Requirements for Simulation platforms within CARMONY project

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1. Executive Summary

This Deliverable outlines the progress made in the CARMONY project following the initial definition of high-level use case requirements, with a specific focus on the virtual-domain respectively simulation building blocks of the project and associated simulation needs. Thereby, the deliverable documents the results from Task 2.3: Requirements and specifications for CARMONY simulation framework.

The task's main objective was to define the requirements and specifications for the CARMONY co-simulation framework, enabling an integration of a set of diverse real-time and offline simulation tools, data sources and tools and thus supporting subsequent development and specification phases in WP3, WP5, and later evaluation in WP6. This report describes the scope of the task, the methodology and elaborates the simulation requirements for the use-cases around the two project pilot sites in Murcia (Use Cases 1-3) and Luxembourg (Use Cases 4-6) in hierarchical order.

Within the process of this task, the requirement properties child and parent requirements were introduced, leveraging the overall quality of the requirements. By introducing and assigning the property of child and parent requirements, an early and preliminary requirement validation is already done in a very early phase of the project.

Additionally, a quality check regarding the requirement completeness was also done and achieved. Through this process missing, related or depending requirements, were able to be identified. For high level requirements with missing related requirements, the need of the definition of additional requirements could be identified. The Deliverable concludes with reflections on challenges during this process, achievements and upcoming work. Contributions from Task partners helped shape requirements related to co-simulation, HMI strategies, traffic simulations, and communication. As a public deliverable, it aims to align project participants on technical implementation while informing a broader audience.

Keywords: Simulation Requirements, Co-Simulation, Requirement dependencies;

2. Introduction

After the initial requirement elicitation work conducted since the kick-off of the CARMONY project, further steps towards a successful implementation of the project targets were conducted. Many tools and concepts for requirement definitions are available [2]. This Deliverable outlines the activities following the definition of High-Level Use Case Requirements, with special consideration and focus on requirements for the virtual domain and simulation.

2.1 Objectives

The purpose of this task was the definition of the requirements and specifications for the CARMONY co-simulation framework, focusing on integrating various simulation tools. This includes real-time (for quick traffic management decisions) and non-real time (for governance development and validation) co-simulation, with results feeding into the development and implementation phases in WP3 and WP5. As a result, requirements enabling further detailed specifications of CARMONY simulation framework were derived.

2.2 Contents of this Deliverable

This deliverable first introduces the content, scope and target audience group. Then the process and method are outlined. In a next step, a hierarchy and therefore a first requirement validation is done. The Deliverable closes with a conclusion reflecting on the achieved results, difficulties in the process and the work in the upcoming months. Table 2-1 below shows the involved partners and their contribution to this deliverable.

Table 2-1: Partner Contributions

Partner	Contribution
ViF	T2.3 - Derive the requirements for Co-Simulation setup for integrating traffic management tools
RISE	T2.3 - Specify requirements for simulations
ETRA	T2.3 - Provide requirements for traffic simulations in Murcia.
HYP	T2.3 - Support in defining communication requirements.

2.3 Intended Target Group

This deliverable addresses both the needs of participants to better align on a common understanding of the actual technical implementation, and the information to the wider public, as this Deliverable is of public nature and will be made publicly available.

2.4 Dependencies and WP I/O

As lined out in Section 2.2 the work builds on the initial results from Task 2.1 (as documented in D2.1 [1]) and uses the high-level requirements as input. The requirements will be further used in WP 3 (especially Tasks 3.1 and 3.5 for detailing the overall architecture and the corresponding information flow and WP 5 (especially for the definition of the specific simulation scenarios). Finally, the results will be used in WP6 for the last project evaluation.

3. Simulation Requirements for Simulation Framework

To ensure a consistent and traceable structure of the requirement set, the high-level requirements from D2.1 CARMONY “Use Cases refinement and specifications definitions” [1] were reviewed and refined following a top-down approach. As a first step, the T2.3 partners verified for each parent requirement defined in Deliverable D2.1 whether one or more corresponding child requirements existed either in D2.2 [2] or D2.4. Parent requirements lacking associated child requirements were identified, defining the need of creating new child requirements within the Volere tool to close these gaps. Volere tool is a web-based service to define and manage requirements developed and maintained by the CARMONY partner ETRA [6]. A short description of the Volere tool is given in D2.1. In parallel, where needed, existing child requirements that could not be linked to any parent requirement were evaluated; depending on their relevance, they were either reassigned to a newly formed cluster of “Additional Technical Requirements” or removed if considered obsolete.

To support consistency across the requirements, formatting and alignment was performed. These included harmonising the identifiers of all parent requirements (left column of the tables following later in the document), ensuring a uniform format for child requirement identifiers (middle column), and aligning the identifiers of any grandchild requirements (right column). Furthermore, each child requirement had to be explicitly linked to its corresponding parent requirement. Additional simulation-related technical requirements were appended at the end of each thematic section, where needed, to maintain a complete and structured overview.

A guiding principle throughout this process should be that every high-level requirement had to be supported by at least one simulation-related requirement, ensuring the completeness and applicability of the specification for the CARMONY co-simulation framework.

The following process steps were done:

- ID of parent requirement was aligned left
    - ID of child requirements was aligned middle
        - ID of grandchild requirement was aligned right
    - Link child requirement with parent ID
- Additional simulation technical requirements added at the end of the list in each section

This leads to the following structure (see Table 3-1) in the upcoming sections:

Table 3-1: Requirement Types

ID	Description
CCR_X (parent)	Requirement X description
CCR_Y (child)	Requirement Y description
CCR_Z (grandchild)	Requirement Z description

This is shown in the upcoming sections for the use case requirements. The maximum level of requirements should be equal or less than 3, however exceptions are allowed, if absolutely necessary.

3.1 Cross-Cutting Requirements

This section summarizes the crosscutting simulation requirements, which are applicable for all use cases investigated in simulation. Table 3-2 shows the hierarchy amongst them.

Table 3-2: Cross-Cutting Simulation Requirements

ID	Description	Type	Parent
CCR_001	Real time and historical traffic information shall be made available to the Orchestrator	Functional and data requirements	
CCR_002	Historic real traffic information must be available for simulations conduction.	Functional and data requirements	**CCR_001**
CCR_003	Solutions shall be integrated and support interaction with traffic management system.	Functional and data requirements	
CCR_096	The simulation should be able to model the connection between Orchestrator and connected (automated) vehicles and VRUs who use the Carmony-App.	Functional and data requirements	**CCR_003**
CCR_100	The simulation framework should be able to generate result files with travel time, traffic density in a human-readable format (preferable csv).	Functional and data requirements	**CCR_003**
CCR_058	The interface for the users should be adaptable to their needs (personalisation)	Operational requirements	**CCR_003**
CCR_064	The Real-Time Traffic Orchestrator shall deliver simulations for real-time guidance to CAVs to support coordinated traffic flow.	The scope of the product	**CCR_003**
CCR_110	All possible interventions / suggestions that are available shall be specified	Functional and data requirements	**CCR_003**
CCR_125	Orchestrator shall be able to learn from previous road experience (e.g. construction sites, road blockage etc.) and mark those zones in its decision making.	Functional and data requirements	**CCR_003**
CCR_130	Orchestration rules (e.g., LEZ, incident, emergency, lane reservations) shall be encoded as machine-readable policies with source traceability and version control.	Functional and data requirements	**CCR_003**
CCR_009	The CAVs localization system shall provide position accuracy within 50 cm.	Functional and data requirements	-
CCR_010	Scenario simulations are needed for system performance validation	Functional and data requirements	-
CCR_066	The scope and context of each simulation such as environment, input	Functional and data requirements	**CCR_010**

ID	Description	Type	Parent
	and output data, shall be defined prior to simulation execution.		
CCR_067	Functional characteristics required for all tools shall be integrated into the simulation environment.	Functional and data requirements	**CCR_010**
CCR_068	The system shall ensure that all data required for the execution of each Use Case is available in the appropriate format.	Functional and data requirements	**CCR_010**
CCR_037	A comprehensive analysis of the current traffic situation as a baseline for future improvements and evaluations.	Operational requirements	**CCR_010**
CCR_089	The simulator should be able to model realistic traffic.	Functional and data requirements	**CCR_010**
CCR_090	The simulation should be able to simulate connected vehicles.	The scope of the product	**CCR_089**
CCR_022	The system shall support both real-time and non-real-time simulation modes for traffic scenarios.	Functional and data requirements	**CCR_089**
CCR_136	Simulations shall be clearly defined in advance, including number of simulations to be conducted, number of traffic participants, required level of detail and accuracy, CVs penetration rate. All this information will be conveniently documented.	Functional and data requirements	**CCR_010**
CCR_034	[ViF] Simulation scenarios shall be designed to explore the impact of varying connected and automated vehicle (CAV) parameters on traffic flow performance.	Functional and data requirements	**CCR_136**
CCR_035	The simulation framework shall support variation of the penetration rate of CAVs and CVs among conventional vehicles.	Functional and data requirements	**CCR_136**
CCR_040	[ViF] Simulations shall allow adjustable fidelity levels of vehicle simulation models to balance accuracy in replicated scenarios.	Functional and data requirements	**CCR_136**
CCR_092	The penetration rate shall be set as % connected vehicles of the overall number of vehicles/overall traffic flow.	The scope of the work	**CCR_136**
CCR_093	The vehicles within the traffic network are represented as single actors without high fidelity multi body vehicle dynamics.	The scope of the work	**CCR_136**

ID	Description	Type	Parent
CCR_095	The simulation should be able to model different penetration values of different road users.	Functional and data requirements	**CCR_136**
CCR_139	The number of traffic participants must be adjustable in the simulator.	Functional and data requirements	**CCR_136**
CCR_052	O-D stands for Origin and Destination	Naming conventions and definitions	-
CCR_053	CV stands for Connected Vehicle	Naming conventions and definitions	-
CCR_054	LEZ stands for Low Emission Zone	Naming conventions and definitions	-
CCR_055	TMS stands for Traffic Management System	Naming conventions and definitions	-
CCR_056	CEV stands for Connected Emergency Vehicle	Naming conventions and definitions	-
CCR_057	VRU stands for Vulnerable Road User	Naming conventions and definitions	-
CCR_019	The involvement of all relevant actors and stakeholders is needed in the implementation process of the Use Cases.	Functional and data requirements	-
CCR_023	The system shall support the integration and execution of pre-existing tools relevant to Use Cases execution.	Functional and data requirements	-
CCR_026	The system shall use public or openly accessible standards.	Functional and data requirements	-
CCR_065	Where real-time communication is required, the temporal resolution threshold for what is considered “real-time” shall be defined beforehand.	Functional and data requirements	-
CCR_059a	CCR_059a The orchestrator must be be able to produce guidance and rules that ensure that all actors receive benefits from participating in the orchestration.		-
CCR_059b	The high-level orchestrator system must use historical and predicted data to run long-time simulations to test the governance, incentives, business models, agreements. These		**CCR_059a**

ID	Description	Type	Parent
	simulations must be based on accurate data and be re-run periodically.		
CCR_059c	If the outcome of the simulations show that some actor does not receive fair value from its participation, the rules and guidelines must be adapated.		**CCR_059a**
CCR_069	Related stakeholders should receive training on the optimal and most effective use of the orchestrator	User documentation and training	**CCR_059a**
CCR_111	Proofed (validated) guidelines and decision logics shall be made available to the orchestrator to support consistent and reliable decision-making	Functional and data requirements	**CCR_059a**
CCR_101	There should be a low fidelity simulation for use in the Orchestrator to assess situations not included in the database.	Functional and data requirements	**CCR_111**
CCR_134	Governance and business-model assumptions that affect orchestration (e.g., incentives, priority rules) shall be documented and linked to KPIs used in impact assessment.	Maintainability and support requirements	**CCR_059a**
CCR_131	A periodic governance review shall assess distributional impacts across actor groups; if any group is systematically disadvantaged, policy adjustments shall be triggered.	Operational requirements	**CCR_059a**
CCR_070	All participants involved in pilots or co-creation activities must be fully informed about the nature, risks, and benefits of the study and must voluntarily provide written or digital consent.	User documentation and training	**-**
CCR_071	Measures must be in place to safeguard participants considered vulnerable (e.g. minors, older citizens, people with cognitive impairments).	User documentation and training	**-**
CCR_072	Data collected and processed within CARMONY shall be proportionate to the pilot's objectives; that is, limited to what is necessary for valid research and operational evaluation. However, where broader data collection is scientifically or technically justified, it	Legal requirements	**-**

ID	Description	Type	Parent
	may be permitted, provided that the purpose, scope, and safeguards are clearly documented in the Data Inventory and validated through the Ethics and Data Protection review process.		
CCR_076	All pilots must undergo an ethics risk assessment, and where applicable, obtain ethics approval from relevant authorities or Ethics boards/committees before initiating any activities involving human participants or personal data.	Legal requirements	-
CCR_077	Physical and digital pilot environments must be safe, accessible and inclusive for all participants.	Usability and humanity requirements	-
CCR_079	The orchestrator back-end and roadside units shall achieve more than 99,5% availability during peak hours.	Operational requirements	-
CCR_080	The orchestrator shall maintain an immutable audit log of all control decisions and data exchanges for a minimum of 36 months.	Maintainability and support requirements	-
CCR_116	A taxonomy definition of the traffic users shall be defined at orchestration level (i.e. non-connected users, CV, CAV, VRUs, fleet vehicle...). This might allow to predict the level of influence for each type of user, or the channel to communicate as well as the percentage of the different type of users and how that percentage would impact in traffic orchestration	The scope of the product	-
CCR_122	All automated vehicles must get public road authorisation before demonstration of UCs	Legal requirements	-
CCR_137	CVs localization shall be based on GNSS technology.	Functional and data requirements	-
CCR_140	The simulator shall assume that it is given correct positions from CEVs.		**CCR_137**

3.2 High Level UC1 Requirements and Linked Simulation Requirements - Murcia

This Use Case considers an urban traffic scenario in which LEZs are implemented. The action will take place in the city of Murcia, in which at least one LEZ will be considered for the conduction of the Use Case. In this scenario, CVs travelling in the city will receive route recommendation from the Orchestrator, which shall consider LEZ restrictions. This section summarizes the UC1 simulation requirements.[5] Table 3-3 shows the hierarchy amongst them.

Table 3-3: UC1 Simulation Requirements

ID	Description	Type	Parent
UC1_001	The CV app shall permit the driver to indicate whether its vehicle is allowed to enter the LEZ.	Functional and data requirements	-
UC1_041	The orchestrator needs information about particular zones like LEZ and driving conditions within this zone	Functional and data requirements	**UC1_001**
UC1_002	The CV app must send the vehicle profile information to the orchestrator.	Functional and data requirements	-
UC1_009	Real-time communications must be performed by means of a publish/subscribe protocol (MQTT, AMQP, NATS...)	Functional and data requirements	**UC1_002**
UC1_003	The CV app must allow the driver to select the destination of the route.	Functional and data requirements	-
UC1_022	The simulated connected vehicles should be able to send end destination to Orchestrator Framework at the beginning of the trip.	The scope of the work	**UC1_003**
UC1_005	The orchestrator shall calculate the CV optimal route from Origin to Destination considering LEZ restrictions, CV profile and traffic conditions.	Functional and data requirements	-
UC1_023	The simulated connected vehicles shall be able to receive recommendations provided by the orchestrator.	The scope of the work	**UC1_005**
UC1_024	The simulated connected vehicles shall be able to parse the information received by the orchestrator.	The scope of the work	**UC1_023**
UC1_025	The simulated connected vehicles should be able to adjust their target destination based on orchestrator recommendations.	The scope of the work	**UC1_023**
UC1_006	The TMS shall provide the orchestrator with traffic and environmental real time information.	Functional and data requirements	-

ID	Description	Type	Parent
UC1_030	An interface needs to be provided from traffic management to indicate all vehicle positions form Murcia at every timestep.	The scope of the work	**UC1_006**
UC1_020	Information about roads, public transport, parking lots, and traffic restrictions has to be available	The scope of the work	**UC1_006**
UC1_041	The orchestrator needs information about particular zones like LEZ and driving conditions within this zone	Functional and data requirements	**UC1_006**
UC1_007	The CV app must inform the driver on LEZ restrictions, route recommendation and parking options in the destination.	Functional and data requirements	**-**
UC1_010	Communications that do not require of real-time monitoring shall be over HTTPS	Functional and data requirements	**UC1_007**
UC1_008	The CV app shall represent the CV position in real time.	Functional and data requirements	**-**
UC1_021	The simulated vehicles should be able to send start destination to Orchestrator Framework at the beginning of the trip.	The scope of the work	**UC1_008**
UC1_043	The simulation needs to take into account Murcia site special characteristics.	Functional and data requirements	
UC1_014	The simulation should simulate X hours/minutes of traffic.	The scope of the work	**UC1_043**
UC1_015	The simulation does not include adverse weather conditions.	The scope of the work	**UC1_043**
UC1_016	The simulation does not consider the quality of signal (signal loss) for connectivity.	The scope of the work	**UC1_043**
UC1_019	The simulation shall not include a high fidelity model of automated driving functions.	The scope of the work	**UC1_043**
UC1_026	The simulation does not simulate the driver and the interaction with the app, but simplifies this by receiving and sending of messages.	The scope of the work	**UC1_043**
UC1_027	An overall architecture needs to show the interplay between traffic management and simulation architecture.	The scope of the work	**UC1_043**
UC1_028	The architecture shall show the building blocks, interfaces and data types.	The scope of the work	**UC1_027**
UC1_040	In the simulation, simulation of traffic, simulation of the orchestrator, and simulation of communication should be connected.	Functional and data requirements	**UC1_027**
UC1_034	The simulator should be able to simulate multimodal traffic, e.g. using a private car	Functional and data requirements	**UC1_043**

ID	Description	Type	Parent
	– parking the private car – continuing the journey by public transport		
UC1_042	The simulation should be able to model the connection between Orchestrator and connected (automated) vehicles and VRUs who use the Carmony-App.	Functional and data requirements	**UC1_043**
UC1_011	The simulation shall reflect an urban environment within the city of Murcia.	The scope of the work	**UC1_043**
UC1_017	The density of traffic should change according to daytime (commuting).	The scope of the work	**UC1_011**
UC1_012	The simulation shall include a low emission zone and standard city zone.	The scope of the work	**UC1_011**
UC1_013	The simulation shall build on a road network showing relevant parts of the city of Murcia.	The scope of the work	**UC1_011**
UC1_033	The simulator should be able to simulate Low Emission Zones (LEZs) restrictions.	Functional and data requirements	**UC1_011**
UC1_039	In the simulation traffic sensors should be modelled.	Functional and data requirements	**UC1_011**
UC1_018	The city traffic simulation shall include passenger vehicles, heavy duty vehicles, cyclists, busses and pedestrians.	The scope of the work	**UC1_011**
UC1_035	The simulator should be able to model vulnerable road users (VRUs) like pedestrians.	Functional and data requirements	**UC1_018**
UC1_036	The simulator should be able to model public transportation.	Functional and data requirements	**UC1_018**

3.3 High Level UC2 Requirements and Linked Simulation Requirements-Murcia

UC 2 considers a scenario in which a CV is running in the open traffic environment in Murcia, when it suddenly experiences a failure and gets stopped at an intersection. The action will take place in the city of Murcia, where a specific intersection will be selected for the conduction of the proposed scenario in the real world. Additionally, this use case will be also tested in simulation, where the damaged vehicle will be a bus, to evaluate a more critical scenario, minimizing real traffic disruption. [5]

This section summarizes the UC2 simulation requirements. Table 3-4 shows the hierarchy amongst them.

Table 3-4: UC2 Simulation Requirements

ID	Description	Type	Parent
UC2_001	The CV app must notify the user of the presence of obstacles on the road within a concrete radius.	Functional and data requirements	-
UC2_024	The simulated vehicles shall send their current position and target destination to orchestrator every minute.	The scope of the work	**UC2_001**
UC2_002	The orchestrator shall calculate the new route for the CV, taking into account obstacles and closed roads.	Functional and data requirements	-
UC2_026	The simulated vehicles shall be able to receive recommendations provided by the orchestrator.	The scope of the work	**UC2_002**
UC2_003	The CV app must notify the user of the new optimal route proposed by the orchestrator.	Functional and data requirements	-
UC2_043	The simulation should be able to provide an alternative means of transport and simulate the fulfillment of the transport wish.	Functional and data requirements	**UC2_003**
UC2_041	The model of connected (automated) vehicles should be able to receive updated route recommendations and react to them.	Functional and data requirements	**UC2_003**
UC2_004	The app will receive notifications of new proposed routes to bypass the obstacle.	Functional and data requirements	-
UC2_027	The simulated vehicles shall be able to parse the information received from the orchestrator.	The scope of the work	**UC2_004**
UC2_005	The orchestrator will define the optimal route, taking into account real-time road obstacles.	Functional and data requirements	-

ID	Description	Type	Parent
UC2_023	The simulated vehicles should be able to send start destination to Orchestrator Framework.	The scope of the work	**UC2_005**
UC2_025	The simulated vehicles should be able to send end destination to Orchestrator Framework at the beginning of the trip.	The scope of the work	**UC2_005**
UC2_028	The simulated vehicles should be able to adjust their target destination based on orchestrator recommendations.	The scope of the work	**UC2_005**
UC2_007	The app must be able to report a breakdown of the user's car to the orchestrator.	Functional and data requirements	-
UC2_040	The model of the damaged connected (automated) vehicle should be able to pass its state to the simulation of the orchestrator.	Functional and data requirements	**UC2_007**
UC2_042	The model of the damaged connected automated vehicle should be able to send their need for an alternative means of transport to their destination.	Functional and data requirements	**UC2_007**
UC2_006	Communication between the orchestrator and the app will be carried out through real-time protocols as MQTT or AMQP.	Functional and data requirements	**UC2_007**
UC2_008	The automated vehicle shall have access to the status of the traffic signal controller	Operational requirements	-
UC2_009	The vehicle shall receive information from the traffic signal controller either through the communication link provided by the orchestrator solution or, alternatively, via V2X	Operational requirements	**UC2_008**
UC2_010	Route change information shall be delivered asynchronously when a new suggested route is generated	Operational requirements	-
UC2_048	The orchestrator will send updated route recommendations to simulated connected vehicles affected by the road blockage	Operational requirements	**UC2_010**
UC2_011	Route changes shall be suggested directly by the system and not requested by the vehicle	Operational requirements	-
UC2_049	The orchestrator will detect the road blockage based on the information provided from the simulation and calculate new routes for affected vehicles.	Operational requirements	**UC2_011**
UC2_012	A metric to quantify the impact of a blocked road has to be devised	The scope of the work	-

ID	Description	Type	Parent
UC2_050	The system shall measure the impact of the blocked street on traffic using the travel time along the affected road segment.	Functional and data requirements	**UC2_012**
UC2_047	The simulation needs to take into account Murcia site special characteristics.	Functional and data requirements	**-**
UC2_013	The simulation shall reflect an urban environment within the city of Murcia.	The scope of the work	**UC2_047**
UC2_015	The simulation shall build on a road network showing relevant parts of the city of Murcia.	The scope of the work	**UC2_013**
UC2_014	The simulation shall include an intersection where an incident blocks the road.	The scope of the work	**UC2_013**
UC2_016	The simulation shall be able the block roads for the traffic within the road network.	The scope of the work	**UC2_014**
UC2_020	The density of traffic should change according to daytime (commuting).	The scope of the work	**UC2_013**
UC2_033	An interface needs to be provided from traffic management to indicate all vehicle positions form Murcia at every timestep.	The scope of the work	**UC2_020**
UC2_036	The simulation shall run faster than real time as digital twin to provide input to orchestrator/traffic management.	The scope of the work	**UC2_033**
UC2_021	The city traffic simulation shall include passenger vehicles, heavy duty vehicles, busses, cyclists and pedestrians.	The scope of the work	**UC2_013**
UC2_037	The simulator should be able to model vulnerable road users (VRUs) like pedestrians.	Functional and data requirements	**UC2_021**
UC2_038	The simulator should be able to simulate damaged connected (automated) vehicles.	Functional and data requirements	**UC2_021**
UC2_044	The traffic simulation should contain a model of bus, which can have the state “broken down” and is connected.	Functional and data requirements	**UC2_021**
UC2_045	The simulated environment should describe the test region in Murcia respectively a part of it.	Functional and data requirements	**UC2_021**
UC2_017	The simulation should simulate X hours/minutes of traffic.	The scope of the work	**UC2_047**
UC2_018	The simulation does not include adverse weather conditions.	The scope of the work	**UC2_047**

ID	Description	Type	Parent
UC2_019	The simulation does not consider the quality of signal (signal loss) for connectivity.	The scope of the work	**UC2_047**
UC2_022	The simulation shall not include a high fidelity model of automated driving functions.	The scope of the work	**UC2_047**
UC2_029	The simulation does not simulate the driver and the interaction with the app, but simplifies this by receiving and sending of messages.	The scope of the work	**UC2_047**
UC2_046	The simulation should be able to model the connection between Orchestrator and connected (automated) vehicles and VRUs who use the Carmony-App.	Functional and data requirements	**UC2_029**
UC2_030	An overall architecture needs to show the interplay between traffic management and simulation architecture.	The scope of the work	**UC2_047**
UC2_031	The architecture shall show the building blocks, interfaces and data types.	The scope of the work	**UC2_030**

In an early phase of the project, crosscutting requirements for UC2 and UC3 were defined. Table 3-5 shows the simulation requirements particularly relevant for UC2.

Table 3-5: Additional UC2 Requirements, Cross-cutting for UC2 and UC3

ID	Description	Type	Parent
CCR_082	Automated vehicles shall be deployed in open-air areas without urban canyons for Use Cases 2 and 3	Relevant facts and assumptions	**-**
CCR_083	The automated vehicle shall be capable of reaching the speed limit in urban environments (approximately 30 km/h) for UC 2 and 3	Functional and data requirements	**-**
CCR_084	Vehicles shall possess the necessary authorizations to operate in automated mode for Use Cases 2 and 3 (such as a controlled environment permit or equivalent homologation document	Relevant facts and assumptions	**-**
CCR_085	Automated vehicle testing shall be conducted only on days without rain due to insufficient IP protection of certain devices (UC2 and 3)	Relevant facts and assumptions	**-**
CCR_086	An operator equipped with an emergency stop control shall remain within 70 meters of the automated vehicle to enable manual intervention if necessary (UC2 and 3)	Functional and data requirements	**-**

CCR_087	An operator shall be present inside the vehicle (UC2 and UC3)	Operational requirements	-
CCR_088	The automated vehicle shall receive updated routes in case of changes, including the origin, destination, and all intermediate nodes (UC 2 and 3)	Operational requirements	-

3.4 High Level UC3 Requirements and Linked Simulation Requirements Murcia

There are no simulation requirements defined for UC3, since it is only conducted in the real-world. All non-simulation requirements for UC3 can be found in D2.2.

3.5 High Level UC4 Requirements and Linked Simulation Requirements – Luxembourg

This use case focuses on simulated optimization of the A3 carpool lane using real and historical data. It does not include real-world lane management implementation. This section summarizes the UC4 simulation requirements.[5] Table 3-6 shows the hierarchy amongst them.

Table 3-6: UC4 Simulation Requirements

ID	Description	Type	Parent
UC4_001	The orchestrator shall continuously monitor real time occupancy of the carpool and general purpose lanes on Highway A3.	Functional and data requirements	-
UC4_039	The simulator should be able to model carpool and bus lanes.	Functional and data requirements	**UC4_001**
UC4_041	The simulator should provide data to compute KPIs like number of traffic jams, carpool lane utilization, number of accidents, fuel consumption, as results.	Functional and data requirements	**UC4_001**
UC4_044	The simulator should model traffic counters and sensors.	Functional and data requirements	**UC4_001**
UC4_047	The number of entering vehicles and the lane capacity to trigger the orchestrator has to be defined	The scope of the work	**UC4_001**
UC4_002	The system shall compute and update the available reservation slots for non carpool vehicles whenever the lane utilisation falls below a configurable threshold.	Functional and data requirements	-
UC4_041	The simulator should provide data to compute KPIs like number of traffic jams, carpool lane	Functional and data requirements	**UC4_002**

	utilization, number of accidents, fuel consumption, as results.		
UC4_043	The simulator should restrict the use of certain lanes to registered users.	Functional and data requirements	**UC4_002**
UC4_046	The simulation must be able to simulate a sufficient number of vehicles	The scope of the work	**UC4_002**
UC4_047	The number of entering vehicles and the lane capacity to trigger the orchestrator has to be defined	The scope of the work	**UC4_002**
UC4_008	The orchestrator shall prioritise certified carpool vehicles over non carpool vehicles when allocating lane slots.	Functional and data requirements	**-**
UC4_043	The simulator should restrict the use of certain lanes to registered users.	Functional and data requirements	**UC_008**
UC4_048	The simulation does not simulate the driver and the interaction with the app, but simplifies this by receiving and sending of messages.	The scope of the work	**UC_008**
UC4_023	The orchestrator shall broadcast carpool lane reservation offers to eligible vehicles at least 2 minutes before predicted entry point.	Operational requirements	**-**
UC4_048	The simulation does not simulate the driver and the interaction with the app, but simplifies this by receiving and sending of messages.	The scope of the work	**UC4_023**
UC4_025	The system shall revoke reservations and instruct vehicles to vacate the lane within 60s if carpool occupancy exceeds 80%	Operational requirements	**-**
UC4_041	The simulator should provide data to compute KPIs like number of traffic jams, carpool lane utilization, number of accidents, fuel consumption, as results.	Functional and data requirements	**UC4_025**
UC4_044	The simulator should model traffic counters and sensors.	Functional and data requirements	**UC4_025**
UC4_047	The number of entering vehicles and the lane capacity to trigger the orchestrator has to be defined	The scope of the work	**UC4_025**
UC4_048	The simulation does not simulate the driver and the interaction with the app, but simplifies this by receiving and sending of messages.	The scope of the work	**UC4_025**
UC4_026	Roadside and in-Vehicle HMIs shall present lane-change guidance in less than 500 ms after an orchestrator message is received.	Usability and humanity requirements	**-**
UC4_048	The simulation does not simulate the driver and the interaction with the app, but simplifies this by receiving and sending of messages.	The scope of the work	**UC4_026**

UC4_028	The orchestrator shall log all lane-reservation transactions for a minimum of 24 months for auditing purposes.	Maintainability and support requirements	-
UC4_030	All communication concerning lane reservations shall comply with GDPR and anonymise vehicle identifiers.	Legal requirements	-
UC4_048	The simulation does not simulate the driver and the interaction with the app, but simplifies this by receiving and sending of messages.	The scope of the work	**UC4_030**
UC4_034	The infrastructure needs to detect the congestion limit to trigger orchestration recommendations.	The scope of the work	-
UC4_041	The simulator should provide data to compute KPIs like number of traffic jams, carpool lane utilization, number of accidents, fuel consumption, as results.	Functional and data requirements	**UC4_034**
UC4_037	An interface to a trucking management system is needed to provide individual recommendations for truck drivers.	The scope of the work	-
UC4_048	The simulation does not simulate the driver and the interaction with the app, but simplifies this by receiving and sending of messages.	The scope of the work	**UC4_037**
UC4_038	An interface to a passenger vehicle recommendation system is needed to provide passenger vehicle recommendations.	The scope of the work	-
UC4_048	The simulation does not simulate the driver and the interaction with the app, but simplifies this by receiving and sending of messages.	The scope of the work	**UC4_038**
UC4_049	The system shall use high-definition maps with lane-level detail at a spatial resolution of at least 50 cm		
UC4_042	The simulated environment should describe the test region in Luxembourg respectively the necessary part of it.	Functional and data requirements	**UC4_049**

3.6 High Level UC5 Requirements and Linked Simulation Requirements Luxembourg

There are no simulation requirements defined for UC5, since it is only conducted in the real-world. All non-simulation requirements for UC5 are listed in D2.2.

3.7 High Level UC6 Requirements and Linked Simulation Requirements Luxembourg

UC 6 aims to optimise the overall traffic flow and safety on the A3 by proactive speed management under realistic, data-driven simulation. The study stops short of real-world deployment of VSL signs or enforcement systems. This section summarizes the UC6 simulation requirements.[5] Table 3-7 shows the hierarchy amongst them.

Table 3-7: UC6 Simulation Requirements

ID	Description	Type	Parent
UC6_001	The orchestrator shall predict the formation of traffic jams on A3 at least 5 min in advance based on flow, density and shock-wave models.	Functional and data requirements	-
UC6_002	When a jam is predicted, the system shall compute an optimal speed profile to mitigate congestion within the affected corridor.	Functional and data requirements	-
UC6_010	The simulator should be able to simulate variable speed limit signs (VSLs), where the speed limit is an input from the orchestrator.	Functional and data requirements	**UC6_002**
UC6_004	Variable speed-limit "signs" shall be updated by the orchestrator within 30 s of a speed-management decisions.	Functional and data requirements	-
UC6_010	The simulator should be able to simulate variable speed limit signs (VSLs), where the speed limit is an input from the orchestrator.	Functional and data requirements	**UC6_004**
UC6_005	The system shall ensure that no recommended speed exceeds the legal limit or drops below, except under hazardous conditions.	Legal requirements	-
UC6_007	Predicted and actual KPIs (travel time, fuel, emissions) shall be logged for each control cycle.	Functional and data requirements	-
UC6_009	The orchestrator shall provide a fallback plan to static speed-limit signs if communication to variable signs fails for more than 2 min.	Operational requirements	-

4. Conclusion

Within the task the requirements for the simulation framework were defined and the task successfully closed. By linking the high-level requirements identified in Task 2.1 with existing or newly defined child requirements, we ensured consistency and completeness across the requirement set. We reviewed the existing high-level requirements and defined them as parent requirements. Then we linked existing child requirements to a parent requirement. After the review missing child requirements were identified and defined. The newly introduced child requirements were integrated into the Volere tool. Unlinked but relevant requirements were grouped into an “Additional Technical Requirements” cluster to maintain their visibility for future development. This process established clear traceability between parent and child requirements, providing a solid foundation for subsequent design and validation phases.

The identified structure of requirements will be used in a later task (WP3) step to derive the system architecture with its various modules for different tasks and the interfaces between the modules of the complete system. This deliverable will be the basis for the design specifications of each module. Continuous traceability checks during implementation to ensure alignment with project objectives [8].

The conducted work is beneficial for the project because of the following reasons: By reviewing high-level requirements from D2.1, it was possible to improve traceability between high-level and detailed simulation requirements. This increases a consistency across deliverables (D2.2, D2.3) and the Volere repository. Moreover, this approach enhances coverage of technical aspects by introducing additional clusters for relevant requirements.

In the subsequent tasks of WP 3, the system architecture (T3.1) will be developed using the requirements defined in this task. The architecture will consist of various building blocks, later described with specification sheets (Definition of the simulation framework in T3.5). The specification phase will be facilitated and made more efficient through the requirement clusters. The architecture specification will also include a specification and definition of interfaces and signal flows (T3.5).

5. Abbreviations

Term	Definition
CARMONY	Coordinated Action For Responsive Mixed Orchestration and Network Yield
CCR	Cross-Cutting Requirement
CEV	Connected Emergency Vehicle
CV	Connected Vehicle
DEM	Demonstrator, Pilot, Prototype
I/O	Input/Output
LEZ	Low Emission Zone
O-D	Origin and Destination
PU	Public
R	Document, Report
TMS	Traffic Management System
UC	Use Case
WP	Work Package

6. References

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