



TRACE

inTegration & haRmonizAtion
of logistiCs opERations

D2.4: Ecosystem Development, Safety, and Use Cases (A)

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List of authors

Author Name	Organization
Stathes Hadjiefthymiades, Vassilis Papataxiarhis, Anestis Papakotoulas	NKUA
Themistoklis Anagnostopoulos, Konstantina Papachristopoulou	INTRA
Dr Kostas Kolomvatsos, Nikolaos Tymplalexis, Christos Kylafas, Panagiotis Fountas	UTH
Carlos Catalán, Sheila Sánchez, Miquel Cantero	ROBOTNIK
Lara Seel, Vaghar Bahojb Ghodsi, Florian Pühringer, Jonathan Fetka, Anthony Dionigi, Dr. Martin Berger	TU WIEN
Dr. Fazal Raheman, Tejas Bhagat, Rushi Chavan	BC5
Dr Panagiota Papadopoulou	UNISYSTEMS
Panagiotis Kanellopoulos, Mahi Matsouri	ACS
Markos Bonazountas, Dimitrios Petridis, Nikos Xyderis, Lia Makri	EPSILON
Dr. Theofilos Triommatis, Prof. Ioannis Papamichail, Prof. Markos Papageorgiou, Vasileios Markantonakis	TUC
Ioanna Mesogiti, Elina Theodoropoulou	COSMOTE

Tomislav Letnik, Ines Pentek	UM
Alessio Masola, Paolo Burgio	UNIM
Lucrezia Lattanzi, Valentino Vaia, Emanuele Zarfati	MOD
Maurizio Bernard	DIFLY
Blaž Vukelić	AVLL
Enrico Pavesi, Diego Brunello, Marcello Scardi	OLV
Kristijan Perčić, Alen Kahvedžić	PS
Alexandros Dalkalitsis, Panagiotis Georgas, Petros Arvanitis	HT
Denis Grasso	ITL
Martin Sénéclauze, Damian Vizár	CSEM
Shameem Puthiya Parambath, Christos Anagnostopoulos	UGLA

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	Reviewer Name	Organization	Date
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1.0	Emanuele Zarfati	MOD	August 30 2024

Quality Manager Review

	Reviewer Name	Organization	Date
1.0	Dr Ioannis Neokosmidis	INC	August 30 2024

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Executive Summary

TRACE deliverable D2.4, "Ecosystem Development, Safety and Use Cases (A)", focuses on the development and implementation of a conceptual framework related to safety and operational use cases within the TRACE project.

This deliverable outlines the safety considerations, stakeholder engagement, requirements analysis, Suitability Framework and the development of demonstrators within the TRACE project. It is intended for stakeholders involved in the project's execution, including project partners, external evaluators, and relevant regulatory bodies.

The report is organised as follow:

Introduction: Overview of the scope and objectives of the D2.4 Report, providing a roadmap for understanding the detailed analyses and findings presented in the subsequent sections.

Stakeholder Engagement: This section details the methodologies used for engaging stakeholders, ensuring their needs and concerns are addressed throughout the project's lifecycle.

Requirements Analysis: A detailed analysis of the functional and non-functional requirements is provided, focusing on the project's drivers and constraints, particularly safety and reliability.

Demonstrator Descriptions: The report describes the Greek, Italian, and Slovenian demonstrators. These are pilot projects designed to showcase the practical applications of TRACE's innovations in real-world settings, particularly focusing on logistics optimization, resilience in disruptive events, and the use of autonomous vehicles.

Functional and Non-Functional Requirements: These sections outline the technical and operational specifications needed to achieve the project's objectives, covering aspects like cloud infrastructure, communication systems, and safety protocols.

Suitability Framework: This framework assesses the viability and effectiveness of the automated delivery robots (ADRs) within the project, incorporating use cases, scenarios, and evaluation logic.

Validation of Requirements: Methods and criteria for validating the project's requirements are discussed, ensuring that the developed systems meet the necessary safety and operational standards.

The D2.4 user requirements are produced based on the ISO/IEC/IEEE 29148:2018 standard, which ensures well-formed and traceable requirements, and the VOLERE methodology, which provides a structured framework for gathering and managing requirements, emphasizing stakeholder involvement and clear documentation (TRACE_Requirement_Analysis.doc)

Key Outcomes and Conclusions documented are:

The report emphasizes the importance of integrating advanced technologies like blockchain and autonomous vehicles into logistics operations, aiming to improve efficiency, reduce environmental impact, and ensure safety.

- The demonstrators are expected to provide significant insights into the operational challenges and benefits of TRACE innovations, particularly in managing logistics under normal and disruptive conditions.
- These pilots' success will be measured through specific Key Performance Indicators (KPIs), such as energy reduction, operational cost savings, and successful transport mode integration.
- The deliverable plays a crucial role in guiding the development of safe, reliable, and efficient logistics solutions within the TRACE project, with a strong focus on practical application and real-world validation through its demonstrators.

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Definitions, Acronyms, Abbreviations

Term/Abbreviation	Definition
ACS	Air Courier Services
FMPA	First Mile Pick-up Agent
HT	Hellenic Train
ICT	Information and Communication Technology
LMDA	Last Mile Delivery Agent
LM	Last Mile
LOS	Level of Service
MMLA	Middle Mile Logistic Agent
PS	Post Office

1 INTRODUCTION

1.1 General

This introduction aims to orient the reader to the scope and objectives of the D2.4 report, offering a roadmap for understanding the detailed analyses and findings presented in the following sections. The D2.4 report, titled "Ecosystem Development Safety and Use Cases (A)", is a crucial deliverable within the TRACE project, funded under the Horizon Innovation Actions initiative (Project No. 101104278). Produced as part of Work Package 2 (WP2), this report lays the conceptual foundation for achieving the TRACE project's objectives. The report addresses several key areas:

- **Safety:** This refers to ensuring the safe operation of innovative logistics technologies, including autonomous vehicles and automated delivery systems. Safety considerations are vital to meeting regulatory standards and gaining public trust, which are critical for the successful deployment of these technologies in real-world environments.
- **Use Cases:** The report outlines specific scenarios that demonstrate how TRACE technologies can be applied in various logistics contexts. These use cases are carefully selected to align with the project's overarching goal of enhancing logistics efficiency, sustainability, and resilience. They provide practical examples of how the innovations can address real-world challenges, from optimizing last-mile delivery to improving resilience in the face of disruptions.
- **Stakeholder Engagement:** The report emphasizes the importance of involving all relevant stakeholders, including industry partners, regulatory bodies, and end-users, in the development process. Engaging stakeholders ensures that the solutions developed are not only technically sound but also meet the needs and expectations of those who will be using them.
- **Requirements Analysis:** Detailed analysis of the functional and non-functional requirements necessary for the successful implementation of TRACE innovations is provided. This analysis is essential for aligning the project's technical development with its operational goals and ensuring that all critical aspects, such as safety, infrastructure, and user needs, are adequately addressed.
- **Operationalization through Demonstrators:** The report also discusses the practical implementation of TRACE technologies through demonstrators in three European sites. These demonstrators serve as testbeds for validating the innovations in real-world settings, providing insights that will guide future deployments.

By covering these topics, D2.4 contributes to the **theoretical** framework of TRACE and provides practical guidance for its **operationalization**, ensuring the project objective is met efficiently and effectively.

1.2 Scope of deliverable

D2.4 serves as a comprehensive guide to the safety considerations, technical requirements, and practical implementations necessary for the successful deployment of TRACE advanced logistics solutions. It is designed to ensure that the project's innovations not only meet the operational goals but also adhere to the highest standards of safety and reliability. D2.4 covers three main areas: stakeholder engagement, requirements analysis, and the description and evaluation of demonstrators that test and validate the TRACE technologies in real-world settings.

1.3 Relation with other work packages/deliverables

D2.4 is closely related to other deliverables within WP2 and the broader TRACE project WPs, forming a critical link in the project's overall development process. It builds on the foundations laid by earlier deliverables, such as D2.1, which documented the technical requirements essential for the project. Additionally, D2.2 focused on the initial identification and assessment of potential use cases, and D2.3 provided an in-depth analysis of stakeholder requirements and their integration into the project's design framework. These earlier deliverables established the groundwork for the safety, infrastructure, and use cases explored in D2.4.

Looking ahead, D2.4 will provide vital inputs for subsequent work packages. WP3, for example, will leverage the requirements and use cases defined in D2.4 to guide the technical development of TRACE solutions, ensuring they are both functional and aligned with the project's safety and operational goals. WP4 will focus on testing and validating these solutions, using the demonstrators discussed in D2.4 to assess their performance in real-world scenarios. Moreover, WP5 will handle the deployment and scaling of these solutions, utilizing insights from D2.4 to refine and optimize implementation across regions.

The interdependencies between these deliverables create a cohesive approach that ensures each stage of the project builds upon the previous one, leading to the successful realization of TRACE's overarching objectives. This integrated approach not only strengthens the project's internal consistency but also enhances its potential for delivering impactful, sustainable innovations in logistics.

1.4 Intended audience

The primary audience for this report includes TRACE project partners, external evaluators, regulatory bodies, and other stakeholders involved in the project's execution. The report is also intended to inform broader industry stakeholders, policymakers, and academic audiences interested in the advancements in logistics technology, particularly in the areas of automation, resilience, and sustainability.

1.5 Deliverable Methodology

The user requirements methodology in the TRACE project is a systematic approach designed to ensure that the developed solutions align with the needs and expectations of all stakeholders. This methodology integrates two widely recognized frameworks: the ISO/IEC/IEEE 29148:2018 standard and the VOLERE methodology. By combining these approaches, TRACE aims to create a robust, reliable, and user-centred system that meets both functional and non-functional requirements.

1.5.1 ISO/IEC/IEEE 29148:2018 Standard

The ISO/IEC/IEEE 29148:2018 standard is a globally recognized framework for requirements engineering. It provides guidelines for the development and management of requirements across the system lifecycle, ensuring that all stakeholder needs are accurately captured and addressed. In the context of TRACE, this standard plays a crucial role in the formulation of stakeholder, system, and system element requirements. One of the key features of this standard is its emphasis on well-formed requirements. A well-formed requirement should be clear, unambiguous, and verifiable. It must specify what the system should do or possess to solve a problem, achieve an objective, or address a stakeholder concern. Additionally, it should

be qualified by measurable conditions and bounded by constraints, ensuring that the requirement can be tested and validated throughout the development process. TRACE adopts this standard to ensure that all requirements are documented in a manner that facilitates validation and traceability. This approach not only supports the accuracy and completeness of requirements but also enhances communication among stakeholders by providing a common language and structure for requirement specifications.

1.5.2 VOLERE Methodology

The VOLERE methodology complements the ISO/IEC/IEEE 29148:2018 standard by providing a structured approach to requirements gathering and management. Developed by James and Suzanne Robertson, VOLERE is a comprehensive framework that emphasizes the importance of understanding stakeholders' underlying needs and desires, rather than just their expressed requirements. VOLERE offers a detailed template and a set of best practices for capturing and documenting requirements. This template categorizes requirements into 27 categories within five main groups: project drivers, project constraints, functional requirements, non-functional requirements, and project issues. By using this template, TRACE ensures that all aspects of the project are considered, from high-level business goals to specific technical constraints. The VOLERE methodology is particularly valuable for its focus on stakeholder engagement and iterative refinement. Throughout TRACE requirements are continuously reviewed and updated based on stakeholder feedback and evolving project needs. This iterative process helps to resolve ambiguities, inconsistencies, and conflicts early in the development cycle, reducing the risk of costly revisions later on. One of the strengths of the VOLERE approach is its flexibility. It can be adapted to different project types and sizes, making it suitable for the diverse and complex nature of the TRACE project. The methodology also emphasizes the importance of clear communication, ensuring that all stakeholders have a shared understanding of the requirements and their implications.

1.5.3 Integration of Methodologies

In the TRACE project, the integration of the ISO/IEC/IEEE 29148:2018 standard and the VOLERE methodology creates a comprehensive and resilient requirements management framework. The ISO standard ensures that all requirements are well-formed, traceable, and verifiable, while the VOLERE methodology provides a detailed and stakeholder-focused approach to requirements gathering and documentation.

This integrated approach is crucial for managing the complexity of the TRACE project, which involves multiple stakeholders, advanced technologies, and stringent regulatory requirements. By adhering to these methodologies, TRACE not only ensures that the developed solutions meet the technical and operational needs but also align with the broader goals of sustainability, safety, and innovation.

Thus, the user requirements methodology in TRACE, based on the ISO/IEC/IEEE 29148:2018 standard and the VOLERE methodology, provides a structured and comprehensive framework for developing a system that meets all stakeholder needs. This approach ensures that requirements are clear, verifiable, and aligned with the project's objectives, leading to the successful implementation of TRACE technologies in real-world logistics operations.

1.6 Deliverable structure

D2.4 is structured to guide the reader through the key components of TRACE ecosystem development:

Stakeholder Engagement: Discusses the methodologies and outcomes of engaging relevant stakeholders to ensure their needs and concerns are integrated into the project.

Requirements Analysis: Provides a detailed analysis of both functional and non-functional requirements, focusing on the safety, reliability, and operational efficiency needed for TRACE's success.

Demonstrators Description: Offers an in-depth look at the Greek, Italian, and Slovenian demonstrators, which serve as real-world testbeds for the TRACE innovations.

Suitability Framework and Use Cases: Introduces the frameworks and models used to evaluate the suitability of TRACE technologies in various operational scenarios.

Validation of Requirements: Outlines the methods used to ensure that the project's requirements are met and validated through rigorous testing and stakeholder feedback.

Conclusions and Future Outlook: Summarizes the findings and sets the stage for future developments within the TRACE project.

2 STAKEHOLDERS ENGAGEMENT

2.1 General

Stakeholder engagement ensures that the needs, expectations, and concerns of all relevant parties are adequately addressed throughout the project's lifecycle. The successful implementation of TRACE advanced logistics solutions depends not only on technical excellence but also on the active participation and support of stakeholders, ranging from industry partners to regulatory bodies and end-users.

To ensure effective stakeholder engagement, the TRACE project has undertaken several key activities described in subsequent paragraphs: Stakeholder Workshops, Surveys and Questionnaires, Regular Stakeholder Meetings, Public Consultations, Pilot Demonstrations. These engagement activities have led to several significant outcomes that have positively influenced the TRACE project. Firstly, they facilitated the refinement of technical requirements and operational strategies, ensuring that the developed solutions are well-suited to the needs of stakeholders. Secondly, the active involvement of regulatory bodies helped ensure compliance with relevant regulations, thereby smoothing the path for the deployment of TRACE technologies. Lastly, the engagement activities fostered strong partnerships with industry stakeholders, who have committed to supporting the project's goals and participating in future deployments.

2.2 Mission of stakeholders' engagement

2.2.1 Overall Mission

The mission of stakeholder engagement is:

Understanding Stakeholder Needs: To gather and understand the requirements, concerns, and expectations of all stakeholders, ensuring that these are integrated into the project's design and implementation.

Facilitating Communication: To establish and maintain open lines of communication between the project team and stakeholders, fostering a collaborative environment where feedback can be easily exchanged.

Ensuring Compliance and Acceptance: To ensure that the project's outcomes align with regulatory requirements and receive the necessary approvals from relevant authorities, thereby facilitating broader acceptance and adoption.

Building Stakeholder Trust: To build and maintain trust among stakeholders by transparently sharing progress, addressing concerns, and demonstrating the project's value.

Stakeholders Range: TRACE involves a diverse range of stakeholders, each with a unique interest and influence on the project outcome. These stakeholders have been systematically identified and categorized into primary and secondary groups, as described in the following sections.

2.2.2 Primary Stakeholders:

Project Partners: Organizations directly involved in the execution of the TRACE project, including technology developers, logistics companies, and research institutions.

Regulatory Bodies: National and European authorities responsible for overseeing compliance with regulations related to logistics, transportation, and data security.

Local Authorities: City and regional governments in the areas where the TRACE demonstrators are implemented, responsible for infrastructure and local policy.

Industry Partners: Companies in the logistics and transportation sectors that will implement and benefit from the TRACE innovations.

2.2.3 Secondary Stakeholders:

End-Users: Businesses and residents who will be the ultimate beneficiaries of the improved logistics services, including those within the demonstration sites.

Academic Institutions: Universities and research centers involved in evaluating and validating the project outcomes.

Non-Governmental Organizations (NGOs): Organizations with an interest in sustainability, environmental impact, and urban development, who may influence public opinion and policy.

Media and Public: General public and media outlets that play a role in shaping the project's public perception.

2.3 Engagement Methods and Tools

The TRACE project employs a variety of methods and tools to engage stakeholders effectively:

Workshops and Focus Groups: Regular workshops and focus groups are held to gather input from stakeholders on specific aspects of the project, such as safety concerns, operational requirements, and technology acceptance.

Surveys and Questionnaires: Targeted surveys are distributed to collect quantitative data on stakeholder needs, expectations, and feedback on project developments.

Stakeholder Meetings: Regular meetings with key stakeholders, including regulatory bodies and industry partners, ensure that the project remains aligned with their requirements and receives ongoing support.

Communication Platforms: A dedicated online platform facilitates continuous communication with stakeholders, allowing for real-time updates, feedback, and collaboration.

Public Consultations: Public consultations are conducted, particularly in the areas where demonstrators are deployed, to gather input from local communities and address any concerns they may have.

2.4 Key Outcomes of Stakeholder Engagement

The engagement process has yielded several key outcomes that will influence the TRACE project via:

Refinement of Requirements: Feedback from stakeholders has led to the refinement of both functional and non-functional requirements, ensuring that the project meets the needs of end-users and complies with regulatory standards.

Enhanced Collaboration: The engagement process has fostered stronger collaboration among project partners and stakeholders, leading to more integrated and effective solutions.

Increased Stakeholder Buy-In: By involving stakeholders early and consistently in the project, the TRACE team has secured broad support and buy-in, which is critical for the project's long-term success and scalability.

Identification of Risks and Mitigation Strategies: Engagement activities have helped identify potential risks related to stakeholder concerns, enabling the project team to develop and implement effective mitigation strategies.

2.5 Integration with other WPs

The insights and feedback gathered through stakeholder engagement are closely integrated with other work packages within the TRACE project.

WP1 (Project Management): Ensures that stakeholder concerns are addressed in project planning and management activities.

WP3 (Technical Development): Uses stakeholder input to guide the development of technical solutions, ensuring they are user-friendly and meet regulatory requirements.

WP4 (Demonstration and Validation): Leverages stakeholder feedback to design and execute demonstrators that are relevant and effective in real-world scenarios.

2.6 Challenges and Lessons Learnt

Engaging a diverse group of stakeholders across different countries and sectors has presented several challenges, including:

Diverse Interests and Priorities: Balancing the different interests and priorities of stakeholders, particularly when they conflict, has required careful negotiation and compromise.

Communication Barriers: Overcoming language, cultural, and technical communication barriers has been essential to ensuring clear and effective stakeholder engagement.

Maintaining Engagement: Keeping stakeholders consistently engaged throughout the project's lifecycle has required ongoing effort and the use of varied engagement methods.

Lessons learnt from these challenges include the importance of early and continuous engagement, the need for clear and transparent communication, and the value of flexibility in responding to stakeholder feedback.

2.7 Activities and Outcomes of Stakeholder Engagement

While section 2 of the D2.4 report outlines the methodologies for engaging stakeholders and emphasizes the importance of incorporating their needs into the TRACE project, it is crucial to provide a detailed account of the actual activities conducted and the outcomes achieved through these engagements. This section addresses that gap by documenting the specific activities carried out and the results that emerged from these efforts

2.8 Stakeholder Engagement Activities

Throughout the TRACE project, a series of structured activities were conducted to engage stakeholders across different levels. These activities were designed to ensure that the project benefitted from a broad range of insights, ensuring that the developed solutions were aligned with real-world needs and expectations. The key activities included:

1. Workshops and Focus Groups:

- **Description:** A series of workshops and focus groups were organized at various stages of the project, involving different stakeholder groups, including industry partners, regulatory bodies, local authorities, and end-users. These sessions focused on gathering detailed feedback on the project's design, safety considerations, and the proposed operational scenarios.
- **Outcome:** These workshops led to the refinement of several project aspects, such as the adaptation of safety protocols to meet local regulatory requirements and the incorporation of specific user-friendly features in the TRACE platform, addressing concerns raised by logistics operators.

2. Surveys and Questionnaires:

- **Description:** Targeted surveys were distributed to collect quantitative data on stakeholder needs, expectations, and feedback regarding the ongoing development of TRACE technologies. The surveys were tailored to capture the perspectives of both primary stakeholders (e.g., project partners, industry professionals) and secondary stakeholders (e.g., local communities, end-users).
- **Outcome:** The survey results highlighted critical areas for improvement, such as the need for enhanced data privacy measures and better integration with existing logistics systems. These insights were instrumental in guiding the project's technical development and ensuring compliance with data protection regulations.

3. Stakeholder Meetings:

- **Description:** Regular meetings with key stakeholders, including regulatory authorities and industry leaders, were held to ensure ongoing alignment with project goals and to address any emerging concerns. These meetings served as a platform for direct communication between the project team and stakeholders.
- **Outcome:** These meetings resulted in several critical agreements, including the endorsement of TRACE's operational frameworks by regulatory bodies and the commitment of industry partners to support pilot implementations. Additionally, these discussions facilitated the timely resolution of potential conflicts, such as concerns over the deployment of autonomous vehicles in urban environments.

4. Public Consultations:

- **Description:** Public consultations were conducted, particularly in the areas where TRACE demonstrators were to be deployed. These consultations aimed to gather input from local communities and address any concerns related to the environmental and social impact of the project.
- **Outcome:** The consultations led to several modifications in the deployment strategy, such as the selection of specific routes for autonomous vehicles that minimized disruption to local traffic and the introduction of additional safety measures to address public concerns. This proactive approach helped build community support for the project.

5. Pilot Demonstrations:

- **Description:** As part of the stakeholder engagement activities, pilot demonstrations were organized in Greece, Italy, and Slovenia. These pilots showcased the TRACE technologies in real-world settings, allowing stakeholders to observe their functionality and provide feedback.
- **Outcome:** The pilot demonstrations were highly successful, with stakeholders expressing confidence in the technology's potential. The feedback collected during these demonstrations was crucial in fine-tuning the system's operational capabilities, particularly in areas such as route optimization and real-time monitoring.

2.9 Outcome of Stakeholders Engagement

The activities conducted throughout the stakeholder engagement process yielded several significant outcomes that positively influenced the TRACE project:

1. Refinement of Requirements:

- The engagement process resulted in the refinement of both functional and non-functional requirements.
- Stakeholders' feedback led to the enhancement of data security features, adjustments in the user interface design, and the incorporation of additional safety protocols.
- These refinements ensured that the project was better aligned with stakeholder needs and regulatory expectations.

2. Enhanced Collaboration:

- The engagement activities fostered stronger collaboration among project partners and stakeholders.
- The workshops, meetings, and public consultations facilitated a more integrated approach to problem-solving, leading to the development of more robust and effective solutions.
- The collaborative spirit was particularly evident in the successful pilot demonstrations, where stakeholders worked closely with the project team to test and validate the TRACE technologies.

3. Increased Stakeholder Buy-In:

- The proactive engagement of stakeholders throughout the project lifecycle helped secure broad support and buy-in.
- Stakeholders, including local authorities, industry partners, and end-users, expressed confidence in the TRACE solutions, which is critical for the project's long-term success and scalability.
- This buy-in was further evidenced by the willingness of stakeholders to participate in pilot demonstrations and provide constructive feedback.

4. Identification and Mitigation of Risks:

- The engagement process played a crucial role in identifying potential risks related to stakeholder concerns, such as data privacy issues, regulatory compliance, and public acceptance of autonomous vehicles.
 - Early identification of these risks allowed the project team to develop and implement effective mitigation strategies, thereby reducing the likelihood of adverse outcomes.
- 5. Positive Public Perception:**
- The public consultations and transparent communication strategies employed during the project helped build a positive perception of TRACE within the communities where demonstrators were deployed.
 - The project commitment to addressing public concerns and incorporating community feedback contributed to its acceptance and success in these areas.
- 6. Overall**
- The stakeholder engagement activities conducted as part of the TRACE project have been instrumental in shaping the development of the project's technologies and ensuring their alignment with stakeholder needs.
 - The outcome of these activities, including refined requirements, enhanced collaboration, increased stakeholder buy-in, and positive public perception, underscore the importance of proactive and continuous engagement in achieving project success.
 - Moving forward, TRACE will continue to prioritize stakeholder engagement as a core component of its development strategy, ensuring that the solutions developed are not only technically sound but also widely accepted and supported by all relevant parties.

2.10 Conclusion for section 2

Effective stakeholder engagement has been, and will continue to be, a cornerstone of the TRACE project's success. By actively involving stakeholders in every phase of the project, TRACE ensures that its innovations are not only technically robust but also widely accepted and supported by the communities and industries they are designed to serve. Moving forward, the project will continue to prioritize stakeholder engagement to drive successful outcomes and sustainable impact.

3 REQUIREMENTS ANALYSIS

3.1 Methodology

The requirements analysis is a fundamental part of TRACE, ensuring that the developed solutions meet the necessary functional and non-functional specifications required to achieve the project's goals. This section outlines the methodology used for gathering requirements, the project drivers and constraints, and the detailed analysis of both functional and non-functional requirements essential for the successful implementation of TRACE technologies. The requirements analysis process in TRACE has been structured to ensure a comprehensive understanding of all the needs and constraints related to the project. The methodology involved several key steps:

1. **Stakeholder Consultation:** Initial consultations with stakeholders, including project partners, regulatory bodies, and end-users, were conducted to gather insights into the needs and expectations for the TRACE system. This was achieved through workshops, surveys, interviews, and focus group discussions.
2. **Review of Existing Systems:** A thorough review of existing logistics and transportation systems was conducted to identify current capabilities, limitations, and areas where TRACE could introduce improvements. This review also included an examination of relevant standards and regulations that the project must comply with.
3. **Functional and Non-Functional Requirement Elicitation:** Based on the stakeholder inputs and system reviews, a detailed set of functional and non-functional requirements was elicited. Functional requirements define what the system should do, while non-functional requirements specify the quality and performance standards the system must meet.
4. **Prioritization:** The identified requirements were prioritized based on their importance to the project's objectives, stakeholder needs, and the feasibility of implementation within the project's scope and timeline.
5. **Validation:** The requirements were validated through iterative feedback loops with stakeholders to ensure that they accurately reflect the needs of the project and that all critical requirements were captured.

3.2 Scope of Requirements Elicitation

The scope of the requirements elicitation process for TRACE is specifically focused on three critical areas: safety, infrastructure, and use cases. This targeted approach was designed to align with the project's overarching goals and the key objectives outlined in D2.1.

1. **Safety Requirements:** The safety requirements are paramount in ensuring that all aspects of the TRACE project comply with the highest standards of operational safety. This includes requirements for the safe operation of autonomous vehicles, the implementation of safety protocols for all logistical processes, and the integration of emergency response mechanisms. The elicitation of these requirements involved close collaboration with regulatory bodies and safety experts to ensure that the developed solutions would meet both national and international safety standards.
2. **Infrastructure Requirements:** The infrastructure requirements focus on the physical and digital infrastructure necessary to support the TRACE technologies. This includes the deployment of communication networks (such as 4G/5G), the integration of IoT sensors, and the establishment of data management systems that are robust, secure, and scalable. These requirements also cover the

physical logistics infrastructure, such as warehouses, transportation hubs, and the interfaces between different transport modes. The scope of this elicitation was to ensure that the infrastructure could support the innovative aspects of TRACE while being compatible with existing systems.

- 3. Use Case Requirements:** The use case requirements are centered on the specific scenarios in which TRACE technologies will be deployed. These use cases were carefully selected to demonstrate the practical applications of the TRACE innovations in real-world settings. The elicitation of these requirements involved detailed scenario planning, where stakeholders provided input on the operational challenges and needs within their specific contexts. This ensured that the requirements were grounded in actual operational environments and could guide the development of solutions that address real-world logistics challenges.

This focused scope, which is limited to safety, infrastructure, and use cases, distinguishes the requirements elicitation in this phase of the project from the broader requirements documented in D2.1. The approach in D2.4 was specifically designed to support the practical implementation of TRACE technologies through the development of demonstrators and the validation of their effectiveness in operational settings.

3.3 Project Drivers & Constraints

Understanding the key drivers and constraints of the TRACE project is crucial to aligning the requirements with the broader project goals and external conditions.

3.3.1 Project Drivers

- **Sustainability:** One of the primary drivers of the TRACE project is the need to reduce the environmental impact of logistics operations. This includes minimizing carbon emissions, optimizing resource use, and promoting the use of sustainable technologies such as electric vehicles and renewable energy sources.
- **Safety and Reliability:** Ensuring the safety and reliability of logistics operations is a critical driver. TRACE technologies must be designed to operate safely under various conditions and demonstrate high reliability, particularly in scenarios involving autonomous vehicles and real-time decision-making.
- **Innovation in Logistics:** TRACE aims to introduce innovative solutions in the logistics sector, such as blockchain for secure transactions, autonomous delivery robots, and advanced route optimization algorithms. These innovations are driven by the need to improve efficiency, reduce costs, and enhance the overall performance of logistics systems.
- **Regulatory Compliance:** Compliance with local, national, and international regulations is a key driver for the project. This includes adherence to transportation laws, data protection regulations, and safety standards.

3.3.2 Project Constraints

- **Technical Constraints:** The project must operate within certain technical limitations, including the capabilities of existing infrastructure (e.g., communication networks, road systems) and the technical maturity of new technologies being integrated (e.g., autonomous vehicles, IoT sensors).
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- **Budgetary Constraints:** Financial resources allocated to the TRACE project impose constraints on the scope of development, particularly in terms of the scale of demonstrators and the extent of technology deployment.
- **Timeline Constraints:** The project is bound by a strict timeline, requiring all developments, testing, and deployments to be completed within the designated project duration. This necessitates efficient project management and prioritization of critical tasks.
- **Regulatory and Legal Constraints:** Regulatory requirements, particularly those related to safety, data privacy, and environmental impact, impose constraints on how TRACE solutions can be developed and deployed. Ensuring compliance with these regulations is non-negotiable and must be factored into all stages of the project.

3.4 Functional Requirements

The functional requirements for the TRACE project define the core functionalities that the system must provide to meet its objectives. These requirements are categorized based on the different components and operations within the TRACE system.

3.4.1 Cloud Infrastructure Requirements:

- **Data Storage and Management:** The cloud infrastructure must support secure, scalable storage solutions for the large volumes of data generated by the TRACE system, including real-time logistics data, sensor outputs, and transaction records.
- **Data Processing Capabilities:** The system must be capable of processing complex datasets in real-time to enable dynamic decision-making, such as route optimization, load balancing, and disruption management.
- **Security Measures:** Strong security protocols must be implemented to protect sensitive data, particularly in contexts involving personal information, commercial transactions, and proprietary algorithms.

3.4.2 Communications and Physical Infrastructure Requirements:

- **Connectivity:** The system must ensure robust and reliable communication channels between all components, including vehicles, sensors, cloud servers, and user interfaces. This includes the deployment and integration of 4G/5G networks, IoT devices, and edge computing nodes.
- **Sensor Integration:** The physical infrastructure must support the integration of various sensors (e.g., GPS, environmental sensors, cameras) that provide the necessary data for monitoring and decision-making in logistics operations.
- **System Redundancy:** To ensure continuous operation, the infrastructure must include redundant systems for critical components, such as backup communication channels and fail-safe mechanisms for autonomous vehicles.

3.4.3 Safety and Reliability Requirements:

- **Operational Safety:** All components of the TRACE system, particularly those involving autonomous vehicles and robots, must meet stringent safety standards to prevent accidents and ensure safe interaction with human operators and the environment.
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- **Reliability Metrics:** The system must demonstrate high reliability, with defined metrics for uptime, error rates, and recovery times in the event of system failures or disruptions.

3.5 Non-Functional Requirements

The non-functional requirements outline the quality attributes that the TRACE system must meet to ensure it performs effectively and efficiently.

3.5.1 Cloud Infrastructure Non-Functional Requirements:

- **Scalability:** The cloud infrastructure must be scalable to accommodate growth in data volume, number of users, and system complexity over time
- **Performance:** The system must provide high performance, with low latency and fast response times, particularly for real-time data processing and decision-making tasks.

3.5.2 Communications and Physical Infrastructure Non-Functional Requirements

- **Interoperability:** The communication infrastructure must be interoperable with various devices, platforms, and standards to ensure seamless integration across different components and systems
- **Resilience:** The system must be resilient to disruptions, whether due to hardware failures, network issues, or external threats, ensuring continuous operation with minimal downtime.

3.5.3 Safety and Reliability Non-Functional Requirements

- **Compliance with Standards:** All safety and reliability protocols must comply with relevant industry standards and regulatory requirements, including those related to transportation safety, data protection, and environmental impact
- **Usability:** The system must be user-friendly, with interfaces and operational protocols that are easy to understand and operate for all stakeholders, including logistics operators, drivers, and end-users.

3.6 Industry Feedback Integration

The study of requirements for TRACE was not solely based on internal technical requirements but instead, it systematically incorporated inputs by the industry stakeholders. Towards meeting the above, questionnaires, interviews, and workshops were utilized among the stakeholders involved in the TRACE project, in order to determine their requirements, concerns, and priorities.

This input was then converted into specific technical requirements and system specs, ensuring that the developed TRACE framework incorporates both operational needs and market demands. The table below provides a consolidated mapping of the areas most influenced by stakeholder input, and thus establishes a direct relationship between stakeholder demands and final system design.

Requirement Description	Stakeholder Input	Document Source
Real-time vehicle tracking and ETA estimation	Strong demand for more efficient routing and ETA	<ul style="list-style-type: none"> T2.2 Questionnaire (Q24) D5.1 (Table 3, G3, G5, I6, S5)
Geofencing and delivery disruption	Interest in alerts for delivery disruptions and route deviations	<ul style="list-style-type: none"> T2.2 Questionnaire (Q21, Q22)
Environmental impact and emission tracking	Many companies collect fuel/emission data	<ul style="list-style-type: none"> T2.2 Questionnaire (Q20) D5.1 (Table 3, S2)
Smart contracts and blockchain-based	Interest in smart contracts and tokenization, some experience with blockchain	<ul style="list-style-type: none"> T2.2 Questionnaire (Q42, Q43, Q44)
User dashboards with KPI	Use of internal KPIs and interest in delivery-related functionalities	<ul style="list-style-type: none"> T2.2 Questionnaire (Q27, Q28)
Societal and ethical transparency	Concerns raised about transparency and discrimination (Q46)	<ul style="list-style-type: none"> T2.2 Questionnaire (Q46)
Support for last-mile logistics	High perceived potential in optimizing last-mile logistics	<ul style="list-style-type: none"> T2.2 Questionnaire (Q36) D5.1 (Table 3, G7, I1)

More detailed reports are presented in **Annex B** where the requirements for the various areas of the TRACE system (Platform, Interfaces, Reporting & Analytics, Vehicles & Sensors, Cloud Infrastructure, Security & Data protection, Comms & Physical Infrastructure, Data Management, Events, Monitoring & Optimization, Blockchain, Safety & Reliability, Virtual Cockpit, Ethics) were considered and validated by the stakeholders, for each demonstration (Greek, Italian, Slovenian).

3.7 Closure

- The requirements analysis for TRACE establishes a solid foundation for the development and deployment of innovative logistics solutions that are safe, reliable, and efficient.
- By systematically identifying and analysing both functional and non-functional requirements within the focused scope of safety, infrastructure, and use cases, the project ensures that all critical aspects of the system are addressed.
- This comprehensive approach to requirements analysis will guide the successful implementation of TRACE technologies, leading to enhanced logistics operations and broader adoption of sustainable practices in the industry.

4 DEMONSTRATORS DESCRIPTION

TRACE project implements three demonstrators to enhance logistics and last-mile delivery through advanced technology and multi-modal transportation systems. By integrating drones, cargo bikes, and intelligent algorithms, the project reduces reliance on traditional vehicles, optimizes delivery routes, and improves efficiency. These demonstrators showcase innovative approaches to coordinating resources, streamlining delivery processes, and minimizing environmental impact, ultimately advancing the future of urban logistics. To demonstrate the feasibility and effectiveness of these solutions, three pilot sites have been selected across Europe: Greece, Italy, and Slovenia. Each of these sites presents unique logistical challenges and opportunities, allowing the TRACE technologies to be tested and validated in diverse environments.

- **Greek Demonstrator:** The Greek demonstrator focuses on optimizing logistics operations between Thessaloniki and Athens. This site emphasizes synchro-modal and intermodal logistics operations, where different modes of transport, including trucks and trains, are integrated to reduce environmental impact and improve operational efficiency. The Greek pilot also explores the resilience of the TRACE platform in managing logistics during disruptive events.
- **Italian Demonstrator:** Located in Modena, Italy, this demonstrator aims to revolutionize last-mile delivery through the use of autonomous cargo bikes and other innovative delivery methods. The Italian site is particularly focused on reducing operational resources and environmental impact by optimizing delivery routes and integrating autonomous vehicles into urban logistics.
- **Slovenian Demonstrator:** The Slovenian demonstrator is designed to enhance urban logistics within the city of Ljubljana. This site tests the TRACE solutions in a dense urban environment, focusing on optimizing last-mile delivery through the use of automated delivery robots (ADRs) and other advanced technologies. The Slovenian pilot aims to improve the efficiency of urban logistics while minimizing the disruption to city life.

Each of these demonstrator sites plays a critical role in validating the TRACE technologies in real-world scenarios, providing valuable insights that will inform the broader deployment of these solutions across Europe.

4.1 Hellenic Demonstrator

4.1.1 Part A: Synchro Modal and Intermodal logistics operations

The Greek Demonstrator aims to optimize logistics operations between Thessaloniki and Athens using the TRACE logistics services. The goal is to demonstrate significant improvements in efficiency and environmental impact by reducing the number of trucks used and incorporating HT services for a 50% reduction in transport resources.

<p>Infrastructure and Constraints</p>	<p>Current Infrastructure:</p> <ul style="list-style-type: none"> • Vehicles: Trucks are utilized for ACS courier delivery while trains serve HT (Hellenic Trains) needs. • Communication: Deployment of 4G/5G networks along the Thessaloniki to Athens corridors supports robust connectivity. • Processing Units: Embedded platforms mounted on roller cages enable continuous monitoring and data processing. <p>Sensors:</p> <ul style="list-style-type: none"> • GPS: Provides precise location tracking of shipments. • Environmental Sensors: Monitor temperature and humidity conditions. • Cameras: Used for real-time assessment of shipment status and conditions. <p>Constraints:</p> <ul style="list-style-type: none"> • Resource Limitations: Initially planned use of 4 trucks will be reduced to 2 trucks, alongside HT services, to optimize resource utilization. • Regulatory Compliance: Strict adherence to local transportation regulations and environmental standards ensures legal and environmental responsibility throughout operations.
<p>Stakeholders Involved</p>	<p>Primary Stakeholders:</p> <ul style="list-style-type: none"> • ACS: Responsible for scheduling and executing shipments using trucks within the logistics network. • HT: Provides intermodal transport services via trains, ensuring efficient and large-volume cargo movement. • TRACE: Offers comprehensive logistics services including route optimization and real-time monitoring of shipments, enhancing operational efficiency and reliability. <p>Secondary Stakeholders:</p> <ul style="list-style-type: none"> • Local Authorities: Provide regulatory oversight and essential infrastructure support to facilitate smooth operations and compliance with transportation standards. • Businesses and Residents: Benefit from enhanced logistics services, resulting in improved delivery times and operational efficiencies within the region served by the network.

**High Level
Operational
Scenario****Step 1: Initial Planning and Resource Request**

ACS initiates the logistics process by planning to use 4 trucks initially. They request available resources, define the number of roller cages per route, and allocate shipments based on weight and route requirements.

Step 2: Optimization and Scheduling by TRACE

TRACE utilizes advanced algorithms to optimize the allocation of roller cages and resources. They integrate operational activities between ACS and HT, calculating Estimated Time of Arrival (ETA) considering traffic conditions, potential delays, and other relevant parameters.

Step 3: Approval and Monitoring Setup

ACS approves the optimized schedule generated by TRACE. IDs for roller cages are assigned, each equipped with processing units for continuous monitoring. TRACE updates ACS and HT's Information and Communication Technology (ICT) systems with the connected IDs for tracking and management purposes.

Step 4: Blockchain Integration

TRACE establishes blockchain records and smart contracts between ACS and HT, leveraging the unique IDs assigned to roller cages. This integration ensures transparent and secure transaction records throughout the logistics chain.

Step 5: Route Calculation

TRACE calculates the most efficient route for ACS to transfer shipments to the HT hub, optimizing for time and resource utilization.

Step 6: Intermodal Transport

HT takes over the intermodal transport, moving shipments from Thessaloniki to the Thrasio hub in Athens via trains. TRACE monitors the transfer continuously using embedded units on roller cages to ensure smooth transit and adherence to schedule.

Step 7: Final Delivery

ACS retrieves shipments from HT's Athens hub upon arrival and executes final deliveries to designated recipients, completing the logistics cycle.

Priorities of the Demonstrator

Primary Objectives:

1. Achieve a 50% reduction in the number of trucks used by integrating HT services: ACS aims to optimize transportation logistics by leveraging HT train services alongside trucks. This integration is expected to streamline operations, reduce costs, and minimize the environmental footprint associated with transportation.

2. Enhance operational efficiency and reduce environmental impact: By integrating HT services and optimizing routes and resource allocation through advanced algorithms, ACS seeks to improve overall operational efficiency. This initiative aligns with efforts to reduce greenhouse gas emissions and environmental impact associated with transportation activities.

Secondary Objectives:

1. Demonstrate the feasibility and benefits of synchromodal logistics: ACS intends to showcase the effectiveness of synchromodal logistics, where multiple transportation modes (trucks and trains) are seamlessly integrated and dynamically chosen based on operational and environmental factors. This approach aims to set a precedent for sustainable and efficient logistics practices.

2. Gather data to refine algorithms and improve future operations: Throughout the logistics process, ACS and TRACE will collect data on route optimization, resource utilization, and environmental metrics. This data will be analyzed to enhance algorithms, improve decision-making processes, and further optimize logistics operations in future deployments.

<p>Key Performance Indicators (KPIs) and Acceptance Criteria</p>	<p>KPIs (Key Performance Indicators):</p> <ul style="list-style-type: none"> • Energy Reduction: Targeting a 50% reduction in overall energy consumption through optimized logistics operations. • Fuel Consumption: Aiming for a 50% reduction in fuel consumption by integrating efficient transport modes and routes. • Emission Reduction: Goal of achieving a 50% decrease in emissions, contributing to environmental sustainability. • Operational Costs: Targeting a 50% reduction in operational costs through improved efficiency and resource allocation. • Blockchain Throughput: Ensuring blockchain operations support throughput rates of >10-20 operations per node per second, ensuring efficient transaction processing and data integrity. • Interoperable Operations Success: Targeting 100% success in interoperability between ACS and HT operations facilitated by TRACE, ensuring seamless coordination and data exchange. • Combined Transport Modes: Successful integration of two transport modes (trains and trucks) to optimize logistics efficiency and flexibility. <p>Acceptance Criteria:</p> <ul style="list-style-type: none"> • Successful integration of ACS and HT operations via TRACE: Demonstrated seamless integration and coordination between ACS (trucks) and HT (trains) facilitated by TRACE's logistical management. • Real-time monitoring and data accuracy from embedded units: Ensuring continuous and accurate monitoring of shipments and operational metrics through embedded units on roller cages. • Positive feedback and efficiency improvements demonstrated through KPIs: Validation of efficiency gains and positive feedback from stakeholders based on achieved KPI targets, indicating improved logistics performance and reduced environmental impact.
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4.1.2 Part B: Resilience in disruptive events

The Hellenic Demonstrator aims to showcase the resilience of the TRACE platform in managing logistics operations between Thessaloniki and Athens during disruptive events. By simulating unexpected events, the project seeks to prove that TRACE can dynamically reallocate shipments to maintain delivery goals and constraints.

<p>Infrastructure and Constraints</p>	<p>Current Infrastructure:</p> <p>Vehicles: Trucks are utilized for ACS, while trains serve HT needs.</p> <p>Communication: Deployment of 4G/5G networks along the Thessaloniki to Athens corridors ensures reliable connectivity for data transmission and communication.</p> <p>Processing Units: Embedded platforms are installed on both trucks and roller cages, enabling continuous monitoring and data processing throughout the logistics chain.</p> <p>Sensors:</p> <ul style="list-style-type: none"> • GPS: Provides accurate location tracking for shipments. • Environmental Sensors: Monitor temperature and humidity levels to ensure cargo integrity. • Cameras: Used for real-time monitoring of shipment status and conditions. <p>Constraints:</p> <ul style="list-style-type: none"> • Resource Limitations: Availability of trucks and train capacity poses challenges in scheduling and optimizing transportation resources effectively. • Regulatory Compliance: Strict adherence to transportation regulations and environmental standards is crucial to ensure legal compliance and minimize environmental impact. • Geographical Challenges: Navigating deviations and re-routing across diverse terrains and varying traffic conditions between Thessaloniki and Athens requires robust logistical planning and real-time adjustments.
<p>Stakeholders Involved</p>	<p>Primary Stakeholders:</p> <ol style="list-style-type: none"> 1. ACS: ACS plays a pivotal role in scheduling and executing shipments using trucks within the logistics network. They are responsible for ensuring timely and efficient transport operations. 2. HT: HT provides essential intermodal transport services primarily through trains. Their role is critical in facilitating large-volume and efficient cargo movement across the logistics network. 3. TRACE: TRACE offers comprehensive logistics services including event detection, route optimization, and real-time monitoring. They play a crucial role in enhancing operational efficiency and ensuring smooth logistics operations. <p>Secondary Stakeholders:</p> <ol style="list-style-type: none"> 1. Local Authorities: Local authorities provide regulatory oversight and essential infrastructure support. Their involvement is crucial in ensuring compliance with transportation regulations and maintaining infrastructure integrity. 2. Businesses and Residents: Businesses and residents are key beneficiaries of the resilient logistics services provided by ACS, HT, and TRACE. They benefit from improved delivery times, reliability, and overall efficiency in logistics operations.

High Level
Operational
Scenario

Step 1: Initial Planning and Departure

ACS initiates operations with 2 trucks departing at different times from Chalkida to transport shipments.

HT manages the initial shipment transfer by train from Thessaloniki to continue the logistics chain.

Step 2: Disruptive Event Detection

During the journey, at a specific location like Oinoi, the HT train encounters an unexpected event such as loss of electricity or mechanical failure.

Step 3: Event Detection by TRACE

TRACE detects the event promptly through continuous GPS monitoring or receives confirmation from HT regarding the disruption.

Step 4: Feasibility Assessment

TRACE assesses the situation, considering the sensitivity of the shipments, available truck capacities, and route constraints, to determine the feasibility of re-routing the affected shipments.

Step 5: Route Re-Scheduling

TRACE re-schedules the route for the appropriate truck that can accommodate the re-routed shipments. The driver is informed of the new route and schedule through a graphical user interface (GUI).

The driver confirms the re-scheduling to proceed with the updated logistics plan.

Step 6: ICT Systems Update

TRACE updates the Information and Communication Technology (ICT) systems of ACS and HT with the revised schedule and connects the updated shipment IDs to track the progress accurately.

Step 7: Blockchain Integration

TRACE creates updated blockchain records and adjusts the smart contract between ACS and HT based on the re-scheduled shipments, ensuring transparency and accuracy in transaction records.

Step 8: Final Transfer and Delivery

ACS completes the transfer of the re-scheduled shipments to HT's Athens hub, ensuring continuity in logistics operations despite the initial disruption.

Priorities of the Demonstrator

Primary Objectives:

- Prove the resilience of the TRACE platform in handling disruptive events: The primary objective is to demonstrate the capability of the TRACE platform to effectively detect and manage unexpected disruptions, such as mechanical failures or power outages, during logistics operations.
- Ensure timely delivery of shipments despite unexpected disruptions: Ensuring that despite disruptions, TRACE can promptly re-route shipments and maintain the delivery schedule, showcasing its ability to minimize the impact of unforeseen events on logistics efficiency.

Secondary Objectives:

- Demonstrate effective collaboration between ACS and HT: Highlighting the seamless collaboration between ACS (trucks) and HT (trains) facilitated by TRACE in responding to disruptions. This includes efficient communication and coordination to implement alternative logistics plans swiftly.
- Gather data to improve TRACE's algorithms for future resilience: Utilizing data gathered from handling disruptive events to enhance TRACE's algorithms. This includes refining route optimization, re-scheduling protocols, and decision-making processes to further strengthen resilience in future operations.

<p>Key Performance Indicators (KPIs) and Acceptance Criteria</p>	<p>KPIs (Key Performance Indicators):</p> <ul style="list-style-type: none"> • Logistic Operations Time Improvement: Targeting a 50% reduction in overall logistic operations time, demonstrating increased efficiency in handling shipments. • Route Rescheduling Time: Ensuring route rescheduling is completed in less than 1 second to swiftly adapt to disruptive events and maintain delivery schedules. • Shared Logistics Routes Suggestions: Providing more than 1 shared logistics route suggestion, enhancing flexibility and efficiency in route planning and optimization. • Operational Costs Reduction: Aiming for a 50% reduction in operational costs through optimized resource allocation and logistics management. • Blockchain Block Throughput: Ensuring blockchain operations support throughput rates of >10-20 operations per node per second, ensuring efficient transaction processing and data integrity. • Interoperable Operations Success: Achieving 100% success in interoperability between different means of transport (trains and trucks), facilitated by seamless coordination and data exchange. • Means of Transport Combined: Successfully integrating 2 means of transport (trains and trucks) to optimize logistics operations and flexibility. <p>Acceptance Criteria:</p> <ul style="list-style-type: none"> • Successful detection and management of disruptive events: Demonstrating TRACE's capability to detect and effectively manage disruptive events such as mechanical failures or power outages during logistics operations. • Real-time re-scheduling and data accuracy from embedded units: Ensuring real-time adjustment of logistics plans and accurate monitoring through embedded units on trucks and roller cages. • Positive feedback and efficiency improvements demonstrated through KPIs: Validation of efficiency gains and positive feedback from stakeholders based on achieved KPI targets, indicating improved logistics performance and resilience.
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4.1.3 Part C: Define city corridors and safe exchange areas for deliveries performed by autonomous vehicles

This pilot project focuses on utilizing unmanned vehicles for last-mile deliveries within the NKUA campus, leveraging autonomous ground vehicles and drones to enhance delivery efficiency and safety. The goal is to perform at least 30 delivery attempts, demonstrating the practical application of autonomous delivery systems and integrating services from different last-mile delivery companies.

Infrastructure and Constraints

Current Infrastructure:

Vehicles: Utilization of unmanned ground vehicles (UGVs) and drones for various operational tasks within the NKUA (National and Kapodistrian University of Athens) campus environment.

Communication: Deployment of 5G networks specifically tailored to provide robust communication capabilities within the NKUA campus, essential for real-time data transmission and control.

Processing Units: Embedded platforms integrated into unmanned vehicles enable real-time monitoring, collision avoidance, and emergency management functionalities. These platforms support autonomous operation and ensure safety during missions.

Sensors:

- **GPS:** Provides precise location tracking for unmanned vehicles, facilitating accurate navigation and operational oversight.
- **Environmental Sensors:** Ensure safety and operational monitoring by detecting environmental conditions such as temperature, humidity, and air quality.

Constraints:

Regulatory Compliance: Strict adherence to campus safety regulations and operational guidelines governing unmanned vehicle usage within the NKUA campus. Compliance ensures safety protocols are followed during all operations.

Geographical Challenges: Navigational challenges include maneuvering through specific in-city corridors and safe exchange areas within the NKUA campus environment. These areas require precise navigation and operational planning to avoid obstacles and ensure safe operations.

Technical Limitations: Challenges include ensuring the reliability of autonomous systems and maintaining robust real-time communication infrastructure. These technical aspects are critical for the seamless operation and control of unmanned vehicles and drones within the campus environment.

<p>Stakeholders Involved</p>	<p>Primary Stakeholders:</p> <ol style="list-style-type: none"> 1. ACS: ACS manages feeder vehicle operations, facilitating initial parcel deliveries to designated exchange areas within the NKUA campus. They play a crucial role in the initial logistics chain from distribution centers to campus locations. 2. Collaborating Last-Mile Delivery Company: This company operates autonomous ground vehicles and drones for last-mile deliveries within the NKUA campus. Their role is vital in ensuring efficient and timely delivery of parcels to specific recipients and locations on campus. 3. TRACE: TRACE provides comprehensive logistics services including route optimization, real-time monitoring of delivery operations, and system integration. They facilitate coordination between ACS, the last-mile delivery company, and NKUA campus authorities to ensure seamless logistics operations. <p>Secondary Stakeholders:</p> <ol style="list-style-type: none"> 1. NKUA Campus Authorities: NKUA campus authorities provide essential support and regulatory oversight for the operation of unmanned vehicles and drones on campus. They ensure compliance with campus safety regulations and facilitate the smooth execution of delivery operations. 2. Employees and Students at NKUA Campus: Employees and students at the NKUA campus are the recipients of delivered parcels. They benefit directly from the efficient and reliable delivery services provided by ACS, the collaborating last-mile delivery company, and TRACE.
<p>High Level Operational Scenario</p>	<p>Step 1: Feeder Vehicle Delivery ACS feeder vehicle enters the NKUA campus through specific in-city corridors. It deposits several shipments, such as small boxes, in a designated safe exchange area within the campus.</p> <p>Step 2: Transfer to Unmanned Vehicles Autonomous ground vehicles and drones operated by the collaborating last-mile delivery company enter the NKUA campus. Under the supervision of a human operator, they safely collect shipments from the designated exchange area.</p> <p>Step 3: Shipment Allocation and Route Planning TRACE informs the ACS ICT system about the allocation of shipments to unmanned vehicles. Using advanced algorithms, TRACE calculates and determines the optimal route for each vehicle based on the destination of the parcels.</p> <p>Step 4: Continuous Monitoring and Safety TRACE ensures continuous monitoring of the entire transfer process. A human operator remains on standby to intervene and halt deliveries if any safety concerns arise during the transportation of parcels within the campus.</p> <p>Step 5: Customer Interaction and Delivery Confirmation Customers interact with the unmanned vehicles upon their arrival to receive their parcels. TRACE records successful delivery and updates the ACS ICT system with delivery confirmation and any pertinent details.</p>

Priorities of the Demonstrator**Primary Objectives:**

Successfully integrate autonomous vehicles for last-mile deliveries within the NKUA campus:

The primary goal is to seamlessly integrate autonomous ground vehicles and drones operated by different last-mile delivery companies into the logistics operations within the NKUA campus. This includes efficient navigation through campus corridors and safe delivery to designated exchange areas.

Demonstrate the safety and efficiency of unmanned vehicle operations:

Showcase the reliability, safety protocols, and operational efficiency of unmanned vehicle operations for last-mile deliveries within the campus environment. This involves demonstrating compliance with safety regulations, minimizing risks, and ensuring timely parcel delivery.

Secondary Objectives:

Enhance collaboration between different last-mile delivery companies:

Foster effective collaboration and coordination between multiple last-mile delivery companies operating autonomous vehicles within the NKUA campus. This includes optimizing resource sharing, coordinating schedules, and ensuring seamless interaction between different delivery systems.

Gather data to improve the TRACE platform and autonomous delivery systems:

Utilize operational data and feedback to enhance the TRACE platform's algorithms and functionalities. This includes refining route optimization, improving real-time monitoring capabilities, and enhancing autonomous vehicle performance for future deployments.

<p style="text-align: center;">Key Performance Indicators (KPIs) and Acceptance Criteria</p>	<p>KPIs (Key Performance Indicators):</p> <ul style="list-style-type: none"> • Average Energy Reduction: Achieve a reduction in average energy consumption by more than 60% compared to traditional delivery methods, demonstrating the efficiency of autonomous vehicles. • Average Fuel Consumption Reduction: If feeder vehicles are electric, aim for a 100% reduction in fuel consumption, showcasing environmental sustainability in campus logistics. • Average Emission Reduction: Similarly, if feeder vehicles are electric, target a 100% reduction in emissions, contributing to a cleaner campus environment. • Means of Transport Combined: Successfully integrate 2 means of transport - unmanned vehicles (drones and ground vehicles) and conventional vans - to optimize last-mile delivery operations. • Operational Costs Reduction: Achieve a 50% reduction in operational costs through efficient route planning, resource optimization, and minimized maintenance expenses. • Market Opportunities: Identify and capitalize on 2-4 new market opportunities enabled by the deployment of autonomous delivery systems within the NKUA campus. <p>User Appreciation Score (1-5): Attain a user satisfaction score ranging between 4 and 5 based on feedback from recipients, reflecting high levels of satisfaction with delivery services.</p> <p>Acceptance Criteria:</p> <ul style="list-style-type: none"> • Successful completion of at least 30 delivery attempts: Demonstrate the reliability and effectiveness of autonomous delivery operations by successfully completing a minimum of 30 delivery missions within the NKUA campus. • Real-time monitoring and data accuracy from embedded units: Ensure continuous real-time monitoring of delivery operations and accurate data collection through embedded units on autonomous vehicles, maintaining operational transparency and reliability. • Positive feedback from recipients and operational efficiency demonstrated through KPIs: Gather positive feedback from recipients regarding delivery experience and demonstrate improved operational efficiency through the achievement of predefined KPI targets.
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4.2 Italian Demonstrator

4.2.1 Part B: “Last-mile” parcel delivery, City of Modena

The implementation of autonomous cargo bikes aims to be innovative last-mile parcel delivery logistics. By reducing the number of trips required and incorporating optimized planning, the goal is to demonstrate significant improvements in efficiency, cost-effectiveness and CO2 emissions. This is achieved through a

platooning scenario, where cargo bikes can split and merge at different intersection points. Parcels are loaded and carried on multiple cargo bikes at the start of the delivery phase, minimizing operational resources and streamlining the process. Additionally, difficult-to-deliver or high-priority parcels can be transported by drones placed on the top shelf of the cargo bike, ensuring all parcels reach their destinations efficiently.

<p>Infrastructure and Constraints</p>	<p>Current Infrastructure:</p> <ul style="list-style-type: none"> • Vehicles: Cargo bikes that are autonomous and can be arranged in a platooning configuration and potentially others unmanned vehicles such as drones attached to the top shelf of the cargo bikes. • Communication: Use the already existent 4G/5G networks • Processing Units: Embedded platforms mounted on Cargo Bike. <p>Sensors:</p> <ul style="list-style-type: none"> • GPS: Provides precise location tracking of shipments. • Camera/s: Used for autonomous software stack to have unmanned vehicles and follow a cargo leader (with a human operator on it) or another unmanned vehicle inside a platooning configuration. • Gyroscope: Provides measure of orientation and angular velocity. <p>Constraints:</p> <ul style="list-style-type: none"> • Resource Limitations: Initially the operators return to the central hub almost 3 times a day. To avoid unnecessary returning to central hub to load more parcels by reducing the number of trips required and incorporating optimized planning decisions for a substantial reduction in operational resources. • Regulatory Compliance: Strict adherence to local transportation regulations and environmental standards ensures legal and environmental responsibility throughout operations.
<p>Stakeholders Involved</p>	<p>Primary Stakeholders:</p> <ul style="list-style-type: none"> • URBICO: Responsible for scheduling and executing parcels delivering with unmanned and manned Cargo Bikes. • TRACE: Offers comprehensive logistics services including route optimization and real-time monitoring of shipments, enhancing operational efficiency and reliability. <p>Secondary Stakeholders:</p> <ul style="list-style-type: none"> • Local Authorities: Provide regulatory oversight and essential infrastructure support to facilitate smooth operations and compliance with transportation standards. • OLV: Cargo bike producer. • Businesses and Residents: Benefit from enhanced logistics services, resulting in improved delivery times and operational efficiencies within the region served by the network.

**High Level
Operational
Scenario****Step 1: Initial Planning and Routing Request Based on Parcels**

URBICO initiates the logistics process for the last mile delivery by planning to use 3 autonomous cargo bikes and the daily parcels that must be delivered to customers. They sent to TRACE the available resources (number of delivery operators, number of vehicles, the information regarding parcels to deliver, parcels weights, volumes, etc.)

Step 2: Scheduling and Route Optimization by TRACE

TRACE utilizes advanced algorithms to optimize the scheduling and the routing of the available cargo bike, personals and resources. Trace will calculate the Estimated Time of Arrival (ETA) considering traffic conditions, potential delays, and other relevant parameters.

Step 3: Approval and Monitoring Setup

URBICO approves the optimized schedule generated by TRACE.

The operators present in the URBICO facility hub will assemble the shipment according to the solution provided by TRACE. Cargo bikes will send information to TRACE to keep track and monitor the general information of the delivery process.

Step 4: Blockchain Integration (optional)

TRACE establishes blockchain records and smart contracts between URBICO and other partners, leveraging the unique IDs assigned to the delivery. This integration ensures transparent and secure transaction records throughout the logistics chain.

Step 5: Delivering Parcels

By taking the information of routing provided by the TRACE system, the delivery driver will accomplish the delivery phase.

Step 6: Final Delivery

The Delivery driver committed the last delivery and returned to the central URBICO lab facility.

Priorities of the Demonstrator

Primary Objectives:

Implementation of Autonomous Stack and Vehicle (Cargo Bike) capable of handling the AV Software: With the introduction of smart and automated bikes, each bike is now equipped with self-navigation capabilities. This eliminates the need for manual guidance by operators, freeing them to focus on other tasks and increasing overall efficiency and brings more bikes together to increase their transportation capabilities.

Parcel Reloading multiple times: The TRACE project introduces a platooning of vehicles. Instead of operators having to return multiple times to reload parcels, this process is now optimized and automated, reducing downtime and increasing productivity.

Optimized Route Planning: Through advanced algorithms and data analytics, the TRACE project optimizes route planning for parcel delivery. Factors such as parcel weight, delivery location, traffic conditions, and terrain determine the most efficient and cost-effective routes.

Centralized Decision-Making: The TRACE project centralizes decision-making for delivery routes, considering real-time data and external factors such as weather conditions and traffic patterns. This ensures that routes are dynamically adjusted to optimize delivery efficiency and minimize delays.

Continuous Monitoring and Improvement: The TRACE project incorporates monitoring and feedback mechanisms to continuously evaluate and improve the delivery process. Performance metrics are tracked in real-time, allowing for immediate adjustments and optimization of operations.

2. Enhance operational efficiency and reduce environmental impact: By integrating URBICO services and optimizing routes and resource allocation through advanced algorithms, URBICO seeks to improve overall operational efficiency in the last mile delivery. This initiative aligns with efforts to reduce greenhouse gas emissions and environmental impact associated with transportation activities.

Key Performance Indicators (KPIs) and Acceptance Criteria

KPIs (Key Performance Indicators):

- Energy Reduction: Targeting a 50% reduction in overall energy consumption through optimized logistics operations.
- Fuel Consumption: Aiming for a 50% reduction in fuel consumption by integrating efficient transport modes and routes.
- Emission Reduction: Goal of achieving a 50% decrease in emissions, contributing to environmental sustainability.
- Operational Costs: Targeting a 50% reduction in operational costs through improved efficiency and resource allocation.
- Blockchain Throughput: Ensuring blockchain operations support throughput rates of >10-20 operations per node per second, ensuring efficient transaction processing and data integrity.
- Interoperable Operations Success: Targeting 100% success in interoperability between ACS and HT operations facilitated by TRACE, ensuring seamless coordination and data exchange.
- Combined Transport Modes: Successful integration of two transport modes (cargo bike and drone) to optimize logistics efficiency and flexibility.

Acceptance Criteria:

- Successful integration of URBICO via TRACE: Demonstrated seamless integration and coordination of the last mile delivery by TRACE's logistical management.
- Real-time monitoring and data accuracy from embedded units: Ensuring continuous and accurate monitoring of shipments and operational metrics through embedded units on cargo bikes and drones.
- Positive feedback and efficiency improvements demonstrated through KPIs: Validation of efficiency gains and positive feedback from stakeholders based on achieved KPI targets, indicating improved logistics performance and reduced environmental impact.

4.2.2 Resilience to disruptive events

The Italian B Demonstrator aims to showcase the resilience of the TRACE platform in managing logistics operations between the URBICO facility and customers during disruptive events. By simulating unexpected events, the project seeks to prove that TRACE can dynamically reallocate shipments to maintain delivery goals and constraints.

<p>Infrastructure and Constraints</p>	<p>Current Infrastructure:</p> <ul style="list-style-type: none"> • Vehicles: Cargo bikes that are autonomous and can be arranged in a platooning configuration and potentially others unmanned vehicle as drones attached to the top shelf of the cargo bikes. • Communication: Use the already existent 4G/5G networks • Processing Units: Embedded platforms mounted on Cargo Bike. <p>Sensors:</p> <ul style="list-style-type: none"> • GPS: Provides precise location tracking of shipments. • Camera/s: Used for autonomous software stack to have unmanned vehicles and follow a cargo leader (with a human operator on it) or another unmanned vehicle inside a platooning configuration. <p>Gyroscope: Provides measure of orientation and angular velocity.</p> <p>Constraints:</p> <ul style="list-style-type: none"> • Resource Limitations: Initially the operators return to the central hub almost 3 times a day. To avoid unnecessary returning to central hub to load more parcels by reducing the number of trips required and incorporating optimized planning decisions for a substantial reduction in operational resources. • Regulatory Compliance: Strict adherence to local transportation regulations and environmental standards ensures legal and environmental responsibility throughout operations.
<p>Stakeholders Involved</p>	<p>Primary Stakeholders:</p> <ul style="list-style-type: none"> • URBICO: Responsible for scheduling and executing parcels delivering with unmanned and manned Cargo Bikes. • TRACE: Offers comprehensive logistics services including route optimization and real-time monitoring of shipments, enhancing operational efficiency and reliability. <p>Secondary Stakeholders:</p> <ul style="list-style-type: none"> • Local Authorities: Provide regulatory oversight and essential infrastructure support to facilitate smooth operations and compliance with transportation standards. • OLV: Cargo bike producer. • Businesses and Residents: Benefit from enhanced logistics services, resulting in improved delivery times and operational efficiencies within the region served by the network.

<p>High Level Operational Scenario</p>	<p>Step 1: Initial Planning and Departure URBICO initiates operations with 2 cargo bikes arranged in platooned configuration departing from the same hub with only one delivery operator.</p> <p>Step 2: Disruptive Event Detection During the journey, at a specific location in the middle of the “Diagonale Verde” of Modena, the cargo bike, headed leader of the platooning encounters an unexpected event such as mechanical failure or issue with the electric motor.</p> <p>Step 3: Event Detection by TRACE TRACE detects the event promptly through continuous GPS monitoring or receives confirmation from delivery operator regarding the disruption.</p> <p>Step 4: Feasibility Assessment TRACE assesses the situation, considering the sensitivity of the shipments, available truck capacities, and route constraints, to determine the feasibility of re-routing the affected shipments.</p> <p>Step 5: Route Re-Scheduling TRACE re-schedules the route for the appropriate bike that can accommodate the re-routed shipments. The driver is informed of the new route and schedule through a graphical user interface (GUI). The driver confirms the re-scheduling to proceed with the updated logistics plan.</p> <p>Step 6: Systems Update TRACE updates the systems of URBICO with the revised schedule and connects the updated shipment IDs to track the progress accurately.</p> <p>Step 7: Blockchain Integration TRACE creates updated blockchain records and adjusts the smart contract based on the re-scheduled shipments, ensuring transparency and accuracy in transaction records.</p> <p>Step 8: Final Transfer and Delivery URBICO operational driver completes the transfer of the re-scheduled shipments to customers, ensuring continuity in logistics operations despite the initial disruption.</p>
<p>Priorities of the Demonstrator</p>	<p>Primary Objectives:</p> <ul style="list-style-type: none"> • Prove the resilience of the TRACE platform in handling disruptive events: The primary objective is to demonstrate the capability of the TRACE platform to effectively detect and manage unexpected disruptions, such as mechanical failures or issues, during logistics operations. • Ensure timely delivery of shipments despite unexpected disruptions: Ensuring that despite disruptions, TRACE can promptly re-route shipments and maintain the delivery schedule, showcasing its ability to minimize the impact of unforeseen events on logistics efficiency.

<p>Key Performance Indicators (KPIs) and Acceptance Criteria</p>	<p>KPIs (Key Performance Indicators):</p> <ul style="list-style-type: none"> • Logistic Operations Time Improvement: Targeting a 50% reduction in overall logistic operations time, demonstrating increased efficiency in handling shipments. • Route Rescheduling Time: Ensuring route rescheduling is completed in less than 1 minute to swiftly adapt to disruptive events and maintain delivery schedules. • Operational Costs Reduction: Aiming for a 50% reduction in operational costs through optimized resource allocation and logistics management. • Blockchain Block Throughput: Ensuring blockchain operations support throughput rates of >10-20 operations per node per second, ensuring efficient transaction processing and data integrity. • Interoperable Operations Success: Achieving 100% success in interoperability between different means of transport (trains and trucks), facilitated by seamless coordination and data exchange. • Means of Transport Combined: Successfully integrating 2 means of transport (trains and trucks) to optimize logistics operations and flexibility. <p>Acceptance Criteria:</p> <ul style="list-style-type: none"> • Successful detection and management of disruptive events: Demonstrating TRACE's capability to detect and effectively manage disruptive events such as mechanical failures or power outages during logistics operations. • Real-time re-scheduling and data accuracy from embedded units: Ensuring real-time adjustment of logistics plans and accurate monitoring through embedded units on cargo bikes and drones. • Positive feedback and efficiency improvements demonstrated through KPIs: Validation of efficiency gains and positive feedback from stakeholders based on achieved KPI targets, indicating improved logistics performance and resilience.
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4.2.3 Define city splitting and merging point for the platooning configuration

To optimize the transportation of shipments from different Modena hubs to the Modena center/smart area, it is essential to define the merging and splitting points of the cargo bike platoons. These points are crucial for the coordination of different cargo bike platoons for the delivery of parcels. Initially, a cargo bike departs from the hub with multiple parcels destined for various city areas. Upon reaching a predetermined crossroads, information about delivery locations is exchanged among the platoons, selecting the most suitable platoon to continue the delivery. In cases where bike lanes are absent or roads are difficult to cross or places are difficult to reach, drones can complete the final leg of the shipment (optional).

Additionally, the personnel operating a bike, who can potentially be the leader of a platoon, can decide to detach from the platoon at certain points. They can later rejoin another cargo bike platoon at a different point, exchange the bike they were riding with another loaded with parcels for delivery, and send the previously emptied bike back to the hub, as all parcels have been delivered. These exchange points ensure efficient and flexible delivery management, reducing the number of trips needed and enhancing service coverage.

4.2.4 Italian B Use Case in Detail

A shipment needs to be transported from the Modena hub (44.651072, 10.891938) to the Modena centre/smart area (44.657887, 10.932957), initially using vans. However, with the assistance of multiple cargo bikes organized into platoons, the shipment process becomes feasible. Additionally, for last-meter delivery in areas without bike lanes or difficult roads to cross, autonomous drones can be utilized.

At the start, a cargo bike departs from the Modena hub (44.651072, 10.891938) with multiple parcels destined for different areas of the city (Delivery Area + others). Upon reaching specific crossroads, platoons of cargo bikes exchange information regarding delivery locations. The most suitable cargo bike platoon is then selected, and the goods are transferred accordingly. Optionally, drones can handle the final leg of the shipment if a bike lane is absent or there are difficult roads to cross.

Early in the morning, various parcels located at the Modena Hub (44.651072, 10.891938) near the cycle road must be delivered to nearby zones, such as customers residing in the Emilia Ovest area, near the center, and to the Modena Smart Area hub.

As there are 2-3 autonomous cargo bikes and 1 drone available at the initial hub, all parcels for delivery are loaded onto these bikes. Since there is only one delivery personnel at the hub, they will use a platoon of autonomous bikes to transport all loaded parcels efficiently.

Starting the journey, the first cargo bike, with the operator onboard, proceeds to the first intersection point for delivery (A). At a designated point, the operator halts and instructs the platoon of two cargo bikes to converge at a high intersection point (B), while they make deliveries in nearby areas. Upon completing deliveries in the zone, the operator's bike becomes empty, and they head to the second (B) intersection point, where two previous bikes await.

At this juncture (B), the operator reorganizes the cargo bike platoon, possibly placing the empty cargo bike at the rear. They direct the empty cargo bike to autonomously return to the hub (44.651072, 10.891938) via the cycle road for further deliveries. Subsequently, the operator, now joined with another cargo bike platoon, proceeds to the next intersection point. Here (C), they instruct the second cargo bike of the platoon to reach a final bike lane point (D) through a vehicle-to-vehicle communication, where a van is ready for a scheduled delivery in the Modena Smart Area.

Upon arrival, the contents of the cargo bike are transferred to the van by the van's operator for additional deliveries, without significantly altering the van's original route.

The cargo bike present near the van autonomously returns to the hub (44.651072, 10.891938).

Meanwhile, the cargo bike operator continues with subsequent zone deliveries. For a single parcel located in an opposite distant area, the operator employs a drone for delivery. Once the drone departs, completes the delivery, and returns to the intersection point (C), it reattaches to the cargo bike's roof rack for further transportation. Each piece of information regarding the progress of deliveries and the related events arising from them, such as GPS position updates, parcel delivery status, and so forth, is updated and communicated, through 4G antennas, into the Trace infrastructure.

HUB: [44.651072, 10.891938](#)

Communication and Control Systems: The ADRs are supported by a robust communication infrastructure that includes 4G/5G networks, IoT sensors, and cloud-based data management systems. These systems enable real-time monitoring and control of the ADRs, ensuring that they can navigate efficiently and safely through the city streets. The communication network also facilitates the seamless exchange of data between the ADRs, the central logistics management system, and other stakeholders involved in the delivery process.

Urban Infrastructure: The Slovenian Demonstrator leverages existing urban infrastructure in Ljubljana, including designated delivery zones, pedestrian pathways, and roadways adapted for the safe operation of ADRs. The infrastructure is equipped with sensors and cameras to monitor traffic, pedestrian movements, and environmental conditions, providing the data necessary for the ADRs to make informed decisions.

4.3.2 Operational Workflow

The operational workflow in the Slovenian Demonstrator is carefully designed to optimize last-mile delivery. The process begins at a central logistics hub where parcels are sorted and loaded onto the ADRs. The ADRs then navigate through the city, following optimized routes generated by the TRACE platform's advanced algorithms. These routes take into account real-time traffic data, pedestrian density, and environmental factors to ensure timely and efficient deliveries.

As the ADRs move through the city, they communicate continuously with the central logistics management system, which monitors their progress and provides updates. In the event of any disruptions, such as a blocked pathway or mechanical issue, the system can reroute the ADRs or dispatch human operators for assistance. Upon reaching their destinations, the ADRs deliver the parcels directly to end-users, who can track the delivery in real-time through a mobile application.

4.3.3 Expected Outcome

The Slovenian Demonstrator shall showcase the feasibility and benefits of using ADRs in urban logistics. By integrating these robots into the delivery process, the project aims to reduce delivery times, lower operational costs, and minimize the environmental impact of last-mile logistics. The demonstrator also seeks to gather data on the performance of ADRs in a real-world setting, which will be used to refine the technology and improve future deployments. Furthermore, it is expected to contribute to the broader goal of making urban logistics more sustainable and resilient. By reducing reliance on traditional delivery vehicles, the project aims to decrease traffic congestion and emissions in Ljubljana, enhancing the quality of life for residents and supporting the city's environmental goals.

Operating ADRs in a dense urban environment presents several challenges, including navigating through crowded pedestrian areas, dealing with unpredictable traffic conditions, and ensuring the safety of both the robots and the public. The TRACE project addresses these challenges through the use of advanced sensor technologies, real-time monitoring, and dynamic route optimization. Additionally, the project

involves close collaboration with local authorities to ensure that the deployment of ADRs aligns with city regulations and public expectations.

Overall, the Slovenian Demonstrator is critical for TRACE, providing valuable insights into the integration of autonomous technologies in urban logistics. By successfully deploying ADRs in Ljubljana, the project not only demonstrates the potential of these technologies to transform last-mile delivery but also sets the stage for their broader adoption across European cities.

4.3.4 Parts of the Pilot

The pilot will consist of one part (Part A), and it will include first/last mile delivery and pickups using environmentally friendly vehicles, as well as use of small-scale pilot consolidation centre of BTC Logistics operator and the Post of Slovenia.

Actors involved in the Slovenian demonstration are the following:

- last mile delivery agent (LMDA);
- first mile pick-up agent (FMFA);
- mid mile logistics agent (MMLA);
- consolidation agent.

Slovenian demonstration consists of 3 scenarios:

- last mile delivery of shipments;
 - first mile pick-up of shipments;
 - process of simultaneous pick-up and delivery of vehicles.
-
- Last mile (LM) delivery involves the delivery of shipments within the BTC City pilot area. Shipments delivered to the BTC City area can be directly delivered to the end customer, or they can be sent to the urban consolidation centre (UCC), from where zero – emission LM delivery will be executed. The process of LM delivery in the BTC City area is indicated by red arrows.
 - First mile (FM) refers to the pick-up of shipments within the BTC City pilot area. Shipments picked up (FM) with various zero – emission vehicles in the BTC City area can directly continue transport into the mid mile (MM), or they can be handed over to the urban consolidation centre, from where the mid mile logistics agent (MMLA) will execute the MM transport.
 - Mid mile (MM) relates to the transportation of goods to and from the BTC City area. In the case of the Slovenian pilot, MM transport will be performed by the Post of Slovenia (PS). For PS, mid mile presents the transport from their (postal) logistics centres in Slovenia to the BTC City area and vice versa.

For ease of understanding, the pick-up (first mile) and delivery (last mile) processes are shown in Figure 1, that illustrates the Business Process Model and Notation (BPMN) diagram for the Slovenian Demonstrator

within the TRACE project. This diagram captures the workflow for last-mile delivery operations in the city of Ljubljana, using automated delivery robots (ADRs) and other advanced logistics technologies. The BPMN swimlanes represent the different stakeholders involved in the process, including the ADRs, the central logistics management system, and the end-users receiving the deliveries. Each swimlane delineates the responsibilities and actions of these stakeholders throughout the delivery process.

The diagram also employs different arrow colors to signify various types of interactions and flows between the stakeholders. Black arrows represent the standard sequence flow, indicating the progression of tasks and events within the process. Red arrows denote exception flows, which are triggered in response to errors or disruptions, such as route blockages or system failures. Green arrows highlight the communication flow between stakeholders, particularly focusing on the real-time exchange of data and updates crucial for the smooth operation of the ADRs and the overall logistics system. This visual representation in Figure 1 provides a comprehensive overview of the operational dynamics within the Slovenian Demonstrator, emphasizing the integration of technology and stakeholder collaboration to achieve efficient urban logistics.

TRACE platform will collect the data on the arrival time of MM shipments to the BTC City area for LM execution. Thus, the optimization process for LM delivery starts with a list of deliveries by the mid mile logistics agent (MMLA). This list, which is crucial input data for the Trace platform, includes all deliveries the Last mile delivery agent (LMDA) will perform in the BTC City area. Based on this list and other necessary data (e.g., quantity of shipments, vehicle load factor, type of vehicle, expected arrival time in BTC City, external data), the Trace platform schedules, routes, and optimizes delivery within the BTC City area.

The platform first assesses whether the MM logistics agent can directly execute the LM delivery to the end customer or a retailer in BTC City area. Alternatively, the MM may need to complete the delivery at the urban consolidation centre, where the shipments will be handed over. After consolidation and commissioning, the LM delivery is then carried out by the LMDA based on the TRACE optimised schedule.

If the MM logistics agent fulfils the conditions for direct LM delivery (without consolidation process), we follow red arrows 1, 2, 3 (Only delivery / Pick-up and Delivery) on the Figure 1. If it needs to hand over the delivery to the urban consolidation centre, we follow arrows 1, 2, 3, 4, 4 (including fulfilment order in last mile delivery), 5, 6, 7.

The process of FM pick-up is presented with green arrows. If the First mile pick-up agent (FMPA) performs only FM pick-up of shipments within the BTC City area, the process starts at green arrows, numbered 1, 2, 3, 4. However, if the pick-up (FM) occurs simultaneously with shipment delivery (LM), the process continues at red numbers 8, 9, 10, 11, 12. In this scenario, shipments undergo consolidation, commissioning, and preparation for MM transport.

The Mid mile logistics agent, Last mile delivery agent, and First mile pick-up agent can, in certain cases, be the same company (e.g., Post of Slovenia), only the transport operations performed by the company are different (MM or LM or FM). One such example is as follows: If the MMLA (Post of Slovenia) brings shipments to the BTC City area using a zero-emission vehicle with an appropriate load factor, it can, under these conditions, avoid unnecessary consolidation process. Then, within the BTC City area, it carries out the pick-up and delivery of shipments (LM and FM). If, at the end of collecting shipments (FM), the zero-

emission vehicle has a sufficient load factor, it can bypass the consolidation process and continue transport of collected shipments in the mid mile (MM).

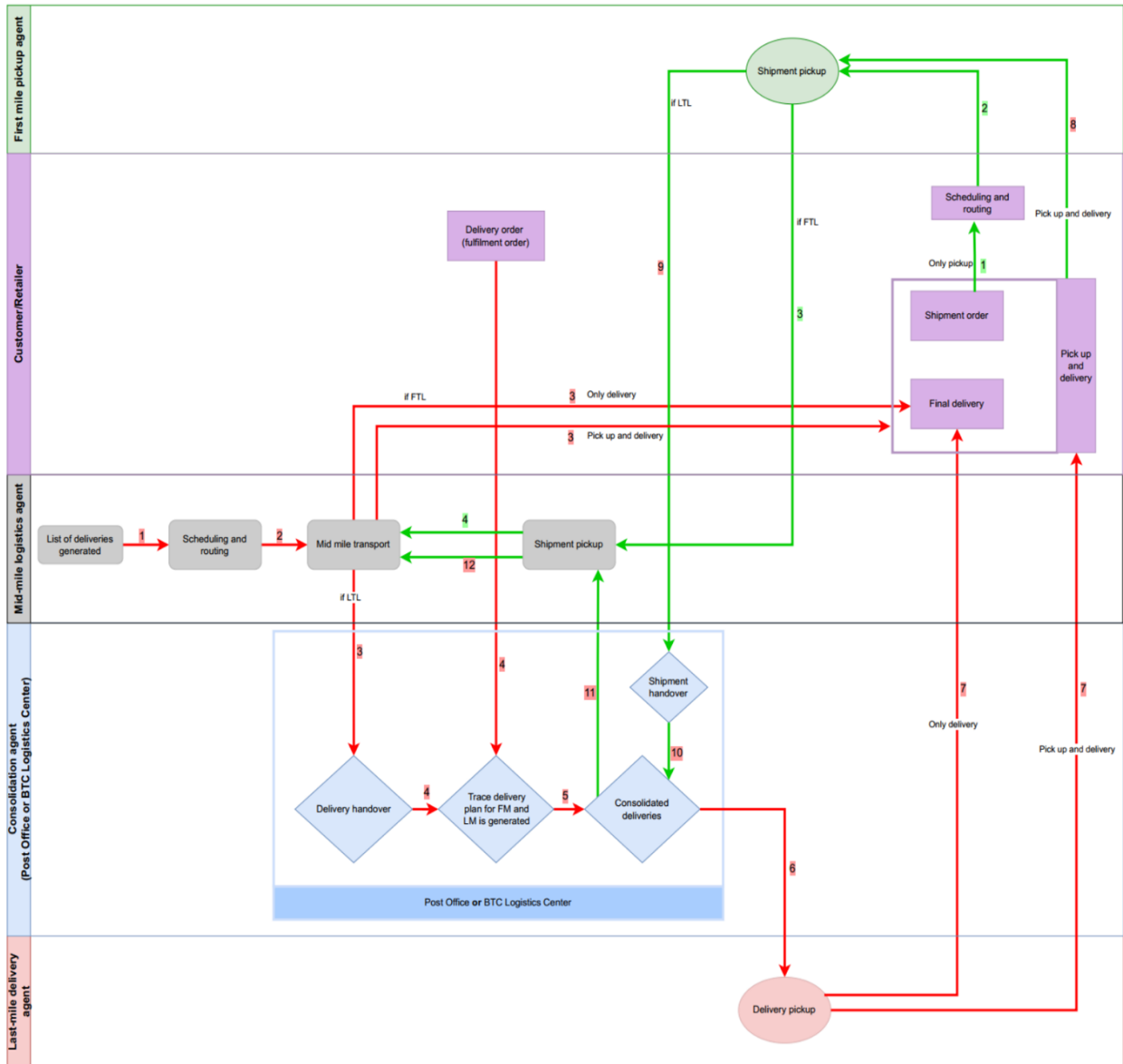


Figure 1: Last mile and first mile high-level diagram

4.3.5 Infrastructure and Constraints

The pilot scenarios will take place in the 0.5 square kilometre in AV Living Lab ecosystem in BTC City Ljubljana, a business, retail, leisure, and logistic district owned by BTC Company. The area is content and people rich, with 12 million vehicle entries per year and 21 million visits per year, visiting its 450 shops and 70 restaurants/bars (AV Living Lab, ‘City as a Lab ecosystem’, AV Living Lab. Accessed: 16 July 2024. [Online]. Available: <https://avlivinglab.com/city-as-a-lab-ecosystem/>).

The pilot scenarios will take place in the outdoor areas of the ecosystem – on parts of 11 km of roads and adjacent sidewalks, road crossings, roundabouts and intersections.



Figure 2: Location of BTC City within City of Ljubljana



Figure 3: Map of BTC City Ljubljana with Post office (yellow), location of BTC Company premises (blue), and end-users potential location (green)

BTC City Ljubljana physical infrastructure includes:

- 11 kilometers of public-accessible roads [BTC, d. d., ‘BTC Digit’, BTC d.d. Accessed: Jan. 16, 2024. [Online]. Available: <https://www.btc.si/btc-digit/>],
- 34 intersections and roundabouts [BTC, d. d., ‘BTC Digit’, BTC d.d. Accessed: Jan. 16, 2024. [Online]. Available: <https://www.btc.si/btc-digit/>],
- 8500 free parking spaces for vehicles (Figure 8)[BTC, d. d., ‘BTC Digit’, BTC d.d. Accessed: Jan. 16, 2024. [Online]. Available: <https://www.btc.si/btc-digit/>],
- 11 charging stations for e-vehicles [‘BTC City Poslovno’, BTC-CITY. Accessed: Jan. 19, 2024. [Online]. Available: <https://www.btc-city.com/poslovno>] with 22 charging points [vir: gremonaelektriko.si],
- 4 charging stations of the vehicle sharing system [BTC, d. d., ‘Letno poročilo za poslovno leto 2022’. Mar. 27, 2023. [Online]. Available: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.btc.si/wp-content/uploads/2023/04/Letno-porocilo-BTC-2022-z-mnenjem.pdf],
- 4 e-bike charging stations with e-bike rental system [AV Living Lab, ‘City as a Lab ecosystem’, AV Living Lab. Accessed: Jan. 16, 2024. [Online]. Available: <https://avlivinglab.com/city-as-a-lab-ecosystem/>],

- 3 non-electric bike sharing locations [AV Living Lab, 'City as a Lab ecosystem', AV Living Lab. Accessed: Jan. 16, 2024. [Online]. Available: <https://avlivinglab.com/city-as-a-lab-ecosystem/>] The speed limit in the entire area is 30 km/h [BTC, d. d., 'BTC Digit', BTC d.d. Accessed: Jan. 16, 2024. [Online]. Available: <https://www.btc.si/btc-digit/>], but speeding is frequent [<https://drajv.triglav.si/zemljevid>]. There are 4 public city bus lines in the BTC City area [AV Living Lab, 'City as a Lab ecosystem', AV Living Lab. Accessed: Jan. 16, 2024. [Online]. Available: <https://avlivinglab.com/city-as-a-lab-ecosystem/>].
- Within the area, there are approximately 8500 parking spaces [AV Living Lab, 'City as a Lab ecosystem', AV Living Lab. Accessed: Jan. 16, 2024. [Online]. Available: <https://avlivinglab.com/city-as-a-lab-ecosystem/>]
- The area was selected as a pilot site as it resembles situation in city centers, where similar issues with high number of logistic needs and high number of people and content intersects.
- Slovenian scenarios will include BTC logistics center and Slovenian Post (PS) facilities, acting as pickup/drop-off points or consolidation center.
- The Slovenian pilot will take place in BTC City Ljubljana, utilizing two urban consolidation centers (UCC):
 - the PS Post Office and
 - BTC logistics center.

The UCCs will manage the consolidation and deconsolidation of shipments for first-mile (FM) and last-mile (LM) deliveries.

4.3.6 Logistic resources: Post office

The mail delivery post office (1122) of PS is located at the heart of the BTC area (Avstrijska ulica 3, Ljubljana). The total area of the post office is approximately 380 m². Access to the post office is possible via stairs or a ramp with a width of one meter (suitable for unmanned ground vehicle - UGV).

The office has appropriate space for transshipment and consolidation activities, in line with the objective of establishing synchromodal operations in the designated pilot area.

Additionally, the post office has parcel lockers, which permit recipients to retrieve their shipments outside of normal business hours. The delivery post office is equipped with personal computers and mobile phones, both of which are intended for executing postal and business operations. Transactions related to postal and business activities are conducted via our internal (native) business application, designated as the Universal Postal Counter (Univerzalno poštno okence). This application is utilized for the collection, processing, accounting, and delivery of shipments.



Figure 4: Entrance to delivery post office



Figure 5: Parcel lockers next to the Post office

4.3.7 Logistic resources: BTC logistics center (AVLL)

Within the ecosystem, BTC logistics center (BTC LC) operates as logistic company, offering storage, serving more than 1200 B2B customers daily, delivering food products, cold logistics, and fast moving consumer goods (FMCG), with more than 70 years of experience.

The storage areas of the BTC LC include:

- 101,500 m2 of enclosed storage areas [BTC, d. d., 'PORTRET DRUŽBE BTC, d. d.' Jun. 2019. Accessed: Jan. 16, 2024. [Online]. Available: <https://www.btc.si/wp-content/uploads/2019/04/BTC-portret-dru%C5%BEbe-1.pdf>],
- 5,500 m2 of storage areas with a temperature regime ['BTC Logistični center', BTC d.d. Accessed: Jan. 16, 2024. [Online]. Available: <https://www.btc.si/logisticni-center/>],
- 12,000 m2 of truck terminal space ['BTC Logistični center', BTC d.d. Accessed: Jan. 16, 2024. [Online]. Available: <https://www.btc.si/logisticni-center/>],
- 25,000 m2 for the large distribution center of SPAR Slovenia [D. Čuk, 'Optimiziranje transportnih poti v logističnem centru BTC'. May 2021. Accessed: Jan. 16, 2024. [Online]. Available: <https://bb.si/f/docs/diplomska-dela/Cuk-Dejvid.pdf>].
- BTC LC provides storage, sorting, picking, wrapping, palletizing, and customs clearance services. It is equipped with a truck terminal that can accept up to 300 freight vehicles [D. Čuk, 'Optimiziranje transportnih poti v logističnem centru BTC'. May 2021. Accessed: Jan. 16, 2024. [Online]. Available: <https://bb.si/f/docs/diplomska-dela/Cuk-Dejvid.pdf>].
- Storage is one of the most crucial services provided by the BTC Logistics Center. The forms of storage conducted by BTC LC include:
 - Storage handling: sorting, picking, wrapping, and palletizing.
 - Storage in covered and open spaces.
 - Storage of non-customs and customs goods.
 - Temperature-controlled storage including heated or cooled storage.
 - Communication center including facilitating computer connectivity with freight forwarding, cargo owners, and customs.
 - Utilization of EANCOM standard for data exchange.
 - Use of SSCC and EAN 128 standardization for data labelling [D. Čuk, 'Optimiziranje transportnih poti v logističnem centru BTC'. May 2021. Accessed: Jan. 16, 2024. [Online]. Available: <https://bb.si/f/docs/diplomska-dela/Cuk-Dejvid.pdf>].
- The center is equipped with the requisite technology for the standardization of internal transport and warehouse equipment, supported by the use of a barcode system.
- The information system is managed by external partner. The system is not dependent on a particular equipment manufacturer, such as wireless equipment, servers, and handheld terminals. The equipment is flexible and compatible when integrated into a variety of software environments. The implementation of the Mentek Goods Logistics information system is expected to result in comprehensive control over the flow and utilisation of materials and goods, leading to a notable reduction in logistics costs, optimization of inventory quantities, flexible and efficient workflow, and traceability of material and information flow [D. Čuk, 'Optimiziranje transportnih poti v logističnem centru BTC'. May 2021. Accessed: Jan. 16, 2024. [Online]. Available: <https://bb.si/f/docs/diplomska-dela/Cuk-Dejvid.pdf>].
- The partner company of BTC Company is responsible for the management of hardware. Their duties include the oversight of internet, network, security, and protection of the information technology infrastructure; the procurement of hardware; the development of dedicated applications; the maintenance of information systems; and the provision of consulting and design services for

information technology projects [D. Čuk, 'Optimiziranje transportnih poti v logističnem centru BTC'. May 2021. Accessed: Jan. 16, 2024. [Online]. Available: <https://bb.si/f/docs/diplomska-dela/Cuk-Dejvid.pdf>].

4.3.8 Vehicles

During the Slovenian pilot, at least three different types of vehicles will be used, such as unmanned robots, cargo bikes, electric vans and light electric delivery vehicles.

Unmanned autonomous delivery robots will be provided by the project partners (Robotnik) and carefully selected external supplier, while cargo bikes, electric vans and light electric delivery vehicles are already in the PS fleet.

Based on a visual analysis of the area, there are a few **constraints** on the infrastructure that can be physically modified, or the route of the vehicles can be changed accordingly so that pilots will proceed according to plan.

4.3.9 Digital infrastructure

BTC City area has full fiber coverage, full 4G/4G+ and 5G coverage, 243 CCTV cameras and 50 public WI-FI hotspots [13].

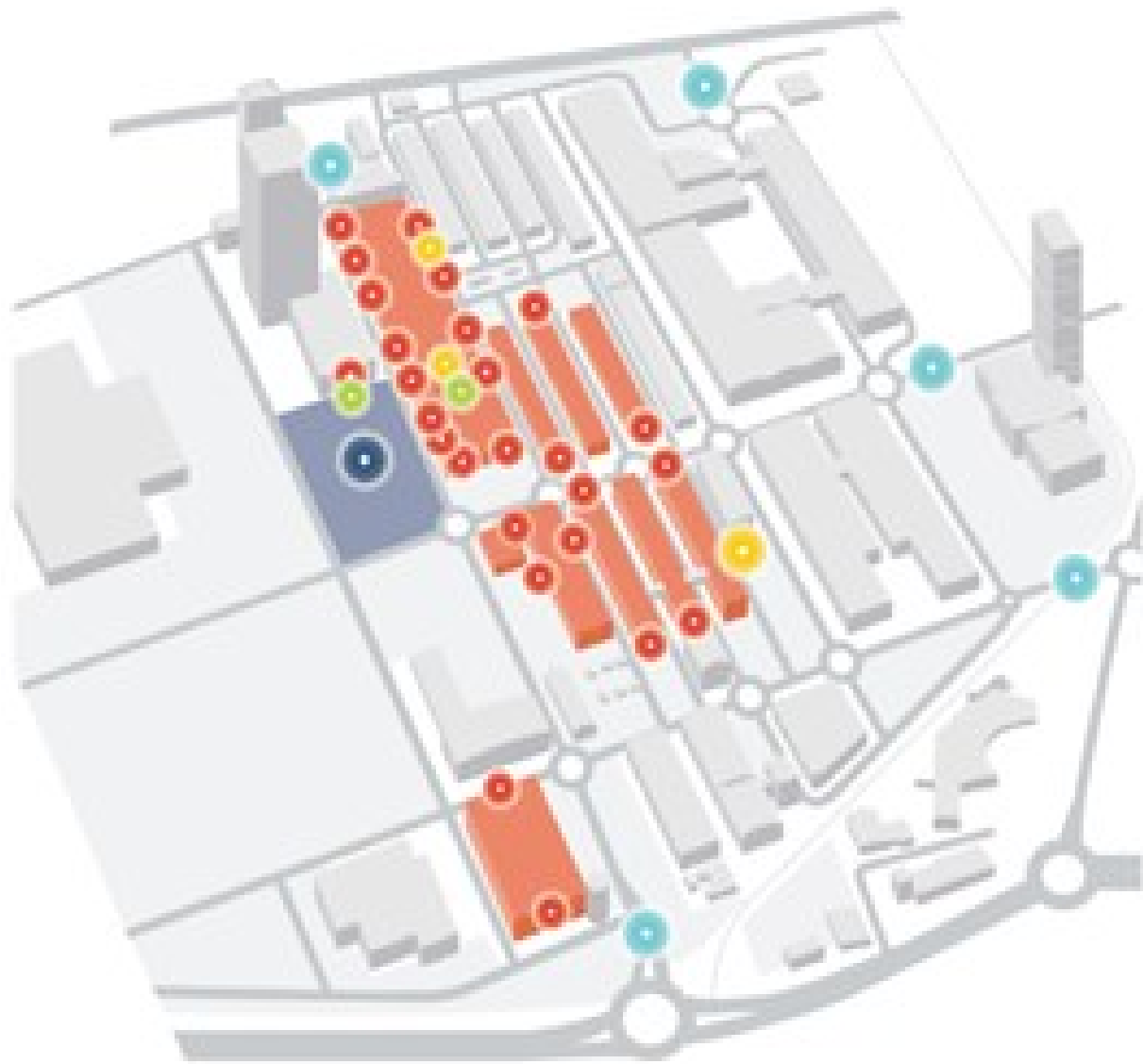
BTC City area is also covered with sensory equipment:

- sensors for tracking customer flow on selected areas,
- sensors for detecting parking space occupancy on selected parking spaces,
- air quality sensor,
- inductive loops for detecting vehicle traffic for all car entrances/exits,
- light sensors ['BTC City Poslovno', BTC-CITY. Accessed: Jan. 19, 2024. [Online]. Available: <https://www.btc-city.com/poslovno>].

While maps are available publicly, either for free or for charge (such as OpenStreetMap, Google Maps, Apple Maps, Tomtom, Garmin, etc.), precise mapping needs to be performed by each specific autonomous vehicle.

We have not identified any **constraints** in terms of digital infrastructure.

Sensors and Cameras



- Optical sensors for tracking customer flow
- Built-in sensors for detecting parking space occupancy
- Air quality sensors
- Inductive loops for detecting vehicle traffic
- Light sensors

Figure 6: BTC City sensors [‘BTC City Poslovno’, BTC-CITY. (2024 <https://www.btc-city.com/poslovno>)]

4.3.10 Stakeholders Involved

Within Part A, Scenarios 1, 2 and 3, several stakeholders will be involved:

Primary stakeholders

Post of Slovenia: The national postal operator and one of the logistics operators in the pilot, responsible for last/first mile delivery and consolidation activities.

- AV Living Lab
- BTC Logistics center
- University of Maribor
- Providers of autonomous delivery robot
- Secondary stakeholders
- Local businesses/end-users
- Citizens
- Local and national government

4.3.11 High Level Operational Scenario

Three possible scenarios for the Slovenian pilot will be presented. The first scenario involves MM transport and LM delivery, the second scenario involves only FM pick-up of shipments and MM transport, and the third scenario represents simultaneous pick-up and delivery of shipments (FM and LM) and the MM transport. The third scenario is the most challenging to execute and encompasses the first and second scenarios.

All three scenarios involve **two possible urban consolidation centres** (PS Post Office and BTC Logistics Centre), **customers** (delivery to consumers (B2C)) and **retailers** (delivery to businesses (B2B)).

Scenario 1 (Last mile delivery)

The LM scenario represents the delivery of shipments from the mid mile to the inside of BTC City area (pilot area).

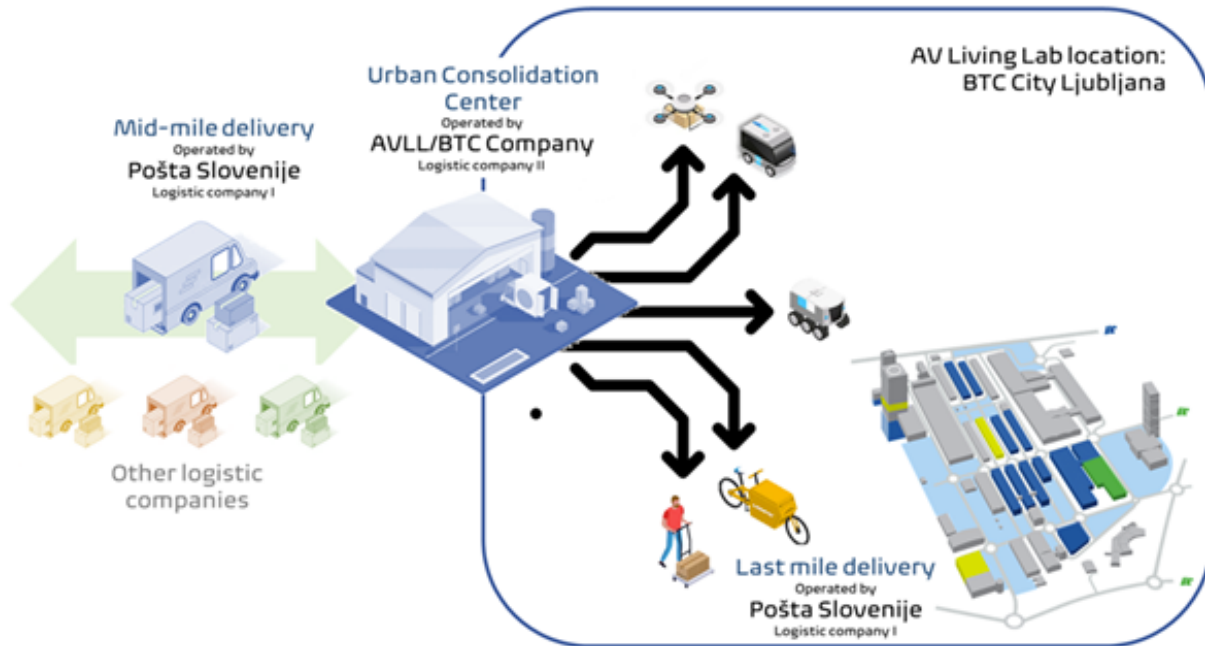


Figure 7: Last mile delivery scheme

TRACE
Delivery within Slovenian pilot



Figure 8: Last mile delivery scheme

In the first step, the MMLA creates a list of deliveries to the BTC City area. This list is stored in the MMLA database. From this database, the Trace platform will prepare an optimized LM plan for deliveries to the BTC City area and forward it to the MMLA. In this step, the Trace platform will check whether the MMLA meets the conditions (zero-emission vehicle, load factor, etc.) to directly execute LM delivery to the end customers or if it will hand over its delivery at the urban consolidation centre.

If the MM logistic agent hands over its delivery to consolidation, we follow the yellow numbers 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18. (In step 9, Figure 1) the TRACE platform will also take into account the fulfilment orders from the retailers within BTC City. When the retailer runs out of stock for a particular product, they will place an order for LM delivery of goods from the fulfilment centre (UCC), which can be delivered together with shipments that were handed over in the UCC from MM.

If the MM logistic agent can directly execute the LM delivery (without the consolidation process), in we follow the numbers 1, 2, 3, 4 (cyan), 5 (cyan), 6 (cyan), 15, 16, 17, 18. Figure 1

Within scenario 1, the Trace platform will provide an optimized plan for LM delivery. It will facilitate the transfer of shipments between MMLA (Mid-mile logistics agent) and Consolidation agent; between Consolidation agent and LMDA (Last-mile delivery agent); and between LMDA and Customer/Retailer (end customers). Simultaneously, in the Trace platform, all statuses (e.g., Shipment is in delivery), events (e.g., Shipment was handed over), necessary KPIs and parameters will be monitored in real-time. This information will be used to execute profit-sharing and generate a delivery performance report after the LM delivery is completed.

Scenario 1	Last mile delivery	
Initial Plan	Urban consolidation centre (UCC) established in BTC City Ljubljana. A MMLA delivering to UCC or directly to end customers/retailers, a consolidation agent handling UCC and a logistic company performing LM delivery. Minimum of three different vehicles for transport (unmanned vehicles, cargo bikes, transport carts, electric vans, light electric delivery vehicle).	
Target	Reduced number of vehicles and emissions in the BTC City Ljubljana, new business model for optimized LM delivery.	
Step 1	MMLA enters data for an upcoming delivery to the pilot area, including approximate delivery time, shipment data, end-customer data, smart contract data, and any special conditions (e.g., fragile, special handling, cold storage, etc.). The status "shipment in transit" is recorded.	
Step 2	TRACE runs the appropriate algorithms and provides MMLA with optimised LM delivery plan (direct delivery including LM or handover of delivery in the UCC).	
Step 3	In case of delivery to the UCC TRACE provides MMLA with data on shipment exchange (gate location, approximate time etc).	In case of direct delivery to the end customer/retailer including LM delivery, TRACE provides MMLA with optimised delivery plan (route, time,

		the sequence, and locations of end customers for delivery). MMLA carries out also LM delivery, therefore it performs two functions: a MMLA and then the LMDA.
Step 4	TRACE adds shipments data from MMLA and shipments data from retailers' fulfilment orders to the pool of shipments for LM delivery. Then it calculates optimal route, time and defines the best available vehicle for LM delivery according to current constraints (i.e. available resources, planned deliveries, occupancy rates, real-time events, weather conditions, traffic conditions) and delivery demands (delivery on/by time, accompanying services - i.e. authorization/payment needed, etc.)	TRACE follows the delivery of a shipment in a real-time manner and provides data of delivery to the end-users (i.e. clock with approximate time of delivery, adjusting to the real time conditions).
Step 4	TRACE creates the appropriate records in the blockchain infrastructure and delivers the smart contract between UCC and MMLA.	Event "Shipment was delivered" is sent to the Trace platform.
Step 5	TRACE adds the shipment data to the schedule of selected Last mile delivery agent (LMDA), creates the appropriate records in the blockchain infrastructure, creates smart contract between UCC and LMDA, and notifies LMDA on upcoming delivery.	Delivery performance report is made.
Step 6	After shipment take-over TRACE notifies LMDA about the details of shipment exchange, smart contract number, cost of LM delivery service and information on further logistic steps (mode and time of delivery to end-customer).	Determination of cost and revenue for the MMLA based on the smart contract. TRACE creates the appropriate records in the blockchain infrastructure.
Step 7	TRACE adds the shipment data to the schedule of selected LMDA, creates the appropriate records in the blockchain infrastructure, including smart contract	

	between UCC and LMDA, and notifies LMDA.	
Step 8	TRACE notifies MMLA and end-user about shipment delivery (shipment data, end-user data, smart contract data, cost data, special conditions (if any)) - traceability purpose.	
Step 9	TRACE follows the delivery of a shipment in a real-time manner and provides data of delivery to the end-users (i.e. clock with approximate time of delivery, adjusting to the real time conditions).	
Step 10	Event "Shipment was delivered" is sent to the Trace platform.	
Step 11	After successfully completed delivery TRACE notifies MMLA about completed process.	
Step 12	Delivery performance report is made.	
Step 13	Sharing the profit of the delivery between MMLA, consolidation agent and LMDA, based on the smart contract. TRACE creates the appropriate records in the blockchain infrastructure.	

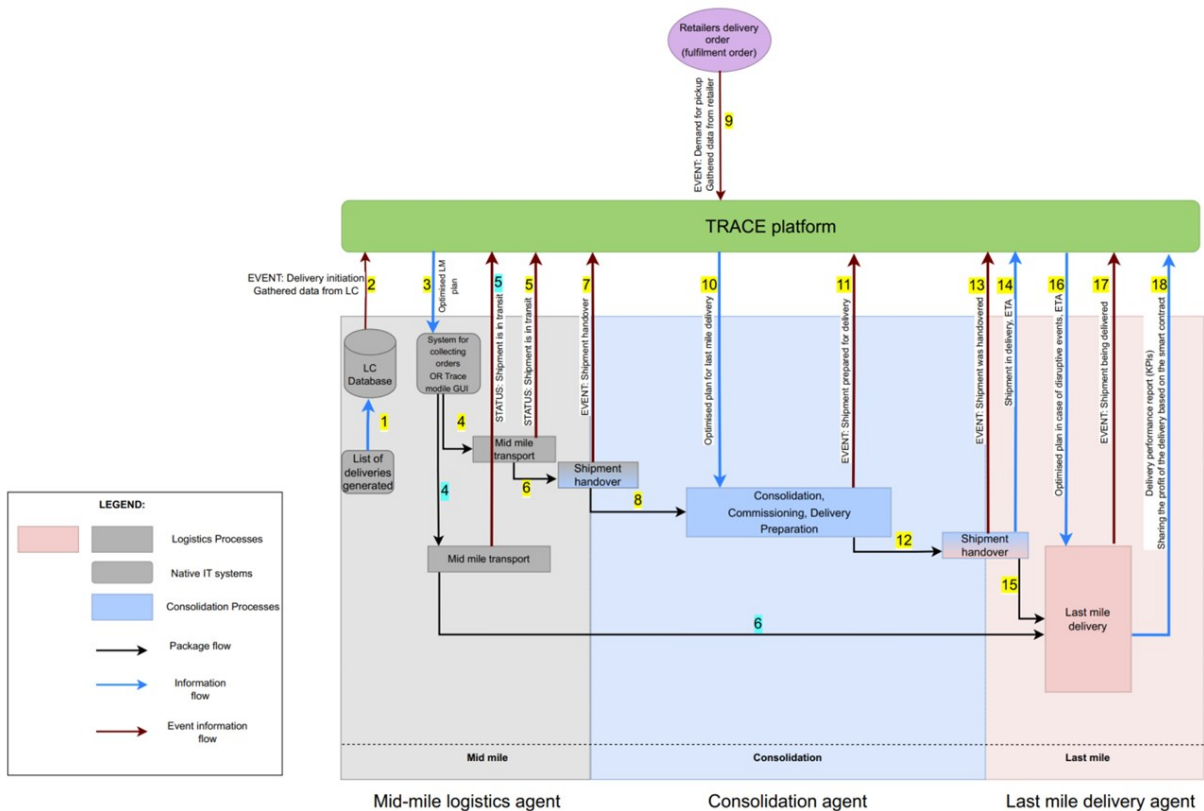


Figure 9: Last-mile delivery diagram

Scenario 2 (First mile pick-up)

FM is the reverse process of the LM logistics process. Vehicles will collect shipments and mail inside the pilot area and deliver them to the Urban Consolidation Centre (BTC LC or PS office)– Figure 5. From these UCCs, various MMLAs will manage mid mile transport.

Under certain conditions, it will be possible to bypass the consolidation process (e.g., full truck load and zero-emission vehicle). In such cases, a logistics company can execute FM and transition directly to MM transport without intermediate consolidation, as the vehicle will already be sufficiently utilized.

If we follow the processes in the diagram, first, all the demands for FM pick-up of shipments within the area come into the Trace platform. This demand can come:

- Directly from logistics companies.
- A customer may place an order through an online store of a retailer located within BTC City. A retailer then forwards the customer’s order to the Trace platform.

Based on all the collected orders for FM pick-up of shipments within BTC City, the Trace platform sends an optimized FM plan for the pick-up of shipments to the FMLPA. This plan determines the appropriate vehicle, pick-up time, pick-up route, etc.



Figure 10: First mile delivery scheme

If FM is carried out with a suitable vehicle (e.g., a zero-emission van) with a sufficient load factor, the same logistics company can perform both FM and MM simultaneously, directly and without consolidation. In this case, in Figure 9 we follow the arrows 1a, 1b, 1a, 1b, 2, 3, 4, 5, 6. In this case the same transport company will be in form of FMPA and MMDA.

On the other hand, after the FM collection of shipments, follows the consolidation and handover of shipments to MMLA. In this case, in the diagram, we follow the arrows 1a, 1b, 1a, 1b, 2, 3, 4a, 4b, 4c, 4d, 4e, 4f, 4g, 4h, 4i, 4j, 5, 6.

Within scenario 2, the Trace platform will provide the FM delivery optimization plan. It will facilitate the transfer of shipments between Customer/Retailer and FMPA (first mile pick-up agent); between FMPA (first mile pick-up agent) and Consolidation agent; between Consolidation agent and MMLA (mid mile logistics agent). Simultaneously, in the Trace platform, all statuses (e.g., Shipment in delivery), events (e.g., Shipment delivered), and all necessary KPIs and parameters will be monitored in real-time. This information serves as the basis for profit sharing and the Delivery Performance Report.

Scenario 2	First mile pick-up
Initial Plan	Urban consolidation centre (UCC) established in BTC City Ljubljana. A FMPA delivering to UCC, a logistic company handling UCC and a MMLA handling MM transport (Scenario 2). Minimum of three different vehicles for transport (unmanned vehicles, cargo bikes, transport carts, electric vans, light electric delivery vehicle).
Target	Reduced vehicles and emissions in the BTC City Ljubljana area, new business model of UCC for optimized FM pick-up of shipments.

Step 1	Logistics companies and retailers enter data for an upcoming pick-up of shipments, including shipment data, end-customer data, and any special conditions (e.g., fragile, special handling, cold-storage, etc.).	
Step 2	TRACE runs the appropriate algorithms and provides FMPA with an optimized FM pick-up plan, which includes the pick-up of shipments and delivery to the UCC or the pick-up of shipments and direct transport in MM.	
Step 3	TRACE calculates the optimal route and defines the best available mode for pick-up according to current constraints (i.e., available resources, planned deliveries, occupancy rates, real-time events, weather, and traffic conditions) and pick-up demands (pick-up time, authorization/payment requirements, etc.).	In the case of FM pick-up and direct transit in MM, TRACE provides FMPA with an optimized pick-up plan (route, time, sequence of customers for pick-up). In this case, FMPA and MMLA are the same company, performing both the FM and MM transport.
Step 4	In the case of delivery to the UCC, TRACE provides FMPA with data on shipment exchange, including information about the gate and other relevant details.	TRACE notifies the end-user about shipments pick-up (shipment data, end-user data, smart contract data, cost data, and any special conditions) for traceability purposes.
Step 5	TRACE adds the shipment data to the schedule of the selected FMPA and notifies FMPA of the upcoming pick-up.	TRACE monitors the pick-up of shipments in real-time.
Step 6	TRACE creates the appropriate records in the blockchain infrastructure and delivers the smart contract between UCC and FMPA.	The event "shipment is picked up" is sent to the Trace platform.
	TRACE notifies the end-user about shipments pick-up (shipment data, end-user data, smart contract data, cost data, special conditions, if any) for traceability purposes.	MMLA notifies that the shipment is in mid mile (MM) transport.
Step 7	TRACE monitors the pick-up of shipments in real-time and provides data to the UCC, including a clock with the approximate time of shipment handover, adjusting it to real-time conditions.	Determination of cost and revenue of the FM and MM transport for the MMLA based on the smart contract. TRACE creates the appropriate records in the blockchain infrastructure.

<p>Step 8</p>	<p>The event "shipment is picked up" is sent to the Trace platform.</p>	
<p>Step 9</p>	<p>After executing the FM plan, shipments are handed over to UCC. The transfer of shipments to UCC is recorded, and a pick-up performance report is generated.</p> <p>During consolidation, the shipment status is updated to "In the consolidation process."</p>	
<p>Step 10</p>	<p>When the shipment is handed over to the MMLA, this information is communicated to the Trace platform, which then generates a consolidation report and initiates the sharing of costs and profits between FMPA, consolidation agent and MMLA based on the smart contract.</p>	

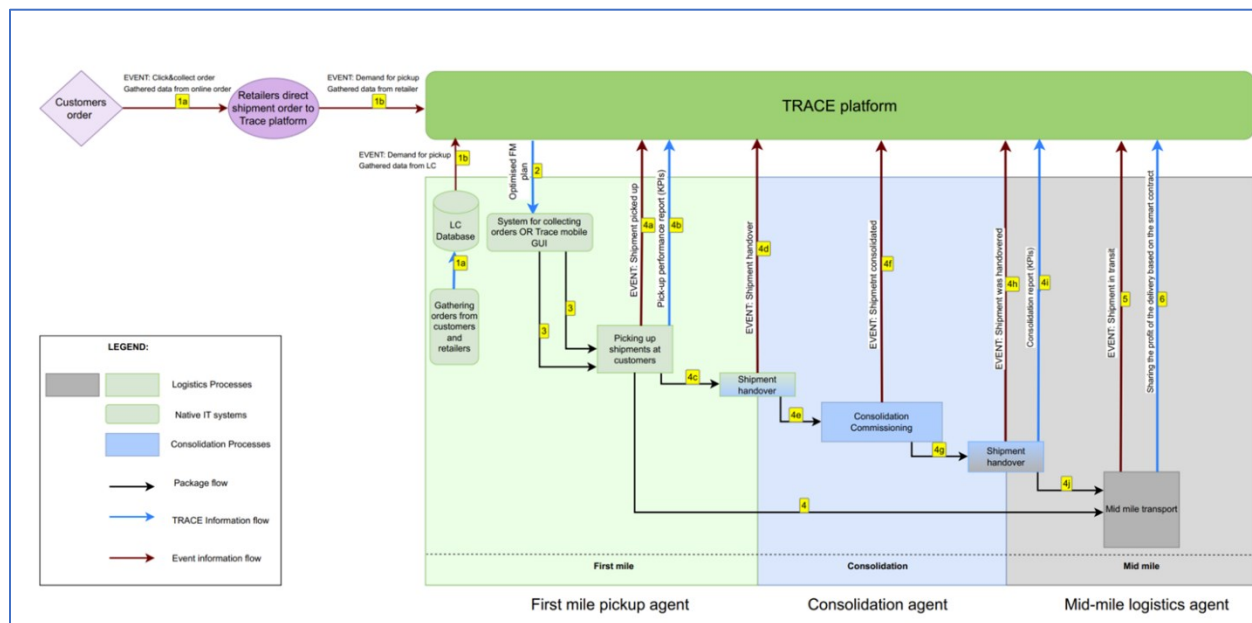


Figure 11: First mile pickup diagram

Scenario 3 (Pick-up & Delivery)

Scenario 3 represents a case where LM (Last Mile) and FM (First Mile) are executed simultaneously. In this scenario, the shipments in BTC City are both delivered (LM) and picked up (FM) at the same time. In this

case, the Last Mile Delivery Agent (LMDA) and the First Mile Pick-up Agent (FMPPA) are the same logistics company.

The entire process starts similarly to LM delivery. According to the diagram, the process is as follows. In steps 1 and 2, data about all the necessary LM deliveries are entered into the Trace platform. Simultaneously, all requirements for FM pick-up of shipments are provided to the Trace platform (via logistics companies – shown in grey, and through direct entries by retailers – shown in purple). Based on LM and FM demand, in step 3, Trace generates an optimized PADP (Pick-up and Delivery Plan). The PADP determines whether the MMLA can directly execute Pick-up and Delivery based on given conditions or if the delivery must be handed over to the UCC, where both LM and FM will be executed by the Pick-up and Delivery agent.

In the first case (MMLA bypasses the consolidation process and directly executes Pick-up and Delivery) on the diagram, we follow numbers 1, 2, 3, 4 (cyan), 5 (cyan), 6 (cyan), 7 (cyan), 28, 29.

In the second case (MMLA hands over the shipments in the UCC, Pick-up and Delivery agent executes LM and FM), we follow only the yellow numbers on the diagram.

Scenario 3	Pick-up & Delivery	
Initial Plan	Urban consolidation centre (UCC) established in BTC City Ljubljana. A logistic company (MMLA) delivering to UCC, a logistic company handling UCC and a logistic company performing Pick-up and Delivery (LM and FM) with a minimum of three means of transport (unmanned vehicles, cargo bikes, transport carts, electric vans, light electric delivery vehicle).	
Target	Reduced vehicles and emissions in the BTC City Ljubljana area, new business model for UCC for optimized urban delivery.	
Step 1	MMLA enters data for an upcoming delivery to the pilot area, including approximate delivery time, shipment data, end-customer data, smart contract data, and any special conditions (e.g., fragile, special handling, cold-storage, etc.). The status "shipment is in transit" is recorded. Logistics companies and retailers enter data for an upcoming pick-up of shipments, providing shipment data, end-customer data, smart contract data, and any special conditions (e.g., fragile, special handling, cold-storage, etc.).	
Step 2	TRACE runs the appropriate algorithms and provides MMLA with a PADP plan (direct Pick-up and Delivery or delivery to the UCC).	
Step 3	In the case of delivery to the UCC, TRACE provides MMLA with data on shipment exchange (gate, etc.).	In case MMLA directly performs Pick-up and Delivery, TRACE provides MMLA with an optimized PADP (route, time, sequence of customers for pick-up and delivery).

	<p>Event sent to the Trace platform: Shipment was handed over to the UCC.</p>	<p>TRACE notifies MMLA and the end-user about shipment delivery (shipment data, end-user data, smart contract data, cost data, special conditions, if any) for traceability purposes.</p> <p>TRACE notifies the end-user about shipments pick-up (shipment data, end-user data, smart contract data, cost data, special conditions, if any) for traceability purposes.</p>
<p>Step 4</p>	<p>TRACE adds shipment data from MMLA, shipment data from retailers' fulfilment orders, and shipment data for FM pick-up to the pool of shipments. It calculates the optimal route and defines the best available mode for pick-up and delivery according to current constraints (i.e., available resources, planned deliveries, occupancy rates, real-time events, weather, and traffic conditions) and delivery demands (delivery on/by time, accompanying services - i.e., authorization/payment needed, etc.).</p>	<p>TRACE follows the delivery and pick-up of a shipment in real-time and provides data on delivery and pick-up to the end-users (i.e., clock with approximate time, adjusting to real-time conditions).</p>
<p>Step 5</p>	<p>TRACE creates the appropriate records in the blockchain infrastructure and delivers the smart contract between UCC, MMLA, and pick-up and delivery agent.</p>	<p>Event sent to the Trace platform: Shipment picked up (FM) or shipment delivered (LM).</p>
<p>Step 6</p>	<p>TRACE adds the shipment data to the schedule of the selected pick-up and delivery agent, creates the appropriate records in the blockchain infrastructure, and notifies the pick-up and delivery agent of the upcoming delivery and pick-up.</p>	<p>MMLA notifies that the shipment is in mid mile (MM) transport.</p>
<p>Step 7</p>	<p>After the UCC handovers the shipments to the pick-up and delivery agent, TRACE notifies the pick-up and delivery agent about the PADP and details of shipments,</p>	<p>A Pick-up & Delivery performance report is made.</p>

	smart contract number, cost of service, and information on further logistic steps (mode and time of delivery and pick-up at the end-customer).	
Step 9	<p>TRACE notifies the end-user about shipment delivery (shipment data, end-user data, smart contract data, cost data, special conditions, if any) for traceability purposes.</p> <p>TRACE notifies the end-user about shipments pick-up (shipment data, end-user data, smart contract data, cost data, special conditions, if any) for traceability purposes.</p>	Determination of cost and revenue of the pick-up and delivery and MM transport for the MMLA (he executed MM and pick-up and delivery) based on the smart contract and Pick-up & Delivery performance report. TRACE creates the appropriate records in the blockchain infrastructure.
Step 10	TRACE follows the delivery and pick-up of a shipment in real-time.	
Step 11	Event sent to the Trace platform: Shipment picked up or shipment delivered.	
Step 12	After the FM plan is executed (all shipments are picked up), the shipments are handed over to the UCC. Information about the handover of shipments to the UCC is recorded. During the consolidation process, the status of the shipment is communicated (in the consolidation process).	
Step 13	When the shipment is handed over to the MMLA, this information is communicated to the Trace platform, which then provides a consolidation report.	
Step 14	MMLA reports the status of the shipments: "Shipment is in MM transport."	
Step 15	A Pick-up & Delivery performance report is made.	

<p>Step 16</p>	<p>Sharing the cost and profit of the pick – up and delivery between pick-up and delivery agent, consolidation agent and MMLA based on the smart contract and Pick-up & Delivery performance report.</p>	
<p>Step 17</p>	<p>TRACE creates the appropriate records in the blockchain infrastructure.</p>	

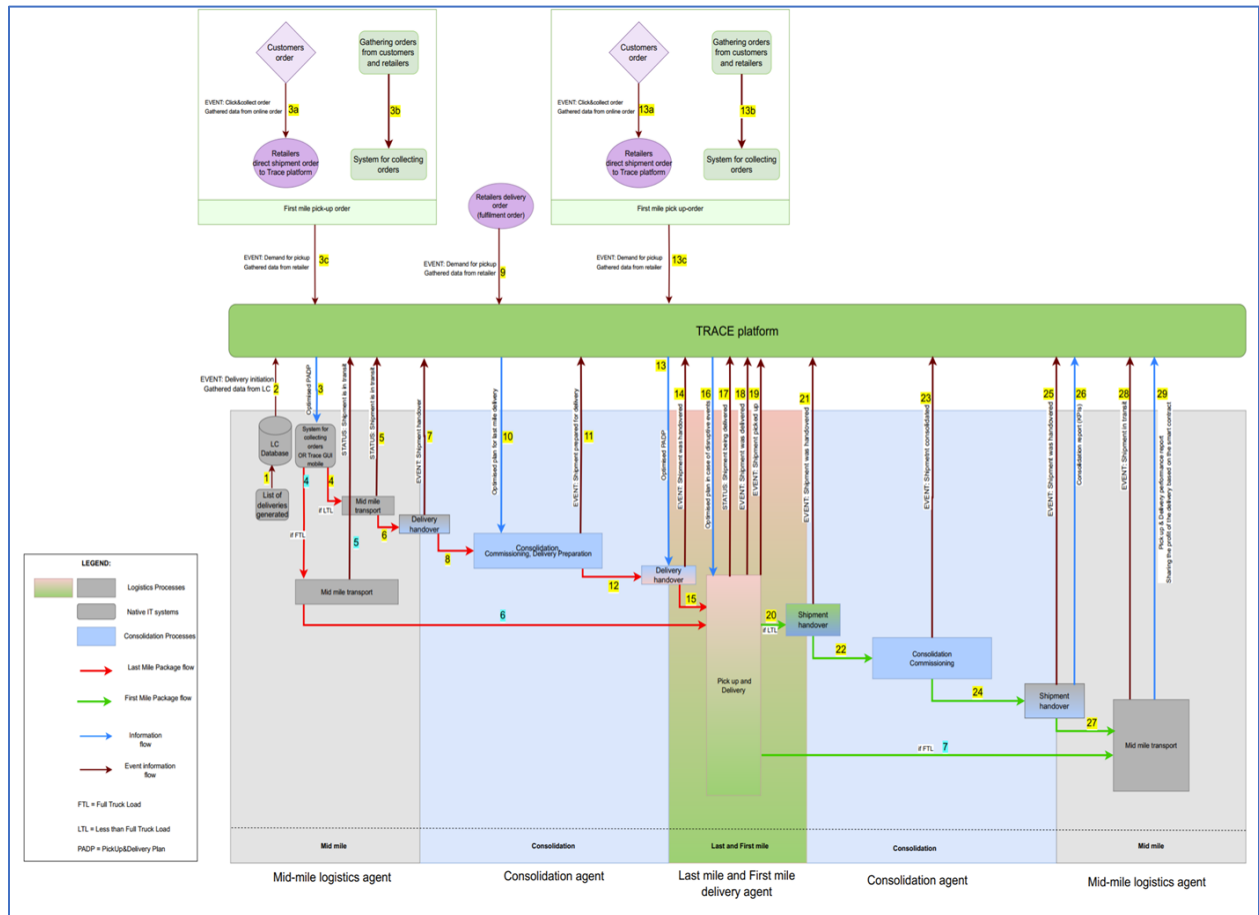


Figure 12: Pick-up and delivery diagram

4.3.12 Priorities of the Demonstrator

The Slovenian pilot project will focus on several key objectives. The initial objective is to **integrate and harmonize the logistics networks of two independent logistic providers**, BTC and Post of Slovenia. This integration will result in the streamlining of operations and an improvement in overall efficiency. Furthermore, the project will include the testing and analysis of various delivery modes and vehicles.

A further objective of the project is to investigate the **potential of autonomous delivery solutions**, specifically the use of delivery robots. This will facilitate an understanding of the viability and efficacy of robotic delivery in a dynamic urban context.

A significant objective is to **optimize the logistics services associated with the first and last mile** using the TRACE platform, with a particular focus on enhancing the performance of consolidation centers. This encompasses enhancements to route planning, delivery schedules and resource utilization to improve load factors and make logistics more cost-efficient.

Furthermore, the project will examine **potential business models** that could be implemented to facilitate these advanced logistics operations. This analysis will assist in identifying sustainable and scalable business strategies that could be replicated in other urban areas. The key objective of the project is also to reduce traffic volume and emissions within the BTC City ecosystem.

By optimizing logistics and utilizing innovative delivery methods, the project aims to develop a model that can be scaled up and replicated to achieve similar effects in other environments.

4.3.13 Key Performance Indicators (KPIs) and Acceptance Criteria

The Slovenian pilot project will adhere to the key performance indicators (KPIs) set in the proposal to guarantee the successful evaluation and demonstration of the TRACE platform's capabilities. The stated KPIs are designed to measure the efficiency, environmental impact, and operational success of the integrated logistics system.

The primary KPIs include an average reduction in energy consumption per vehicle of 30%. This metric is of great importance for the evaluation of the project's efficacy in reducing energy consumption through the optimization of delivery routes and vehicle utilization.

Furthermore, the project aims to achieve a 30% reduction in the average fuel consumption per vehicle, which serves to illustrate the commitment to sustainability and cost-efficiency. This KPI will facilitate the demonstration of the project's capacity to reduce fuel consumption, contributing to overall operational cost savings and environmental benefits.

Another crucial performance indicator is the average reduction in emissions, which has been set at 30% per vehicle. This objective serves to illustrate the project's intention to reduce the carbon footprint of logistics operations within BTC City.

A further significant KPI is that of operational cost reduction, with a target of 40%. This objective reflects the project's emphasis on enhancing cost-efficiency through the implementation of more efficient processes, optimized resource utilization and innovative delivery methods.

It is anticipated that there will be an improvement of 40% in the throughput of blockchain blocks. This KPI assesses the efficacy and scalability of our blockchain technology in facilitating logistics transactions, thereby guaranteeing secure and transparent operations.

The objective is to achieve 100% success in interoperable operations. This KPI will serve to validate the project's ability to integrate and harmonize the various logistics service providers, demonstrating seamless coordination and cooperation.

Lastly, the project aims to utilize at least three different means of transport. This KPI ensures that a diverse range of vehicles, including delivery robots, e-cargo bikes, and electric vans, are tested and evaluated for their effectiveness in urban logistics operations.

Table 1: Performance Metrics and Operational Efficiency in Multi-Modal Transport Using Blockchain

<i>Average energy reduction</i>	-30% (per vehicle)
<i>Average fuel consumption reduction</i>	-30% (per vehicle)
<i>Average emission reduction</i>	-30% (per vehicle)
<i>Operational costs reduction</i>	-40 %
<i>Blockchain Block throughput</i>	40 %
<i>Success of interoperable operations</i>	100 %
<i>Means of transport combined</i>	3

5 FUNCTIONAL REQUIREMENTS

5.1 Cloud Infrastructure Requirements

Id	CLD-FUN-001	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Continuous Monitoring of Resource Usage and Health								
Description	TRACE Cloud Infrastructure shall enable continuous monitoring of resource usage and health, with automated alerts for anomalies or issues								
Rationale	Continuous monitoring is essential for maintaining the operational integrity and performance of the cloud infrastructure. It allows for proactive management of resources and quick response to potential issues, thereby reducing downtime and improving service reliability								
Dependencies	None								
Conflict	None								
Additional Info (comments)	The monitoring system should be capable of integrating with existing infrastructure elements and support scalable deployment as the infrastructure grows								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

Id	CLD-FUN-002	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Dynamic Resource Allocation								
Description	The TRACE Cloud dynamically allocates and deallocates resources based on workload requirements, ensuring optimal performance and efficiency.								
Rationale	Dynamic resource allocation is essential for optimizing resource utilization and cost-efficiency, enabling the system to adjust resources based on actual demand rather than static predictions								
Dependencies	CLD-FUN-001, CLD-FUN-004								
Conflict	None								
Additional Info (comments)	Implementation should consider peak load scenarios to ensure that resource scaling does not impact performance negatively								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

Id	CLD-FUN-003	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Implementation of Security Measures								
Description	TRACE Cloud Infrastructure shall implement security measures to protect the integrity and confidentiality of data								
Rationale	Security measures such as firewalls, encryption, and access control are crucial to ensure compliance with regulatory requirements and maintaining trust with stakeholders								
Dependencies	CLD-FUN-002, CLD-FUN-004								
Conflict	None								

Additional Info (comments)	The implementation should adhere to the latest industry standards and best practices in cybersecurity. Regular audits and updates to these security measures should be scheduled to adapt to evolving threats
Related Scenario(s)	Greek, Italian and Slovenian pilot

Id	CLD-FUN-004	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Automated Provisioning of Compute, Storage, and Network Resources								
Description	TRACE Cloud Infrastructure shall offer automated provisioning of compute, storage, and network resources								
Rationale	Automated provisioning enables rapid scaling and deployment of resources, which is essential for maintaining performance and meeting varying demand without manual intervention. This capability supports operational efficiency and agility within the cloud infrastructure								
Dependencies	CLD-FUN-002, CLD-FUN-005								
Conflict	None								
Additional Info (comments)	This requirement should consider the integration of intelligent algorithms to predict and manage resource needs proactively. It is also crucial to ensure that the automation processes are secure and comply with all relevant data protection regulations.								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

Id	CLD-FUN-005	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Scalability of Resource Allocation								
Description	TRACE Cloud Infrastructure shall support the ability to scale resources up or down based on demand								
Rationale	Scalability is essential for managing fluctuations in demand and ensuring that the infrastructure can accommodate growth without compromising performance or incurring unnecessary costs								
Dependencies	CLD-FUN-004, CLD-FUN-002, CLD-FUN-001								
Conflict	None								
Additional Info (comments)	The scalability feature should include predictive mechanisms to forecast future demands based on historical data and trends to proactively scale resources								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

Id	CLD-FUN-006	Type	FUNC	Priority	MEDIUM	Source	Consortium Know-how	Ver	1
Title	Workload Distribution Across Multiple Compute Nodes								
Description	TRACE Cloud Infrastructure should be able to distribute workloads across multiple compute nodes to ensure high availability and reliability								
Rationale	Efficient distribution of workloads across various resources is crucial for maintaining system performance and availability, especially under high demand situations. This strategy helps in balancing the load and minimizing the risk of system overloads or failures								
Dependencies	CLD-FUN-002, CLD-FUN-004								

Conflict	None
Additional Info (comments)	The implementation should consider the use of modern load balancing techniques and possibly incorporate predictive analytics to forecast workload spikes
Related Scenario(s)	Greek, Italian and Slovenian pilot

5.2 Communications and Physical Infrastructure Requirements

Id	COM-FUN-001	Type	FUNC	Priority	MEDIUM	Source	Consortium Know-how	Ver	1
Title	4G/5G Communication Support for Drones in Logistic Network Integration								
Description	Drones should support 4G/5G communication for integration with logistic network								
Rationale	4G/5G communication is essential for real-time data transfer and effective integration of drones into the logistic network.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian pilot								

Id	COM-FUN-002	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Management of Flight Paths and Operational Volumes for Simultaneous Drone Operations								
Description	Flight paths and operational volumes shall consider the possibility of more drones operating simultaneously, for instance on opposite directions								
Rationale	Designing for simultaneous drone operations ensures safe and efficient flight path management, accommodating multiple drones and avoiding potential collisions.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian pilot								

Id	COM-FUN-003	Type	FUNC	Priority	MEDIUM	Source	Consortium Know-how	Ver	1
Title	4G/5G Communication Support for LifeBox Integration with Logistic Network								
Description	LifeBox should support 4G/5G communication for integration with logistic network, regardless of vehicle used								
Rationale	4G/5G communication is essential for ensuring consistent and reliable data integration between LifeBox and the logistic network, irrespective of the vehicle used.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								

Related Scenario(s)	Italian pilot
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Id	COM-FUN-004	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Limited capacity for delivering parcels with UGVs								
Description	The capacity of unmanned vehicles in terms of the number of parcels shall be part of the processing in the TRACE platform								
Rationale	UGV's capacity for deliveries is limited by the available number of parcel lockers on the UGV. The availability of parcel lockers should be considered in delivery planning processes.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Greek and Italian pilot								

Id	COM-FUN-005	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Single bike drivers								
Description	The TRACE system shall allow a single operator to use a platoon of autonomous bikes for efficient parcel transportation								
Rationale	Enables more efficient transportation								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian cargo bike demonstrator								

Id	COM-FUN-006	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Intra-bike communications								
Description	The TRACE system shall allow platoons of cargo bikes to exchange information regarding delivery locations at specific crossroads								
Rationale	Enables more efficient movement of parcels to reduce CO2								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian cargo bike demonstrator								

Id	COM-FUN-007	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Bike platoon reorganization								

Description	The TRACE system shall enable cargo bike operators to reorganize platoons and direct empty cargo bikes to autonomously return to the hub for further deliveries
Rationale	Enables more efficient movement of parcels to reduce CO2
Dependencies	None
Conflict	None
Additional Info (comments)	None
Related Scenario(s)	Italian cargo bike demonstrator

Id	COM-FUN-008	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Bike loading								
Description	The TRACE system shall enable cargo bikes to depart from hub with multiple parcels destined for different areas of the city								
Rationale	Enables more efficient movement of parcels to reduce CO2								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian cargo bike demonstrator								

Id	COM-FUN-009	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Bike-to-drone exchange of parcels								
Description	The TRACE system shall enable drones to handle the final leg of shipments in the absence of bike lanes or in difficult road conditions								
Rationale	Enables delivery of parcels out of bike lanes								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian demonstrators								

Id	COM-FUN-010	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Inter-bike movement of parcels								
Description	The TRACE system shall facilitate the transfer of goods between the most suitable cargo bike platoons								
Rationale	Enables more efficient movement of parcels to reduce CO2								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian cargo bike demonstrator								

Id	COM-FUN-011	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Bikes and drones loading								
Description	The TRACE system shall support the loading of parcels onto autonomous cargo bikes and drones for efficient delivery from the Modena hub.								
Rationale	Enables more efficient movement of parcels to reduce CO2								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian pilot								

Id	COM-FUN-012	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Usage of bike platoons								
Description	The TRACE system shall support the use of multiple cargo bikes organized into platoons for the transportation of shipments								
Rationale	Enables more efficient movement of parcels to reduce CO2								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian cargo bike demonstrator								

Id	COM-FUN-013	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Bike sends live data to MASA								
Description	The TRACE system shall update and communicate delivery progress, GPS position updates, and parcel delivery status through 4G/5G antennas into the TRACE infrastructure								
Rationale	Enables connectivity, and interaction with the Trace platform								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian pilot								

Id	COM-FUN-014	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	V2V communication								
Description	The TRACE system shall use vehicle-to-vehicle communications, This requirement may be merged with COM-FUN-006								

Rationale	It will enables cargobike to be grouped in platoon while ensuring connectivity, and safety
Dependencies	None
Conflict	None
Additional Info (comments)	None
Related Scenario(s)	Italian cargo bike pilot

Id	COM-FUN-015	Type	FUNC	Priority	HIGH	Source	Standards	Ver	1
Title	Vehicles should have minimum 4G network access								
Description	Each vehicle is required to have 4G/5G network access. The TRACE system shall update and communicate delivery progress, GPS position updates, and parcel delivery status through 4G/5G antennas into the TRACE infrastructure								
Rationale	It will enable vehicle to vehicle communications and communications between vehicles and the TRACE platform.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

Id	COM-FUN-016	Type	FUNC	Priority	LOW	Source	Know-how	Ver	1
Title	Platform should support variable communications								
Description	TRACE platform should support various communication channels, including text-based, voice-based, and video-based communication, to accommodate different preferences and situations								
Rationale	Enables connectivity, and safety								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian pilot								

5.3 Safety and Reliability Requirements

Id	SRY-FUN-001	Type	SEC	Priority	HIGH	Source	Control Systems	Ver	1
Title	TRACE shall provide collision detection and avoidance.								
Description	A safety system shall provide collision detection and collision avoidance mechanisms to ensure the safety of autonomous vehicles in the pilots, any nearby objects and cargo.								
Rationale	Ensures the safety of vehicles, cargo, and nearby objects by preventing collisions.								
Dependencies	PLT-FUN-003,CLD-FUN-002,DM-PRM-003,BLK-FUN-005, VR-FUN-002, RA-FUN-003, RA-FUN-004, RA-FUN-005, COM-PRM-033, COM-PRM-031, COM-PRM-030, COM-FUN-013, COM-PRM-001, COM-PRM-002, COM-PRM-008, COM-PRM-009, COM-PRM-011, COM-PRM-012, COM-PRM-013, COM-PRM-014, COM-PRM-015, COM-PRM-016, COM-PRM-020, COM-PRM-021, COM-PRM-022, COM-PRM-024, COM-PRM-028, COM-PRM-029								
Conflict	PLT-FUN-003,DM-PRM-002,BLK-PRM-004,ETH-PRM-011,SEC-FUN-002,SRY-FUN-002,SRY-PRM-001								
Additional Info (comments)	None								
Related Scenario(s)	Greek and Slovenian pilot								

Id	SRY-FUN-002	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Autonomous Vehicle progressive introduction								
Description	The autonomous vehicle will be introduced in a step-by-step process - from control mode to full autonomy								
Rationale	Lots of complexity are brought by the introduction of autonomous vehicles. In order to optimise safety and reliability of the system, autonomous vehicles will first be introduced on the TRACE platform controlled manually, their behaviour evaluated and step by step go to the Autonomous mode where they will bring all their capabilities to the project.								
Dependencies	None								
Conflict	None								

Additional Info (comments)	None
Related Scenario(s)	Italian and Slovenian pilot

Id	SRY-FUN-003	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	TRACE economic safety mechanisms								
Description	The TRACE system shall implement safety mechanisms when performing economic interactions								
Rationale	When TRACE components, involved in the scenario, will be handling cost related activities, the people monitoring the system will have a way to stop those activities if the behaviour is detected as not conform.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Greek, Slovenian pilot								

Id	SRY-FUN-004	Type	ENV	Priority	HIGH	Source	Monitoring	Ver	1
Title	Platform shall accounting environmental factors.								
Description	TRACE platform shall account for various environmental factors, such as weather and road conditions, that may affect logistics operations.								
Rationale	Enhances operational reliability and safety under varying environmental conditions.								
Dependencies	CLD-FUN-004, BLK-FUN-007, INT-FUN-005, ETH-PRM-006, RA-FUN-001 ,RA-FUN-002, RA-FUN-004								
Conflict	PLT-FUN-004, DM-PRM-001, BLK-PRM-002, ETH-PRM-006, SEC-PRM-003								

Additional Info (comments)	None
Related Scenario(s)	Greek and Slovenian pilot

Id	SRY-FUN-005	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	TRACE platform risk prevention.								
Description	TRACE platform shall define fail-safe mechanisms to minimise the risk of system failure and enhance system redundancy								
Rationale	Conditions under which the TRACE platform should be stopped to ensure people, environment or economic issues shall be clearly defined and implemented								
Dependencies	SRY-FUN-002								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

Id	SRY-FUN-006	Type	PERF	Priority	MEDIUM	Source	Enhanced Automation	Ver	1
Title	Vehicles should set driving assistance systems.								
Description	TRACE vehicles should set driving assistance systems, such as lane-keeping assistance and automatic braking, to enhance the degree of smoothness and steadiness of automation.								
Rationale	Improves vehicle control and safety through advanced assistance systems.								
Dependencies	PLT-FUN-003,CLD-FUN-005,ETH-PRM-016, RA-FUN-004,, RA-PRM-005, RA-PRM-008, COM-PRM-002, COM-PRM-003, COM-PRM-009, COM-PRM-012, COM-PRM-014, COM-PRM-015, COM-PRM-021, COM-PRM-024, COM-PRM-026, COM-PRM-027, COM-PRM-029, COM-PRM-030, COM-PRM-031, COM-PRM-033, COM-PRM-034								

Conflict	PLT-FUN-003,DM-PRM-005, ETH-PRM-015,SEC-PRM-005,SRY-FUN-002,SRY-PRM-001
Additional Info (comments)	None
Related Scenario(s)	Greek and Slovenian pilot

Id	SRY-FUN-007	Type	ENV	Priority	LOW	Source	Blockchain	Ver	1
Title	TRACE shall provide transparency and reliability.								
Description	TRACE shall encrypt and create hash of shipment lifecycle and update it in Blockchain for making the content more reliable and tamper proof.								
Rationale	Ensures the safety and integrity of the records.								
Dependencies	COM-PRM-030, COM-FUN-013, COM-PRM-001, COM-PRM-002, COM-PRM-008, COM-PRM-009, COM-PRM-011, COM-PRM-012, COM-PRM-013, COM-PRM-014, COM-PRM-015, COM-PRM-016, COM-PRM-020, COM-PRM-021, COM-PRM-022, COM-PRM-024, COM-PRM-028, COM-PRM-029								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

6 NON-FUNCTIONAL REQUIREMENTS

6.1 Cloud Infrastructure Requirements

Id	CLD-PRM-001	Type	NF	Priority	MEDIUM	Source	Consortium Know-how	Ver	1
Title	Edge computing for storage and computing.								
Description	Edge computing shall be deployed for storage and computing.								
Rationale	Compute resources shall be deployed near the operational site for data storage and computing purposes.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

Id	CLD-PRM-002	Type	SEC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Updating, Patching, and Maintaining the Deployed Virtual Infrastructure								
Description	TRACE Cloud Infrastructure shall enable updating, patching, and maintaining the deployed virtual infrastructure								
Rationale	Regular updates and maintenance are vital for securing the infrastructure against vulnerabilities, complying with regulatory requirements, and ensuring that the infrastructure performs optimally and without disruptions								
Dependencies	CLD-FUN-001, CLD-FUN-003								
Conflict	None								

Additional Info (comments)	The update and patch management process should be automated where possible to reduce downtime and human error. The system should also support scheduled maintenance without significant impact on service availability
Related Scenario(s)	Greek, Italian and Slovenian pilot

Id	CLD-PRM-003	Type	SUP	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Backup and Disaster Recovery								
Description	TRACE Cloud Infrastructure shall implement data backup								
Rationale	Ensuring that data is backed up and that there are effective disaster recovery processes in place is essential for maintaining business continuity and protecting data against loss or corruption, which is critical for operational stability and trust								
Dependencies	CLD-FUN-003								
Conflict	None								
Additional Info (comments)	The TRACE Cloud Infrastructure shall offer robust backup solutions and disaster recovery plans to ensure data integrity and system availability in the event of hardware failure, data corruption, or other catastrophic events. The backup and disaster recovery solutions should be tested regularly to ensure they are effective and can be activated swiftly when needed								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

Id	CLD-PRM-004	Type	PERF	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	High Performance with Low Latency for Resource Provisioning and Data Access								
Description	The TRACE Cloud intelligently adjusts resource allocation in real-time, scaling up or down based on the specific demands of each workload, ensuring both efficiency and responsiveness.								
Rationale	High performance with low latency is crucial for maintaining user satisfaction and operational efficiency, especially in a cloud environment where resources are dynamically allocated and reallocated. This requirement ensures that the system can								

	handle operations and data transactions swiftly, thus minimizing delays and improving the overall user experience
Dependencies	CLD-FUN-004, CLD-FUN-005
Conflict	None
Additional Info (comments)	Consideration must be given to the integration of performance monitoring tools to continuously assess and ensure compliance with this performance standard
Related Scenario(s)	Greek, Italian and Slovenian pilot

Id	CLD-PRM-005	Type	PERF	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Support High Availability (HA) and Minimal Downtime of Cloud Services								
Description	TRACE Cloud Infrastructure shall support High Availability (HA) and minimal downtime of cloud services								
Rationale	High availability is essential to minimize service disruptions and maintain user trust, particularly in cloud environments where services are expected to be accessible at all times. This requirement is critical to prevent financial losses, reputational damage, and user dissatisfaction that can arise from unexpected downtime								
Dependencies	CLD-FUN-004, CLD-FUN-005, CLD-PRM-004								
Conflict	None								
Additional Info (comments)	This requirement should consider the implementation of failover mechanisms, redundancy, and regular system health checks to ensure ongoing service availability								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

Id	CLD-PRM-006	Type	PERF	Priority	MEDIUM	Source	Consortium Know-how	Ver	1
Title	Offer Redundancy in Cloud Infrastructure								

Description	TRACE Cloud Infrastructure should offer redundancy
Rationale	Redundancy is critical in a cloud environment to prevent service disruptions due to hardware failures, network issues, or other unforeseen circumstances. This requirement supports high availability by allowing the system to remain operational even if one or more components fail
Dependencies	CLD-FUN-006, CLD-PRM-005
Conflict	None
Additional Info (comments)	This requirement should include strategies such as implementing duplicate systems, data mirroring, and failover processes to ensure that there are no single points of failure in the cloud infrastructure
Related Scenario(s)	Greek, Italian and Slovenian pilot

6.2 Communications and Physical Infrastructure Requirements

Id	COM-PRM-001	Type	PERF	Priority	MEDIUM	Source	Law Regulation	Ver	1
Title	Compliance of Autonomous Unmanned Ground Vehicles with Italian Regulations								
Description	Autonomous unmanned ground vehicles for the Italian demonstrators should be compliant to Italian regulations: "Decreto Smart Road", 333ef4thbD.M. 70/2018								
Rationale	Compliance with Italian regulations is essential for legal operation and safety of autonomous unmanned ground vehicles in Italian demonstrations.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian Pilot								

Id	COM-PRM-002	Type	PERF	Priority	MEDIUM	Source	Standards	Ver	1
Title	UGV use legislation gaps								
Description	Autonomous UGVs should be compliant with national and international regulations								
Rationale	The UGV's have to respect the limitations and boundaries that are set up by the city/national authority.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	Various cities and countries have different approach in tackling the current legislation gaps. In most of the cases, the municipalities are in charge of setting up the rules on UGV use. Often times we have seen transitory institutes being installed such as testing sandboxes, living labs etc.								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

Id	COM-PRM-003	Type	PERF	Priority	MEDIUM	Source	Consortium Know-how	Ver	1
Title	Clear Marking of Bike Lanes Through Intersections for Cargo Bike Navigation								
Description	Bike lanes should be clearly marked and continue through intersections, allowing cargo bike users to navigate through without conflicts with motor vehicles								
Rationale	Clear marking and continuity of bike lanes through intersections are crucial for preventing conflicts between cargo bikes and motor vehicles, ensuring safer and more efficient navigation.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								

Related Scenario(s)	Italian bike demonstrator
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Id	COM-PRM-004	Type	PERF	Priority	HIGH	Source	Standards	Ver	1
Title	Drone may travel at 10 m/s								
Description	This is the appropriate speed of the drone to safely operate while performing deliveries as provided by partner DIFLY.								
Rationale	Ensures optimal safety by allowing sufficient reaction time for obstacle avoidance, maintaining payload stability, and complying with regulatory limits to prevent accidents and minimize noise pollution.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	Requirement to be reviewed during pilot testing phase.								
Related Scenario(s)	Italian Pilot								

Id	COM-PRM-005	Type	PERF	Priority	MEDIUM	Source	Consortium Know-how	Ver	1
Title	Drone Operation Restrictions for Communication and Signal Integrity								
Description	Drones should avoid areas that interfere with communications and signal transmission, e.g., military bases, airports, etc								
Rationale	Avoiding areas that interfere with communications and signal transmission is essential for maintaining operational safety and signal integrity.								
Dependencies	None								
Conflict	None								

Additional Info (comments)	None
Related Scenario(s)	Italian Pilot

Id	COM-PRM-006	Type	PERF	Priority	HIGH	Source	Standards	Ver	1
Title	Drones should avoid sensitive areas and obstacles.								
Description	Drones should avoid areas that 1) interfere with communications and signal transmission, e.g., military bases, airports, etc., 2) are sensitive areas (e.g. privacy concerns, specialized ecosystems, schools, residential towers, designated bird habitats etc.)								
Rationale	Such areas could interfere and prevent normal operations including preventing communications between vehicles and to the platform and could cause serious injury or harm to others.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	Drivability component of Suitability framework may assist in determining these areas and obstacles. Risk areas related to drone flight shall preserve the characteristics discussed with NAA per UAS operational authorization.								
Related Scenario(s)	Italian Pilot								

Id	COM-PRM-007	Type	PERF	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Avoidance of Aerial Obstacles for Drones								
Description	Drones shall avoid known aerial obstacles that impact flight path such as power lines, wind turbines etc								
Rationale	Avoiding aerial obstacles is crucial for ensuring safe and reliable drone operations by preventing collisions and maintaining clear flight paths.								

Dependencies	None
Conflict	None
Additional Info (comments)	None
Related Scenario(s)	Italian Pilot

Id	COM-PRM-008	Type	PERF	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Clear Ground Markings for Drone Takeoff and Landing								
Description	Ground markings for take off and landing shall be clear								
Rationale	Clear ground markings are essential for safe and accurate drone takeoff and landing, minimizing the risk of errors and enhancing operational safety.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian Pilot								

Id	COM-PRM-009	Type	PERF	Priority	HIGH	Source	Standards	Ver	1
Title	Ideal sidewalk width may be 2m.								
Description	The recommended size to accommodate a delivery robot safely on a sidewalk that has bi-directional pedestrian traffic.								
Rationale	The sidewalk needs to be wide enough to allow the unmanned vehicles to navigate safely.								

Dependencies	None
Conflict	None
Additional Info (comments)	This requirement is a target as it is understood that 2m may not be achievable in every jurisdiction where robots are piloted. Requirement to be reviewed during pilot testing phase.
Related Scenario(s)	Greek and Slovenian pilot

Id	COM-PRM-010	Type	PERF	Priority	HIGH	Source	Regulations	Ver	1
Title	If additional specialized infrastructure is required for robots, it should be non-intrusive, and robots may be guided by localized infrastructure								
Description	Specialized infrastructure could be temporary or permanent modifications to pedestrian infrastructure to accommodate a delivery robot but that might interfere or worsen conditions for sidewalk users such as pedestrians or wheelchair users.								
Rationale	Ensures that any modifications made to pedestrian infrastructure to accommodate delivery robots do not compromise the safety, accessibility, or convenience of other sidewalk users, such as pedestrians or wheelchair users.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Greek and Slovenian pilot								

Id	COM-PRM-011	Type	FUNC	Priority	HIGH	Source	Standards	Ver	1
Title	Landing and take-off platforms for drones shall be 3m wide area with clear vertical.								
Description	This is the appropriate width of a platform, as provided by partner DiFly.								

Rationale	This allows for the safe take-off and landing of UAV's.
Dependencies	None
Conflict	None
Additional Info (comments)	Ground markings for take-off and landing should also be clearly identifiable.
Related Scenario(s)	Italian Pilot

Id	COM-PRM-012	Type	ENV	Priority	HIGH	Source	Regulation	Ver	1
Title	Approved operating conditions for UV								
Description	The TRACE platform shall accept operations specifications for unmanned vehicles.								
Rationale	Local authorities and National Aviation Authorities provide the operational authorization and specify the operational areas and rules to support UGVs and UASs operations.								
Dependencies	PLT-FUN-003, PLT-FUN-004, INT-FUN-006,								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian pilot								

Id	COM-PRM-013	Type	PERF	Priority	HIGH	Source	Standards	Ver	1
Title	Max step/curb height for the robot should not exceed 5 cm								
Description	Less than 5 cm is the preferred height for the delivery robot vehicle. This is the maximum height that a robot supplied by Robotnik can safely navigate over.								
Rationale	Exceeding this height could present challenges and delays to deliveries. The requirement allows for improved routing and navigation.								
Dependencies	None								
Conflict	None								

Additional Info (comments)	Drivability component of Suitability framework may assist in determining suitable areas. Requirement to be reviewed during pilot testing phase.
Related Scenario(s)	Greek, Italian and Slovenian pilot

Id	COM-PRM-014	Type	PERF	Priority	LOW	Source	Consortium Know-how	Ver	1
Title	Maximum Travel Speed Limits for Vehicles on Travel Paths								
Description	Max travel speed may be 25 km/h with driver and 6km/h without on travel paths								
Rationale	Setting maximum travel speed limits ensures safety and operational control on travel paths, accommodating both scenarios with and without a driver.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian bike demonstrator								

Id	COM-PRM-015	Type	PERF	Priority	HIGH	Source	Regulations	Ver	1
Title	Max travel speed for robot on pedestrian infrastructure should not exceed 5km/h								
Description	The maximum speed for the robot operating on sidewalks should not exceed 5km/h to prevent issues with sidewalk users.								
Rationale	For safety and ergonomic reasons, the unmanned vehicles should not drive faster than typical speeds of pedestrians.								
Dependencies	None								
Conflict	None								

Additional Info (comments)	The suggested speed also aligns with the approximate speed of sidewalk users, namely pedestrians on foot. Requirement to be reviewed during pilot testing phase.
Related Scenario(s)	Greek, Italian and Slovenian pilot

Id	COM-PRM-016	Type	PERF	Priority		Source	Regulations	Ver	1
Title	Alignment of Vehicle Altitude with Local and National Flight Regulations								
Description	Minimum and maximum allowable vehicle altitude shall align with local and national flight regulations for drones								
Rationale	Aligning vehicle altitude with local and national flight regulations is essential for regulatory compliance and ensuring safe and legal drone operations.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

Id	COM-PRM-017	Type	PERF	Priority	HIGH	Source	Standards	Ver	1
Title	Mobile (5G or 4G/NB IoT) network availability.								
Description	Mobile (5G or 4G/NB IoT) Network coverage shall be available over the sites of operation at 90%-99.99% availability (depending on the application requirements). Network shall be deployed in such way to provide mobile network coverage.								
Rationale	It will enable communication with the TRACE platform.								
Dependencies	None								
Conflict	None								

Additional Info (comments)	None
Related Scenario(s)	Greek, Italian and Slovenian pilot

Id	COM-PRM-018	Type	PERF	Priority	HIGH	Source	Standards	Ver	1
Title	Mobile (5G or 4G/NB IoT) Network Reliability & availability								
Description	Mobile (5G or 4G/NB IoT) Network coverage shall be available over the sites of operation at 90%-99.99% reliability (depending on the application requirements). Network shall be deployed in such way to provide mobile network coverage with relevant reliability.								
Rationale	It will enable communication with the TRACE platform.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

Id	COM-PRM-019	Type	PERF	Priority	HIGH	Source	Standards	Ver	1
Title	Mobile (5G or 4G/NB IoT) network Data rate and Latency								
Description	Mobile (5G or 4G/NB IoT) network performance shall achieve the required application Data rate (in Mbps) and the required latency (msec) (depending on the application requirements). Network shall be deployed in such way to provide mobile network coverage with relevant performance.								
Rationale	It will enable communication with the TRACE platform.								

Dependencies	None
Conflict	None
Additional Info (comments)	None
Related Scenario(s)	Greek, Italian and Slovenian pilot

Id	COM-PRM-020	Type	PERF	Priority	HIGH	Source	Regulation	Ver	1
Title	Authorization of Operational Volume for Drone Flights								
Description	Operational volume for intended drone flight shall authorized by NAA								
Rationale	Authorization by the NAA is essential for ensuring that drone operations are conducted safely within regulated airspace and comply with aviation standards.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian pilot								

Id	COM-PRM-021	Type	PERF	Priority	HIGH	Source	Standards	Ver	1
Title	Path markings may be used for robot to determine appropriate travel path and location of hubs								
Description	Some markings can be used to trigger events or for traceability functionalities in an automated way. They also assist in robot navigation and to warn pedestrians of alternative uses for the sidewalk.								
Rationale	Enables automated systems to use markings for event triggering and traceability, while also assisting robot navigation and informing pedestrians of alternative sidewalk uses.								

Dependencies	None
Conflict	None
Additional Info (comments)	None
Related Scenario(s)	Greek, Italian and Slovenian pilot

Id	COM-PRM-022	Type	PERF	Priority	HIGH	Source	Regulation	Ver	1
Title	Preservation of Risk Area Characteristics in Drone Flight Operations								
Description	Risk areas related to drone flight shall preserve the characteristics discussed with NAA per UAS operational authorization								
Rationale	Maintaining the characteristics of risk areas as discussed with the NAA ensures that drone operations remain compliant with safety standards and regulatory requirements.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian pilot								

Id	COM-PRM-023	Type	PERF	Priority	HIGH	Source	Regulations	Ver	1
Title	Robot occupancy and waiting at a hub or defined space shall not create obstacles for pedestrians or congestion on public paths.								
Description	Hubs must be located and designed to host the vehicles without disturbing the normal road/sidewalk flow								

Rationale	Minimize pedestrian-robot accidents, maintain pedestrian flow smooth and don't disturb normal behaviour.
Dependencies	None
Conflict	None
Additional Info (comments)	None
Related Scenario(s)	Greek, Italian and Slovenian pilot

Id	COM-PRM-024	Type	PERF	Priority	HIGH	Source	Regulations	Ver	1
Title	Robots shall prioritize first: defined pedestrian paths or sidewalks as operational areas.								
Description	The planned route for the robot will treat designated pedestrian paths and sidewalks as their primary operational areas. Whenever possible, the planned route will include only pedestrian paths and sidewalks.								
Rationale	Road rules are more complex than in pedestrian areas and the regulations are undefined or unmanned vehicles are forbidden in some countries. Pedestrian areas rules and regulations are more flexible.								
Dependencies	None								
Conflict	Robots traversing on city streets may increase the likelihood of conflict with road users due to the size of the vehicle and speed difference.								
Additional Info (comments)	None								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

Id	COM-PRM-025	Type	PERF	Priority	HIGH	Source	Regulations	Ver	1
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Title	Robot should cross streets at clearly identifiable pedestrian crossings (e.g., zebra crossings, signalized intersection)
Description	The planned route for the robot will include the points that the robot will use to cross the streets.
Rationale	The robot behaviour should be similar to the pedestrian one to prevent negative incidents.
Dependencies	None
Conflict	None
Additional Info (comments)	None
Related Scenario(s)	Greek and Slovenian pilot

Id	COM-PRM-026	Type	FUNC	Priority	HIGH	Source	Standards	Ver	1
Title	Robots may grant pedestrians space and the right-of-way.								
Description	Robots may grant pedestrians an appropriate space (e.g., m) and the right-of-way to pedestrians in close proximity on pathways.								
Rationale	Allows for improved routing and navigation, and safety for sidewalk users.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Greek Pilot, Slovenian Pilot								

Id	COM-PRM-027	Type	PERF	Priority	HIGH	Source	Standards	Ver	1
Title	Surfaces may be smooth, well-maintained surfaces, free of potholes, debris, and obstacles.								
Description	The selection of paths, streets and roads used for deliveries during pilot testing should be maintained and allow vehicles to drive without issues.								
Rationale	Vehicles need clean and maintained paths, streets and roads to prevent incidents.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

Id	COM-PRM-028	Type	PERF	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Take off Platform Specifications								
Description	Take off platform shall be 3m wide area with clear vertical.								
Rationale	A 3-meter wide take off platform with clear vertical space is essential for ensuring safe and unimpeded drone take off operations.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian pilot								

Id	COM-PRM-029	Type	FUNC	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Cargo Bike buffer zone (potential if realistic)								
Description	The buffer zone (space between bike and other vehicles) may be at least 1.5 to 2 meter (5 to 6.5 feet)								
Rationale	Enables operational flow and safety as recommended by cargo bike operator.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Italian and Slovenian pilot								

Id	COM-PRM-030	Type	PERF	Priority	HIGH	Source	Standards	Ver	1
Title	The max slope incline of path for the cargo bike shall not exceed 3%								
Description	Maximum slope of paths used should not exceed 3% as provided by OLV, URBICO.								
Rationale	Exceeding this would impact the performance of vehicles and potentially impact KPI's.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	Requirement to be reviewed during pilot testing phase.								
Related Scenario(s)	Italian pilot								

Id	COM-PRM-031	Type	PERF	Priority	HIGH	Source	Standards	Ver	1
Title	The max slope incline of path for the robot shall not exceed 47%								
Description	Maximum slope of pathways used should not exceed 47% as provided by Robotnik.								

Rationale	Exceeding this would impact the performance of unmanned vehicles and potentially impact KPI's.
Dependencies	None
Conflict	COM-PRM-030
Additional Info (comments)	Requirement to be reviewed during pilot testing phase.
Related Scenario(s)	Greek and Slovenian pilot

Id	COM-PRM-032	Type	PERF	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	Minimum Width for Bike Lane Accommodating Cargo Bikes								
Description	The minimum recommended width for a bike lane accommodating cargo bikes should be 2m, preferably 2.6m								
Rationale	A width of 2 meters, preferably 2.6 meters, is essential for safely accommodating cargo bikes and ensuring smooth, conflict-free travel.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	Requirement to be reviewed during pilot testing phase.								
Related Scenario(s)	Italian bike demonstrator								

Id	COM-PRM-033	Type	PERF	Priority	MEDIUM	Source	Regulation	Ver	1
Title	Compliance with Directive (EU) 2019/2144								
Description	TRACE should comply with the requirements laid down in Directive (EU) 1019/2144 on the general safety and the protection of vehicle occupants and vulnerable road users.								

Rationale	Compliance with Directive (EU) 2019/2144 is crucial for ensuring that TRACE meets safety standards and effectively protects both vehicle occupants and vulnerable road users.
Dependencies	None
Conflict	None
Additional Info (comments)	None
Related Scenario(s)	Greek, Italian and Slovenian pilot

Id	COM-PRM-034	Type	PERF	Priority	MEDIUM	Source	Consortium Know-how	Ver	1
Title	Travel paths may contain temporary and permanent obstacles.								
Description	Unmanned vehicles shall be able to avoid and navigate around ground obstacles to prevent incidents such as garbage bins, benches etc.								
Rationale	Streets and pathways are complex environments, and it is possible to face obstacles.								
Dependencies	VS-FUN-004								
Conflict	None								
Additional Info (comments)	The Drivability analysis considers obstacles.								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

Id	COM-NF-035	Type	PERF	Priority	HIGH	Source	Standards	Ver	1
Title	User equipment compatibility								

Description	User Equipment Mobile (5G or 4G/NB IoT) shall be compatible with mobile network Frequency/ Bandwidth allocation.
Rationale	It will enable communication with the TRACE platform.
Dependencies	Depends on Network configuration and deployment characteristics, and on devices / applications and last mile network architecture.
Conflict	None
Additional Info (comments)	None
Related Scenario(s)	Greek, Italian and Slovenian pilot

Id	COM-PRM-036	Type	FUNC	Priority	HIGH	Source	Standards	Ver	1
Title	The routing shall consider the available charging infrastructure								
Description	Vehicle charging infrastructure location should consider battery life, route length and other determinants.								
Rationale	Allows for vehicle navigation and performance optimization.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	None								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

Id	COM-PRM-037	Type	PERF	Priority	HIGH	Source	Standards	Ver	1
Title	Vehicles may have Wi-Fi								
Description	Vehicles may have Wi-Fi 02.11a/b/g/n/ac Bluetooth 5.1 (5G/4G optional)								
Rationale	Streets are complex environments and it is possible to have obstacles								
Dependencies	COM-PRM-017, COM-PRM-018, COM-PRM-019, COM-PRM-035								
Conflict	COM-FUN-001, COM-FUN-003, COM-FUN-013 (similar for each vehicle) More than one device in one requirement.								
Additional Info (comments)	None								
Related Scenario(s)	Greek, Italian and Slovenian pilot								

6.3 Safety and Reliability Requirements

Id	SRY-PRM-001	Type	PERF	Priority	MEDIUM	Source	Consortium Know-how	Ver	1
Title	Enhancing Unmanned Vehicle Navigation								
Description	The outdoor localization accuracy of unmanned vehicles shall be lower than 10 meters on average (or less, if possible within 1 meter)								
Rationale	Achieving an outdoor localization accuracy of under 10 meters for unmanned vehicles ensures that navigation and operational tasks can be performed reliably in diverse environments. This limit balances practical constraints of GPS and sensor-based localization technologies, offering acceptable inaccuracy for many applications. However, targeting an accuracy within 1 meter, where feasible, significantly enhances performance in precision-demanding scenarios such as urban navigation, obstacle avoidance, and autonomous deliveries. By striving for higher precision, the risk of collisions, errors in navigation, and mission failure is minimized, thereby enhancing the overall safety and efficiency of unmanned vehicle operations.								
Dependencies	None								
Conflict	None								

Additional Info (comments)	None
Related Scenario(s)	Greek, Italian and Slovenian pilot

Id	SRY-PRM-002	Type	PERF	Priority	HIGH	Source	Consortium Know-how	Ver	1
Title	The TRACE safety mechanism								
Description	The TRACE safety mechanism shall prevent unauthorized access and hacker access to TRACE data centers.								
Rationale	The TRACE platform is composed of software running on the cloud and on a number of devices distributed until the vehicle. Each of those devices are prone to be hacked and serve as intermediate vector to access data center. Given the fact that this platform is a prototype, care shall be taken to ensure proper isolation of the TRACE elements to prevent unauthorized access.								
Dependencies	None								
Conflict	None								
Additional Info (comments)	The TRACE platform at this stage is a demonstrator. Incentive to hack it will probably stay very low. Nevertheless, the elements should be kept active and online only the time necessary to conduct development and demonstration in order to limit the time exposition								
Related Scenario(s)	Greek and Slovenian pilot								

Id	SRY-PRM-003	Type	PERF	Priority	MEDIUM	Source	Consortium Know-how	Ver	1
Title	The TRACE system shipment handling								
Description	The TRACE system should provide mechanisms for the safe and authorized handover of shipments to another stakeholder								
Rationale	The goal of TRACE is to facilitate the communication between stakeholder to deliver shipments. Those shipments will change hands a number of time from the sender to the receiver. TRACE will implement way to follow, validate and track every handover.								

Dependencies	None
Conflict	None
Additional Info (comments)	None
Related Scenario(s)	Greek and Slovenian pilot

7 SUITABILITY FRAMEWORK

7.1 Introduction

7.1.1 Focus on Automated Delivery Robot (ADR) Suitability

The technological advancement of robots for the transportation of goods is currently progressing at a fast pace, creating a sense of urgency for many municipalities and cities to act. It raises the question of whether these robots, with their economic potential and impacts on urban spaces, can be integrated into our cities. This new aspect is often considered from the perspective of the robots' ability to navigate public spaces, without considering their Compatibility with human presence. This is precisely where our research approach comes in: it analyzes both the Compatibility of robots in terms of their impact on the usability of public spaces and the situational navigability of street spaces. Together, these aspects form the concept of Suitability. This dual analysis ensures that the integration of robots into urban environments is not only efficient and economically beneficial but also socially acceptable and conducive to the quality of life [1],[2],[4].

7.1.2 Scope

The table below delineates the boundaries of the evaluation approach across various aspects. These boundaries may evolve over the project.

Table 2: Framework and Boundaries for Robot Integration Assessment

Aspect	Boundary Definition
Spatial Boundaries	The spatial boundary encompasses the entire city.
Spatial Resolution	The spatial resolution is at the network level, with only preliminary consideration of the street-level spaces.
Modal Boundaries - Robots	Sidewalk-Robot, Automated Cargo-Bike, (Automated Truck), (Automated Drone)
Modal Boundaries - Others	Impacted by Robots: Pedestrians, Cyclists Not considered: Cars, Trucks, Scooters, Mopeds, Motorcycles, Trams, Buses, Trains
Temporal Boundaries	The evaluation approach encompasses the current situation. Future projections developments are not addressed.
Legislative Boundaries	Legal aspects are not considered.

<p>Technological Boundaries</p>	<p>The technological development in terms of the automation level of the robots is classified according to the SAE levels. Classification is yet to be determined.</p>
<p>Vehicle Technical Boundaries</p>	<p>The technical functionality aligns with the development status of the robots from the project partners.</p>

7.1.3 Main Components of the Framework and their Interconnections

This detailed framework establishes the scope within which the TRACE project will operate, providing clarity on the various dimensions of the evaluation approach. It ensures a focused and structured analysis while allowing flexibility for adjustments as the project progresses.

The framework is designed to assess the suitability of street spaces for automated logistics vehicles. This evaluation involves determining the Drivability and Compatibility of the street spaces through two GIS models, which are subsequently integrated to form the overall Suitability assessment. Additionally, a Freight Demand Model (for goods transportable by robots, thus excluding construction and service sector) is also used to evaluate Compatibility.

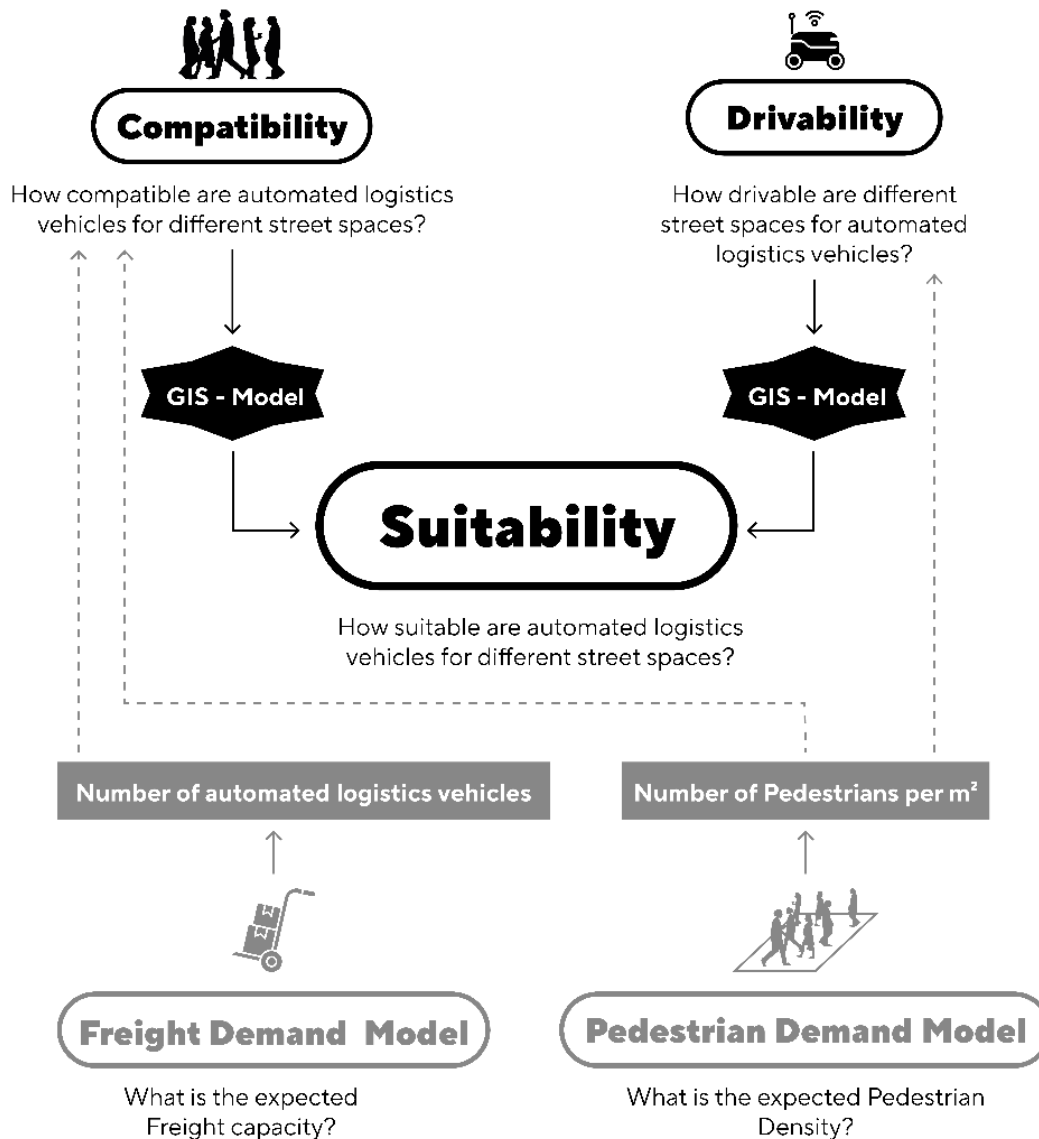


Figure 13: Suitability of street spaces

7.1.4 Combination of Model Output

The integration of the Drivability and Compatibility models provides a comprehensive assessment of street space suitability for automated logistics vehicles. This integration is a multi-layered process that begins with feeding data from both a Pedestrian Demand Model and a Freight Demand Model into base layers such as pedestrian density, static obstacles, and dynamic obstacles that are essential for evaluating both Drivability and Compatibility. Additionally, these models contribute to additional layers, including social segmentation, environmental factors, temporary modifications, and digital infrastructure and guidance.

These layers also inform the Drivability and Compatibility assessments and can be modified in their weighting. They are then merged to form a unified Suitability score. This approach ensures that all critical factors from physical and operational feasibility to social and environmental considerations are comprehensively evaluated, leading to more informed and effective decision-making in the deployment of automated logistics vehicles in urban environments.

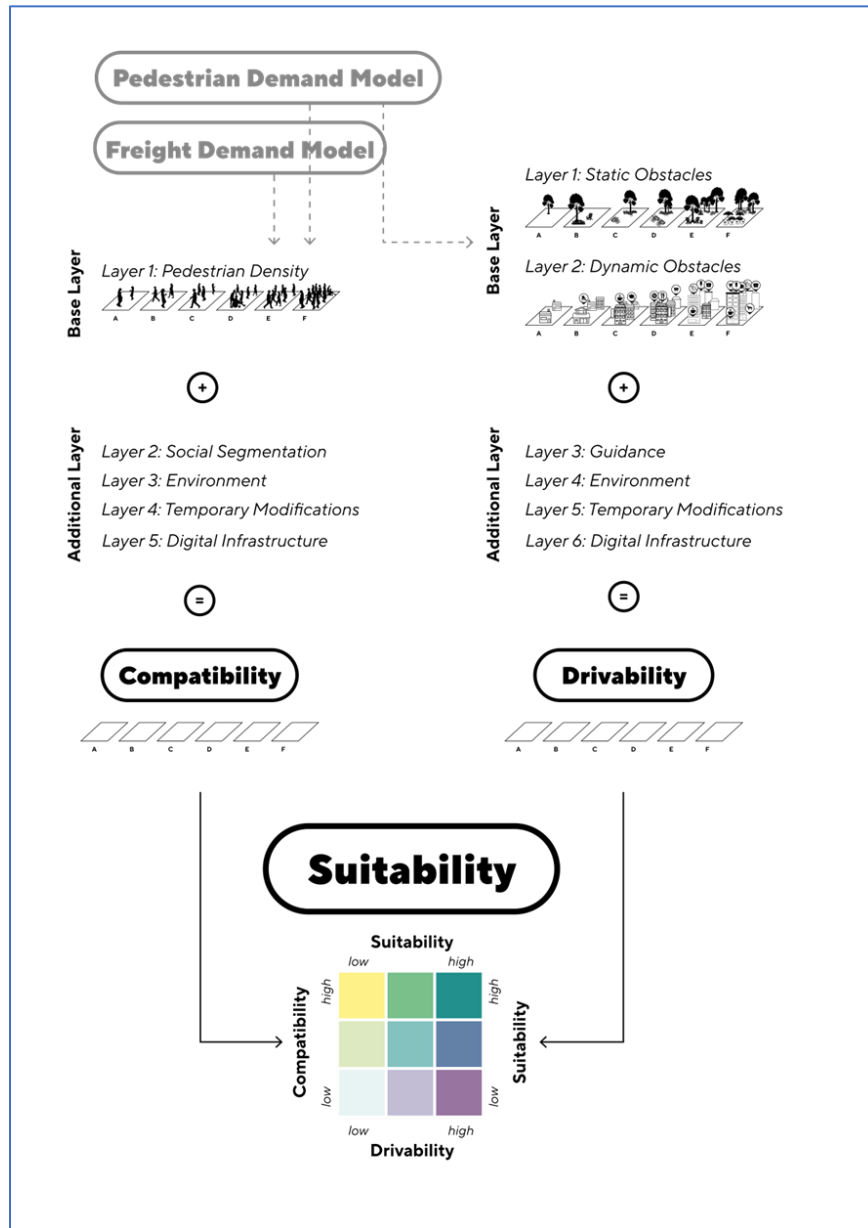


Figure 14: Combination of Model Output

7.2 Use Cases & Scenarios

Use Case: A Use Case describes the application of automated vehicles. This can be described in different layers (a) the specific vehicle (with specific specifications) in (b) a specific environment (i.e. sidewalk) with

(c) a specific purpose (delivering parcels). The Compatibility and Drivability are dependent on the Use Case type as each has their own set of conditions and infrastructure requirements.

Scenario: Scenarios are all occurring situations, in which the robot finds itself in, and is defined by the robot's intended purpose and function within the infrastructure and its moving and static objects and conditions. In the past, the ability of a robot to drive autonomously was validated via miles or kilometers driven without human interference (disengagement or accidents). Scenarios are a sounder approach to make statements on Drivability, as they clearly represent situations that can occur on certain infrastructures [3]. For the infrastructural approach in determining the Drivability, only certain scenarios are of relevance [7]. The focus is on infrastructural conditions (infrastructure type, width, number and behaviour of static and dynamic objects) and not on trajectory or manoeuvre-based scenario indicators (i.e. “robot turns left when a green bike is approaching with 20mph”) [8].

Thus, the basis of the suitability is the infrastructure type (below) and the spatial conditions (determining type and quantity of static and dynamic objects).

7.2.1 Infrastructure Types

Sidewalk: A paved pathway normally designated for pedestrians only and typically located adjacent to a street.

Pedestrian Zone: an area designated for pedestrian use only, where vehicle traffic is limited or completely prohibited. These zones are commonly found in urban areas, particularly in city centres, shopping districts, and historic areas.

Residential Zone: an area zoned or designated primarily for housing and living purposes within a municipality.

University campus zone: is a designated area within or surrounding a university, encompassing facilities dedicated to academic, administrative, recreational, and residential activities associated with the institution. In these zones, above average pedestrian activity can typically be expected.

Bicycle Lane: A lane used for bicycles only.

One-way cycle path: is a lane or path specifically designed for bicycle traffic that moves in a single direction.





Two-way cycle path: is a lane or path specifically designed for bicycle traffic that moves in two directions, also known as bidirectional.

Shared Path, Mixed Pedestrian-Cycle Path or Multi-purpose Lane: A pathway used for various uses including pedestrians, bicycles and other active travel modes.

Intersections: A point where two or more streets and/or paths cross each other. For example, a signalized intersection which has the capability for various modes (e.g., cars and pedestrians) to intersect with one another in a controlled environment.

The Table below illustrates scenarios from the TRACE project that involve both robots and bicycles, the infrastructure type used, speed and pilot site location.

Table 3: Robot Integration Scenarios

Scenario	Infrastructure Type	Modes	Vehicle Speed	Movement Direction(s)	Pilot Site(s)
1	Sidewalk	Robots, pedestrians	Robot: 2.5m/s		Slovenia, Greece
2	Shared Path	Robots, pedestrians, bicycles	Robot: 2.5m/s		Slovenia, Greece
3	Bike-only lane	Cargo bike, bicycles	Cargo bike: 25km/h with driver, 5km/h driverless		Italy, Slovenia
4	Street	Cargo bike, bicycles, cars	Cargo bike: 25km/h with driver, 5km/h driverless		Italy, Slovenia

7.3 Framework: Model Structure, Layer Concept and Evaluation Logic

7.3.1 Model Structure: Characteristics

Figure 7.1.3 summarizes the model structure and the relationships between the model components. The relevance of the Compatibility Model and the Drivability Model lies in their direct impact on the integration of robots within urban spaces.

The model structure consists of two primary components:

- Compatibility Model:** This model assesses the interactions between robots and the existing urban infrastructure and human activities. It examines factors such as pedestrian flow, street capacity, and the potential for conflicts between robots and other road users. The Compatibility Model is crucial for ensuring that the presence of robots does not detract from the quality of urban life. It

directly influences the number and types of robots that can be harmoniously integrated into street spaces.

- **Drivability Model:** The Drivability Model evaluates the technical navigability of urban environments from the robot's perspective. It considers factors such as road conditions, obstacles, and the overall feasibility of robot operations in various settings. This model is essential for determining the practical aspects of robot deployment, ensuring that robots can efficiently and safely navigate the streets.

The two primary components are supplemented by two additional models:

- **Freight Demand Model:** The relevance of the Freight Demand Model lies in its direct impact on the Compatibility Model, as it determines the number of robots that potentially are in use. This quantity significantly influences the Compatibility within street spaces.
- **Pedestrian Demand Model:** The Pedestrian Demand Model provides an estimate of the pedestrian frequency and pedestrian density for each street section. It is integrated into both Compatibility and Drivability.

The interconnection between these models is pivotal for achieving a balanced approach to robot integration. While the Compatibility Model focuses on social acceptance and urban liveability, the Drivability Model confirms the technical feasibility of operations. Together, they provide a comprehensive view that supports informed decision-making for urban planners and policymakers.

In summary, the integrated model structure, as depicted in Figure 9 illustrates the dynamic interplay between maintaining harmonious urban environments and ensuring the technical feasibility of robot operations. This dual focus is essential for developing sustainable and socially acceptable solutions for the future of urban mobility.

7.3.2 Layer Concept

The Layer Concept is a pivotal framework within the different Models, designed to systematically evaluate both Drivability and Compatibility. This structured approach allows for a detailed and nuanced analysis by categorizing various factors into distinct layers, each composed of specific indicators that can be represented either directly or indirectly.

The Layer Concept is divided into two primary categories:

- **Base Layers** constitute the fundamental components necessary for evaluating the basic feasibility of robot operations. These layers focus on essential indicators that must be considered to determine whether an environment can support robotic activities. The indicators in Base Layers provide the core data required for initial assessments.
 - **Additional Layers** provide supplementary information that enhances the evaluation process. These layers encompass indicators that, while not essential for basic feasibility, offer valuable insights into optimizing and refining robot operations. By incorporating Additional Layers, a more detailed and precise analysis can be achieved, addressing potential challenges and opportunities for improvement.
-

As part of the Layer Concept, several presumptions were established to define the overarching framework and boundaries of the analysis. These presumptions set the foundational context for both the Base and the Additional Layers, guiding the overall evaluation strategy.

Each layer, whether Base or Additional, is composed of various indicators. These indicators serve as measurable elements that reflect specific conditions or characteristics relevant to robot integration.

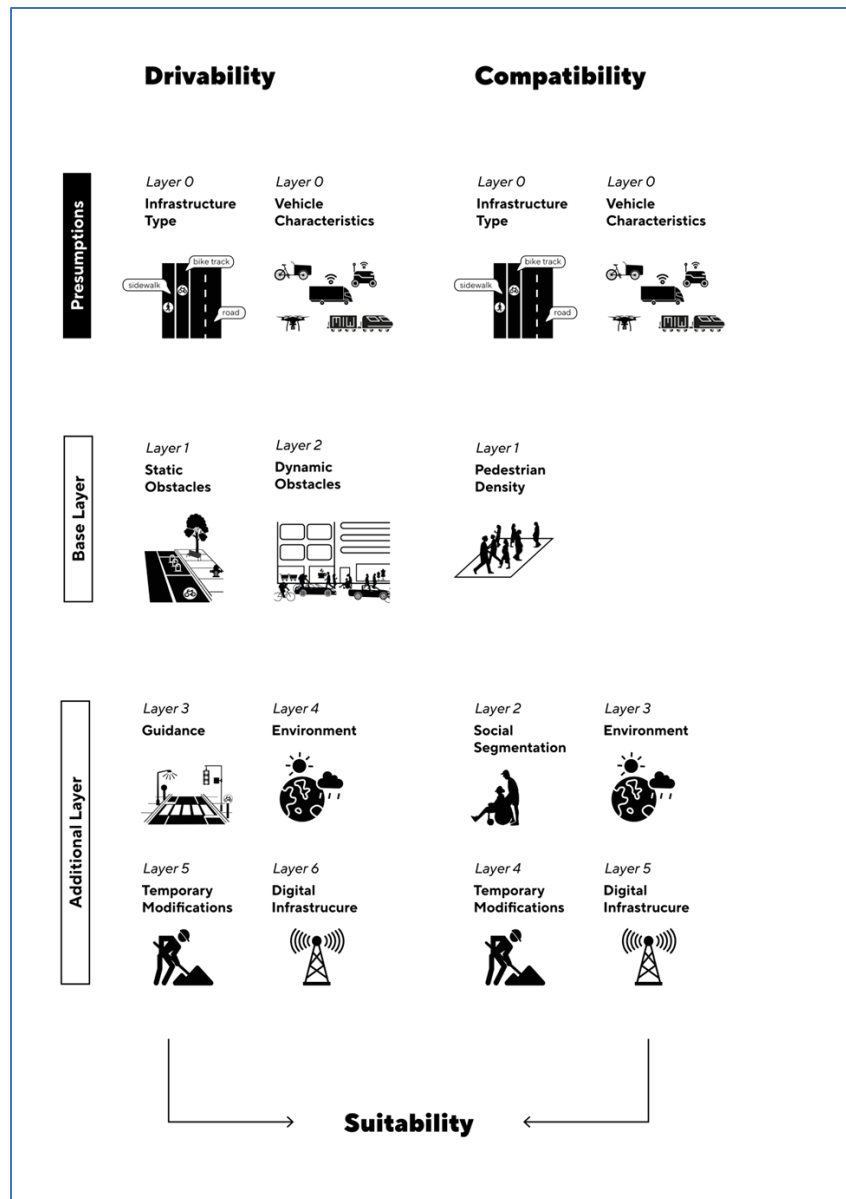


Figure 14: Layer Concept

7.3.3 Layers: Drivability

Focus on evaluating the operational conditions that affect the robot's ability to navigate urban environments.

For both the Drivability assessment, the context is defined by the following presumptions: the vehicle characteristics of each automated logistics vehicle and the infrastructure type. Each vehicle is designated to operate on specific types of infrastructure; for example, delivery robots should only travel on sidewalks or other areas designated for pedestrian use.

The Drivability base layers consist of static and dynamic obstacles. Indicators for static obstacles include trees, urban greening, and benches, while the dynamic obstacle layer comprises indirect indicators that suggest higher pedestrian activity, which could interfere with Drivability. Indirect indicators in this layer include the presence of shops, cafés, schools, and other educational institutions.

Additional layers affecting Drivability are guidance, environment, temporary modifications, and digital infrastructure. Example indicators for the guidance layer include streetlights and traffic lights.

7.3.4 Layers: Compatibility

Assess the interaction between robots and other urban elements, such as pedestrian flow and infrastructure suitability. These layers ensure that robot operations are harmonious with existing urban dynamics, considering both core and extended indicators.

In the Compatibility assessment, the context is determined by the following same assumptions: the specific characteristics of each automated logistics vehicle and the type of infrastructure. Each vehicle is intended to operate on certain infrastructure types. For instance, delivery robots are meant to travel exclusively on sidewalks or other areas designated for pedestrian use.

The Compatibility base layer is modelled on pedestrian density, with additional layers including social segmentation, environment, temporary modifications, and digital infrastructure. The social segmentation layer consists of indirect indicators that identify if vulnerable individuals are likely to use the infrastructure. Indicators include schools, healthcare, elderly care etc.

7.3.5 Freight Demand Model

Understanding the specific local freight demand (i.e. number of freight vehicles making last mile deliverables in each section) is pivotal for understanding the potential demand for automated vehicles on the road. For the use case of sidewalk delivery robots, every potential delivery of a certain side means one trip per delivery robot, thus leading to an unknown number of potential robots on a street or a sidewalk.

Freight demand models for urban contexts can roughly be distinguished in a macro, meso and a micro level. Macro generally defines the focus at the whole city (or a more general spatial and freight-demand aggregation), the meso-level on a certain area of a city and the micro-level on a section of a street space or a building block (with the highest resolution of freight attractors and demand). Alternatively, or complementary, agent-based approaches can be used as well [11]. For each spatial and knowledge-focus, different data is needed. Existing surveys (i.e. for modelling purposes) look at freight generation/demand, freight trip generation/demand and freight weight generation/demand [12]. A suitable method for gaining this data is establishment-based freight surveys [13].



Figure 15: Freight and sidewalk delivery vehicles in Vienna, Austria [9].

For determining the number of potential deliveries (and thus vehicles occupying the road/sidewalk-space) for the TRACE-project, an establishment-based approach on a meso- and micro-level is chosen as the most viable approach. In doing so, the following steps are taken to determine the level of freight demand and furthermore the number of freight trips suitable for robots in street sections. For this, the freight demand of certain goods categories must be known (robot transportability: size, weight, need for cooling etc.):

- The number of establishments and residents (e-commerce-behavior) is assessed per street section (for example via OSM or data provided by the partner cities). This leads to the knowledge of density of establishments, allowing for a first deduction of possible freight intensity.
- The establishments are clustered in freight intensity groups (according to categorizations in existing literature and past surveys), allowing for further distinguishing and showcasing more freight intensive street sections.
- The density and number of residents are clustered in demographic groups, allowing for further distinguishing and showcasing more freight intensive street sections. A previous survey in Austria showed, that the age cohorts have the most correlation with e-commerce-behaviour, thus parcels ordered per person. Due to the size and weight of these parcel deliveries, this criterion has a high robot transportability factor.
- The establishments clusters (classifications according to economic activity, type of labour etc.) are matched with freight generation rates (trips and deliveries) from previous surveys and literature, further iterating the knowledge on freight demand on the level of a street section.
- Centrality (like pedestrian density as an indicator for consumer density) and employment (estimations of employees per establishment; the current available data hinders this option) factors are weighted into the model - deriving from the findings of diverse studies - that freight demand is not linearly distributed.
- A space sensitive survey (due to the non-linearity of freight demand) is set up to establish a specific knowledge base of freight demand per establishment group in different spatial conditions. The results are then extrapolated to the focus area. This stage of iteration allows for the most detailed estimation of freight volumes and trips demanded in a street section and allows to deduct the percentage of suitability of a shift in transport modes (i.e. to sidewalk delivery robots).

- An assignment of sources (i.e. micro-hubs or consolidation centers) of freight flows and allocation on freight axis for measuring freight traffic volumes highlights not only where goods are delivered to (and in what density) but also shows the potential freight volumes on a street section for through traffic.

7.3.6 Pedestrian Demand Model

The Pedestrian Demand Model within the TRACE project is a straightforward yet effective tool designed to estimate pedestrian frequencies across different segments of the street network. This model plays a crucial role in understanding pedestrian dynamics, as it allows for the calculation of pedestrian densities by combining frequency estimates with the available pedestrian space on each street segment. This model is based on a 2022 approach which looks at the amounts of pedestrian traffic on individual routes in footpath networks of various Swiss cities [6].

The model operates by leveraging spatially localized data, including population distribution and key Points of Interest (POIs) such as commercial areas, schools, and public transport hubs. By integrating this data with a routing algorithm, the model effectively projects pedestrian movements onto the street network. This process enables the model to simulate the likely paths that pedestrians will take, providing detailed insights into pedestrian traffic volumes for various street segments.

Once the pedestrian frequencies are estimated, they can be intersected with data on the physical space available for pedestrians, such as sidewalk width and pedestrian zones. This intersection yields valuable information on pedestrian density, which is a critical factor in assessing the compatibility of robots within these urban spaces.

Overall, the Pedestrian Demand Model is a key component of the TRACE project, offering a practical approach to understanding and managing pedestrian traffic in urban environments. It provides essential data that informs decisions on robot integration, ensuring that pedestrian comfort and safety are maintained in areas with high foot traffic.

7.3.7 Evaluation Logic

The evaluation logic is based on the following assumptions:

- **Evaluation Scale:** The assessment of both Compatibility and Drivability qualities follows the Level of Service (LOS) concept, which is standard in transportation planning. Two approaches of varying detail are pursued: a binary assessment (Y/N) for a coarse evaluation, and a five-level scale from A to F for a more detailed assessment.
- **Simplicity vs. Complexity:** To enhance validation, simplified evaluation approaches are initially developed, which may be further refined during the process.
- **Layer Structure:** These evaluation approaches are structured in layers, grouping well-related influencing factors within a single layer. Building on point 2, a distinction is made between the Base Model and the Additional Model (see previous Figure).

- **Iterative Process:** The evaluation scale and the considered layers are interdependent, necessitating iterative adjustments to the evaluation scale.
- **Exclusion Principle:** Irrelevant elements for the purpose are excluded (e.g., highways are not relevant for Drivability).
- **Pre-Segmentation:** Pre-classification of local situations, such as the type of street (e.g., commercial street), is considered to account for influences that are difficult to capture with existing datasets at an aggregated level.
- **Spatial Resolution of the Network:** Segments of the road network are divided into x-meter sections.
- **Temporal Resolution:** The temporal resolution is currently flexible and is accounted for by a separate layer. No distinction is made between weekdays and weekends. The temporal resolution ranges from hourly to daily intervals. The consideration of peak hours is still under discussion.

These assumptions guide the development and application of the evaluation models, ensuring a structured and adaptable approach to assessing the integration of robots into urban environments.

7.3.8 Evaluation Approach

The Level of Service (LOS) concept is a widely recognized framework in transportation planning, used to evaluate the quality and performance of transportation infrastructure across various modes, including vehicular traffic, public transit, and non-motorized transport such as walking and cycling. The LOS framework provides a systematic way to assess how well transportation facilities meet the needs of users by assigning grades (typically from A to F) that reflect conditions ranging from optimal (free-flowing, low congestion) to poor (highly congested, low mobility).

In the context of pedestrian infrastructure, the LOS concept is particularly focused on the comfort, convenience, and safety of walking environments. Foundational works like Fruin's "Pedestrian Planning & Design" (1971) and Puškarev and Zupan's "Urban Space for Pedestrians" (1975) have significantly shaped pedestrian LOS methodologies.

Fruin introduces key concepts such as speed/density relationships, personal body dimensions, and the overall framework of pedestrian LOS. He advocates for a combined quantitative and qualitative approach to sidewalk evaluation, ensuring pedestrian facilities can handle peak periods while maintaining elements like street vendors, sidewalk cafes, and attractive shop windows to enhance pedestrian life quality [14].

Similarly, Puškarev and Zupan propose "mandatory minimum" standards for pedestrian spaces in New York City, based on the volume of building floor space. Their study establishes a quantitative link between building floor space and pedestrian circulation space and introduces a new LOS scale with levels like Open Flow, Unimpeded, Impeded, and Constrained, replacing the traditional A to F scale. They also observe that pedestrian flows in New York City often form platoons due to intersection signal control [15].

The "Handbuch für die Bemessung von Straßenverkehrsanlagen: HBS" by the Forschungsgesellschaft für Straßen- und Verkehrswesen (2005) considers pedestrian density as the most important quality characteristic, categorizing it from A to F. The key quality indicator for pedestrian traffic in linear movement

is the ability for pedestrians to move freely according to their own abilities without interference from other pedestrians. Therefore, the pedestrian traffic density, measured in persons per square meter, is the criterion for assessing the quality of traffic flow [16].

Table 4: Level of Quality established by Forschungsgesellschaft für Straßen-und-Verkehrswesen [16]

Level of Quality	Pedestrian density [pers/m ²]	
	Pedestrian movement	Waitingsituations
A	≤ 0,10	≤ 1,00
B	≤ 0,25	≤ 1,50
C	≤ 0,40	≤ 2,00
D	≤ 0,70	≤ 3,00
E	≤ 1,80	≤ 6,00
F	≥ 1,80	≥ 6,00

Table 4 categorizes pedestrian density into six levels of service, ranging from A to F. Level A denotes optimal conditions with free-flowing pedestrian movement, while Level F represents critical scenarios with extremely high density, resulting in severe difficulties for pedestrians.

Originally developed to assess vehicular traffic conditions, the LOS concept has been expanded to encompass various modes of transportation, including pedestrian and bicycle traffic. The traditional LOS framework categorizes operational conditions into six levels, from A to F, with A representing optimal conditions and F indicating severe congestion or poor performance.

In the context of urban mobility, the LOS concept is particularly valuable for assessing the capacity and efficiency of transportation networks. For instance, in pedestrian traffic, LOS is typically measured by pedestrian density, evaluating how crowded a walkway or public space is, which directly affects comfort and mobility.

While the classic LOS framework is useful for evaluating the Compatibility of robots with pedestrian traffic based on pedestrian density, it must be expanded to address the unique challenges posed by robotic Drivability. To this end, the TRACE project introduces tailored LOS evaluation scales for various aspects of robot integration, focusing on:

- **Drivability General:** Assessing the overall ease with which robots can navigate urban environments.
- **Dynamic Obstacles:** Evaluating the impact of moving objects (e.g., pedestrians, cyclists) on robot navigation.

- **Static Obstacles:** Considering the density and complexity of fixed objects (e.g., street furniture, parked cars) that robots must navigate around.

Each of these aspects is rated on a scale from A to F, where:

- **Level A** signifies very high Drivability or low obstacle density, indicating optimal conditions for robot navigation.
- **Level F** denotes no Drivability or extremely high obstacle density, representing conditions that are unsuitable for robot operations without significant modifications.

This adapted LOS approach not only supports the technical feasibility of robotic operations but also addresses the broader impacts on urban infrastructure and public spaces.

The **Compatibility Model** currently focuses on evaluating the interaction between robots and pedestrians. By utilizing outputs from the Pedestrian Demand Model, which estimates pedestrian frequencies and densities, the Compatibility Model assesses how well robots can coexist with pedestrian traffic without causing disruption. This model assigns an LOS rating based on the degree of compatibility, with Level A representing high compatibility and Level F indicating significant challenges. Future iterations of the model could incorporate additional aspects, such as cyclist interaction, infrastructure adaptability, and public perception. This would provide a more comprehensive assessment of robot integration, ensuring that the broader impacts on urban environments are fully considered.

7.3.9 Drivability Evaluation

The Drivability Model in the TRACE project assesses the ability of robotic systems to navigate urban environments effectively.

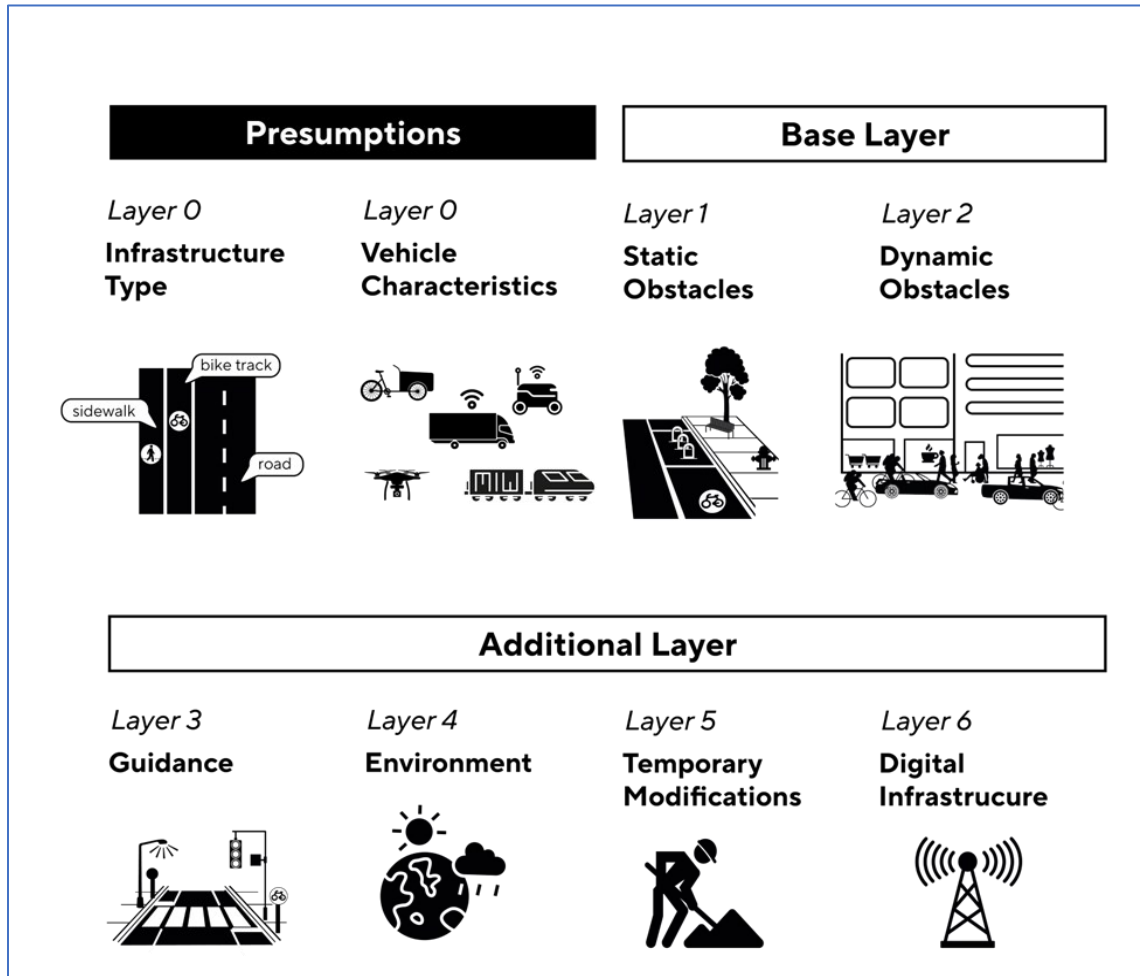


Figure 16: Drivability Evaluation

The Drivability Model utilizes a range of indicators to evaluate different layers, particularly focusing on Static Obstacles and Dynamic Obstacles. These indicators are carefully selected to measure the density, complexity, and predictability of obstacles that robots might encounter. The table of indicators provides a structured approach to understanding how different types of obstacles impact robot drivability, ensuring that the evaluation is thorough and context sensitive.

Table 5: Urban Layer Classification

Layer 1: Static Obstacles	Layer 2: Dynamic Obstacles
Seating (benches, chairs, etc)	Playgrounds
Greenery (Flowerbeds, grass, etc.)	Dog Parks
Trees	Education (schools, universities etc.)

Hydrants	Shops
Fountains	Hospitality (restaurants, cafés etc.)
Bicycle Racks	Markets
Bicycle Sharing	Administrative Offices
Waste Containers	Sport Facilities
Waste Baskets	Population
Outdoor Seating (from Cafés or Restaurants)	Religious Facilities
Steps	Train Stations
Barriers (walls, bollards, hedges etc.)	Corine Landcover
Public Transport Stations	Public Transport Stations
Sidewalk curb	
Car Street Parking	

The Drivability evaluation within the Level of Service (LOS) concept combines insights from multiple layers, particularly focusing on Dynamic Obstacles and Static Obstacles. By integrating these layers, the Drivability Model provides a comprehensive assessment of the overall ease with which robots can navigate urban environments. The LOS rating, ranging from A to F, reflects the cumulative impact of both moving and fixed obstacles on robot operations. A higher LOS rating (Level A) indicates that robots can navigate smoothly with minimal interference from obstacles, while a lower rating (Level F) suggests that the environment poses significant challenges, requiring substantial adjustments to ensure safe and efficient robot movement. This combined evaluation ensures that all relevant factors are considered, providing a robust framework for assessing robot drivability in complex urban settings.

Table 6: Drivability Levels

Level	Description
A	Very high Drivability. Robot can drive without adjustments to routing, infrastructure, or technology (sensors, algorithms, etc.).
B	High Drivability. Some minor adjustments (infrastructural or technical) need to be implemented to ensure Drivability.
C	Moderate Drivability. Some more complex situations and bottlenecks arise. Basic technical (robot), infrastructural, and routing adjustments are necessary.

D	Low Drivability. Complex situations are likely. Significant adjustments to infrastructure, technology, and routing need to be implemented.
E	Very low Drivability. Complex situations are standard and hard to predict. High technological requirements for successful operation. Major changes to infrastructure, robot, and/or routing necessary.
F	No Drivability. Due to complex dynamics or poor infrastructure, critical situations cannot be predicted. Without fundamental changes to infrastructure and the robot, Drivability is not possible.

The Level of Service (LOS) for Dynamic Obstacles within the Drivability Model assesses the impact of moving objects, such as pedestrians, cyclists, and vehicles, on robot navigation. The LOS scale ranges from A to F, where:

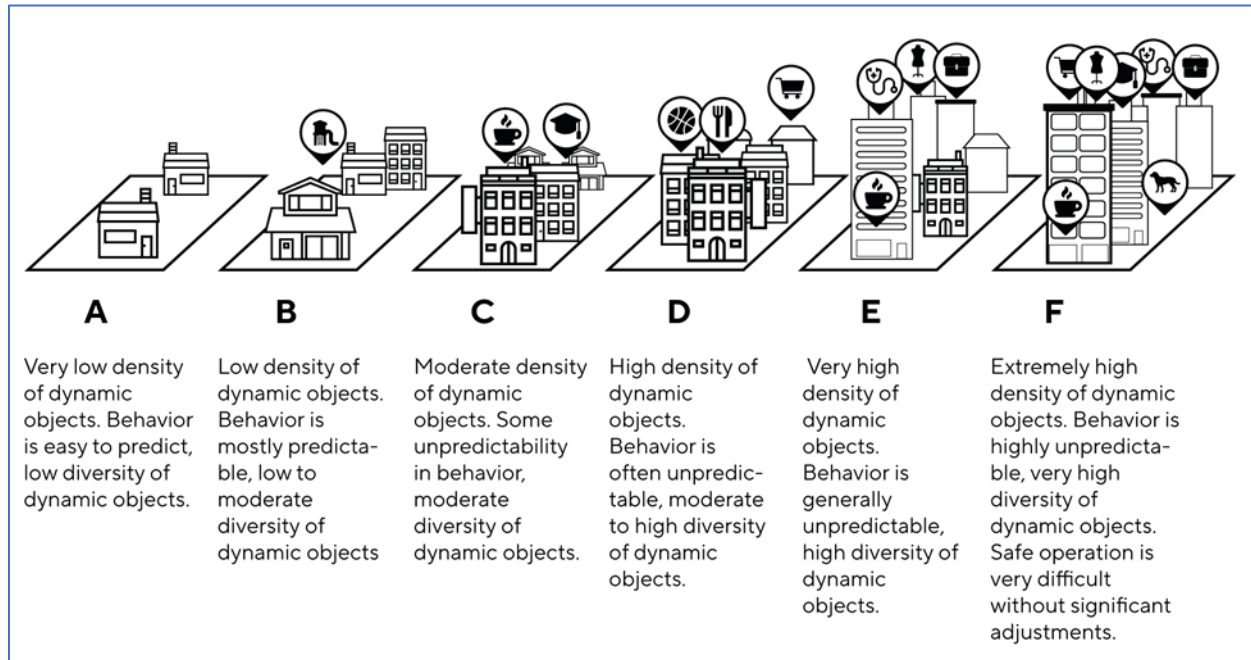


Figure 17: Level of Service (Dynamic Objects)

Table 7: Dynamic Object Density Levels

Level	Description
A	Very low density of dynamic objects. Behavior is easy to predict, low diversity of dynamic objects.
B	Low density of dynamic objects. Behavior is mostly predictable, low to moderate diversity of dynamic objects.

C	Moderate density of dynamic objects. Some unpredictability in behavior, moderate diversity of dynamic objects.
D	High density of dynamic objects. Behavior is often unpredictable, moderate to high diversity of dynamic objects.
E	Very high density of dynamic objects. Behavior is generally unpredictable, high diversity of dynamic objects.
F	Extremely high density of dynamic objects. Behavior is highly unpredictable, very high diversity of dynamic objects. Safe operation is very difficult without significant adjustments.

The Level of Service (LOS) for Static Obstacles evaluates the impact of fixed objects, such as street furniture, parked cars, and infrastructure elements, on robot navigation. The LOS scale also ranges from A to F, as seen below:

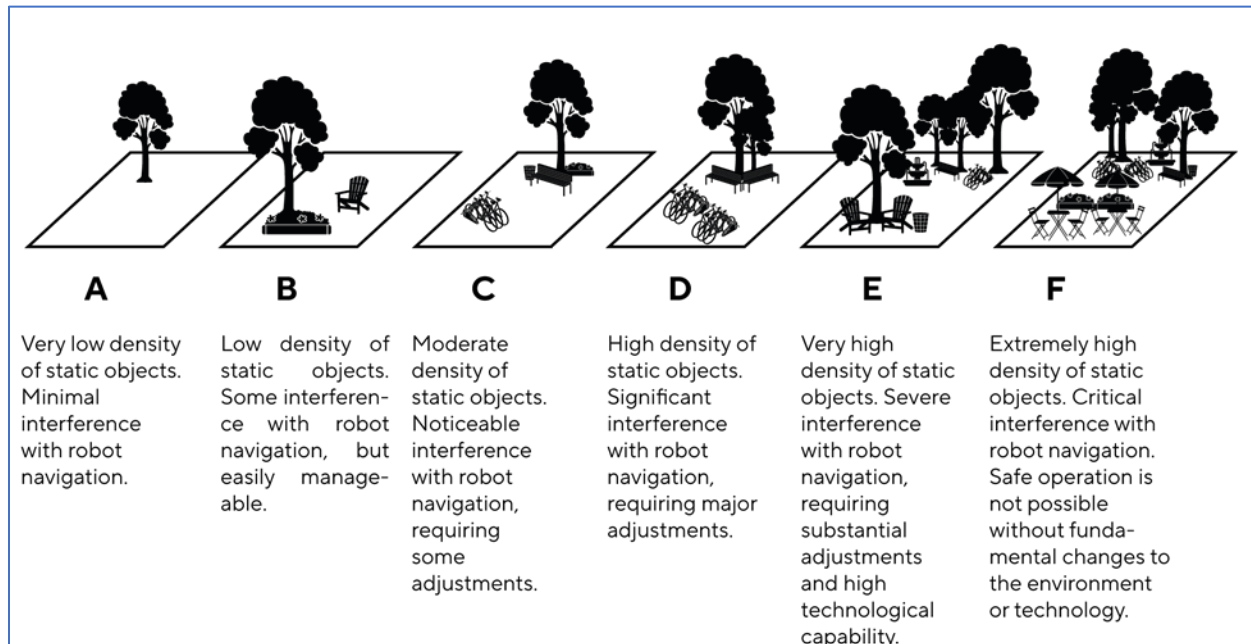


Figure 18: Level of Service (Static Objects)

Table 8: Static Object Density Levels

Level	Description
A	Very low density of static objects. Minimal interference with robot navigation.
B	Low density of static objects. Some interference with robot navigation, but easily manageable.

C	Moderate density of static objects. Noticeable interference with robot navigation, requiring some adjustments.
D	High density of static objects. Significant interference with robot navigation, requiring major adjustments.
E	Very high density of static objects. Severe interference with robot navigation, requiring substantial adjustments and high technological capability.
F	Extremely high density of static objects. Critical interference with robot navigation. Safe operation is not possible without fundamental changes to the environment or technology.

7.3.10 Compatibility

The Compatibility Model in the TRACE project is designed to evaluate how well robotic systems integrate into urban environments, focusing on their interaction with pedestrians and other urban elements.

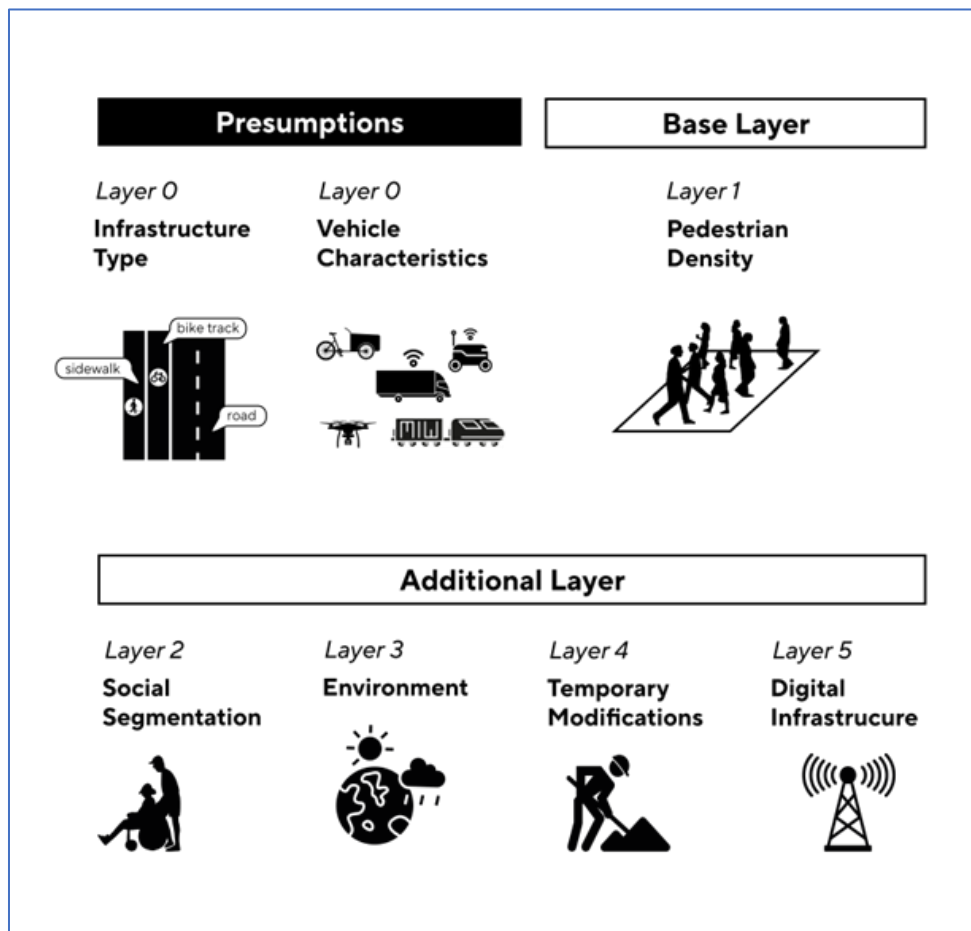


Figure 19: Compatibility Model

Pedestrian Density serves as the Base Layer of the Compatibility Model. It provides critical data on the concentration of pedestrians across different urban areas, which is essential for understanding how robots can coexist with foot traffic. By analyzing pedestrian density, this layer helps to identify potential conflicts and ensures that robots are deployed in a way that maintains pedestrian comfort and safety.

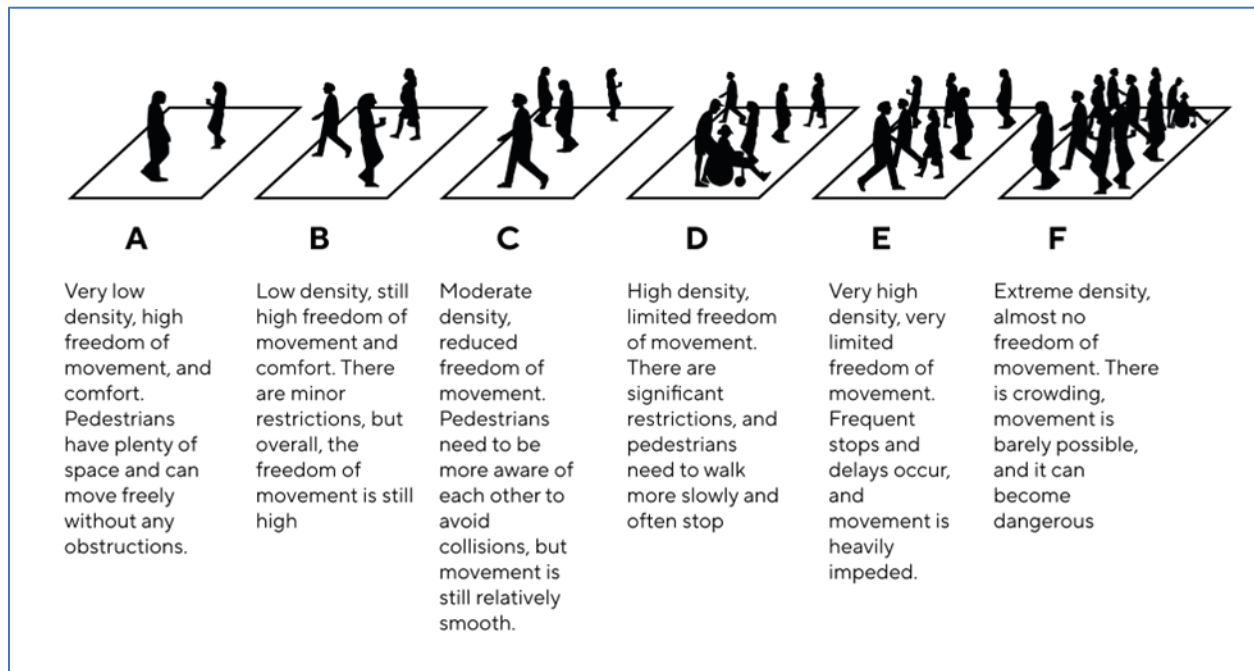


Figure 20: Pedestrian Density

7.4 Data Availability

Data availability for the evaluation can be distinguished into two main categories: supply data and demand data. Both types of data are essential for a comprehensive analysis of robot integration in urban environments.

Supply Data: Supply data provides information about the existing infrastructure and urban environment where robots will operate. This includes the layout and characteristics of the road network, sidewalks, bike lanes, and other relevant infrastructure. By understanding the supply side, we can assess whether the existing infrastructure can support the safe and efficient movement of robots.

Requirements for Supply Data:

- **Network Structure:** The overall layout and connectivity of the road network.
- **Widths:** The width of streets, sidewalks, and other relevant pathways.
- **Geometries:** Detailed geometric properties of the network elements.
- **Infrastructure Types (IS type):** Types of infrastructure present, such as bike lanes, pedestrian zones, etc.

7.4.1 Supply Data Sources

Table 9: Data Sources for Urban Infrastructure Assessment

Source	Description	Advantages	Limitations
OpenStreetMap (OSM)	OSM is a collaborative project to create a free editable map of the world. It includes a wide range of data on network structure, road widths, geometries, and infrastructure types.	Comprehensive coverage, frequently updated, open and free to use.	Data quality and detail can vary significantly by region.
Aerial Imagery	High-resolution images captured from aircraft or satellites, providing detailed visual information about the physical characteristics of urban infrastructure.	High level of detail and accuracy, useful for extracting geometric properties and verifying existing data.	Requires significant processing and interpretation, can be resource intensive.
Local Government Data	Data provided by municipal or local government bodies, including detailed information on road networks, sidewalks, and other infrastructure.	Highly accurate and specific to the locality, often includes official measurements and classifications.	Availability varies by location, may not be easily accessible or openly available.
Open Data Platforms	Platforms that provide access to various datasets made available by governments, organizations, and other entities.	Often freely available and covers a wide range of data types, including infrastructure and network data.	Quality and completeness can vary, and data may require significant cleaning and processing.

Example Sidewalk Width: In the city of Ljubljana, the sidewalk width is only 5% of the street network mapped and not available on other Open Data Platforms. This means that for our analysis we rely either

on Local Government Data from the Municipality of Ljubljana or Tools for an automatic analysis of aerial imagery.

Demand Data: Demand data captures the volume and patterns of traffic, including pedestrians, cyclists, and vehicles. This data helps us understand how different user groups interact with the infrastructure and where potential conflicts, or capacity issues might arise. By analyzing demand data, we can identify peak times, high-traffic areas, and the specific needs of different modes of transportation.

7.4.2 Demand Data Sources

Table 10: Demand Data Sources

Source	Description	Advantages	Limitations
Counts with Extrapolation	Direct counts of pedestrians, cyclists, and vehicles, extrapolated to broader areas to estimate overall traffic volumes.	Provides accurate, localized data and can be tailored to specific study areas.	Labor-intensive, may not capture temporal variations accurately without continuous monitoring.
Pedestrian Traffic Models	Specific models designed to estimate pedestrian traffic volumes based on various input parameters such as land use, population density, and attraction points.	Tailored to pedestrian behaviour, can provide detailed and context-specific insights.	Requires comprehensive input data, can be complex to develop and validate.
Traffic Demand Models	General models used to estimate traffic volumes for different modes of transportation, based on factors like trip generation, distribution, and modal split.	Well-established in transportation planning, can provide comprehensive traffic estimates.	Less effective for pedestrian traffic without significant adjustments, may require extensive data for calibration.
User-Generated Data (e.g., STRAVA)	Data from the STRAVA application, which tracks the movement patterns of its users,	Provides real-time insights into movement patterns, covers a wide	Not representative of the entire population, primarily used by specific user groups

	primarily cyclists and runners.	range of users and locations.	(e.g., athletes, enthusiasts). No usage permit for TRACE-Project now.
Local Government Data	Traffic counts and surveys conducted by local government bodies, including data on pedestrian, cyclist, and vehicle volumes.	Highly accurate, often includes official counts and surveys tailored to local conditions.	Availability varies by location, may not cover all necessary modes or times.

7.5 Direct vs. Indirect Representation of Indicators

Indicators can be represented either directly or indirectly by various datasets. Understanding the difference between these approaches and knowing when to use each is crucial for comprehensive and accurate analysis.

Table 11: Data Representation Types

Representation Type	Description	Advantages	Limitations
Direct Representation	Use of data that explicitly measures the indicator of interest. This approach is straightforward and often preferred when high-quality, specific data is available.	<p>Accuracy: Provides precise and reliable measurements of the indicator.</p> <p>Clarity: Easy to interpret and directly applicable to the analysis.</p>	<p>Data Availability: Might not always be available or feasible to collect, especially for more nuanced or less commonly monitored indicators. Cost: Resource-intensive in terms of time, money, and effort.</p>
Indirect Representation	Using proxy data or related indicators to infer the value of the primary indicator of interest. Useful when direct data is unavailable or difficult to obtain.	<p>Feasibility: Proxy data is often more readily available and easier to collect than direct measurements.</p> <p>Resource-Effectiveness: Generally, less expensive and time-consuming to obtain.</p>	<p>Accuracy: May introduce uncertainties and require assumptions, potentially reducing the precision of the measurement.</p> <p>Complexity: Interpreting proxy data can be more complex and may require sophisticated models</p>

			to accurately estimate the primary indicator.
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Combining direct and indirect representation of indicators allows for a robust and flexible evaluation framework. Direct data provides precise measurements, while indirect data fills in gaps where direct measurements are unavailable. This comprehensive approach ensures that the integration of robots into urban environments is thoroughly assessed, considering all relevant factors to develop efficient, safe, and socially acceptable solutions for future urban mobility. See *Annex A* for Indicator Availability.

7.6 Outlook and Pilot Sites

The Suitability framework can serve pilot testing initiatives through the generation of a network system mapping analysis, using local-specific criteria to indicate where it is most suitable for vehicles to operate and their impact on the local conditions. Once pilot testing begins, trial results will be monitored to further develop the Suitability framework and will factor lessons learned from the demonstrators. In addition to this, a freight demand model will be assessed to determine how future deployments could be scaled, expected impacts to traffic and what kind of infrastructural adjustments could enhance potentials for logistics (Drivability) as well as for citizens (Compatibility).

Following the pilot testing, the framework will evolve based on these insights and lessons learned gathered. This evolution involves:

- **Data Analysis:** Analysing collected data to identify framework modifications, trends, successes, and areas for improvement.
- **Feedback Integration:** Incorporating feedback from participants and stakeholders to refine processes and procedures.
- **Iterative Refinement:** Making iterative adjustments to the framework to enhance its effectiveness and address any identified gaps or issues.
- **Freight Demand:** The model can be used not only to reveal local freight demand conditions, but to better understand the number of dynamic sidewalk obstacles from the perspective of the vehicle.
- **Infrastructure recommendations:** Recommendations to enhance the current state of infrastructure will be considered and noted to improve current Suitability, when needed.
- **Scalability & replicability Planning:** Adjusting the framework to support scalability and replicability, ensuring it can be effectively applied in broader or different contexts.

This iterative approach ensures the framework remains dynamic and responsive to changing conditions, continuously improving in accuracy, efficiency, and relevance. The development of the Suitability framework will not only facilitate the Compatibility of robots, in terms of their impact on the usability of public spaces, and the Drivability, in terms of the robots’ situational navigability of street spaces, but it allows for a broader discussion on last-mile delivery including the assessment of other delivery vehicles,

future implications, potential developments, its broader significance and recommended adaptations to existing infrastructure.

8 FUTURE WORK: SUITABILITY FRAMEWORK

- **Iterative Framework Development:** The framework is to be systematically tested, with iterative improvements made based on feedback and results from the pilot phase, ensuring continuous refinement.
- **Calculation Rule Development:** Further work will focus on summarizing individual assessments into indices and deriving a Level of Service (LoS) value.
- **GIS Implementation:** Future efforts will include the integration of the framework into GIS systems, facilitating spatial analysis.
- **Validation Process:** Validation of the framework will be conducted both with vehicle operators such as Robotnik, the platform and through on-site testing.
- **Application to other Connected and Autonomous Vehicles (CAV's):** The Suitability framework can be applied to other vehicles, like cargo delivery bikes, also being tested in the TRACE project (Figure 21).
- **Discussion Point:** Exploring implementation options for using suitability as spatial resistance, potentially influencing routing costs.
- **Policy and Planning Applications:** Policymakers and public entities may leverage the Suitability framework to identify optimal use cases for specific areas and street spaces, as well as address hurdles to implementation.

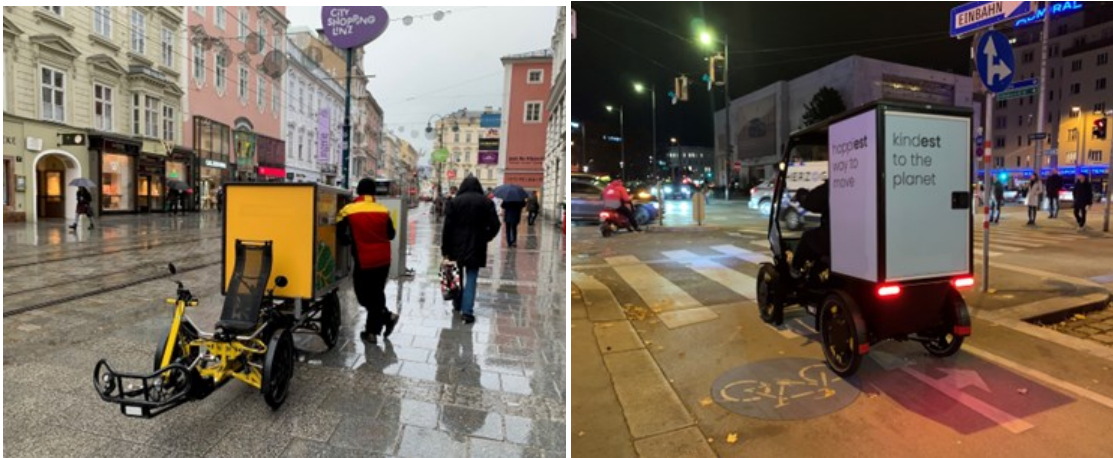


Figure 21: Last Mile delivery vehicle on sidewalk in Linz, Austria (left) & Cargo delivery vehicle in bicycle lane in Vienna, Austria (right) [10].

9 VALIDATION OF REQUIREMENTS

The validation of requirements will ensure that the developed solutions align with the identified needs and constraints, as well as with the project's overall objectives. This section outlines the strategies and methodologies employed to validate the functional and non-functional requirements of the TRACE system, ensuring that they meet the expected standards and deliver the desired outcomes. The validation of requirements in a comprehensive and iterative process. By employing rigorous testing, stakeholder engagement, and continuous feedback loops, the project ensures that the TRACE system is robust, reliable, and ready for real-world deployment. The successful validation of requirements is key to achieving the project's goals of enhancing logistics efficiency, safety, and sustainability across the European transportation network

9.1 Validation of Objectives

The primary objectives of the requirements validation process in the TRACE project are:

Ensuring Compliance: To confirm that all developed solutions comply with the functional and non-functional requirements identified during the requirements analysis phase.

Mitigating Risks: To identify and address potential risks early in the development process, ensuring that the system operates reliably under various conditions.

Aligning with Stakeholder Expectations: To validate that the system meets the needs and expectations of all stakeholders, including end-users, regulatory bodies, and project partners.

Verifying Performance: To ensure that the system's performance aligns with the defined key performance indicators (KPIs) and meets the required safety, reliability, and efficiency standards.

9.2 Validation Methodology

The validation process for the TRACE project is structured around several key methodologies that are applied throughout the development and deployment phases:

9.2.1 Testing and Simulation

Unit Testing: Each component of the TRACE system is subjected to unit testing to verify that it performs its intended function correctly. This includes testing individual software modules, hardware components, and communication protocols.

Integration Testing: Once individual components have been validated, they are integrated, and the system is tested. This ensures that the components work together seamlessly and that the interfaces between them function as expected.

Simulation: Advanced simulation environments are used to model real-world scenarios and test the system's performance under various conditions. This is particularly important for validating the safety and reliability of autonomous systems and the robustness of the communication infrastructure.

9.2.2 Pilot Testing

Demonstrators: The TRACE project includes pilot tests in Greece, Italy, and Slovenia, where the system is deployed in real-world settings. These demonstrators serve as critical validation points, allowing the project team to observe the system's performance in operational environments and gather real-time data.

Field Trials: During the pilot phase, field trials are conducted to validate the system's functionality in live environments. These trials involve key stakeholders and end-users, providing valuable feedback on system usability, reliability, and effectiveness.

9.2.3 Structured Stakeholder Validation Methodology

The TRACE implements a structured and stakeholder-informed methodology for requirement validation, integrated directly into the pilot demonstration phase. Before each pilot, a set of predefined functional and non-functional requirements have been assessed in real-world conditions. To ensure that these requirements meet stakeholder expectations, a standardized questionnaire will be distributed to relevant actors, including logistics service providers and end-users, immediately following each demonstration. Respondents will be asked to rate their satisfaction with each system requirement on a 1–5 scale.

A requirement is considered validated only if it receives a rating of 5 (full satisfaction) across the stakeholder group. If any requirement falls short of this threshold, the demonstrator is required to propose and implement a countermeasure and repeat the demonstration until all requirements are satisfactorily met. This closed-loop feedback mechanism ensures that validation is not only based on technical success but also on end-user appreciation and real-world usability. This method will be applied consistently across all pilot sites and provides an auditable, repeatable process that ties system validation directly to stakeholder acceptance.

9.3 Stakeholders Feedback

User Acceptance Testing (UAT): End-users and other stakeholders are involved in UAT to validate that the system meets their needs and expectations. This process includes usability testing, feedback sessions, and adjustments based on user input.

Surveys and Interviews: Structured surveys and interviews are conducted with stakeholders to gather qualitative data on their experiences with the system. This feedback is used to refine the system and ensure it meets stakeholder requirements.

9.4 Compliance Audit

Regulatory Compliance: The TRACE system is subjected to audits to ensure compliance with relevant regulations, including safety, data protection, and environmental standards. These audits are conducted by independent bodies to validate that the system adheres to all legal requirements.

Standards Compliance: The system is also evaluated against industry standards for safety, reliability, and interoperability. This ensures that the TRACE system meets the highest quality benchmarks.

9.5 Key Performance Indicators (KPIs)

The validation process is closely tied to the evaluation of key performance indicators (KPIs), which are defined to measure the success of the TRACE system. These KPIs include:

Operational Efficiency: Measured by the reduction in transportation costs, energy consumption, and time required for logistics operations.

Safety Metrics: Includes the number of incidents or safety violations, the effectiveness of autonomous vehicle operations, and compliance with safety standards.

System Reliability: Assessed through system uptime, error rates, and the ability to recover from failures.

Environmental Impact: Measured by reductions in emissions, fuel consumption, and overall environmental footprint.

User Satisfaction: Evaluated through user feedback and satisfaction surveys, focusing on the ease of use, reliability, and effectiveness of the system.

9.6 Validation Outcome

The outcomes of the validation process include:

- **Verified Compliance:** Confirmation that the system meets all functional and non-functional requirements, regulatory standards, and stakeholder expectations.
- **Identified Improvements:** The validation process helps identify areas where the system can be improved, leading to refinements in both technology and operational practices.
- **Risk Mitigation:** Early identification and mitigation of potential risks ensure that the system is robust and reliable under various conditions.
- **Stakeholder Confidence:** Successful validation builds confidence among stakeholders, ensuring their continued support and engagement with the project.

9.7 Continuous Validation and Feedback Loop

The TRACE project adopts a continuous validation approach, where feedback from each phase of testing and deployment is used to refine and improve the system. This iterative process ensures that any issues are promptly addressed and that the system evolves to meet emerging requirements and challenges.

9.8 Continuous Monitoring:

Real-Time Monitoring: The system is continuously monitored during pilot deployments, with data collected on performance metrics, user interactions, and environmental factors.

Adaptive Testing: The validation process is adaptive, allowing for ongoing testing and adjustments as new data and feedback are received.

9.9 Iterative Refinement:

Feedback Integration: Stakeholder feedback and validation results are integrated into subsequent development cycles, ensuring that the system remains aligned with user needs and project objectives.

Ongoing Updates: The TRACE system is regularly updated based on validation findings, with improvements deployed to enhance performance, safety, and reliability.

10 OTHER ISSUES

While the TRACE project has made significant progress towards its goals, several issues may arise that require attention. These issues, though not insurmountable, present challenges that must be addressed to ensure the successful completion and implementation of the project. Below is a summary of the key issues encountered:

10.1 Technical Integration Challenges

Description: Integrating various technical components from different partners has proven more complex than initially anticipated. TRACE involves multiple cutting-edge technologies, including autonomous vehicles, IoT sensors, blockchain systems, and cloud computing platforms. Ensuring seamless interoperability between these components has required additional time and resources.

Impact: Delays in integration can affect the project timeline, particularly in the deployment of demonstrators. It also poses risks to the system's reliability and performance during real-world operations.

Mitigation Strategies:

- Establishing a dedicated technical task force to oversee integration efforts.
- Implementing regular cross-partner technical reviews to identify and resolve integration issues early.
- Utilizing modular testing approaches to isolate and address specific integration challenges.

10.2 Regulatory Compliance

Description: Navigating the complex regulatory landscape across different countries has been challenging. TRACE must comply with a variety of regulations related to transportation, data privacy, environmental protection, and autonomous systems. Differences in national regulations have sometimes led to delays in obtaining necessary approvals.

Impact: Regulatory hurdles could delay the deployment of demonstrators and limit the scalability of the TRACE solutions across Europe.

Mitigation Strategies:

- Engaging legal experts with knowledge of EU and national regulations to ensure compliance.
- Proactively communicating with regulatory bodies to clarify requirements and obtain approvals in a timely manner.
- Developing a compliance framework that can be adapted to different regulatory environments.

10.3 Stakeholder Coordination

Description: Coordinating the activities of a diverse group of stakeholders, including project partners, local authorities, and end-users, has been complex. Differences in priorities, expectations, and operational cultures have sometimes led to misalignments in project activities.

Impact: Poor coordination can lead to inefficiencies, miscommunication, and delays in project execution.

Mitigation Strategies:

- Enhancing communication channels between stakeholders to ensure clarity and alignment on project goals.
- Conducting regular stakeholder meetings to review progress, address concerns, and realign efforts.
- Developing a stakeholder engagement plan that includes clear roles, responsibilities, and timelines.

10.4 Data Management and Security

Description: Managing the large volumes of data generated by the TRACE system, while ensuring its security and compliance with GDPR, has been a significant challenge. The project involves sensitive data, including personal information and commercial transactions, which must be protected against breaches and unauthorized access.

Impact: Data management and security issues could undermine stakeholder trust and lead to legal and financial repercussions.

Mitigation Strategies:

- Implementing robust data encryption and access control measures across all platforms.
- Regularly auditing data management practices to ensure compliance with GDPR and other relevant regulations.
- Training project staff and partners on data protection policies and best practices.

10.5 Resource Allocation and Budget Constraints

Description: The project has encountered challenges in resource allocation, particularly in balancing the budget across different work packages. Some activities have required more resources than initially planned, leading to budget constraints in other areas.

Impact: Budget constraints could limit the scope of certain project activities, particularly in the deployment and scaling of demonstrators.

Mitigation Strategies:

- Reassessing project budgets and reallocating resources based on priority needs.
- Seeking additional funding sources or reallocating funds from less critical activities.
- Implementing cost-saving measures, such as optimizing project timelines and reducing operational overheads.

10.6 Environmental and Social Impact

Description: While TRACE is designed to reduce environmental impact, the deployment of new technologies and infrastructure has raised concerns among local communities and environmental groups. Issues such as increased traffic, noise, and potential disruption to local ecosystems have been highlighted.

Impact: Negative perceptions of the project could lead to resistance from local communities and stakeholders, potentially delaying or halting project activities.

Mitigation Strategies:

- Conducting environmental impact assessments for all demonstrator sites to identify and mitigate potential negative effects.
- Engaging with local communities through public consultations to address concerns and incorporate feedback into project planning.
- Promoting the environmental and social benefits of the TRACE project to build support and goodwill among stakeholders.

10.7 Unexpected External Factors

Description: The project has faced unexpected external factors, such as the ongoing impacts of the COVID-19 pandemic and geopolitical tensions, which have disrupted supply chains, labor availability, and international collaboration.

Impact: These external factors have the potential to cause delays, increase costs, and limit the availability of necessary resources and expertise.

Mitigation Strategies:

- Developing contingency plans for key project activities to mitigate the impact of external disruptions.
- Leveraging remote collaboration tools to maintain progress despite travel and logistical challenges.
- Adjusting project timelines and deliverables to accommodate delays caused by external factors.

10.8 Lessons Learnt and Future Considerations

The challenges encountered in the TRACE project have provided valuable lessons up to now that will inform future project activities:

Flexibility and Adaptability: The ability to adapt to changing circumstances and unexpected challenges is crucial for project success. Flexibility in project planning and execution allows for adjustments that can mitigate the impact of unforeseen issues.

Proactive Risk Management: Identifying potential risks early and developing mitigation strategies in advance can help prevent small issues from becoming significant obstacles.

Stakeholder Engagement: Continuous and transparent engagement with stakeholders is essential to maintaining support and alignment, particularly in complex, multi-partner projects.

By addressing above issues proactively down the road, and by learning from the challenges encountered, TRACE can continue to progress towards its goals, ensuring the successful development and deployment of innovative logistics solutions across Europe.

11 CONCLUSIONS

D2.4 represents a significant milestone in TRACE, providing a comprehensive framework for the development, validation, and deployment of advanced logistics solutions. This report has outlined the critical elements necessary for the successful implementation of TRACE technologies, including stakeholder engagement, requirements analysis, demonstrator development, and the validation of requirements.

11.1 Summary of Key Findings

Throughout the report, several key findings have emerged:

Stakeholder Engagement: Effective engagement with a diverse group of stakeholders has been essential in shaping the project's direction and ensuring that the developed solutions meet the needs and expectations of all parties involved. The engagement process has facilitated the refinement of requirements, enhanced collaboration, and increased stakeholder buy-in, which are critical for the project's success.

Requirements Analysis: The thorough analysis of both functional and non-functional requirements has established a solid foundation for TRACE. This analysis ensures that the system's design and implementation align with the project's objectives and comply with relevant regulatory and safety standards. The focus on sustainability, safety, and innovation has guided the development of solutions that address the challenges faced by the logistics industry.

Demonstrator Implementation: The Greek, Italian, and Slovenian demonstrators have been instrumental in testing and validating the TRACE technologies in real-world settings. These pilots have provided valuable insights into the practical applications of the developed solutions and highlighted areas for further refinement and improvement.

Validation of Requirements: The comprehensive validation process, including testing, simulation, and stakeholder feedback, has confirmed that TRACE solutions meet the defined requirements and perform effectively under various conditions. The validation process has also helped identify potential risks and areas for improvement, ensuring that the system is robust, reliable, and ready for deployment.

Challenges and Mitigation: The project has encountered several challenges, including technical integration, regulatory compliance, and stakeholder coordination. By addressing these issues proactively, TRACE has been able to mitigate potential risks and continue progressing towards its goals. The lessons learned from these challenges will inform future project activities and contribute to the overall success of the project.

11.2 Contributions to the Logistics Industry

TRACE is poised to make significant contributions to the logistics industry by introducing innovative solutions that enhance efficiency, reduce environmental impact, and improve safety. The integration of advanced technologies, such as autonomous vehicles, IoT sensors, and blockchain, represents a forward-

thinking approach to modern logistics challenges. The project's focus on sustainability aligns with global efforts to reduce carbon emissions and promote greener logistics practices.

Moreover, the successful implementation of the TRACE system in real-world settings through the demonstrators provides a valuable blueprint for future logistics operations. The lessons learned and best practices developed during this project can be applied to other regions and industries, further expanding the impact of TRACE.

11.3 Future Outlook

As TRACE moves forward, the focus will shift to the full-scale deployment of the developed solutions, continued refinement based on feedback and validation results, and the exploration of new opportunities for innovation. The project's success in the pilot phases has laid the groundwork for broader adoption and scalability, positioning TRACE as a leader in the future of sustainable and efficient logistics.

The continued engagement with stakeholders, ongoing validation, and proactive management of emerging challenges will be critical to ensuring the long-term success of the TRACE project. As the project progresses, it will remain committed to its core objectives of enhancing logistics operations, promoting sustainability, and driving innovation in the industry.

11.4 Final Remarks

In conclusion, D2.4 report demonstrates the TRACE commitment to advancing the logistics industry through innovative, sustainable, and safe solutions. The work completed thus far has established a strong foundation for the project's future activities, ensuring that TRACE remains at the forefront of modern logistics. The project's continued success will depend on the collaborative efforts of all stakeholders, the effective management of challenges, and the unwavering pursuit of excellence in every aspect of the project.

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Annex A

1. Suitability Framework Terms and Definitions

Drivability: looks at where it is best for the vehicle to navigate with a focus on indicators that consider the infrastructure used to operate the vehicle, the technical complexity of the environment and the vehicle itself. The Operational Design Domain (ODD) and the uniqueness of the use case and scenario in question, presents different levels of complexity for consideration (e.g., infrastructure and environmental conditions).

Compatibility: looks at where the vehicle could operate while generating the least negative impact on the current public space and infrastructure conditions for city inhabitants. Compatibility could use similar indicators as Drivability but utilizes them more from a quality-of-life perspective. For example, one might ask, how can we operate a delivery robot on a sidewalk while still maintaining safety and comfort for pedestrians? Is it optimal for deliveries to occur during less traffic times, like during the night, to reduce the chance of potential conflicts or reduce noise for residents?

Suitability: is the combination or overlapping of both Drivability and Compatibility, with achieving positive suitability as the aim. A Suitability analysis could determine that an area may be positive for a delivery robot to operate from a Drivability perspective but not from a Compatibility perspective. This may be due to the infrastructure conditions being favourable to drive but the likelihood for conflict with pedestrians being high. A Suitability analysis outcome is positive when both the Drivability and Compatibility are acceptable.

Data Sets: Data collected and used in Geographic Information System (GIS) for the Suitability analysis. Data sets are collected from Open Street Maps (OSM), stakeholders in the TRACE project and from public sources.

Direct & Indirect Indicators: Indicators are the result of taking the data sets collected and using them to provide additional information in the context of determining Suitability. Direct indicators are those that are directly related to either Drivability or Compatibility, with their impact on the analysis being generally known but dependent on weighting. Indirect indicators support the determination of Drivability and Compatibility, but their impact can be ambiguous but still support the determination of Suitability, with the need to be assigned a weighting category remaining relevant.

Weighting: is a scoring given to indicators establishing their importance amongst other indicators and allowing compensation to occur, especially for indicators that may distort the outcome. A weighting score is determined based on the indicators relevance and appropriateness with respect to Drivability and Compatibility.

Layer/Segment: is a distinct category within the framework used to evaluate the Drivability and Compatibility by organizing them into specific indicators. Base Layers provide fundamental data for assessing basic feasibility, while Additional Layers offer supplementary insights to refine and optimize the evaluation process.

Index: is a composite measure that combines the layers of Compatibility, Drivability, and Suitability. This combined index, which can be additive, multiplicative, or take other forms, quantifies the overall Drivability, Compatibility, or Suitability of a street segment.

Crossings: A point where two or more streets and/or paths cross one another.

Routing: The process for determining the best or most appropriate path within a network for a delivery robot based on results from the Suitability analysis and the work in Work Package 4 of TRACE.

Street Network: The interconnection of paths (e.g., sidewalks, bicycle paths, street hubs and nodes) to form a larger network and to facilitate the movement of people and vehicles.

Network Graph: used in GIS analysis, is a representation of a transportation network where nodes represent intersections and endpoints, and edges depict various routes such as roads, sidewalks, bicycle paths, etc. It is used to analyse and model connectivity, accessibility, and movement patterns within a geographic area.

Level of Service (LOS): is a measure of the quality and comfort of pedestrian environments based on pedestrian density. It uses a grading scale, often from A to F, where LOS A indicates a spacious and unobstructed pedestrian experience, and LOS F signifies high congestion and limited movement ease.

Freight Demand Model: used to estimate the number of deliveries in street sections and the quantitative potential for robot deliveries for the Last Mile. The models' results are a determining factor of Compatibility and understanding the current and future potential freight demand.

1. Suitability Framework Indicator Availability

zoning category	Corine Landcover	+
population	EuroStat	o
slope	EuroStat	+
elevation	EuroStat	+
sidewalk width	Missing Data	-
bicycle lane width	Missing Data	-
bicycle track width	Missing Data	-
shared path width	Missing Data	-
pedestrian only width	Missing Data	-
on-street, car parking space width	Missing Data	-

number of travel lanes	Missing Data	-
street width	Missing Data	-
quality of intersection crossings	Missing Data	-
path markings	Missing Data	-
building type	Missing Data	-
gas station	Missing Data	-
motor vehicle volume	Missing Data	-
bicycle volume	Missing Data	-
aerial vehicle volume	Missing Data	-
presence of construction zone or special events	Missing Data	-
scooter rental spot	Missing Data	-
precipitation	Missing Data	-
temperature	Missing Data	-
wind speed	Missing Data	-
average speed vehicles	Missing Data	-
average speed bicycles	Missing Data	-
average speed pedestrians	Missing Data	-
building height	Missing Data	-
overhead lines	Missing Data	-
communication tower	Missing Data	-
no fly zones	Missing Data	-
freight volume	Modeled	
pedestrian volume	Modeled	
pedestrian density	Modeled	
conventional sidewalk	OpenStreetMap	+
separated bike-only track	OpenStreetMap	+
shared path (mixed active users: peds, scooters, bikes)	OpenStreetMap	+

street (cars, heavy vehicles, bicycles)	OpenStreetMap	+
street with a bike lane	OpenStreetMap	+
pedestrian only (street or zone)	OpenStreetMap	+
surface quality	OpenStreetMap	-
zebra crossing	OpenStreetMap	+
signalized intersection	OpenStreetMap	+
signalized crossing for pedestrians	OpenStreetMap	+
pedestrian and bike path junction	OpenStreetMap	+
crossing need (number of crossings ratio)	OpenStreetMap	
streetlights	OpenStreetMap	+
rail crossing	OpenStreetMap	+
step or curb	OpenStreetMap	-
barrier	OpenStreetMap	o
speed bump	OpenStreetMap	o
train station	OpenStreetMap	+
public transport stop	OpenStreetMap	+
parking lot	OpenStreetMap	o
on street parking	OpenStreetMap	o
garage parking	OpenStreetMap	o
bicycle parking	OpenStreetMap	o
playgrounds	OpenStreetMap	+
dog parks	OpenStreetMap	+
schools	OpenStreetMap	+
shops, markets & restaurants	OpenStreetMap	+
administrative offices	OpenStreetMap	o
sport facilities	OpenStreetMap	+
religious facilities	OpenStreetMap	+

building count	OpenStreetMap	+
plant beds	OpenStreetMap	+
trees	OpenStreetMap	+
fire hydrant	OpenStreetMap	o
fountains	OpenStreetMap	+
bike rack count	OpenStreetMap	+
bike rental spot	OpenStreetMap	+
waste container	OpenStreetMap	o
benches	OpenStreetMap	o
waste container	OpenStreetMap	o
waste basket	OpenStreetMap	o
max speed limit	OpenStreetMap	o

Annex B

Table 12: Platform Requirements Validation – Internal Stakeholders

Requirement ID	Requirement Description	Type	Greece	Italy	Slovenia	Evaluation
PLT-FUN-001	The optimization of empty trips and containers should integrate with HoReCa, micromobility, food delivery, and real-time deliveries on a consolidation basis, considering all different channels (possible clients) present in the operational area	Functional				
PLT-FUN-002	The optimization of loading (number of parcels) per cargo bike or platoon shall be based on productivity KPIs and working shifts	Functional				
PLT-FUN-003	The platform shall take into consideration various constraints related to the deliveries (e.g., restrictions based on time, vehicle types, vehicle fuel, total weight, total length, maximum time in delivery area, emission standards, city entry points, etc	Functional	x	x	x	This requirement is based on analysis on how local governments limit logistics and traffic. To align with green transition/carbon neutral goals, cities are imposing various restrictions, which are listed in the requirement
PLT-FUN-004	The platform should be future-proofed for additional restrictions such as zero-emission zones, tighter delivery time zones, restriction of delivery zones and their replacement with delivery lockers, allowing deliveries only to vehicles at full capacity, the establishment of consolidation centres and the introduction of new delivery methods	Functional			X	
PLT-FUN-005	The system should select a wider time window for the availability of the package picker (1-2 hour time window) within which the delivery is made, for both B2B and B2C deliveries.	Functional			x	
PLT-FUN-006	TRACE platform should enable the planning of necessary preventive measures to prevent or mitigate the negative impacts of future events	Functional	x		x	
PLT-FUN-007	TRACE platform may integrate seamlessly with other systems and modules within the transportation	Functional		x		

	ecosystem, such as scheduling, routing, and tracking systems					
PLT-FUN-008	TRACE platform shall dynamically adjust resource allocations, such as vehicle assignments or route schedules, based on real-time performance data and predictive insights to optimize efficiency and responsiveness	Functional	x	x	x	
PLT-FUN-009	TRACE platform shall include functionalities to track and report the emissions associated with each delivery	Functional	x	x	x	Based on the T2.2 questionnaire, the majority of logistic companies, who haven't implemented carbon footprint calculation, are either planning or are interested in this solution.
PLT-FUN-010	TRACE platform shall include tools and frameworks for automated testing, ensuring component quality and compatibility.	Functional	x	x	x	
PLT-FUN-011	TRACE platform shall offer well-documented APIs for integration with other applications and services, enabling custom development and automation	Functional	x	x	x	Based on T2.2 questionnaire, the majority (63 %) of respondents use custom developed software. This supports the need for easy integration
PLT-FUN-012	TRACE platform shall support interoperability with various hardware devices, software systems, and external APIs to facilitate seamless integration.	Functional	x	x	x	
PLT-FUN-013	TRACE platform should accommodate KPIs for measuring the performance of the functionalities	Functional	x	x	x	
PLT-FUN-014	TRACE platform should accommodate notifications and alerts (e.g., SMS, etc)	Functional			x	Based on the T2.2 questionnaire, the most desired communication channel is web dashboard (71 %), followed by mobile app (54 %), email (38 %), and SMS (33 %). 17 % responded API.
PLT-FUN-015	TRACE platform should accommodate reporting and analytics functionalities	Functional	x	x	x	

PLT-FUN-016	TRACE platform should accomodate route optimization functionalities	Functional	x	x	x	Based on T2.2 questionnaire, traffic congestion (4.6/5) and delivery time windows (4.4/5) are a highly-ranked challanges during delivery. Additionally, 67 % of respondents believe routing has the highest potential for optimization of resources.
PLT-FUN-017	TRACE platform should accomodate user authentication and authorization	Functional	x	x	x	
PLT-FUN-018	TRACE platform should allow for easy configuration and customization of individual components without affecting the entire platform	Functional		x	x	
PLT-PRM-001	TRACE may include provisions for support and training for staff, users, and technical personnel	Non-Functional	x	x	x	
PLT-PRM-002	TRACE platform shall be compatible with cloud infrastructure to leverage scalability, flexibility, and cost-effectiveness.	Non-Functional	x	x	x	
PLT-PRM-003	TRACE platform shall be extensible to easily incorporate new features, modules, or functionalities in the future.	Non-Functional	x	x	x	
PLT-PRM-004	TRACE platform should be compatible with other tools, databases, and cloud services to support seamless data exchange and integration.	Non-Functional		x		Based on T2.2 questionnaire, 38 % of the respondents use Cloud software as a service solution, supporting the need for easy integration.
PLT-PRM-005	TRACE platform should be designed with fault tolerance mechanisms to handle failures decently and ensure system resilience.	Non-Functional	x	x	x	
PLT-PRM-006	TRACE platform should support Limited sharing of business-sensitive data	Non-Functional				
PLT-PRM-007	TRACE shall consider availability, including load balancing and designing for single/multiple points of failure	Non-Functional	x	x	x	

PLT-PRM-008	TRACE shall consider maintainability, making sure that updates are easy to perform and documentation is easily retrievable	Non-Functional	x	x	x	
PLT-PRM-009	TRACE shall ensure compliance with industry standards, such as ISO, and be prepared for audits	Non-Functional	x	x	x	
PLT-PRM-010	TRACE should aim for high reliability, such as maintaining a high uptime	Non-Functional	x	x	x	
PLT-PRM-011	TRACE should consider system performance and its optimization	Non-Functional	x	x	x	

Table 13: Interfaces Requirements Validation – Internal Stakeholders

Requirement ID	Requirement Description	Type	Greece	Italy	Slovenia	Evaluation
INT-FUN-001	GUI should incorporate predictive analytics capabilities to forecast future trends, demand, or system performance based on historical data, aiding in proactive decision-making	Functional	X	X	X	Based on pilots workshops feedback, end users and logistic companies are open to use new technologies, including AI-based prediction.
INT-FUN-002	GUI may incorporate collaborative features such as shared workspaces, comments, and notifications to facilitate teamwork and communication among users	Functional	X	X	X	
INT-FUN-003	GUI should allow concerned parties to sign (digital acceptance) the smart contract	Functional		X	X	
INT-FUN-004	GUI should present the calculated optimal routes to the drivers with the capability to recalculate manually with the tap of a button or automatically if a disruption occurs	Functional	X	X	X	
INT-FUN-005	GUI should seamlessly integrate with external systems and APIs to fetch real-time data such as weather updates, traffic conditions, and inventory levels	Functional	X	X	X	
INT-FUN-006	GUI should support different level of users (e.g., driver, manager, admin, etc)	Functional	X		X	
INT-FUN-007	GUI should support one master account per company and functionalities to give access and permissions to other users of the same company	Functional	X		X	
INT-FUN-008	The GUI should offer to the users the capability to seamlessly integrate a cryptocurrency wallet into their user profiles, along with the option to add credit card details, facilitating transactions for return shipments or other services	Functional	X	X	X	

INT-FUN-009	The GUI should show the location of the vehicle (AV) and the ETA for the delivery of the consignment	Functional	X		X	
INT-FUN-010	TRACE platform shall be scalable to accomodate increasing data volumes and user loads as the system grows	Functional	X	X	X	
INT-FUN-011	TRACE shall implement a feature for recipients to book on the designated area (operational) the possibility for real time/same day deliveries on a consolidation approach in order to reduce numbers of vehicles on the designated area	Functional	X		X	
INT-PRM-001	GUI may allow users to customize their interface preferences, layouts, and views based on their specific roles and requirements	Non-Functional			X	
INT-PRM-002	GUI may include interactive features such as filtering, sorting, and drill-down capabilities to facilitate data exploration and analysis	Non-Functional	X	X	X	Based on T2.2. questionnaire, just 16 % of respondents use customized reporting, while 28% are planning and 16 % are interested in this functionality, opening a potential for new uses.
INT-PRM-003	GUI shall enforce security measures such as user authentication, role-based access control, and data encryption to protect sensitive information	Non-Functional	X	X	X	
INT-PRM-004	GUI shall have an intuitive design that is easy to navigate and understand for users with varying levels of technical expertise.	Non-Functional	X	X	X	
INT-PRM-005	GUI shall provide real-time visualization of data, events, and system status to enable quick decision-making.	Non-Functional	X	X	X	
INT-PRM-006	GUI should be responsive and compatible with different devices and screen sizes, including desktops, tablets, and smartphones	Non-Functional	X	X	X	
INT-PRM-007	GUI should have an offline mode functionality, allowing users to access and interact with essential features and data even when internet connectivity is intermittent or unavailable	Non-Functional	X	X	X	
INT-PRM-008	TRACE platform shall ensure high availability to minimize downtime and maintain system functionality	Non-Functional	X	X	X	
INT-PRM-009	TRACE platform shall provide interactive and visually appealing data visualizations, such as charts, graphs, and maps, to help	Non-Functional	X	X	X	

	users understand complex transportation data					
INT-PRM-010	TRACE should prioritize usability, ensuring easy navigation and adherence to user interface standards	Non-Functional	X	X	X	
INT-PRM-011	TRACE should support interoperability with systems like ERP, CRM, and provide a developer interface	Non-Functional			X	
INT-PRM-012	Users should be able to access communication and collaboration features from mobile devices, such as smartphones and tablets, to stay connected while on the go	Non-Functional	X		X	Based on pilots workshops feedback, end users and logistic companies are open to use new technologies, including AI-based prediction.

Table 14: Reporting & Analytics Requirements Validation – Internal Stakeholders

Requirement ID	Requirement Description	Type	Greece	Italy	Slovenia	Evaluation
RA-FUN-001	TRACE platform may include predictive analytics capabilities to forecast future transportation demand, resource utilization, and potential disruptions	Functional	X	X	X	General feedback on Reporting - Based on T2.2 Questionnaire, 28 % of respondents are planning to implement customized reporting, while 16 % are interested to implement in near future. Only 16 % are not interested.
RA-FUN-002	TRACE platform may incorporate geospatial analysis capabilities to analyze transportation data based on geographic location, such as route optimization, traffic patterns,	Functional	X	X	X	General feedback on Reporting - Based on T2.2 Questionnaire, 28 % of respondents are planning to implement customized reporting, while 16 % are interested to implement in

	and spatial distribution of demand					near future. Only 16 % are not interested.
RA-FUN-003	TRACE platform should enforce data governance policies to ensure data integrity, accuracy, and compliance with regulatory requirements, including data privacy and security regulations	Functional	X	X	X	General feedback on Reporting - Based on T2.2 Questionnaire, 28 % of respondents are planning to implement customized reporting, while 16 % are interested to implement in near future. Only 16 % are not interested.
RA-FUN-004	TRACE platform should support real-time reporting capabilities to provide up-to-date insights into the performance and status of the transportation system	Functional	X	X	X	General feedback on Reporting - Based on T2.2 Questionnaire, 28 % of respondents are planning to implement customized reporting, while 16 % are interested to implement in near future. Only 16 % are not interested.
RA-FUN-005	TRACE platform should be able to use API for reporting and analytics purposes to integrate with existing internal systems and platforms	Non-Functional	X			General feedback on Reporting - Based on T2.2 Questionnaire, 28 % of respondents are planning to implement customized reporting, while 16 % are interested to implement in near future. Only 16 % are not interested.
RA-PRM-001	The system shall track the total cost of	Non-Functional	X	X	X	General feedback on Reporting -

	delivery, total cost of logistics, total time of delivery, total delays, delays per route, capacity utilization, on-time delivery rate, order accuracy rate, carbon footprint and emission measurement (linkage with Admiral project), customer satisfaction, and return shipments (unclaimed, damaged, etc.)					Based on T2.2 Questionnaire, 28 % of respondents are planning to implement customized reporting, while 16 % are interested to implement in near future. Only 16 % are not interested.
RA-PRM-002	TRACE platform may allow users to compare the performance of different transportation routes, vehicles, and operators against industry benchmarks or predefined standards	Non-Functional	X	X	X	General feedback on Reporting - Based on T2.2 Questionnaire, 28 % of respondents are planning to implement customized reporting, while 16 % are interested to implement in near future. Only 16 % are not interested.
RA-PRM-003	TRACE platform may enable users to analyze historical data trends, patterns, and performance metrics to identify areas for improvement and make data-driven decisions	Non-Functional	X	X	X	General feedback on Reporting - Based on T2.2 Questionnaire, 28 % of respondents are planning to implement customized reporting, while 16 % are interested to implement in near future.

						Only 16 % are not interested.
RA-PRM-004	TRACE platform may generate reports to highlight the improvements from using the architecture compared to what the company did in the past or to show how, on certain days in the past, the company's solution was not optimal	Non-Functional		X	X	General feedback on Reporting - Based on T2.2 Questionnaire, 28 % of respondents are planning to implement customized reporting, while 16 % are interested to implement in near future. Only 16 % are not interested.
RA-PRM-005	TRACE platform may have the ability to perform ad hoc queries and exploratory analysis to investigate specific questions or scenarios using the available data	Non-Functional	X	X	X	General feedback on Reporting - Based on T2.2 Questionnaire, 28 % of respondents are planning to implement customized reporting, while 16 % are interested to implement in near future. Only 16 % are not interested.
RA-PRM-006	TRACE platform should be able to create customized reports per company tailored to specific requirements, including selecting relevant data fields, applying filters, and choosing display formats	Non-Functional	X		X	General feedback on Reporting - Based on T2.2 Questionnaire, 28 % of respondents are planning to implement customized reporting, while 16 % are interested to implement in near future. Only 16 % are not interested.
RA-PRM-007	TRACE platform should be able	Non-Functional	X	X	X	General feedback on Reporting -

	to export reports and analytics results in various formats, such as PDF, Excel, or CSV, and share them with other stakeholders within the organization					Based on T2.2 Questionnaire, 28 % of respondents are planning to implement customized reporting, while 16 % are interested to implement in near future. Only 16 % are not interested.
RA-PRM-008	TRACE platform should optimize the performance of reporting and analytics queries to ensure fast response times, especially when dealing with large volumes of data	Non-Functional	X	X	X	General feedback on Reporting - Based on T2.2 Questionnaire, 28 % of respondents are planning to implement customized reporting, while 16 % are interested to implement in near future. Only 16 % are not interested.

Table 15:: Vehicles and Sensors Requirements Validation – Internal Stakeholders

Requirement ID	Requirement Description	Type	Greece	Italy	Slovenia	Evaluation	Rationale
VS-FUN-001	Battery powered vehicles may reduce the location transmission frequency and/or accuracy when battery level is less than 20% of a full charged battery.	Non-Functional	X	X	X		Support power saving at low charge conditions
VS-FUN-002	A battery management system should monitor the battery of the vehicles that base their movement on electricity (e.g., an autonomous cargo bike performing a last-mile delivery)	Functional	X	X	X		

VS-FUN-003	Any payload carrying device (e.g. secondary/tertiary medical container) integrated in TRACE platform, even if it is not a vehicle, shall provide its position and status as mentioned for autonomous vehicles	Functional			X	X	Based on T2.2 questionnaire, 3/4 of respondents are already using real-time monitoring of shipments, while the remaining 1/4 is either planning or considering to implement in near future.	
VS-FUN-004	Autonomous vehicles shall be equipped with obstacle sensors in order to avoid any obstacles; Aerial vehicles may avoid obstacles based on detailed trajectory planning and validation	Functional	X		X	X		
VS-FUN-005	Barcodes shall be attached to shipments	Functional	X			X		
VS-FUN-006	Each unmanned vehicle shall measure its own position using a dedicated GPS receiver device mounted on it	Functional			X	X	System design	Use GPS to meet the accuracy requirement
VS-FUN-007	Each vehicle shall transmit to TRACE its operational status in real-time (e.g., offline, online, operative, idle, etc)	Functional	X		X	X	System design	The position of the vehicles shall be known in real-time to provide the service and ensure QoS, availability...
VS-FUN-008	If the shipments are going to be delivered at the final recipient directly, then the shipments should be in different compartments when carried by an unmanned vehicle	Functional	X		X	X		

VS-FUN-009	Inertial measurement unit (IMU) combining 3-axis accelerometers, gyroscope, and magnetometers, a barometric pressure sensor, calibrated IMU data and a real-time 3D attitude solution that is continuous over the complete 360 degrees of motion shall support an unmanned vehicle (e.g., a drone)	Functional			X			
VS-FUN-010	Load capacity of a vehicle in terms of volume (e.g., length, width, and height) shall be known for tracking a suitable vehicle (e.g., type of a truck)	Functional	X	X	X			
VS-FUN-011	Scanner readers for Barcodes shall be available at various checkpoints along a delivery route to update the system with location and status data	Functional	X		X			
VS-FUN-012	System should allow remote operation of autonomous vehicles	Functional			X			
VS-FUN-013	The autonomous delivery robot should display information about the number, size, and availability of drawers. This information aids in planning the loading of shipments for specific delivery routes	Functional			X			
VS-FUN-014	The platform should be able to integrate with	Functional						

	existing vehicle-tracking/telematics solutions						
VS-FUN-015	The platform should enable indirect calculation of fuel consumption for vehicles where this data is not available	Functional			X		
VS-FUN-016	The platform should know the number of vehicles are expected to be available	Functional			X		
VS-FUN-017	The System should optimize routes and/or vehicle selection to avoid heavy traffic roads for cargo bikes	Functional					
VS-FUN-018	When navigating in full autonomy outside the authorised operating area and exceeding the buffer distance from the authorised operating area boundary, the terrestrial unmanned vehicle shall stop navigation	Functional	X	X	X	System design	If too distant from the authorised operating area don't go further
VS-FUN-019	The TRACE System should provide a breakage push button for the operator in case of mechanical failure of the cargo bike	Functional					
VS-FUN-020	There should be a way for the recipient to be notified when the unmanned vehicle approaches	Functional	X	X	X	Based on feedback of workshops, where stakeholders discussed the optimization of autonomous delivery options.	
VS-FUN-021	TRACE platform should know the	Functional					

	'changing point of leaders' during the platooning delivery						
VS-FUN-022	TRACE should know the exact types of unmanned vehicles	Functional			X		
VS-FUN-023	UAVs shall have a specific take off / landing points	Functional					
VS-FUN-024	Vehicles shall support communication hardware and software to transmit and receive data over wireless networks to/from TRACE system or perform coordination tasks with other vehicles (e.g., V2V communication) or any centralized control systems (e.g., V2I communication)	Functional	X	X	X		
VS-FUN-025	When a manned cargo bike finishes its delivery round, the TRACE System should initiate platoon transshipment	Functional					
VS-FUN-026	When a manned vehicle is not equipped with a dedicated GPS receiver device, TRACE shall approximate the vehicle location with the location of the GPS-enabled mobile phone/tablet of the vehicle operator	Functional		X	X	System design	The position of the vehicle still shall be known
VS-FUN-027	When equipped with a dedicated GPS receiver device, each manned vehicle shall measure its own position using	Functional		X	X	System design	Manned vehicles are not strictly required to have a GPS

	such dedicated GPS receiver device.						
VS-FUN-028	When navigating in full autonomy and crossing the outside of the authorised operating area, the unmanned vehicle shall change trajectory to re-enter the authorised operating area	Functional	X	X	X	System design	Try reentering the authorised operating area
VS-PRM-001	2D/3D LiDAR camera sensor or 360 cameras should perform the mapping of the environment (e.g., for ground unmanned vehicles)	Non-Functional		X	X		
VS-PRM-002	Autonomous vehicles should have a operational limitation range/time	Non-Functional		X			
VS-PRM-003	Dimensions (e.g., length, width, and height) of vehicles performing in a bounded pathway (e.g., cycle lanes) should be considered	Non-Functional	X	X	X		
VS-PRM-004	Each vehicle shall transmit its location to TRACE regularly, with the maximum time elapsing between two transmissions computed as the minimum between the time to travel 100 meters at the current speed and 1 minute	Non-Functional	X	X	X	Timing respected 97% of times under no failure conditions	Ensure updated information
VS-PRM-005	When in operation, fuel-powered vehicles shall calculate the average fuel consumption	Non-Functional			X	System design	Support the assessment of KPIs related to the fuel consumption gain based on

							optimization provided by the TRACE platform.
VS-PRM-006	Image sensors (e.g, a 2D camera, RGB-D cameras, 6-DOF tracking camera sensor, depth sensor cameras) shall enable unmanned vehicles to capture images of the surroundings, detect an object, autonomous navigation and route planning	Non-Functional					x
VS-PRM-007	Temperature and humidity sensors should provide insight into the shipment's environment (e.g., an RFID-sensor tag could provide real-time cold chain data such as temperature, humidity, moisture, tampering, etc.)	Non-Functional					
VS-PRM-008	The location information transmitted by each vehicle may provide additional fields, such as measured vs estimated flag, accuracy, altitude, and velocity	Non-Functional	x	x	x	System design	Additional information not essential for operations
VS-PRM-009	The location information transmitted by each vehicle shall provide, at a minimum, the following fields: latitude, longitude, and timestamp with locale	Non-Functional	x	x	x	System design	Minimum information to qualitatively assess the position of the vehicle
VS-PRM-010	Vehicles should be considered upon weather restrictions	Non-Functional	x	x	x		Support power saving at low charge conditions

Table 16: Cloud Infrastructure Requirements Validation – Internal Stakeholders

Requirement ID	Requirement Description	Type	Greece	Italy	Slovenia
CLD-FUN-001	TRACE Cloud Infrastructure shall enable continuous monitoring of resource usage and health, with automated alerts for anomalies or issues	Functional	X	X	X
CLD-FUN-002	TRACE Cloud Infrastructure shall enable dynamic allocation and deallocation of resources as per workload requirements	Functional	X	X	X
CLD-FUN-003	TRACE Cloud Infrastructure shall implement several security measures such as firewalls, encryption, and access controls	Functional	X	X	X
CLD-FUN-004	TRACE Cloud Infrastructure shall offer automated provisioning of compute, storage, and network resources	Functional	X	X	X
CLD-FUN-005	TRACE Cloud Infrastructure shall support the ability to scale resources up or down based on demand	Functional	X	X	X
CLD-FUN-006	TRACE Cloud Infrastructure should be able to distribute workloads across multiple resources to ensure high availability and reliability	Functional	X	X	X
CLD-PRM-001	Edge computing shall be deployed for storage and computing	Non-Functional	X	X	X
CLD-PRM-002	TRACE Cloud Infrastructure shall enable updating, patching, and maintaining the deployed virtual infrastructure	Non-Functional	X	X	X
CLD-PRM-003	TRACE Cloud Infrastructure shall offer backup	Non-Functional	X	X	X
CLD-PRM-004	TRACE Cloud Infrastructure shall offer high performance with low latency for resource provisioning and data access	Non-Functional	X	X	X
CLD-PRM-005	TRACE Cloud Infrastructure shall support High Availability (HA) and minimal downtime of cloud services	Non-Functional	X	X	X
CLD-PRM-006	TRACE Cloud Infrastructure should offer redundancy	Non-Functional	X	X	X

Table 17: Security & Data Protection Requirements Validation – Internal Stakeholders

Requirement ID	Requirement Description	Type	Greece	Italy	Slovenia
SEC-FUN-001	The TRACE system shall provide secure authentication of vehicle devices that connect to the TRACE platform	Functional		X	

SEC-FUN-002	TRACE platform shall provide robust security features, such as role-based access control (RBAC), encryption (at rest and in transit), and multi-factor authentication	Functional	X		
SEC-FUN-003	TRACE system shall perform access control mechanisms to protect data integrity and prevent unauthorized access	Functional		X	
SEC-PRM-001	TRACE platform shall implement encryption algorithms to secure personal data and business-sensitive data	Non-Functional	X	X	X
SEC-PRM-002	TRACE platform shall implement robust authentication and authorization mechanisms.	Non-Functional	X	X	X
SEC-PRM-003	TRACE shall implement sufficient technical security measures to ensure protection of personal data, in compliance with the GDPR	Non-Functional	X	X	X
SEC-PRM-004	TRACE should comply with the requirements laid down in Directive (EU) 2022/2555 on measures for a high common level of cybersecurity across the Union	Non-Functional	X	X	X
SEC-PRM-005	TRACE should comply with the requirements laid down in Directive (EU) 2022/2557	Non-Functional	X	X	X

	on the resilience of critical entities				
SEC-PRM-006	TRACE should comply with the requirements laid down in the Regulation of the EU Parliament and of the Council on horizontal cybersecurity requirements for products with digital elements	Non-Functional		X	X

Table 18: Comms & Physical Infrastructure Requirements Validation – Internal Stakeholders

Requirement ID	Requirement Description	Type	Greece	Italy	Slovenia	Evaluation	Rationale
COM-FUN-001	Drones should support 4G/5G communication for integration with logistic network	Functional		X			
COM-FUN-002	Flight paths and operational volumes shall consider the possibility of more drones operating simultaneously, for instance on opposite directions	Functional		X			
COM-FUN-003	LifeBox should support 4G/5G communication for integration with logistic network, regardless of vehicle used	Functional		X		Based on T2.2 questionnaire, 3/4 of respondents are already using real-time monitoring of shipments, while the remaining 1/4 is either planning or considering to implement in near future.	
COM-FUN-004	The capacity of unmanned vehicles in terms of the number of parcels	Functional					

	should be part of the processing in the TRACE platform						
COM-FUN-005	The TRACE system shall allow a single operator to use a platoon of autonomous bikes for efficient parcel transportation	Functional		X			
COM-FUN-006	The TRACE system shall allow platoons of cargo bikes to exchange information regarding delivery locations at specific crossroads	Functional		X		System design	
COM-FUN-007	The TRACE system shall enable cargo bike operators to reorganize platoons and direct empty cargo bikes to autonomously return to the hub for further deliveries	Functional		X		System design	
COM-FUN-008	The TRACE system shall enable cargo bikes to depart from hub with multiple parcels destined for different areas of the city	Functional		X			
COM-FUN-009	The TRACE system shall enable drones to handle the final leg of shipments in the absence of bike lanes or in difficult road conditions	Functional		X			

COM-FUN-010	The TRACE system shall facilitate the transfer of goods between the most suitable cargo bike platoons	Functional			X		
COM-FUN-011	The TRACE system shall support the loading of parcels onto autonomous cargo bikes and drones for efficient delivery from the Modena hub.	Functional			X		
COM-FUN-012	The TRACE system shall support the use of multiple cargo bikes organized into platoons for the transportation of shipments	Functional			X		
COM-FUN-013	The TRACE system shall update and communicate delivery progress, GPS position updates, and parcel delivery status through 4G/5G antennas into the TRACE infrastructure	Functional			X		
COM-FUN-014	The TRACE system shall use vehicle-to-vehicle communications	Functional			X		
COM-FUN-015	Vehicle should have minimum 4G network access	Functional	X			X	
COM-FUN-016	TRACE platform should support various communication channels, including text-	Functional	X			X	

	based, voice-based, and video-based communication, to accommodate different preferences and situations						
COM-PRM-001	Autonomous unmanned ground vehicles for the Italian demonstrators should be compliant to Italian regulations: "Decreto Smart Road", D.M. 70/2018	Non-Functional		X			
COM-PRM-002	Autonomous unmanned ground vehicles should be compliant to National and International regulations	Non-Functional		X		System design	
COM-PRM-003	Bike lanes should be clearly marked and continue through intersections, allowing cargo bike users to navigate through without conflicts with motor vehicles	Non-Functional		X			Intersection design plays a crucial role in accommodating cargo bikes. Consider dedicated turning lanes or advanced stop lines for cargo bikes at intersections to improve visibility and safety.
COM-PRM-004	Drone may travel at 10m/s	Non-Functional		X		Based on feedback of workshops, where stakeholders discussed the optimization of autonomous delivery options.	
COM-PRM-005	Drones should avoid areas that interfere with communications and signal	Non-Functional		X			

	transmission, e.g., military bases, airports, etc						
COM-PRM-006	Drones may avoid sensitive areas (e.g. privacy concerns, specialized ecosystems etc), e.g., schools, residential towers, designated bird habitats etc	Non-Functional		X			
COM-PRM-007	Drones shall avoid known aerial obstacles that impact flight path such as power lines, wind turbines etc	Non-Functional		X			
COM-PRM-008	Ground markings for take off and landing shall be clear	Non-Functional		X			
COM-PRM-009	Ideal sidewalk width may be 2m	Non-Functional	X		X		Suitable size for robot to safely navigate sidewalk alongside other users: pedestrians, wheelchairs etc.
COM-PRM-010	If additional specialized infrastructure is required for robots, it should be non-intrusive and robots may be guided by localized infrastructure	Non-Functional	X		X	System design	
COM-PRM-011	Landing platform shall be 3m wide area with clear vertical	Non-Functional		X		System design	
COM-PRM-012	Local authorities and National Aviation Authorities should provide	Non-Functional		X		System design	

	dedicated operational areas and rules to support UAS operations						
COM-PRM-013	Max step/curb height should not exceed 5cm	Non-Functional	X		X		
COM-PRM-014	Max travel speed may be 25 km/h with driver and 6km/h without on travel paths	Non-Functional		X			
COM-PRM-015	Max travel speed on pedestrian infrastructure should not exceed 5km/h	Non-Functional	X		X		
COM-PRM-016	Minimum and maximum allowable vehicle altitude shall align with local and national flight regulations for drones	Non-Functional		X		Timing respected 97% of times under no failure conditions	
COM-PRM-017	Mobile (5G or 4G/NB IoT) Network coverage shall be available over the sites of operation at 90%-99.99% availability (depending on the application requirements)	Non-Functional	X	X	X	System design	Network shall be deployed in such way to provide mobile network coverage
COM-PRM-018	Mobile (5G or 4G/NB IoT) Network coverage shall be available over the sites of operation at 90%-99.99% reliability (depending on the application requirements)	Non-Functional	X	X	X		Network shall be deployed in such way to provide mobile network coverage with relevant reliability
COM-PRM-019	Mobile (5G or 4G/NB IoT) network performance	Non-Functional	X	X	X		Network shall be deployed in such way to provide mobile

	shall achieve: XX Mbps Datarate and XX msec latency (depending on the application requirements)						network coverage with relevant performance
COM-PRM-020	Operational volume for intended drone flight shall authorized by NAA	Non-Functional		X		System design	U-Space geographical zones should be agreed with National Aviation Authorities. Regulatory sandbox can be established by local authorities and stakeholders, for the sake of drone logistics, in a transition timeframe. Temporary Reserved Airspace can be established for the demonstration activities but a permanente solution is sought for recurring logistics.
COM-PRM-021	Path markings may be used for robot to determine appropriate travel path and location of hubs	Non-Functional	X		X	System design	
COM-PRM-022	Risk areas related to drone flight shall preserve the characteristics discussed with NAA per UAS operational authorization	Non-Functional		X			Drone routes shall be designed in order to target safety conditions that will be agreed with NAA. Infrastructures should support these issues in monitoring effective population in

							these areas and offering mitigation means for specific locations (e.g. cover for highways crossing).
COM-PRM-023	Robot occupancy and waiting at a hub or defined space shall not create obstacles for pedestrians or congestion on public paths.		X		X		
COM-PRM-024	Robot shall prioritize first: defined pedestrian paths or sidewalks as operational areas		X		X		
COM-PRM-025	Robot should cross streets at clearly identifiable pedestrian crossings (e.g., zebra crossings, signalized intersection)		X		X		
COM-PRM-026	Robots may grant pedestrians 2m of space and the right-of-way to pedestrians in close proximity on pathways		X		X		
COM-PRM-027	Surfaces may be smooth, well-maintained surfaces, free of potholes, debris, and obstacles			X	X		Smooth, well-maintained surfaces are essential for cargo bike operation and accident prevention. Ensure that bike lanes are free of potholes, debris, and other obstacles that could

							impede cargo bike travel or cause accidents.
COM-PRM-028	Take off platform shall be 3m wide area with clear vertical			X			
COM-PRM-029	The buffer zone (space between bike and other vehicles) may be at least 1.5 to 2 meter (5 to 6.5 feet)			X			
COM-PRM-030	The max slope incline of path shall not exceed 3%			X			
COM-PRM-031	The max slope incline of path shall not exceed 47%		X		X		
COM-PRM-032	The minimum recommended width for a bike lane accommodating cargo bikes should be 2m, preferably 2.6m			X			
COM-PRM-033	TRACE should comply with the requirements laid down in Directive (EU) 1019/2144 on the general safety and the protection of vehicle occupants and vulnerable road users.		X	X	X		
COM-PRM-034	Travel paths may contain temporary and permanent obstacles such as garbage bins, benches etc. that the robot shall be able to navigate around		X		X		
COM-PRM-035	User Equipment Mobile (5G or		X	X	X		

	4G/NB IoT) shall be compatible with mobile network Frequency/ Bandwidth allocation						
COM-PRM-036	Vehicle charging infrastructure shall be located strategically with consideration given to battery life and route length			X	X		
COM-PRM-037	Vehicles may have Wifi 02.11a/b/g/n/ac Bluetooth 5.1 (5G/4G optional)	X		X	X		

Table 19:Data Management Requirements Validation – Internal Stakeholders

Requirement ID	Requirement Description	Type	Greece	Italy	Slovenia
DM-FUN-001	TRACE platform shall integrate data from different sources and formats to provide a unified view of the transportation system	Functional	X		
DM-FUN-002	TRACE platform should support both structured and unstructured data	Functional	X		
DM-PRM-001	TRACE platform shall define data retention policies to manage the lifespan of data and comply with regulatory requirements	Non-Functional	X	X	X
DM-PRM-002	TRACE platform shall ensure data quality by implementing validation, cleansing, and normalization processes to remove inconsistencies and errors	Non-Functional	X		
DM-PRM-003	TRACE platform shall ensure low latency and high throughput for data processing and retrieval	Non-Functional	X		
DM-PRM-004	TRACE platform should implement backup and recovery mechanisms to protect against data loss and ensure data integrity in case of system failures	Non-Functional	X		
DM-PRM-005	TRACE should ensure data integrity by maintaining accuracy, consistency, and minimizing errors	Non-Functional	X	X	X

Table 20: Events Requirements Validation – Internal Stakeholders

Requirement ID	Requirement Description	Type	Greece	Italy	Slovenia	Evaluation
EVT-FUN-001	Events should be generated when a) a shipment is loaded to a vehicle, b) when the shipment is delivered at the platform and/or the logistic company's system in real-time	Functional	X	X	X	
EVT-FUN-002	TRACE event management module shall integrate seamlessly with other modules, such as the Fleet Monitoring Manager and Mitigation Manager, to facilitate event-driven actions and decision-making	Functional	X	X	X	
EVT-FUN-003	TRACE platform may allow for the assessment of the impact of events on various aspects of logistic processes, including operational costs, time delays, and customer satisfaction	Functional	X		X	
EVT-FUN-004	TRACE platform shall be capable of detecting various types of events, such as delays, disruptions, or anomalies, in real-time	Functional	X	X	X	T2.2 Questionnaire: slightly more than half of respondents are already using delivery disruption alerts, while everyone else would like to receive these types of alerts.
EVT-FUN-005	TRACE platform shall prioritize events based on predefined criteria to ensure appropriate response and resource allocation	Functional	X	X	X	
EVT-FUN-006	TRACE platform shall provide notification and alerting capabilities to inform users about important events, updates, or changes in transportation operations, ensuring timely awareness and response	Functional	X		X	
EVT-FUN-007	TRACE platform shall store actions taken in response to specific events (e.g., assessing the effectiveness of the action and the timeframe for its execution). This confirms the suitability of each action for a particular event, enabling the platform's machine learning capabilities to improve future actions for similar events	Functional	X	X	X	
EVT-FUN-008	TRACE platform shall store historical event data for analysis, reporting, and future reference	Functional	X	X	X	
EVT-FUN-009	TRACE platform should have an adequate track and trace system of events available in real time	Functional	X	X	X	

EVT-FUN-010	TRACE platform should use machine learning algorithms to identify patterns in event occurrences	Functional	X		X	Based on focus group discussions with stakeholders, they are generally willing to use AI and similar technologies for these purposes.
EVT-FUN-011	When an low-battery alert event is arised from an unmanned vehicle, TRACE should forced to return to consollidation center for a battery charging or switching	Functional			X	
EVT-FUN-012	When an unmanned vehicle approaches the limits of its authorised operating area, TRACE shall trigger a warning event	Functional	X	X	X	Observe warning event within x seconds from condition met in normal operating conditions
EVT-FUN-013	When an unmanned vehicle has a mechanical or electronic breakdown, TRACE shall trigger a fault event	Functional			X	
EVT-FUN-014	When an unmanned vehicle leaves the limits of its authorised operating area, TRACE shall trigger a fault event	Functional	X	X	X	Observe warning event within x seconds from condition met in normal operating conditions
EVT-PRM-001	TRACE platform shall support automated responses to certain types of events, such as triggering re-allocations or updating schedules	Non-Functional	X	X	X	

Table 21: Monitoring & Optimization Requirements Validation – Internal Stakeholders

Requirement ID	Requirement Description	Type	Greece	Italy	Slovenia
MON-FUN-001	Platform should have live data on status of consolidation center	Functional			X
MON-FUN-002	The Proof of delivery should be possible by using TRACE platform	Functional			
MON-FUN-003	The TRACE System should calculate the shipment ETA for the recipient based on the optimization algorithm	Functional			
MON-FUN-004	The TRACE system should optimize the payload based on the load capacity of the cargo bike (1.5m ³ per cargo bike)	Functional			
MON-FUN-005	TRACE platform may integrate with maintenance management systems to monitor vehicle health and maintenance schedules, optimizing fleet availability and reliability	Functional	X	X	X

MON-FUN-006	TRACE platform should incorporate predictive analytics models to forecast future performance trends, anticipate potential bottlenecks or disruptions, and optimize resource allocation and scheduling accordingly	Functional	X		X
MON-FUN-007	TRACE shall implement a feature for recipients to book on the designated area (operational) the possibility for real time/same day deliveries on a consolidation approach in order to reduce numbers of vehicles on the designated area	Functional			
MON-FUN-008	TRACE system may allow the progressive introduction of increasingly autonomous operations - from constant vehicle monitoring, remote monitoring, to fully automated or driverless	Functional	X		X
MON-FUN-009	When generating delivery routes, TRACE shall consider avoidance of low density areas for cargo bikes delivery	Functional			
MON-FUN-010	When generating trajectories and paths for unmanned vehicles, TRACE shall generate trajectories and paths crossing exclusively the authorised operating areas	Functional	X	X	X
MON-PRM-001	TRACE platform may support scenario modeling and what-if analysis to evaluate the impact of different operational strategies, route optimizations, or resource allocations on performance metrics	Non-Functional	X		X
MON-PRM-002	TRACE platform shall consider cost optimization objectives alongside performance metrics, balancing operational efficiency with cost-effectiveness to maximize overall value and profitability	Non-Functional		X	
MON-PRM-003	TRACE platform should allow users to define performance thresholds and alerting rules to notify them when performance metrics exceed or fall below acceptable levels, triggering proactive intervention	Non-Functional	X	X	X

Table 22: Blockchain Requirements Validation – Internal Stakeholders

Requirement ID	Requirement Description	Type	Greece	Italy	Slovenia
BLK-FUN-001	The TRACE may implement a flexible smart contract ecosystem to dynamically update the values of the NFT in accordance with real-time values. The NFT smart contract will also be updated based on changes in the terms of the collaboration agreement between the partners	Functional	X	X	X
BLK-FUN-002	"The TRACE should automatically initiate a blockchain transaction using the Algorand network whenever login credentials are successfully submitted by the logistics company	Functional	X	X	X
BLK-FUN-003	"The TRACE should capture and retrieve the transaction ID from the Algorand blockchain once a transaction has been processed, facilitating tracking and verification "	Functional	X	X	X
BLK-FUN-004	The TRACE should enhance security by securely storing public keys associated with logistics companies offline, used for verifying transactions	Functional	X	X	X
BLK-FUN-005	The TRACE should generate a unique dNFT for each parcel, allowing digital tracking and management of logistic assets	Functional	X	X	X
BLK-FUN-006	The TRACE should maintain a transparent and immutable record of all transactions on the blockchain, which is accessible via the platform interface	Functional	X	X	X

BLK-FUN-007	"The TRACE should manage and store optimized and collaborative scheduling agreements for shipping goods on the blockchain, automating and securing logistics operations"	Functional	X	X	X
BLK-FUN-008	The TRACE should mark the completion of delivery processes on the blockchain, finalizing the status of logistics tasks	Functional	X	X	X
BLK-FUN-009	The TRACE may log all significant events related to the delivery process on the blockchain, ensuring that all actions are transparent and immutable	Functional	X	X	X
BLK-FUN-010	The TRACE may record comprehensive delivery details such as the delivery medium, personnel involved, pickup times, and other relevant data on the blockchain for enhanced traceability	Functional	X	X	X
BLK-FUN-011	"The TRACE should integrate Algorand wallets into the authentication process to enhance security by leveraging blockchain-based transaction authentication"	Functional	X	X	X
BLK-PRM-001	The system shall optimize the performance of the blockchain network to ensure timely execution of transactions and smart contracts	Non-Functional	X	X	X
BLK-PRM-002	The TRACE shall adhere to relevant regulatory requirements and standards governing blockchain technology and authentication processes	Non-Functional	X	X	X
BLK-PRM-003	"The TRACE shall ensure compliance with relevant regulations and standards governing blockchain technology and logistics operations, providing legal assurance"	Non-Functional	X	X	X
BLK-PRM-004	"The TRACE shall ensure the blockchain network can handle a growing number of transactions as the logistics operations expand"	Non-Functional	X	X	X
BLK-PRM-005	The TRACE shall ensure the integrity and consensus of transactions recorded on the blockchain, providing trust in the system	Non-Functional	X	X	X
BLK-PRM-006	The TRACE shall facilitate integration with other systems or platforms used by stakeholders, ensuring seamless data exchange and communication	Non-Functional	X	X	X
BLK-PRM-007	The TRACE should ensure timely processing of transactions on the Algorand blockchain to minimize authentication delays	Non-Functional	X	X	X
BLK-PRM-008	The TRACE should optimize the performance of the blockchain network to ensure quick transaction processing and verification	Non-Functional	X	X	X
BLK-PRM-009	"The TRACE should utilize the immutability and decentralized nature of the Algorand blockchain to enhance the security of the authentication process"	Non-Functional	X	X	X
BLK-PRM-010	The TRACE shall ensure high availability and reliability of the Algorand blockchain network to prevent disruptions in the authentication process	Non-Functional	X	X	X

Table 23: Safety & Reliability Requirements Validation – Internal Stakeholders

Requirement ID	Requirement Description	Type	Greece	Italy	Slovenia
SRY-FUN-001	A safety system shall provide collision detection and collision avoidance mechanisms to ensure the safety of autonomous vehicles in the pilots, any nearby objects and cargo	Functional	X		X
SRY-FUN-002	The autonomous vehicle will be introduced in a step-by-step process - from control mode to full autonomy	Functional			X
SRY-FUN-003	The TRACE system shall implement safety mechanisms when performing economic interactions	Functional	X		X
SRY-FUN-004	TRACE platform shall account for various environmental factors, such as weather and road conditions, that may affect logistics operations	Functional	X		X
SRY-FUN-005	TRACE platform shall define fail-safe mechanisms to minimise the risk of system failure and enhance system redundancy	Functional	X		X
SRY-FUN-006	TRACE vehicles should set driving assistance systems, such as lane-keeping assistance and automatic braking, to enhance the degree of smoothness and steadiness of automation	Functional	X		X
SRY-PRM-001	The outdoor localisation accuracy of unmanned vehicles shall be lower than 10 meters on average (or less, if possible within 1 meter)	Non-Functional	X	X	X
SRY-PRM-002	The TRACE safety mechanism shall prevent unauthorised access and hacker access to TRACE data centres	Non-Functional	X		X
SRY-PRM-003	The TRACE system should provide mechanisms for the safe and authorised handover of shipments to another stakeholder	Non-Functional	X		X

Table 24: Virtual Cockpit Requirements Validation – Internal Stakeholders

Requirement ID	Requirement Description	Type	Greece	Italy	Slovenia
VR-FUN-001	Virtual Cockpit shall provide alerting mechanisms to notify the user about detected events and their implications	Functional	X	X	
VR-FUN-002	Virtual Cockpit should receive compressed video streams from visual sensors placed on the vehicles that will be used for real-time visualization	Functional	X	X	
VR-FUN-003	Virtual Cockpit should receive geolocation parameters (GPS) from the vehicles that will be used for real-time visualization	Functional	X	X	
VR-FUN-004	Virtual Cockpit should transmit scalar signals to the TRACE platform that will interact with the vehicles to perform predefined actions in the context of the package delivery (e.g. return to base)	Functional	X	X	
VR-PRM-001	Feed Cameras in the Virtual Cockpit should be connect with the current information (e.g., back Hilighting Green background if the delivering is going smoothly, red if there are still problems)	Non-Functional	X		
VR-PRM-002	Virtual Cockpit shall have an intuitive UI/UX that is easy to understand and use for users with varying levels of technical expertise	Non-Functional	X		
VR-PRM-003	Virtual Cockpit shall provide real-time visualization of data, events, and vehicle status to enable instant decision-making	Non-Functional	X		X
VR-PRM-004	Virtual Cockpit should collect and aggregate performance data from various sources, including sensors and GPS trackers, to provide a comprehensive view of transportation performance and security	Non-Functional	X		X
VR-PRM-005	Virtual Cockpit should integrate seamlessly with other user interface modules within the TRACE platform	Non-Functional	X		

VR-PRM-006	Virtual Cockpit should provide a non-immersive alternative for HMD malfunctioning scenarios with seamless transition to ordinary monitors	Non-Functional	X		
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Table 25: Ethics Requirements Validation – Internal Stakeholders

Requirement ID	Requirement Description	Type	Greece	Italy	Slovenia
ETH-PRM-001	Completed Informed consent shall be stored securely by the project partner(s) distributing and collecting them.	Non-Functional	X	X	X
ETH-PRM-002	Ethics self-assessment sheet for research activities shall be completed and sent to Privacy and Ethics manager before the event	Non-Functional	X	X	X
ETH-PRM-003	Informed consent shall be sent and completed by participants before the start of the event	Non-Functional	X	X	X
ETH-PRM-004	Recruitment procedures for participation in testing events shall be clear and recruitment checklist completed before the event and sent to Privacy and Ethics manager	Non-Functional	X	X	X
ETH-PRM-005	TRACE AI components may be certified for cybersecurity	Non-Functional	X	X	X
ETH-PRM-006	TRACE may evaluate if they are any negative impacts of the AI components on environment	Non-Functional	X	X	X
ETH-PRM-007	TRACE may evaluate if they are any negative impacts of the AI components on human work and work arrangements	Non-Functional	X	X	X
ETH-PRM-008	TRACE may evaluate if they are any negative impacts of the AI components on human work and work arrangements	Non-Functional	X	X	X
ETH-PRM-009	TRACE may set up procedures to avoid creating or reinforcing unfair bias of the AI components, both regarding the use of input data as well as for the algorithm design	Non-Functional	X	X	X
ETH-PRM-010	TRACE shall clearly explain the decision of the AI components to the users	Non-Functional	X	X	X
ETH-PRM-011	TRACE should consider including the participation of the widest range of possible stakeholders in the AI components' design and development	Non-Functional	X	X	X
ETH-PRM-012	TRACE should make sure that the AI components correspond to the variety of preferences and abilities in society	Non-Functional	X	X	X
ETH-PRM-013	TRACE should out procedures in place to avoid end-users over-relying on the AI components developed.	Non-Functional	X	X	X
ETH-PRM-014	TRACE should place measures to continuously assess the quality of the input data to the AI components.	Non-Functional	X	X	X
ETH-PRM-015	TRACE should prevent any adversarial, critical or damaging effect (to huma or society) in case of risks or threat (in design, technical faults, defects, attacks, misuse, inappropriate or malicious use)	Non-Functional	X	X	X
ETH-PRM-016	TRACE should support human autonomy and decision making (user agency and human oversight)	Non-Functional	X	X	X