.

Table 8: KPIs defined by the experts of the Evaluation Task Force group.

Traffic management effects	Transport and mobility impacts
Utilization of capacity (%)	Interconnectivity ratio (%)
Cost of congestions	Efficiency of interconnections between networks
Recovery time after a disruption	Number of interconnected networks (descriptive KPI)
Disruption time / number of disruptions	Congestions, magnitude of traffic peaks relative to average traffic
Number of traffic orchestrators required for effective, efficient and safe traffic management	Delays with regard to schedules
Acceptance of traffic orchestration (quantitative) measures (survey)	Waiting times (also in relation to capacity)
	Accuracy of predictions

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4.2 Research methods

Table 9 shows the research methods to be applied in the project in order to collect data and necessary information to answer the research questions.

Table 9: Research methods for the evaluation of the MTME concept.

Research methods	WP	Task	Data type	Description
Workshops and interviews	2	2.1 2.2 2.3	Qualitative	To gain an understanding of opinions and underlying motivations of the different stakeholders and to explore the drivers and barriers for developing the MTME concept. Identification of prerequisite factors.
Desk research analysis	2	2.2	Qualitative	Analysis on existing EU policies for green transport (EU green deal) and legal issues Data collection of traffic and transport data from road, sea, air, railway traffic management
Simulations	5	5.1	Quantitative	Simulations for use case evaluation based on Living labs
Living labs	5	5.2	Qualitative Quantitative	Validation and assessment of two real use cases in Norway and Italy
Training sessions	5	5.3	Qualitative Quantitative	Validation of trials for training staff involved in Living labs
Surveys	6	6.2	Quantitative	Closed questions to evaluate statistically the acceptance of MTME concept
Business aspects and value network	4	4.2	Qualitative	Understanding business aspects for the roll-out of MTME and value exchange between stakeholders
Organisational model analysis	4	4.2	Qualitative	Development of multi-actor organisational models for the roll-out of MTME. Organisational solutions for efficient management.
Economic analysis	4	4.2	Qualitative	Feasibility and cost effects Evaluation of contract and administrative consequences

4.2.1 Living Labs

ORCHESTRA deliverable D5.3, *Plan for Orchestra's Living Labs*, describes the plan, operations and scenarios to be addressed in the Living Labs. This deliverable and D5.3 are both planned to be released at the end of June 2022 (M14 of the project). D5.4, *Final Living Labs* (due in M32), will provide the final report on the Living Labs, involved stakeholders, tools and systems used and lessons learned.

In D5.3, operations to be considered in ORCHESTRA and currently performed at Herøya Industrial Park and Malpensa airport locations and surroundings are described. The operations include various events that happened or believed able to happen. A scenario addresses one operation and one event, but several use cases. Scenarios piloted in the Living labs are described with objectives, pre-conditions, events, actors involved, and their roles planned in response to these events.

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Three different operations are described for the Living Lab at Herøya Industrial Park:

- Operation 1: Incoming goods transport to Herøya
- Operation 2: Ship transport with cargo reload for further transport
- Operation 3: Outgoing transport from Herøya port to Brevik and Larvik ports by trucks

Two different operations are described for the Living Lab at Malsensa airport:

- Operation 1: Passengers travelling from home to foreign destinations
- Operation 2: Passengers travelling from foreign destinations to home

4.2.2 Simulations

D5.1, *Simulation architecture* (Due date in M18), will describe the simulation architecture to be developed in ORCHESTRA in order to assess the MTME concept. A mesoscopic simulation framework is prioritized since traffic management and transport service management are both considered in the Living Labs. In WP5, the simulation developers (HES-SO and TUDELFT) are working on realistic simulation models for Herøya Industrial Park and Malpensa airport, considering the roles and responsibilities of stakeholders and the scenarios (operations and events) described in D5.3.

4.2.3 Scenarios for simulations or Living Labs

Table 10 presents the scenarios elaborated for the Living Labs. The scenarios for Herøya Industrial Park and Malpensa airport are presented with the corresponding operation and event reference numbers. Five scenarios are planned to be piloted at Herøya and three at Malpensa, whereas the simulations will reproduce a total of 14 scenarios.

Table 10: Scenarios to be simulated or piloted at the Living Labs.

Scenarios	D5.3 reference	Living Labs Herøya	Living Labs Malpensa	Simulation	Use cases
Incoming goods transport to Herøya, without any issue	Operation 1, Event 1.1	X		X	- Incoming truck arrives at Herøya - CAV escorts trucks to their internal destination
Incoming ship transport to Herøya is delayed	Operation 1, Event 1.2	X		X	- Notify the delay - Reorganize the queue of truck - Disseminate the delay to others company - Overcome the delay
Incoming truck transport to Herøya is accelerated	Operation 1, Event 1.3	X		X	- Notify the Travel acceleration - Replan the CAV schedule - Replan the truck waiting queue

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Scenarios	D5.3 reference	Living Labs Herøya	Living Labs Malpensa	Simulation	Use cases
Internal transport at Herøya is deleted and will affect incoming transport	Operation 1, Event 1.4	X		X	- Events detection and delay estimation - Replan internal transport - Notify the transport companies - Reorganise the truck waiting queue
Incoming trucks arrive at Herøya out of the opening hours	Operation 1, Event 1.5	X		X	- Preregistration of incoming trucks - CAV planning for out of hours operation - Escort trucks to their destination
Incoming ship transport is delayed, but goods need loading on cargo train for further transport	Operation 2, Event 2.1			X	- Notification of the transport delay - Update the train schedule
Incoming ship transport arrives at the port and needs to load goods onto a cargo train for further transport, but the train transport is unavailable	Operation 2, Event 2.2			X	- Notify the train breakdown - Find alternatives for train transport - Truck substitute train for the outcoming transport
Incoming cargo ship transport arrives at the port and needs to unload cargo using a crane. The crane is broken	Operation 2, Event 2.3			X	- Notify the crane breakdown - Organize the ship queuing to the port - Organize alternative equipment
Incoming trucks arrive late for picking up the outgoing goods transport from Herøya port to Breivik and Larvik ports	Operation 3, Event 3.1			X	- Notify the delays of incoming trucks - Reorganise the internal traffic
Travel from home to Malpensa airport, without issue	Operation 1, Event 1.1		X	X	- Travel plan - Travelling

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Scenarios	D5.3 reference	Living Labs Herøya	Living Labs Malpensa	Simulation	Use cases
Travel from home to Malpensa airport with a maintenance on the railway network	Operation 1, Event 1.2		X	X	- Notify the maintenance - Travel plan - Plan alternatives - Overcome the maintenance issue
Travel from home to Malpensa airport, but a train breakdown occurs	Operation 1, Event 1.3			X	- Travel plan - Disruption occurrence - Monitoring flows - Coping with the disruption
Travel from Malpensa airport to home, without issue	Operation 2, Event 2.1		X	X	- Travel plan - Travelling
Travel from Malpensa airport to home in the evening, but the aircraft land with a delay	Operation 2, Event 2.2			X	- Notify the delay - Plan alternatives - Plan a new travel - Travelling

4.3 Data collection

4.3.1 Living Labs and data collection

Data collected from the simulations or the living labs will be described in D6.2, *Intermediate evaluation results from Living Labs*. These collected data should correspond to/address the KPIs and research questions identified above.

Several technical tools used in the Living Labs will provide data for either the evaluation process or to the simulations in order to make the simulated scenarios as representative as possible. These tools are described in D5.3 for both the Living Labs:

- Tools for Herøya include Mobility insights, Activity registration, Situation awareness, Situation and geofencing data sharing, Transport ordering, Dispatcher, Job generation, Booking and Data sharing infrastructure.
- Tools for Malpensa include Data sharing infrastructure, Transport credentials system, Network representation for use cases, Dynamic guidance for disrupted passengers, Multimodal travel information guidance, Matching electric car-sharing passengers.

However, at this time of the project, knowledge about the data availability from each of these technical tools is lacking. Task 6.2 will clarify this and provide the list of data to be collected and corresponding data collection plan. Other data can be also collected from traffic management, transport and fleet operations and transport services. Data from the CAVs will also contribute to the evaluation process (e.g., distance driven, driving from truck 1 to truck 2, delays, etc.).

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4.3.2 Simulations and data collection

Simulation studies need to provide data corresponding to the list of quantitative KPIs presented in Table 8 (p. 31). List of indicators proposed by previous studies (European projects, Conduits (2015), C-Roads (2019), Payne (2015)) have been considered by the experts of the Evaluation Task Force group.

The experts on simulator development (TUDELFT and HES-SO) have also suggested a list of data types that can be collected from agent-based simulations[5] of different scenarios:

Agent's data:

- Agent Type: Define the nature of the agent. CAV can be considered as vehicles.
- Agent ID: Unique identifier that is attributed to the agent.
- Agent position: Agent's current position. X-Y values in meters.
- Agent speed: Agent's current speed. Value in m/s
- Agent travelled distance: Current distance travelled by agent. Value in meters.
- Agent travelled time: Current distance travelled by agent. Value in meters.
- Agent arrival time: The time when the agent arrived at destination.
- Agent destination: The destination that the agent wants to reach.
- Agent destination time: The planned time to reach the destination. This value is a constraint to be respected.
- Agent priority: Priority assigned to a specific agent. This is not a mandatory data, used only in certain situation.

Edge data:

- Traffic flow: Current traffic flow that is travelling through a specific edge. Value in agents/hour.
- Traffic speed limit: Maximum allowed speed in a traffic edge.
- Flow Capacity: Maximum admitted traffic flow in a specific edge. Value in agents/hour.

Node data:

- Node Current Value: Current number of agents inside a node.
- Node Capacity: Maximum allowed number of agents within a node.

Access data:

- Access restriction: Restriction rules to the access points.
- Access Waiting Time: Waiting time required to pass through a specific access point

These data can be collected from both the simulated Herøya and Malpensa scenarios and will be useful to calculate specific quantitative KPIs. They will simulate a baseline scenario without defining zones and measures (see D3.1 for more information) and simulated scenarios will be defined with zones and scenarios according to the scenarios of the Living Labs.

[5] Agent-based simulations are used to study complex dynamic systems composed of interacting agents. These agents are often humans or vehicles and the behavior and position influence the actions of the others. (Macal & North, 2010)

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The agent-based simulations will be processed to address the KPIs and research questions defined above. Examples of questions translated in terms of agent and system behaviour related questions are proposed below.

- Is the network utilisation well distributed? What is the capacity utilisation rate per network?
- Does the system react fast enough? To which congestion or disruption types?
- What is the deviation between planned arrival times and the real ones?
- Does the agent respect the limitation imposed by the Traffic Orchestrator?
- Does the agent need to change the means of transport? How many times?
- How long does the agent need to wait?
- Are the agent's priorities respected?

Table 11 shows how some KPIs can be translated in terms of agent and system behaviour related questions for the agent-based simulations. The pertinence of these KPIs will be evaluated in task 6.2.

Table 11: Examples of KPIs translated in terms of agent and system behaviour.

KPIs	Format	Description
Network utilization	FLOAT	Is the network well used? Try to avoid traffic edge congestion.
Node utilization	FLOAT	Are the nodes well used? Avoid reaching the maximum node capacity.
Access point utilization	FLOAT	Are the access points well used? Avoid having a lot of waiting time on the access points.
System reaction	FLOAT	How much time has passed between the trigger detection and the Enabling tools response
Response effect	INTEGER	Does the system response cause congestion on other traffic edges or node? Increase a variable for each congested edge or node
Speed limits deviation	FLOAT	Does the agent respect the speed limitations imposed by the TO? Calculate the deviation between the imposed limit and the agent's speed. (Agent speed - Traffic speed limit) / Traffic speed limit
Means of transport usage	INTEGER	Does the Agent/Freight need to change the means of transport several times? A change of the means of transport increases the probability of freight damage (Herøya) and decreases the Passenger comfort/acceptance (Milano) A counter that increases at each change of transport.
Cumulative Waiting Time	FLOAT	How much time does an agent need to wait in total? The objective is to reduce this value as much as possible. Access Waiting Time Tot = Access Waiting Time Tot + Access Waiting Time X

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KPIs	Format	Description
In time arrival	BOOL	Does the agent arrive in time at its destination? If the agent arrives after the planned time, the mission cannot be considered accomplished. The KPI is applied to the final arrival time if this is modified during the simulation. This check will be performed only at the end of the simulation. (Agent arrival time <= Agent destination time)
Arrival time deviation	FLOAT	The arrival time deviation provides the difference between the initially planned arrival time and the final one adjusted by the system. (Final Agent arrival time - Begin Agent arrival time) / Begin Agent arrival time
System priority management	BOOL	Are the selected priorities respected by the agents? (Agent priority <= Access restriction)

4.4 Evaluation analysis

The evaluation analysis will be developed and carried out in task 6.2 and includes assessment of the 12 key performance areas defined in section 3.3.2. Both quasi-experimental and non-experimental research designs will be utilised to address the individual research questions and KPIs.

The qualitative analysis will be based on data from workshops, interviews and surveys among experts and relevant stakeholders, as well as desk research analysis of relevant protocols and documents. Assessment of acceptance, operational practices and decision making, business policy aspects and organisational aspects (mechanisms of change) should be based on well-defined scientific theories explaining the causal mechanisms of how and why the change will occur and the contextual aspects that are likely to influence the outcome.

The quantitative analysis will be based on data from simulation and living labs using statistical analysis. Hypotheses will be tested and evaluated with statistical tests appropriate for the datasets under consideration. To draw meaningful conclusions, it will be important to ensure that the necessary number of simulations and experiments are performed (e.g., using such measures as coefficient of variation). Furthermore, sensitivity analysis will be performed to determine the impact of essential model parameters on the identified KPIs. Moreover, what-if analysis will be done to examine the effects of specific conditions and parameter settings on the system performance.

4.5 Reporting of results

The results from the different evaluation studies should be reported in accordance with the following structure and guidelines to facilitate comparison of results between studies and ensure a common basis for the lessons learned:

1. SUMMARY

A summary of the most important results and how the evaluation study has contributed to new knowledge regarding the MTME functionality, implementation and/or impact.

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2. SCOPE
    a. What part of the MTME functionality and implementation are addressed in the evaluation study? Refer to the program theory and/or the key performance areas (KPAs)
    b. If relevant: Description of the technological maturity (TRL) and limitations, technical quality and performance, and user interface.

3. CONTEXT AND OBJECTIVES
    a. Description of the relevant use case(s), target group(s) and stakeholders involved
    b. Description of user needs, contextual aspects, and objectives
    c. Description of causal relationship between the MTME and effects and/or impact

4. EVALUATION STUDY DESIGN
    a. What are the research questions and key performance indicators (KPIs) addressed in the evaluation study? Refer to list presented in D6.1
    b. Description of the scientific approach in terms of research and data collection methods, including any deviations or limitations

5. ANALYSIS AND RESULTS
    a. Description of analysis technique and evidence requirements (e.g. statistical significance or mechanistic causality)
    b. Presentation of evaluation analysis and results

6. TRANSFERABILITY AND LIMITATIONS
    a. Assessment of uncertainty and sensitivity
    b. Assessment of transferability to other use cases and implementations

7. DISCUSSION AND LESSONS LEARNED

Results should be discussed in relation to the program theory and highlight the causal relationships that have been strengthened through empirical testing, which assumptions that may not have been met, and the knowledge gaps that require further research.

The discussion must provide a basis for assessing whether the MTME is relevant, practical, and adequate within the use case(s) studied. This involves considerations on operational, tactical, and strategic levels:

a. Does the MTME work effectively? How can any adjustments contribute to the optimization of technical or functional performance?
b. Does the MTME realize the intended effects for the target group? Are any unintended effects been identified? What kind of external requirements and conditions would affect the realisation of objectives and goal achievement?
c. Are the MTME relevant and beneficial from a societal perspective?

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5 Conclusion

This evaluation handbook provides a throughout description of the impact assessment framework of ORCHESTRA. The results constitute guidelines for the upcoming evaluation studies to be conducted in task 6.2 and provides input to the data collection to be performed in WP 2, WP 4, and WP 5. Hence, this deliverable makes a significant contribution to the knowledge development and lessons learned in the ORCHESTRA project.

A theory-based evaluation process in eight steps is presented, addressing a) technology readiness, b) problem analysis, c) program theory, d) research questions, e) research methods, f) data collection, g) analysis, and h) results. The evaluation framework will be applicable for impact assessment of the MTME throughout the innovation process, as it allows for combining an analytic approach (for system or components at low levels of technology readiness) with empirical analysis of practical experience and observations in Living Labs.

Notable results from this work on evaluation methodology includes the development of a program theory for the multimodal traffic management ecosystem (MTME), expressing the understanding of how the MTME is expected to operate to release the intended effects on traffic management and expected impacts on society in terms of increased sustainability in the transport system. The program theory forms the basis for the definition of 12 key performance areas (KPAs) to be addressed in the evaluation studies of ORCHESTRA:

1) Policies, governance and regulations
2) Data governance and sharing
3) Smart infrastructure
4) Technological solutions (functionality)
5) Stakeholders' acceptance of traffic management operations and autonomy
6) Operational practices and decision making for traffic orchestrators
7) Business policy aspects
8) Organisational aspects
9) Traffic management effects
10) Economic impact (increased cost-efficiency)
11) Environmental impact
12) Transport and mobility impact

A set of relevant research questions are defined for each KPA, expressing the need for knowledge development within the project. Furthermore, a selection of qualitative and quantitative key performance indicators is suggested, as a basis for further development as part of the simulations and Living Lab experiments in task 5.3. While the qualitative KPIs express the need to develop a deeper understanding of relevant aspects within all the defined KPAs, the quantitative KPIs principally aim at providing evidence on how the MTME will affect traffic management operations and cause impacts on society. The quantitative KPIs are a measure of how well the MTME will obtain results in terms of better utilisation of capacity and better handling of disruptions, support for new multimodal services (like MaaS and PI) and automation (CAVs), and increased use of green modes in transport operations. Furthermore, the quantitative KPIs will express how the MTME are expected to achieve increased sustainability by increased cost-efficiency, reduced environmental impact and more efficient and predictable transport and mobility operations.

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Data collection and research methods include workshops and interviews, desk research analysis, simulations, Living Labs, training sessions, surveys, value network analysis, organisational model analysis and economic analysis.

Some general principles for analysis are described and will be further elaborated in collaboration between task 6.2 and task 5.3 in accordance with the final list of KPIs to be addressed in the evaluation studies.

Finally, the evaluation handbook provides guidelines for presentation of results in the upcoming evaluation studies of ORCHESTRA to facilitate comparison between studies and a common basis for knowledge development and lessons learned.

D6.1 presents novel work as no previous European project has proposed to adapt the program theory evaluation approach for evaluating a multimodal traffic management ecosystem, a complex system expected to contribute to positive impacts on the environment and the society and with various stakeholders interacting with each other. The theory-driven approach provides a mechanistic interpretation of the causality between the technological solutions and functionality, the contextual conditions, and the underlying mechanisms that will influence the outcomes. This approach proposes an explanation of how and why the MTME, or a component of the system, will provide a specific result. Otherwise, in case of failure, it makes it possible to identify the circumstances and conditions that have caused the failure and the ones that would lead to a successful implementation.

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