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1. Executive Summary

CARMONY develops an Interlinked Orchestration Framework to support coordinated traffic management in mixed mobility environments involving conventional vehicles, connected and cooperative automated mobility, public transport, logistics, infrastructure operators and public authorities. This deliverable presents the first governance framework for the CARMONY orchestrator, focusing on actor roles, decision-making responsibilities, accountability, coordination mechanisms, data exchange and regulatory implications.

The deliverable aims to identify the governance conditions needed for the future deployment of the orchestrator in the Murcia and Luxembourg pilot sites. The work is based on a literature review, stakeholder mapping, semi-structured interviews, consultation activities and pilot-specific analysis. This approach makes it possible to understand current governance practices, institutional barriers, data-sharing gaps and operational needs for the forthcoming activities for T4.1 and T4.3 but also WP4 in general.

D4.1 progresses beyond the state of the art by addressing traffic orchestration not only as a technical optimisation challenge, but also as a governance challenge requiring transparency, trust, human oversight, explainability and clear accountability. The main results include an initial governance baseline for both pilot sites, a first set of governance requirements for the orchestrator, and preliminary development pathways towards operational mobility orchestration.

Overall, this deliverable establishes the governance foundations for the next stages of CARMONY, supporting the development of an orchestrator that is technically feasible, institutionally credible, transparent and aligned with public-interest objectives.

Keywords: Traffic Orchestration, Governance Models, Mobility Management, Stakeholder Engagement, Data Governance, Decision-making Mechanisms, Interoperability.

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2. Introduction

The CARMONY project introduces an Interlinked Orchestration Framework for traffic management designed to operate across mixed traffic environments involving both human-driven vehicles and connected and cooperative automated mobility (CCAM) vehicles. The framework integrates governance and business models that are continuously refined through simulation and real-world data, with the goal of generating credible response plans, decision logics, and cooperation agreements that foster trust among operators, institutions, and citizens. The system will be piloted in urban and highway environments respectively in Spain (Murcia) and Luxembourg, and its governance and business dimensions are covered by the activity developed under WP4 *Governance and Business Models*. This activity consists of:

- T4.1 *Co-creation of governance models for the orchestrator framework*
- T4.2 *Understanding incentives for the orchestrator framework and identify potential business models*
- T4.3 *Creation of multilevel governance and data exchange framework for the orchestrator*
- T4.4 *Training for orchestrator users*

The core of WP4 and specially T4.1 is to include the human-centred orchestration logic within the CARMONY's approach: the orchestrator provides personalised guidance and optimises traffic for collective benefit, but final decisions always rest with the human. This design philosophy places governance at the centre of the system's legitimacy and deployment. In other words, studying *who decides what, on what basis, under what conditions, and with what accountability* are not secondary elements but crucial aspects of the orchestrator itself. Besides T4.1, T4.3 are strong related tasks because T4.3 is oriented to develop governance and regulatory models to support orchestration, data exchange and decision-making across multiple levels.

In turn, D4.1 *CARMONY Governance Models — Initial Version* is one of the first outputs of WP4 specifically addressing the governance layer. At M15, before the orchestrator's technical implementation is finalised, consultative activities with external to the project stakeholders are initiated. This timing is important because governance models must inform the system design, not merely ratify it. Therefore, D4.1 content presents both an analytical document and normative instrument. On the one hand, it consolidates what has been learned about governance needs and requirements. On the other hand, it focuses on expressing an initial but structured set of governance principles, actor roles, and decision logics that will guide subsequent development within WP4 but also forthcoming activities in WP5, WP6 and WP7.

This document is structured as follows. Section 3 defines the objectives and scope of D4.1 and its relationships within the project's broader architecture. Section 4 describes the methodological approach adopted in the activities performed from M7 to M15. Section 5 presents the governance baseline, identifying elements from literature and stakeholder engagement activities. For addressing the conceptualisation of governance models from a more operational perspective, Section 6 synthesises the governance requirements for the CARMONY orchestrator and advances an initial governance framework. Section 7 complements this perspective by addressing data exchange, multilevel and regulatory considerations. Lastly, this document presents, in Section 9, conclusions from the current work progress and establishes the pathways and next steps to be followed until M27, which will in turn be reported in D4.3.

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3. Objectives and scope

WP4 is led by EUT within CARMONY project and runs from month 7 to month 33 of the project. As stated already in the GA, the main goal is to establish the governance and business models for the Interlinked Orchestrator, defining actor roles, promoting social acceptance, engaging stakeholders, and developing strategies for sustainability and scalability. WP4 operates at the interface between the technical system design (WP3, WP5) and the real-world deployment conditions (WP6), translating governance principles into operational structures that are credible to stakeholders and compatible with the regulatory environment.

Task 4.1 defines governance models for the orchestration framework at each pilot site, through stakeholder analysis conducted via interviews, workshops, and other participatory methods. Its scope covers the definition of roles, liabilities, hierarchies, and information and decision flows within the context of each use case.

This deliverable also covers the first stages of Task 4.3, led by LUX. This task addresses governance across multiple institutional and regulatory levels: it covers cooperation between traffic managers and diverse stakeholder categories, integrates business model logic, and develops regulatory frameworks that support data exchange and decision-making. T4.3's contribution to D4.1 is therefore primarily about multilevel governance conditions, institutional positioning, and the regulatory and data governance considerations that the orchestrator must satisfy. A more complete output is expected to be presented in D4.3, where the refinements resulting from piloting and simulation will be incorporated.

For clarification, D4.2 (*CARMONY Business Models and Incentives System — Initial Version*) is a parallel deliverable addressing the incentive structures and business model conceptualisation for the orchestrator. While D4.2 focuses on the economic logic of cooperation (how actors are motivated to participate and sustain the system), D4.1 focuses on the governance logic (how authority, accountability, and decision-making are organised). The two deliverables are complementary and mutually informing: governance arrangements shape the feasibility of business models, and incentive structures affect whether governance rules are followed in practice. Together, D4.1 and D4.2 constitute the initial version of CARMONY's framework for the orchestrator from a more economic and social perspective.

Last but not least, it is important to explain further what "initial version" implies at M15 with D4.1 to avoid misunderstanding. M15 sits after the completion of WP2's requirements and baseline work (M1–M9) and at the onset of WP5's and WP6's implementation phases (starting in M13). By this point, output from WP2 like D2.2 has been crucial to set up T4.1 activities regarding foundational stakeholder mapping, interviews, and others. For synergies with WP5 and WP6, the orchestrator itself has not yet been deployed as pilot conditions and demonstrations are still being defined. The governance framework in D4.1 is therefore designed to be structurally sound and analytically grounded, but it is expected to be refined in the forthcoming months of the project and updated in D4.3.

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4. Methodology

The development of a robust governance framework for the interlinked orchestrator requires the involvement of the ecosystem of actors that will interact with, operate, regulate, or be affected by the system.

Given that traffic orchestration in a system-of-systems environment involves multiple stakeholders (including public authorities, infrastructure operators, mobility service providers, logistics companies, technology providers, users, etc.) governance cannot be defined purely from a technical perspective. Instead, it must emerge from a structured process of stakeholder engagement and co-creation.

For this reason, T4.1 adopts a participatory and iterative methodological approach designed to capture the operational realities, institutional constraints, incentives, and expectations of the relevant stakeholders in each pilot site. The goal is to translate this knowledge into practical governance models tailored to the local mobility ecosystem.

The methodological approach builds on established stakeholder-analysis and public-participation methods, which emphasise the systematic identification of relevant actors, the adaptation of engagement processes to their institutional context, and the iterative refinement of initial assumptions through stakeholder feedback (Reed et al., 2009; Bryson et al., 2013). Nonetheless, WP4 team has developed a tailored methodology which follows a structured process composed of the following five main phases:

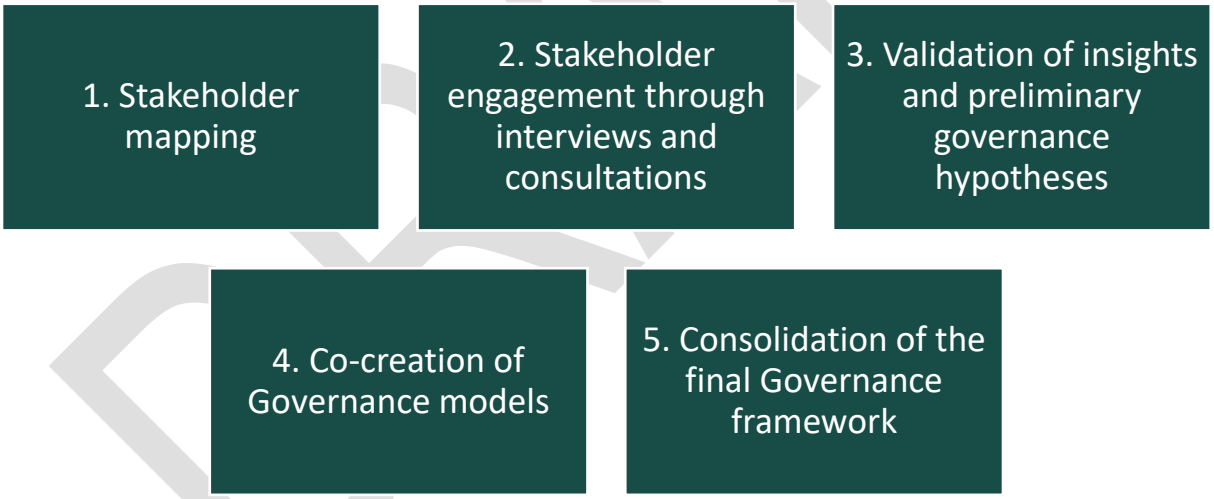


Figure 1: General steps for T4.1

This approach ensures that the governance models developed within the project are not theoretical constructs, but practical frameworks grounded in real-world operational conditions.

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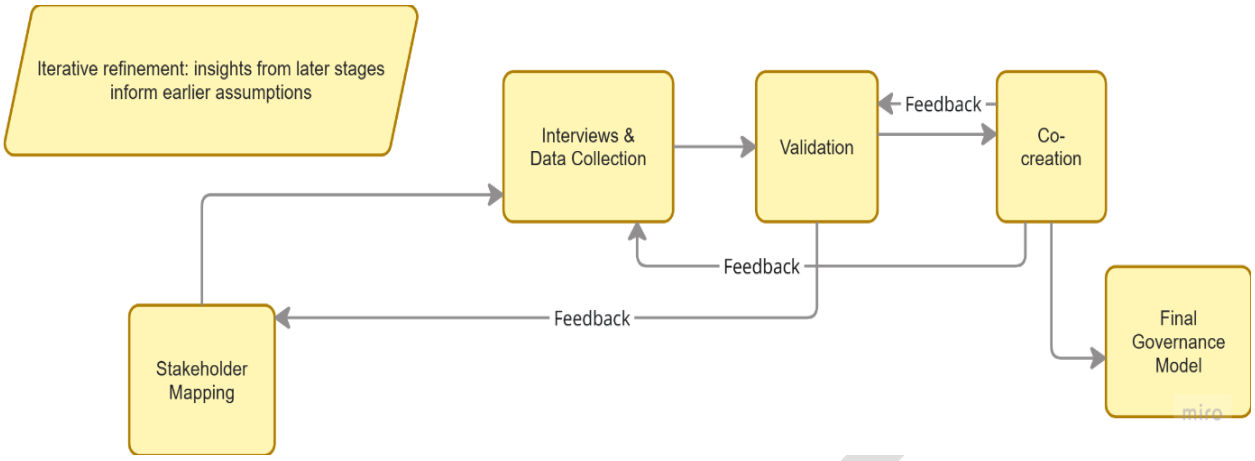


Figure 2: Iterative process and flow along methodological steps within T4.1

To complement, Figure 2 visually represents the iterative nature of the process and highlights that insights from later stages may lead to refinements in earlier assumptions. It should be noted that, given the stage of the project and WP4 activities, currently (M15) the first two steps of the methodology (as presented in Figure 1) have already been realised. Steps 3, 4 and 5 are expected to happen during the forthcoming months and reported in the final deliverable D4.3. However, at this moment, task partners have considered that for the anticipation of next activities within T4.1 and T4.3, Section 8 of the present document is oriented to conceptualise how future operational pathways on governance may look like, as well as the barriers and limitations to the optimal governance models. Regarding the steps adopted for the methodology, following subsections present further details for the steps represented in Figure 1.

4.1.1 Step 1: Stakeholders mapping

The first step of the methodology consists of identifying and categorizing the relevant stakeholders that form part of the mobility ecosystem in each pilot site. The Interlinked Orchestrator operates in an environment characterised by multiple actors with different responsibilities, decision-making capacities, incentives, and operational constraints. Therefore, understanding the stakeholder landscape is a prerequisite for defining viable governance mechanisms.

Stakeholder mapping aims to identify:

(1) The actors involved in mobility management and traffic orchestration
(2) Their roles and responsibilities within the transport system
(3) Their decision-making authority and operational influence
(4) Their potential interaction with the Interlinked Orchestrator
(5) Their incentives, interests, and potential concerns

The stakeholders considered already in D4.2 are:

(1) Agents in Traffic
(2) Fleet Operators
(3) Political Stakeholders
(4) Traffic Managers

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(5) Infrastructure Operators
(6) Societal Stakeholders

This categorisation has been shared with the partners involved in CARMONY pilots, in order to have direct contact with stakeholders and ensure a balanced representation for the forthcoming tasks. However, it is expected that for D4.3 more stakeholders will be involved in the overall process.

4.1.2 Step 2: Stakeholder engagement and data collection

Once the relevant stakeholders have been identified, the project proceeds with a structured stakeholder engagement phase designed to collect qualitative and contextual information regarding governance, coordination mechanisms, data sharing practices, and operational decision-making processes.

The primary objective of this phase is to understand how mobility coordination currently works in practice and to identify the conditions under which an orchestrator could effectively operate.

To achieve this, several complementary consultation methods are expected to be integrated, but by M15 semi-structured interviews have been the core activity employed. Table 1 and 4 displayed in the next sections of the document include the typologies and entities engaged so far. Methodologically, this format has allowed the project team to explore key governance topics while maintaining flexibility to adapt the discussion to the operational context and expertise of each stakeholder.

The interviews are structured around thematic blocks, addressing key dimensions of the governance model, including:

- Organisational governance and decision-making authority.
- Operational coordination mechanisms.
- Incentives and economic considerations.
- Data sharing practices and requirements.
- Training, adoption and organisational readiness.

The semi-structured format allows stakeholders to share insights, operational experiences, and perceived barriers or opportunities related to the deployment of an orchestration system. Literature review performed has guided the elements to be considered in the conversations with stakeholders to specify the innovation gap that CARMONY addresses. The semi-structured format being used can be found in the Annex of the present document.

Besides the interviews, consultations with the members of the CARMONY Outreach Group[1], being promoted under WP7, has been performed. This has been realised mainly through a workshop organised in April 2026, aiming to enhance the ongoing results of WP4 by adding

[1] The CARMONY Outreach Group (COG) is a stakeholder community established within the CARMONY project to strengthen dialogue between research, policy, industry, and operational actors involved in connected, cooperative and automated mobility (CCAM) and smart traffic management. The COG acts as a strategic interface between the CARMONY consortium and external stakeholders, supporting the relevance, transferability, and real-world uptake of project results across Europe and beyond.

the perspective of other types of agents and experts not directly involved in CARMONY pilots but addressing similar challenges.

4.1.3 Step 3 and 4: Validation and co-creation of governance models

Following the stakeholder consultation phase, the insights collected are synthesised and analysed in order to identify recurring patterns, governance challenges, and potential coordination mechanisms.

Based on this analysis, preliminary governance hypotheses are developed. Thes hypotheses describe potential governance structures for the Interlinked Orchestrator, including:

(1) Roles and responsibilities of different actors
(2) Decision-making authority
(3) Coordination mechanisms
(4) Incentives for participation
(5) Data sharing arrangements

These preliminary models are not considered final solutions but rather discussion artefacts used to facilitate further engagement with stakeholders. This is, in turn, the added value of D4.1 that constitute this preliminary work, forming the basis for the execution of Step 3 in the forthcoming months.

4.1.4 Step 5: Consolidation of the final governance framework

The final phase of the methodology consists of consolidating the validated governance structures into a coherent governance framework for each pilot site with the elements included in Figure 3.

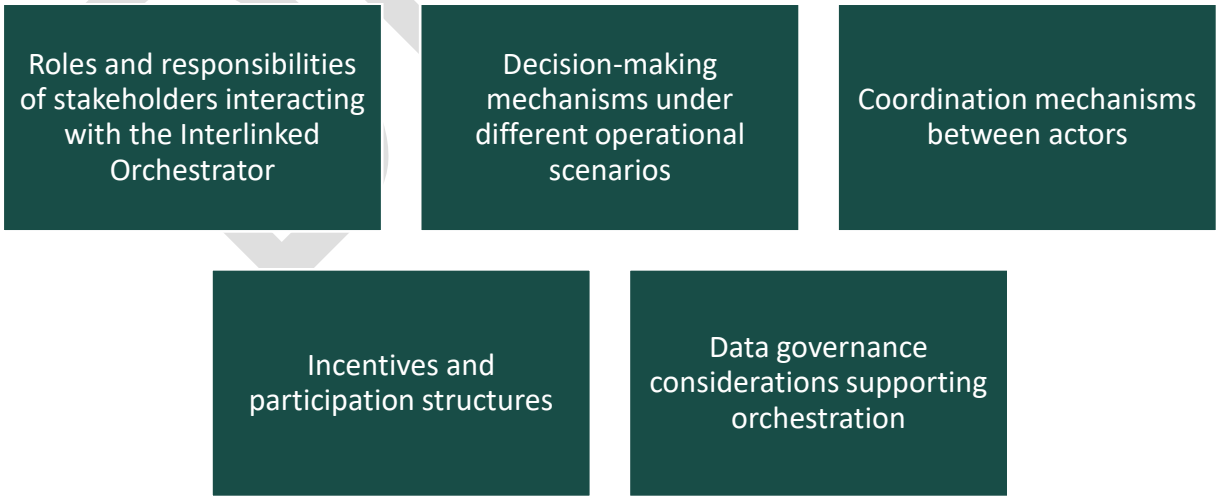


Figure 3: Elements for the conceptualised final governance model

For the elements included in Figure 3, strong synergies with other tasks within WP4 are crucial. For that, coordination at WP4 level is relevant along the implementation of all the steps of Figure 1. With this coordination within WP4 and other tasks, while grounding the governance

design in stakeholder engagement and iterative validation, the methodology ensures that the resulting governance frameworks are not only theoretically sound but also practically applicable within the complex, multi-actor environments which characterise modern mobility ecosystems. However, limitations are expected to be listed and reported in D4.3.

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5. Governance baseline and problem definition

This section establishes the governance starting point for the CARMONY Interlinked Orchestrator by examining how mobility coordination currently operates and where the main institutional and operational gaps lie. It combines findings from the literature with insights from the CARMONY Outreach Group and stakeholders involved in the Murcia and Luxembourg pilots. The analysis focuses on existing actor roles, decision-making authority, accountability arrangements, coordination mechanisms and barriers to cooperation, while recognising the distinct characteristics of the two contexts of the CARMONY project: an urban municipal environment (Murcia) and a multilevel, cross-border motorway context (Luxembourg). By identifying fragmented responsibilities, missing coordination interfaces, underrepresented actors and trust-related challenges, the section defines the governance problems that CARMONY must address and provides the evidence base for the governance requirements developed in Section 6.

5.1 Literature review

Recent research on smart and orchestrated mobility shows that governance has become a central issue in the analysis of transport systems. Mobility is increasingly understood as a socio-technical ecosystem in which public authorities, mobility service providers, digital platforms, and users interact under conditions of interdependence, limited capacity, and competing objectives. In this context, governance concerns not only regulation, but also the design of coordination mechanisms, incentive structures, and institutional arrangements capable of aligning heterogeneous actors and system goals (Zardini et al., 2023). This framing has practical implications for a project like CARMONY. The Interlinked Orchestrator is not solely a routing tool: it is a system that allocates scarce road capacity, shapes travel demand, interfaces with public mobility infrastructure, and generates recommendations that affect how individuals, fleet operators, traffic managers, and municipalities experience the transport network. Any governance framework for such a system must therefore address not only its internal logic — who decides what, when, and on what basis — but also its external legitimacy — whether the actors affected by its decisions perceive them as fair, transparent, and appropriately accountable. Therefore, the review included in this section is organised around the following thematic domains: cooperation and incentive design in multi-provider transport systems; the governance of co-opetitive ecosystems; polycentric governance and institutional design for shared infrastructure. Data governance and trusted information exchange, although mentioned in this section, is covered in more detail in Section 7 of the present document.

A first important topic within related literature focuses on cooperation and incentive design in multimodal transport systems. Deng et al. (2022) examine how multiple transportation service providers may cooperate through an integrated multimodal platform that simplifies journey planning and payment while coordinating profits across modes. Their work combines cooperative game theory with a model of how travellers choose between different route and transport options under uncertainty and shows that incentives can be used to influence passenger flows and support cooperation among providers. The study is especially relevant because it explicitly links incentive design with profit-sharing arrangements, arguing that cooperation among providers requires both behavioural mechanisms and distributive rules perceived as fair. It further shows that asymmetric Nash bargaining can be used to allocate the gains of cooperation among service providers. However, , although it has many implications for establishing effective governance mechanisms, this relies more within the scope of D4.2.

Another relevant contribution to point out is the role of induced demand in multimodal governance. Deng et al. (2022) note that improving convenience or reducing cost may

stimulate additional travel demand, which can in turn undermine wider public objectives if not properly managed. Their framework, therefore, places governance at the intersection of market design, passenger behaviour, and social outcomes. This perspective is particularly useful because it moves beyond isolated operator models and treats cooperation as a system-level design problem in which incentives, demand responses, and distributive effects must be considered together (Deng et al., 2022).

A complementary perspective is offered by Liu et al. (in press) and related work on multi-leader-multi-follower game models for Mobility-as-a-Service (MaaS) platforms, which formalise the coopetition inherent in integrated mobility: service operators both cooperate (by pooling capacity through a shared platform) and compete (by continuing to serve individual-mode passengers on their own terms). These models reveal that MaaS systems are rarely economically sustainable under naive assumptions of full operator compliance, and that governance mechanisms — including pricing rules, participation conditions, and dispute resolution procedures — are necessary structural features of a functioning platform, not optional add-ons.

A second topic of literature proposes shifting the focus of incentives from individuals to organizations. Ghafelebashi et al. (2023) argue that, in new mobility services and situations, routing and travel decisions are increasingly shaped by organizations such as fleet operators, logistic companies, and delivery platforms rather than by isolated drivers alone. On that basis, they propose an organization-level incentive mechanism in which incentives are offered according to the aggregated travel-time losses of all drivers within an organization. Their results suggest that such an approach can reduce system-level travel time and can be substantially more efficient than directly incentivizing individual drivers, in some cases by a factor of up to eight. This shift in perspective has direct implications for the governance of a traffic orchestrator. In the CARMONY context, the relevant actors are not only individual drivers but also fleet managers (for carsharing or logistics operators), traffic management centres, and municipal authorities. This categorisation has already been included in the Methodology section of the present document and aligned with D4.2. The governance framework must therefore operate at multiple actor levels simultaneously, defining what obligations and expectations apply to organisations as collective agents, not only to individuals as end-users. Ghafelebashi et al. (2023) further incorporate fairness, value of time, and operational constraints into the incentive design problem, thereby demonstrating that governance cannot be reduced to system optimisation. Incentive mechanisms also need to be acceptable from participating organisations and must avoid redistributing burdens in operationally or socially unjustifiable ways. This reinforces the principle that governance in orchestrated mobility involves both efficiency-oriented design and the active management of legitimacy and acceptability.

A third line of research approaches the issue through game theory and strategic interaction. Zardini et al. (2023) model multimodal mobility systems as games in which citizens choose among several transportation options while Mobility Service Providers and public authorities shape the wider conditions of access, pricing, and capacity. Their framework is especially relevant because it does not isolate user choice from the broader institutional setting. Instead, it embeds travel decisions in a larger game among stakeholders, showing how mobility outcomes depend on the strategic interaction between municipalities, providers, and citizens. This work is therefore useful for understanding governance as a problem of regulating a complex ecosystem rather than a single market or transport mode.

The same study is also important in normative terms. Zardini et al. (2023) emphasise that policy in future mobility systems must address not only efficiency, but also accessibility,

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fairness, equity, and sustainability. Their analysis shows that private mobility services often depend on public resources (e.g. road space or public traffic infrastructure) while pursuing profit-oriented strategies that may impose negative externalities on the wider system. As a result, governance must equip public actors with tools to analyse these trade-offs and to guide intervention without suppressing the innovation and diversity that multi-provider ecosystems can generate.

Overall, the literature suggests that the baseline and problem definition that governance models should cover in smart and orchestrated mobility can be understood through the following main statements:

- Key elements include cooperation among service providers, incentive design for organizations and users, strategic interaction among stakeholders, and trusted data exchange in connected environments. For this reason, the methodological approach adopted during the initial stages of Task 4.1 has focused on gathering input from real stakeholders who face situations similar to those described in the CARMONY use cases. While the Murcia use cases are mainly concerned with urban mobility management led by the city council, the Luxembourg context involves a wider range of stakeholders whose cooperation is essential for the effective operation of the CARMONY solutions.

- From literature it is stated that mobility systems cannot be governed effectively through technical optimization alone. Their performance depends on how incentives are structured, how cooperation is organised, how strategic conflicts are managed, and how trust is maintained in increasingly data-driven and decentralized transport environments. This, in turn, is the value proposition that WP4 contributes to the whole CARMONY project.

5.2 Insights from the Outreach Group

As stated in the previous section, WP4 establishes the synergies with WP7 for the Outreach Group in order to extract insights from the different profiles and to enhance the perspective beyond the pilots within CARMONY.

From the statements identified during the literature review reported in section 5.1, experts present in the Workshop organised on the 17th April 2026 under WP7, emphasised that the orchestration mechanism should serve multiple types of users which implicitly implies coordination between diverse groups. However, they pointed out that the heterogeneity of stakeholders and users that should be included in the orchestration may impose difficulties on the operationalisation. Therefore, the fact that CARMONY has started from specific use cases that require a certain group of agents may help to ensure a more grounded starting point for orchestration and later, more scenarios can be aggregated as long as more actors and use cases are being integrated into the mechanism. Moreover, they stated that the solution being developed under the project is more oriented to big operators with “muscle”, meaning that they have resources and competences enough to adapt this recommendation-mechanism with a wider impact. This is relevant because they also raised that convergence of interests must take place to ensure coordination. Thus, actors with higher power may have more room to converge interests between different layers within the traffic system (e.g. city vs. regional).

Regarding that the value proposition within mobility should be beyond technical optimization alone, participants in the Outreach group suggested the relevance of having user-friendly tools like digital twins that enable authorities and other types of actors to understand and plan easily.

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Also, they emphasised that the CARMONY solution must operate with tactical and real information as possible.

5.3 Insights from stakeholders present in CARMONY pilots

Before setting up more concrete requirements for the Interlinked Orchestrator, this section is oriented to explaining the current governance and institutional environment (e.g. who decides what, under which authority, and where coordination fails).

5.3.1 Governance Baseline for Murcia Pilot

The Murcia pilot serves as a lighthouse site for urban orchestration, testing dynamic traffic management, Low Emission Zones (LEZs), and emergency corridors through the city's Smart Mobility Platform (MISTRAL). However, the defining institutional challenge is the fragmentation of its municipal departments. While technological deployments undergo centralised filtering by the Smart City Office, ultimate operational and budgetary authority remains decentralised across isolated silos. Consequently, the governance baseline must bridge this critical gap between unified digital orchestration tools and fragmented departmental control.

Stakeholders engaged in the Murcia pilot at M15 are displayed in the following Table 1:

Stakeholder	Title	Actor role types (D4.2)	Governance Role
Smart City / Digital Transformation Office (City Council of Murcia)	Strategic & Standardisation Authority	Political Stakeholders	Technological oversight and centralised filtering of municipal projects, data governance and standardisation (FIWARE/UNE), integration with broader data spaces (e.g., DS4M).
Traffic Department (City Council of Murcia)	Operational Road Authority	Political Stakeholders / Infrastructure Operators	Broad traffic regulation for the urban centre and close districts *(pedanías)*, management of infrastructure, traffic lights, and LEZ access controls, application of the "mobility pyramid" prioritising vulnerable users.
Public Transport Department (City Council of Murcia)	Contractual Public Authority	Political Stakeholders / Traffic Management	Management and modernisation of concession contracts (tram, urban, and interurban buses), implementation of Intelligent Transport Systems (ITS) for service control.
Local Police & Emergency Services (City Council of Murcia)	Enforcement & Emergency Responders	Agents in Traffic	Direct street-level vigilance and enforcement, final human-in-the-loop decisions on traffic light overrides, in person coordination during crises at the CEUS tracking centre with the rest of actors.

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Private Transport Operators (Concessionaires)	Mobility Service Providers	Traffic Management	Operation of public transport fleets, ownership and management of the Automatic Exploitation Systems (SAE) holding crucial real-time passenger data.
ETRA I+D (ETRA Group, project partner)	Technology Provider & Project Lead	Infrastructure Operators	Operation of the city's MISTRAL Smart Mobility Platform, orchestrator testing and digital twin integration.
Citizens & Commuters	Ecosystem Actors / End Users	Societal Stakeholders	Final decision-makers on routing and transport modes, targets for behavioural shifts and LEZ compliance, key feedback providers for alternative routing tools.

Table 1: Stakeholders engaged in the Murcia pilot (M15)

Actual Governance structure

Traffic governance in Murcia operates across distinct municipal departments that traditionally function in "watertight compartments" or silos. Despite this decentralisation of ultimate authority and budget control, their responsibilities can be mapped onto specific governance layers. Each layer holds a distinct type of authority and accountability structure. As local authorities maintain a strict policy of human supervision over automation due to safety and liability concerns, the CARMONY Interlinked Orchestrator sits alongside all layers in a strictly advisory capacity, without being able to issue binding instructions to any of them.

4 identified governance layers for the set of use cases in Murcia:

- **Strategic & Standardisation Layer (Smart City / Digital Transformation Office):** This layer acts as the city's technological filter, providing overarching platforms and technical oversight without directly controlling the streets. It holds authority for data governance, ensuring compliance with standardisation frameworks (like FIWARE and UNE) and integrating Murcia into broader data spaces like the DS4M.
- **Operational Layer (Traffic Department & Local Police):** Holding direct operational road authority, the Traffic Department manages infrastructure, traffic lights, and Low Emission Zone (LEZ) access across the urban centre and its 52 districts (*pedanías*). They apply the "mobility pyramid" to strictly prioritise vulnerable users, whilst the Local Police execute binding street-level decisions, enforcement, and emergency overrides.
- **Contractual Layer (Public Transport Department):** This layer governs the multimodal public transport network through multi-year concession contracts for trams and buses. Lacking direct real-time data, it acts as the obligatory node for interacting with private transport operators, managing service modernisation and Intelligent Transport Systems (ITS) whilst relying heavily on the operators' Automatic Exploitation Systems (SAE) for service control.
- **Ecosystem Layer (Citizens, Commuters, & Private Operators):** The outermost layer includes end-users and private commercial entities. Citizens remain the final decision-makers on routing; whilst many exhibit an "irrational car dependency", "early adopters"

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commuting from the outskirts are primary orchestration targets. Meanwhile, private transport operators supply the physical fleet but operate under their own financial interests, requiring strict contractual governance to ensure compliance.

How coordination works today

Operational coordination in the municipality of Murcia currently relies heavily on manual intervention and operates within departmental silos, rather than through an integrated, real-time systemic approach. The table below maps how coordination currently operates, where the critical gaps lie, and the anticipated contribution of the CARMONY orchestrator.

	Traffic Dept. & Local Police (Road Authority)	Public Transport Dept & Operators	Smart City Office (Strategic Tech)	Citizens & Commuters (End Users)
Incident & Crisis Management	Manual coordination. Gather at the CEUS tracking center with other departments to manually assess screens and direct interventions.	Reactive & isolated. Lack automated priority protocols (e.g., deciding priority between an ambulance and a delayed bus is currently undefined algorithmically).	Data provision. Supplies specific dashboards (e.g., flood maps) for manual assessment, but lacks automated integration with traffic alerts.	Information lag. Receive information through a municipal app, not in real time data, sometimes resulting in behavioural inertia.
Congestion & LEZ Management	Siloed operation. Apply the "mobility pyramid" manually via traffic light timings and similar mechanisms. Little day-to-day coordination with transport tech.	"Information Black Hole". Completely reliant on the private operators' SAE systems for delayed statistics, lacking direct real-time data.	Limited coverage. Deploys sensors and cameras, but data coverage remains limited to specific tech-deployment areas.	Low trust. Rely on traditional routes; hesitant to use current municipal apps due to data lag and unreliable alternative routing.
Planned Works & Tech Rollouts	Physical disruption. Massive roadworks are used to forcefully shift behaviour, as automated digital steering is not yet mature.	Bureaucratic delays. Rely on rigid, multi-year public tenders for ITS upgrades, causing severe execution delays.	Centralised filtering. Evaluates projects via IT committees and uses EU funds to push future infrastructure (e.g., 5G, digital twins).	Forced adaptation. Change habits primarily out of frustration from physical disruptions rather than proactive digital guidance.
CARMONY Contribution	Tactical recommendations. Real-time suggestions for dynamic traffic	Data sovereignty. Direct, real-time integration of public transport	Systemic integration. Plugging the orchestrator directly into the	Trusted routing. Delivering reliable, real-time alternative routes to "early

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	lights, LEZ management, and clearing emergency corridors.	data to break reliance on private operator black boxes.	overarching MISTRAL Smart Mobility platform and digital twins.	adopters" to actively prevent congestion.

Table 2: Snapshot of how coordination works in Murcia today.

Three structural gaps

The current operational landscape in the municipality of Murcia faces **three critical structural barriers that complicate systemic coordination**. These gaps highlight why manual processes are insufficient and where the CARMONY Interlinked Orchestrator must provide strategic and operational integration.

GAP 1 – Lack of direct real-time operational data for Public Transport. One of the most critical barriers for the public administration is the lack of direct, real-time operational data regarding its multimodal transport network. Currently, decision-making is heavily dependent on the private operators' Automatic Exploitation Systems (SAE) to obtain even basic statistics on passenger volumes and service usage. Because private transport operators naturally prioritise their own financial and operational interests, this creates a significant barrier to transparency and data sovereignty. This "information black hole" can prevent the city from making agile, data-driven orchestration decisions today, meaning the orchestrator will need to actively bridge the gap between private fleet operations and public traffic management.

GAP 2 – Siloed departmental operations Municipal departments in Murcia traditionally operate independently in disconnected "watertight compartments", which makes holistic, city-wide orchestration highly complex. For example, in the interviews we learned that the Public Transport department has little daily coordination with an actor like Local Police, who are the actors that actually control the city's traffic signalling and emergency interventions on the streets on a daily basis. Furthermore, existing digital tools lack systemic integration; standalone innovations, such as the city's flood forecasting digital twin, are not currently integrated automatically with the traffic management system to trigger real-time alerts or reroute vehicles.

GAP 3 – Bureaucratic rigidity and technological obsolescence. The slow, rigid nature of public administration acts as a massive bottleneck for deploying agile orchestration technologies. Strategic decisions and ITS upgrades are driven by multi-year public tenders that can take over a year to be published and sometimes even longer to execute, creating a high risk that technical requirements become entirely obsolete by the time the technology is deployed. This bureaucratic rigidity makes the administration to be forced to rely heavily on external contractors to understand and execute complex orchestration systems.

What the orchestrator may and may not do

A defining feature of the Murcia governance baseline is the strict adherence to human supervision over automation. Because traffic managers bear the heavy burden of road safety, they are highly sceptical of fully delegating decisions to machines, believing that the physical infrastructure is not yet ready for fully autonomous, binding control. Furthermore, decision-making strictly follows an ethical "mobility pyramid" that systematically prioritises vulnerable users (pedestrians and cyclists) over private vehicles—a complex hierarchy that is difficult to translate into rigid algorithmic rules.

Consequently, the CARMONY Interlinked Orchestrator must operate in a strictly advisory capacity across all layers. It provides transparent, real-time information and recommendations, empowering the human actors to make the final choice rather than forcing compliance.

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Actor	Can CARMONY recommend?	Who validates?	What triggers rejection?
Traffic Dept. & Local Police (Road Authority)	Yes, tactical suggestions (dynamic traffic lights, clearing emergency corridors, LEZ management).	Human operators at the CEUS tracking centre and police officers directly on the street.	Safety fears; algorithmic failure to respect the "mobility pyramid" (e.g., prioritising a vehicle over pedestrians); complex edge cases (e.g., ambulance vs. crowded bus); uncalibrated physical infrastructure.
Public Transport Dept & Private Operators	Yes, multimodal routing and service optimisation.	The Public Transport Department (contractual validation) and private concessionaires (operational execution).	Conflicts with the private transport operators' own financial and operational interests; breach of multi-year public concession contracts; lack of direct real-time SAE data integration.
Citizens & Commuters (End Users)	Yes, alternative routing, parking availability, and public transport options.	The individual citizen or autonomous vehicle driver.	Severe behavioural inertia; "irrational car dependency" for short trips; fragile user trust if the recommended route fails to deliver an immediately perceptible time saving.

Table 3: How should CARMONY Interlinked Orchestrator operate across all layers in advisory capacity

Accountability structures

Accountability in the Murcia pilot is defined within the isolated "watertight compartments" of each municipal department. However, these structures are currently unprepared to accommodate systemic, automated orchestration, making human supervision and strict adherence to safety frameworks the foundation of the baseline.

Baseline for each actor

- **Traffic Department and Local Police:** Final accountability for traffic-management measures remains with the competent municipal actors. Traffic managers validate proposals concerning network operation, traffic signalling and access restrictions, while Local Police retain authority over on-street implementation and emergency interventions. The orchestrator may support these functions by providing evidence and recommendations, but it does not transfer or dilute their existing decision-making responsibilities.
- **Smart City / Digital Transformation Office:** Accountable for strategic technological oversight and data governance. This layer ensures that any implemented system complies with standardization frameworks (such as FIWARE and UNE) and integrates seamlessly with broader environments like the Mediterranean mobility data space (DS4M). See solutions like CARMONY as the lighthouse, where to go.
- **Public Transport Department:** Holds contractual accountability for multi-year public concessions, including trams and urban buses. Because they lack direct data sovereignty, their accountability operations currently rely on verifying schedule compliance through delayed statistics extracted from the private operators' own Automatic Exploitation Systems (SAE).
- **Private Transport Operators:** Accountable for fulfilling service commitments and fleet provision. However, they naturally prioritize their own financial and operational interests, requiring strict contractual governance to ensure transparency.

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Three accountability design risks to avoid

- **Risk 1 - Algorithmic complexity overriding ethical hierarchies:** Implementing orchestration without ensuring the system respects Murcia's established "mobility pyramid" and relation with the municipalities around the city highly interlinked (pedanías). A purely time-optimizing algorithm might fail to handle the city's complex intersections, struggling with unresolved edge cases—such as establishing a concrete protocol to decide priority between an emergency ambulance and a delayed, highly occupied bus.
- **Risk 2 - Safety fears and mistrust of automation:** Delegating binding decisions to the orchestrator before the physical infrastructure is fully calibrated or trusted. Traffic managers strongly fear that automated system failures could lead to accidents, meaning automation must remain gradual, and decisions must strictly await human authorization.
- **Risk 3 - Fragile user trust:** Expecting citizens to reliably adopt alternative routing without flawless, immediate results. Commuters in Murcia exhibit severe behavioural inertia (as a common human reluctance to change). If a recommended alternative route fails to deliver an immediately perceptible time saving, or if it fails on the very first try, citizens will lose trust in the system and abandon it completely, so the margin to deliver good is quite low.

5.3.2. Governance Baseline for Luxembourg Pilot

To start with, it is important to highlight that the Luxembourg pilot combines motorway traffic management over high-density cross-border corridors (A3 and A13), multimodal public transport operations under contractual governance, logistics dependencies tied to Luxembourg's role as a European logistics hub, and a multilevel institutional structure in which strategic authority, operational authority, and service delivery are held by formally separate actors. Therefore, the institutional challenge for coordination is more than evident as it can be summarised such as:

- Multi-level governance system: each actor within the traffic management system holds a different type and scope of decision power, direct competences.
- Cross-border dependency: beyond the multilevel layers mentioned before, the A13 corridor involves two national governance traffic systems with no real-time shared protocol.
- Underrepresentation of some actors: logistics actors and public transport are currently excluded from real-time traffic coordination.

Stakeholders engaged for the Luxembourg Pilot at M15:

Stakeholder	Title	Actor role types (D4.2)	Governance Role
MMTP / Ministry of the Economy (MINECO)	Strategic & Standardisation Authority	Political Stakeholders	Technological oversight and centralised filtering of municipal projects, data governance and standardisation (FIWARE/UNE), integration with broader data spaces (e.g., DS4M). (1) Traffic policy, (2) Regulatory framework, (3) CCAM readiness, (4) Cross-border coordination

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PCH-CITA (Ponts et Chaussées)	Operational Road Authority	Infrastructure Operators	Broad traffic regulation for the urban centre and close districts *(pedanías)*, management of infrastructure, traffic lights, and LEZ access controls, application of the "mobility pyramid" prioritising vulnerable users. (1) Statutory motorway management, (2) A3/A13, (3) Binding decisions (speed limits, closures)
Sales Lentz	Public Transport Operator	Traffic Management	Management and modernisation of concession contracts (tram, urban, and interurban buses), implementation of Intelligent Transport Systems (ITS) for service control. (1) RGTR bus services under Ministry contract, (2) PTA-governed operations
Cluster for Logistics Luxembourg (C4L)	Sectorial representative and platform	Fleet Operators	Direct street-level vigilance and enforcement, final human-in-the-loop decisions on traffic light overrides, in person coordination during crises at the CEUS tracking centre with the rest of actors. (1) Representation of logistics ecosystem, (2) no direct operational authority, (3) freight interests.
Citizens & Commuters	Ecosystem Actors / End Users	Societal Stakeholders	Final decision-makers on routing and transport modes, targets for behavioural shifts and orchestrator suggestions, key feedback providers for alternative routing tools.

Table 4: Stakeholders engaged in the Luxembourg pilot (M15)

Actual Governance structure

Traffic governance in Luxembourg follows a hierarchy based in layers. Traffic governance in Luxembourg is organized through a multi-layered hierarchy. The specific characteristics of the Luxembourg use cases within the CARMONY project introduce additional governance layers involving different types of authorities, each with distinct responsibilities and areas of competence. Within this structure, the CARMONY Interlinked Orchestrator operates alongside the existing governance layers in a strictly advisory role. It can provide recommendations and support coordination, but it has no authority to issue binding instructions to any stakeholder.

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4 identified governance layers for the set of use cases in Luxembourg:

- **Strategic & Policy Layer (MMTP / Ministry of the Economy MINECO):** This layer acts as Luxembourg's political and regulatory filter for mobility governance, without directly controlling roads or operations in real time. It holds authority over the overall traffic policy framework, the conditions under which managed lanes can be activated, the acceptable evidence base for binding speed measures, and the governance envelope within which any orchestration tool must operate. MMTP defines which objectives take priority (e.g. safety concerns, environmental benefits, mobility equity parameters and others) and sets the political guidelines that CITA, from its operational scope, must follow when activating infrastructure, such as the A3 carpool lane. In parallel, MINECO contributes with mandates focused more on economic competitiveness, CCAM readiness, and the facilitation of public-private coordination in the innovation ecosystem. In turn, these two ministries together constitute the layer that determines what is politically permissible: the orchestrator may not cross boundaries they have not sanctioned, and any transition from advisory to binding orchestration outputs requires their explicit authorisation.
- **Operational Layer (PCH-CITA -Ponts et Chaussées):** Holding direct statutory road authority over the motorway network, CITA manages the A3 and A13 corridors, operates variable speed limit gantries, activates managed lanes, and coordinates incident responses under the current normative. As mentioned previously, CITA is the actor empowered to issue binding traffic measures and is, simultaneously, the most data-rich and most restrictive actor in terms of external system access.
- **Contractual Layer (Public Transport Authority / PTA — Ministry of Mobility, and Sales Lentz):** This layer governs scheduled public transport operations on the A3 and connecting corridors through binding multi-year service contracts between the Public Transport Authority (PTA, part of MMTP) and Sales Lentz. The PTA acts as the obligatory governance node between any traffic orchestration recommendation and the bus operator. Then, Sales Lentz is contractually bound to comply with agreed service schedules and has near-zero operational autonomy in routine conditions (for instance, delays are reported, but rerouting requires PTA approval). The operator maintains GPS tracking of its fleet and a team of operational controllers who manage real-time fleet decisions for unscheduled services under their own authority.
- **Ecosystem Layer (Cluster for Logistics Luxembourg C4L, Citizens, Cross-border Commuters, & Private Operators):** This layer includes the private sector actors, road users, and cross-border participants who are most directly affected by congestion on the A3 and A13 but hold no formal governance authority over the decisions that shape their operational environment. Logistics operators in this case are represented collectively by C4L, but they act independently in operations, meaning that they are the primary freight actors on both corridors. They are passive recipients of traffic conditions, receive no real-time operational information during incidents, and have no coordination channel with CITA or MMTP. They can be one of the industry sectors most directly harmed by unmanaged A13 disruptions and other circumstances. On the other hand, this layer also includes cross-border commuters and CCAM-connected users. For them, a critical operational constraint is linguistic: non-Luxembourgish trucking companies may not respond to or even receive guidance issued only in French or Luxembourgish, making multilingual communication a key element to guarantee efficient traffic management.

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How coordination works today

Systemic coordination is not applied to operational coordination on the Luxembourg motorway network being analysed; it is rather more scenario-specific. The table below maps how coordination currently operates, where the critical gaps lie, and the anticipated contribution of the CARMONY orchestrator.

	CITA (Road Authority)	Sales Lentz (Public transport)	Industry, logistics sector (C4L)	Citizens, Cross-Border Commuters (End Users)
Incident Management	Bilateral protocol. Binding decisions via a traffic management plan.	Delay report to PTA. No rerouting possible. Passive role.	There are no formal coordination mechanisms, they do not receive any information. Passive actors within the system although relevant activity in the area analysed.	Personal contacts with Autobahn GmbH. No real-time protocol.
Congestion prevention	Internal sensors and algorithms only present to anticipate such conditions. No external input or guidance of management.	Focused on traffic. No adaptation capabilities beyond being a "customer" within the traffic system.	No info received. Passive in traffic. No prediction access.	There are information delays, different rules and fragmented channels.
Planned Works & Tech Rollouts	Multi-actor coordination: Police, CFL, municipalities.	Route change needs PTA approval first. Slow process.	Not included in planning process. Freight looks excluded.	Bilateral protocol with DE authorities. Planned events only.
CARMONY Contribution	Earlier incident detection. Congestion prediction. Additional trigger source.	Tactical rerouting proposals (via PTA validation). Real-time awareness.	Advisory push messages. Freight flow coordination. Accessible predictive information.	Shared situational picture. Cross-border early warning. Impact prediction.

Table 5: Snapshot of how coordination works in Luxembourg today

Three structural gaps

The current operational landscape in the Luxembourg area considered for the CARMONY project faces **three critical structural barriers that complicate systemic coordination**. These gaps highlight how the current governance baseline can be insufficient to maximize

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traffic management and where the CARMONY Interlinked Orchestrator must provide strategic and operational integration.

GAP 1 – No multimodal real-time coordination. There is no operational platform through which CITA, Sales Lentz, and logistics actors can share situational awareness and coordinate responses in real time. Each actor manages disruptions through its own internal systems, with communication between actors taking place through administrative channels that are too slow for real-time traffic management.

GAP 2 – Logistics actors excluded from operational governance. Despite their level of presence within this system of roads, freight operators are passive actors during congestion events. They receive no preferential operational information and have no formal channel to communicate the urgency of freight flows.

GAP 3 – No predictive governance mechanisms. According tothe study being carried out so far, all traffic management is reactive. Preventive action (including speed reduction for jam avoidance on the A3) is technically feasible, but the informational basis is limited to CITA's own sensor data, for instance. Therefore, cross-actor predictive information (navigation data, freight arrival estimates, public transport delay patterns) is not systematically available.

What the orchestrator may and may not do

A defining feature of the Luxembourg governance baseline is the convergent and unambiguous rejection, by all operational stakeholders, of binding external orchestration. This convergence is not a provisional position; it derives from the legal and operational accountability structures of each actor.

Actor	Can CARMONY recommend?	Who validates?	What triggers rejection?
PCH-CITA	Yes, as additional trigger source	CITA operator (traffic management centre)	Safety concerns; conflict with internal procedures; lack of explanation
Sales Lentz (scheduled)	Yes, pending PTA validation	Public Transport Authority (PTA)	Breach of contractual obligations; safety risk
Sales Lentz (unscheduled)	Yes, pending controller validation	Operational controllers	Conflict with service commitments; safety risk
C4L / logistics operators / other end-users (cross-border commuters)	Yes, advisory push messages preferred	Individual operators / drivers	Breach of client commitments; lack of transparency; notification message may not be in driver's language

Table 6: How should CARMONY Interlinked Orchestrator operate across all layers in advisory capacity

Accountability structures

Accountability in the Luxembourg pilot is clear within each actor's domain, but it is not currently designed to accommodate external orchestration recommendations. Three structural accountability features define the baseline:

Baseline for each actor

- **CITA**: Accountability is concentrated at the operator level. The CITA operator bears personal and institutional responsibility for every measure implemented. Because an external recommendation cannot be implemented without the operator's decision, the

accountability question for the orchestrator's outputs does not arise at the system level, it is instead resolved entirely at the human operator level.

- **Public transport:** A tripartite accountability chain — PTA (policy and schedule), Sales Lentz operational controllers (fleet decisions), bus drivers (immediate safety). Any orchestration recommendation must transit this full chain before influencing operations. A recommendation that bypasses the PTA and reaches a bus driver directly would expose the operator to contractual liability.
- **Logistics:** Road authorities hold accountability during emergencies; individual operators in routine conditions. C4L expects a formal governance framework co-developed between authorities and the logistics sector, defining how recommendations are generated and how conflicts are resolved.

Three accountability design risks to avoid

- **Risk 1 - Automation creep:** Operators reduced to ratifying algorithmic outputs, eroding the legal boundary between recommendation and decision. Traffic managers bear personal liability for their actions; any system that gradually reduces their effective discretion without formal governance changes creates an unacceptable accountability gap.
- **Risk 2 - Cognitive overload:** Excessive recommendations that overwhelm operators and reduce careful evaluation. CITA explicitly flagged this: *"Triggers should be adjustable so that we do not get overwhelmed by information that is not relevant or needed for us."*
- **Risk 3 - Shadow governance:** Algorithmic recommendations gradually normalising practices that were not formally sanctioned by competent authorities. If CARMONY outputs become de facto operational norms without formal endorsement, the advisory/binding boundary erodes in practice even if maintained in name.

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6. Governance requirements for the CARMONY orchestrator

As mentioned previously, this section translates the governance baseline and problem definition presented in Section 5 into an initial set of requirements for the CARMONY Interlinked Orchestrator by M15. Drawing on the literature review, the CARMONY Outreach Group and consultations with stakeholders from the Murcia and Luxembourg pilots, it identifies the conditions that the orchestrator must respect, embed and enable to achieve operational trust and institutional acceptance. The analysis addresses role allocation and decision rights, human oversight, explainability and accountability, coordination among actors, trusted data exchange, alignment with public-value objectives and gradual deployment according to institutional readiness. These general principles are subsequently adapted to the specific governance structures of each pilot and complemented by governance interoperability requirements concerning data-sharing protocols, scalability concerns, priority rules and accountability for recommendations. In this way, Section 6 advances an initial governance framework that connects the identified problems with practical conditions for the orchestrator's design, deployment and future validation.

6.1 Literature review

The governance requirements for the CARMONY orchestrator cannot be derived from technical performance specifications alone. As the literature reviewed in Section 5 already manifested, the performance of sociotechnical systems in complex, multi-actor environments depend on how governance is designed, not merely on how the technology operates. Across the reviewed studies, governance requirements consistently emerge around a limited number of interconnected themes: role definition and decision rights, incentive compatibility, fairness and public value, strategic coordination among actors, trusted data exchange, and adaptability over time. Together, these themes provide a useful basis for specifying the governance requirements of traffic orchestrators operating in complex and mixed mobility environments that CARMONY seeks for.

To start with the main finding arising from related literature, it is important to state that the orchestrator is not a passive optimisation tool: it is, as it is proposed by Gritsenko and Wood (2022), an instrument of *design-based governance.* This means that it is a system that exercises power ex-ante through choice architectures embedded in its protocols, shaping the decision environment of actors before they choose. When the orchestrator presents a routing recommendation through a smartphone interface, it is not merely providing information; it is structuring the action space of the driver, fleet operator, or traffic manager in ways that have policy consequences. This implies that the governance requirements of the orchestrator are simultaneously requirements for the *system that governs* and requirements for the *governance of the system itself*. Both dimensions must be addressed, and they must be addressed together.

A first research line concerns clear role allocation and decision-making authority. In multimodal and limited-capacity mobility systems, governance cannot rely on the assumption that actors will naturally coordinate around common objectives. Zardini et al. (2023) show that mobility systems are characterised by strategic interactions among citizens, mobility service providers, and public authorities, each operating under their own constraints and preferences. In their framework, equilibrium depends on explicit rules regarding access, capacities, and the conditions under which actors can choose between alternatives. This implies that orchestrators require governance arrangements that define who is entitled to decide, who is subject to coordination, and under what constraints intervention is legitimate. In other words, without clear role definitions, actors default to the strategies that serve their individual interests, and these strategies are unlikely to converge on system-level objectives.

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A second research line focuses on incentive compatibility and the governance of participation. Deng et al. (2022) show that cooperation among transportation service providers is unlikely to be stable unless governance arrangements include mechanisms that align individual and collective incentives. Their analysis of integrated multimodal platforms demonstrates that incentives can be used to influence flows and support cooperation, but also that cooperation becomes durable only when participating actors can see a credible distribution of benefits. This is why their framework combines passenger incentives with provider-level profit sharing and uses asymmetric Nash bargaining to allocate gains. From a governance-requirement perspective, this literature suggests that orchestrators need rules not only for coordination, but also for the fair distribution of gains, burdens, and responsibilities among participating actors. This, under CARMONY project, will be complemented with the work developed under T4.2.

The third governance requirement concerns the explicit protection of fairness, equity, and public value in orchestrator design and operation. The literature establishes this not as a normative aspiration supplementary to technical requirements but as a functional governance necessity: systems perceived as unfair or as serving narrow interests at the expense of broader public value will not attract or sustain the cooperation of the diverse actor base that orchestration requires.

Zardini et al. (2023) argue that future mobility policy must address not only efficiency but also accessibility, equity, and sustainability. Therefore, governance mechanisms and instruments must be explicitly designed to prevent private mobility services, which depend on public infrastructure and resources, from generating negative externalities for the wider system without accountability. This is particularly relevant for the CARMONY context, where the orchestrator will operate across both urban environments (Murcia) with diverse socioeconomic conditions and highway corridors (Luxembourg) with mixed national and cross-border traffic, and where the benefits and costs of orchestration may not be symmetrically distributed across user groups, areas, or mobility modes. Similarly, Ghafelebashi et al. (2023) operationalise this requirement at the design level: they explicitly incorporate fairness constraints and distributional criteria into the incentive mechanism, demonstrating that it is technically feasible — not merely ethically desirable — to build fairness into governance instruments rather than treating it as an external constraint on optimisation. The governance implication is that the orchestrator's decision logic must be designed to satisfy explicit fairness criteria, and that these criteria must be monitored and reported on, not merely stated as principles.

A fourth research line concerns strategic coordination under interdependence and capacity constraints. The literature repeatedly shows that orchestrated mobility must be designed for environments in which actors are interdependent and resources are limited. Zardini et al. (2023) model mobility systems as games with bounded fleet sizes, limited capacities, and equilibrium behaviour among users and providers. Deng et al. (2022) similarly study cooperation in multimodal transport networks under demand responses and network interactions. These studies suggest that governance requirements should include mechanisms for managing conflicts between local optimization and system-level performance, especially where capacity is scarce and actor behaviour is strategic. In practice, this means that orchestrators require governance rules for prioritization, conflict management, and the balancing of system efficiency against the autonomy of participating actors.

Regarding data governance, trust, and validation requirements, Maffiola et al. (2025), through the GOLIATH framework, argue that centralized traffic information systems create both trust problems and structural vulnerabilities because one service provider controls data collection and validation. Their decentralized approach instead builds governance into the data architecture itself: participants generate transactions, a consensus mechanism validates

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information, and reliability is assessed continuously through the history of interactions. They also explicitly define security requirements in relation to malicious behaviour, manipulation, and service disruption. This literature is particularly useful because it shows that governance requirements for orchestrators must include data integrity, accountability, validation procedures, resilience against manipulation, and clear participation rules for data exchange. In other words, governance is partly embedded in the rules of the data layer.

The same work also underlines a further requirement: compatibility between governance design and technological constraints. GOLIATH stresses that decentralized trust mechanisms must remain feasible within automotive environments, where computational resources and communication conditions are constrained. This is an important reminder that governance requirements cannot be specified abstractly, without regard to implementation conditions. If the orchestrator depends on verification, participation, and real-time information exchange, then its governance requirements must be feasible for the technologies, actors, and infrastructures expected to carry them out.

Lastly, another topic concerning literature is the adaptability, learning, and long-term compliance. The orchestration literature in CARMONY's own system-of-systems work (see D2.2) shows that long-term governance is closely linked to trust-building, transparency, and the design of incentives that support compliance over time. It also presents governance as a long-horizon process in which simulations and evidence are used to demonstrate the benefits of adherence and align technical recommendations with stakeholder interests. This complements the external literature by suggesting that governance requirements should include not only static rules, but also mechanisms for iterative refinement, evaluation, and adaptation. In this view, orchestrator governance must remain learnable and revisable as conditions, stakeholders, and observed effects evolve.

In conclusion, the literature indicates that governance requirements for traffic orchestrators systems can be organized around the following five core dimensions:

- Orchestrator systems require clearly defined roles, responsibilities, and decision rights. Accordingly, Task 4.1 will begin by mapping the existing roles, responsibilities, and competences within the mobility systems of the CARMONY pilot sites. By identifying current inefficiencies and governance gaps, the proposed governance models will be designed to address them. This will help ensure that the project takes these requirements and challenges into account when developing traffic management solutions.

- Orchestrator systems also require incentive structures that make participation and cooperation credible for relevant actors. This is addressed both in T4.1 and T4.2 at this point of the project.

- To ensure legitimacy, given that the Orchestrator will provide a set of recommendations and suggestions given the traffic context, the governance models must encourage fairness and public value for the whole society. For that, requirements are constructed gathering experiences and expertise both from local stakeholders but also experts at European level with different profiles and contexts (Outreach Group).

- From literature it is also recommended that Orchestrator systems need coordination rules capable of managing strategic interaction and capacity constraints. This is also being covered by gathering experiences and expertise both from local stakeholders but also experts at European level with different profiles and contexts (Outreach Group).

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- Finally, they require robust data-governance arrangements, including trust, validation, accountability, and resilience. This will be addressed in D4.1 as initial conceptualisation but mainly covered under T4.3 and fully presented in D4.3.

6.2 Insights from the Outreach Group

As stated in the previous section, WP4 establishes the synergies with WP7 for the Outreach Group in order to extract insights from the different profiles and to enhance the perspective beyond the pilots within CARMONY.

This section complements section 5.2 and the additional literature review reported in section 6.1 with the advice and insights that several experts manifested during the Workshop held on the 17th April 2026 under WP7. They confirmed that one of the main elements to be developed is an incentive system that really makes actors and users to adapt the advice in the short term when displaying the orchestrator's functionalities. Having incentives surrounding the orchestrator's recommendations makes targeted users convinced rather than pursued to follow advice or change their routine.

Regarding which type of conditions may enhance the potential of the solution, they recognised that the orchestration may work better within more centralised countries like France rather than countries that deal with many political layers at local, regional and national levels. In line with this, they recommended that this system can be more powerful for big operators within the traffic system. However, they pointed out that educational training must be included for ensuring transferability. In fact, they suggested that some visualisation functionalities can be helpful like simulations with digital twins that are being used for public planners lately.

In conclusion, from the value proposition that CARMONY pursues, experts manifested that the solution can be placed between the existing high-level tools (e.g. dashboards for more administrative tools) and those tools dealing more with day-to-day tasks and decisions. However, they insisted on the fact that this will function in countries where centrality mechanisms prevail rather than places with a more heterogeneous structure.

6.3 Insights from stakeholders present in CARMONY pilots

This initial version of requirements from a governance perspective have been constructed to start mapping what the orchestrator must respect, embed, and enable in order to be operationally trusted and accepted institutionally.

6.3.1 Governance Requirements for Murcia Pilot

The governance baseline analysis in section 5.3.1 reveals a set of structural gaps and accountability challenges that the CARMONY Interlinked Orchestrator can provide as value added for governance mechanisms within urban fragmented traffic contexts like Murcia. For that, this section translates the baseline into five core governance requirements and a set of operational conditions that must be established before and during deployment in the forthcoming phases of the CARMONY project.

REQUIREMENT 1: Advisory operation with human control

It is confirmed that all outputs of the CARMONY Interlinked Orchestrator in the Murcia pilot must be advisory in nature. The orchestrator provides real-time recommendations and

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coordination proposals directed at the relevant human operators within the traffic system and its different departments.

This is not a transitional limitation but the appropriate and necessary governance mode for a decision-support system operating within a jurisdiction where road safety accountability is set by human traffic managers. As identified when analysing the current Traffic department, operators are highly sceptical of fully delegating decisions to machines and believe the physical infrastructure is not yet ready for fully autonomous, binding control. Similarly, technicians in charge of digital transformation strategies confirmed that when adopting automated systems, Murcia prefers a step-by-step approach starting with human supervision to authorise actions. The boundary between recommendation and decision must be maintained at every stage of the orchestrator's operation and communicated clearly to all actors.

What this means in practice:

- Recommendations to the Traffic Department and Local Police are evaluated by human operators at the CEUS tracking centre and by officers on the street, who retain final authority on all traffic management actions.
- Recommendations with public transport implications must transit the Public Transport Department (as the contractual authority) before reaching private operators.
- Recommendations to citizens are structured as alternative routing suggestions rather than instructions; the final routing decision rests with the individual user.
- No actor should feel obligated to follow an orchestrator recommendation in order to comply with their governance obligations. Any automated output influencing traffic signalling or emergency corridors requires explicit human authorisation before implementation.

REQUIREMENT 2: Respect for the current "mobility pyramid" and ethical priority hierarchies

The orchestrator must embed Murcia’s existing mobility hierarchy into its recommendation logic. The Traffic Department applies a “mobility pyramid” that prioritises vulnerable users, pedestrians, cyclists, public transport, and only then private vehicles. This hierarchy is not a technical preference but an operational and ethical principle of local traffic management. The orchestrator must therefore not only optimise traffic flow purely on travel time or vehicle throughput. Recommendations must be filtered against pedestrian safety, cyclist protection, emergency access, public transport continuity, and the wider public interest.

It is true that interviews revealed that edge cases within this hierarchy remain unresolved algorithmically. There is currently no defined protocol for situations, such as establishing priority between an emergency ambulance and a delayed, highly occupied bus. The orchestrator must not attempt to resolve such conflicts only autonomously. Instead, it must surface them transparently to human operators with the relevant contextual data, enabling an informed human decision.

This requirement also extends to the geographic dimension of Murcia's governance: the 52 dispersed districts (*pedanías*) involve cross-boundary coordination between the urban core and surrounding municipalities. Orchestration recommendations must account for these jurisdictional boundaries and not optimise the urban centre at the expense of outlying areas whose residents are primary targets for adoption.

What this means in practice:

- The orchestrator's decision logic must embed explicit priority rules aligned with the mobility pyramid before deployment.

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- Unresolved edge cases (e.g. ambulance vs. occupied bus) must be escalated to human operators with clear contextual information rather than resolved algorithmically.
- Any recommendation affecting pedestrian or cyclist safety must carry explicit flags visible to the validating operator.

REQUIREMENT 3: Data sovereignty and real-time public transport integration

A central governance requirement in Murcia is to reduce the municipality's dependence on private operators' Automatic Exploitation Systems (SAE). The current baseline identifies an "information black hole" in public transport data: for instance, the Public Transport Department lacks direct, real-time access to operational data and relies on delayed or operator-mediated information. This limits the municipality's capacity to make agile, data-driven decisions. The orchestrator should therefore support public data sovereignty by integrating real-time public transport information into the orchestration layer. This includes vehicle location, service delays, occupancy where available, and operational disruptions.

This requirement is directly tied to the data governance architecture managed by the Smart City / Digital Transformation Office, which is responsible for standardising data access (using FIWARE and UNE standards) and connecting Murcia to broader data spaces such as the Mediterranean mobility data space (DS4M). Any data integration protocol for the orchestrator must comply with these frameworks and obtain sign-off from this strategic layer before activation.

What this means in practice:

- Formal data-sharing agreements must be established between the Public Transport Department and private concessionaires to grant the orchestrator direct access to real-time SAE data.
- Data integration must comply with FIWARE/UNE standards and be validated by the Smart City Office as the data governance authority.
- An automated compliance-reporting mechanism — allowing the Public Transport Department to verify schedule adherence and detect deviations in real time — should be built into the orchestrator as a governance deliverable alongside its traffic management functions.

REQUIREMENT 4: Cross-departmental coordination protocol

The Murcia's governance baseline shows that municipal departments operate in fragmented silos. Traffic, Local Police, Public Transport, Smart City, and emergency actors do not yet function through a single systemic coordination mechanism. The orchestrator can add value only if its outputs are routed through a clear inter-departmental protocol.

This protocol must define which department receives which recommendation, when outputs are escalated, how multi-actor conflicts are managed, and how emergency scenarios are coordinated. The Smart City Office can act as the technical and institutional interface for the orchestrator, but it must not be confused with the operational authority of the Traffic Department or the contractual authority of the Public Transport Department.

What this means in practice:

- A written inter-departmental protocol must be agreed prior to deployment, starting with UCs of CARMONY project.
- Integration of the flood forecasting digital twin and other standalone urban systems with the traffic management layer should be treated as a parallel governance prerequisite, addressed through the same inter-departmental protocol.

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REQUIREMENT 5: Phased deployment aligned with institutional readiness and trust-building

The Murcia pilot should follow a phased deployment model. The governance baseline identifies bureaucratic rigidity, technological obsolescence in procurement cycles, limited internal capacity, and mistrust of automation as barriers to full immediate deployment. For this reason, the orchestrator should first demonstrate value through low-risk information and advisory functions before moving toward more complex coordination support. In other words, a phased governance deployment is therefore not merely a technical choice but a governance necessity to build the institutional trust and operational familiarity required for the system to be accepted and sustained.

The interviews further confirm that European projects like CARMONY are perceived as "lighthouses" that set a technological direction long before local capacity is ready to absorb it. This framing is instructive: the orchestrator must deliver demonstrable value at each phase even in the absence of full integration, so that each phase builds the institutional legitimacy needed for the next.

Governance interoperability requirements

Beyond the five core governance requirements identified for the Murcia pilot, the baseline analysis highlights a set of specific governance interoperability requirements that must be addressed through co-creation before the orchestrator can function effectively within the city's institutional and operational ecosystem.

Requirement	Current status	What is needed
Data sharing protocols	Partially available but fragmented.	Formal data-sharing protocols defining which data are shared, by whom, under what conditions, and with which access rights. This should include real-time public transport data, traffic signal data, LEZ access data, incident data, and parking or routing information where relevant. Agreements must respect GDPR, cybersecurity requirements, municipal data governance rules, and FIWARE/UNE standardisation principles.
Trigger conditions and escalation hierarchies	Current coordination relies heavily on manual assessment, especially in crisis situations where actors gather at the CEUS tracking centre.	Agreed definitions of when an orchestrator output is generated, which actor receives it, when it is escalated, and how multi-departmental situations are handled.
Accountability rules for recommendations	Partially covered by existing structures: Traffic managers and Local Police are accountable for road safety and street-level interventions; the Public Transport Department is accountable for	A traceability mechanism distinguishing clearly between: (1) orchestrator recommendation, (2) human validation or rejection, (3) operational implementation, and (4) observed outcome.

	concession contracts; Smart City is accountable for technical standardisation and data governance.	
Priority rules for competing objectives	Murcia already applies a “mobility pyramid” prioritising vulnerable users, pedestrians, cyclists, public transport, and private vehicles. However, edge cases are not yet operationalised algorithmically.	The mobility pyramid must be translated into explicit orchestration rules. The orchestrator should not autonomously resolve sensitive conflicts, such as ambulance priority versus a delayed and highly occupied bus. Instead, it should surface the conflict to human operators with contextual information and suggested options.
Public transport data sovereignty and concessionaire interoperability	The municipality lacks direct real-time operational control over some public transport data because private operators manage SAE systems. This creates an information dependency that limits agile orchestration.	A contractual and technical protocol allowing the Public Transport Department and the orchestrator to access relevant SAE data in real time or near real time. This should include vehicle position, delays, service disruptions, occupancy where available, and compliance indicators. The protocol should clarify that data access supports public-interest orchestration and does not modify concessionaire responsibilities unless contractually agreed.
Emergency and crisis-management interoperability	Emergency coordination is highly dependent on human judgement and manual coordination at CEUS. This is appropriate from an accountability perspective but limits predictive and automated coordination.	The orchestrator should provide a common operational picture for emergency scenarios, while preserving final authority for Local Police and emergency actors. Emergency corridor recommendations must remain human-validated and must include safety flags, expected impact, alternative options, and potential conflicts with public transport or pedestrian flows.

Table 7: List of governance interoperability requirements for Murcia pilot.

6.3.2 Governance Requirements for Luxembourg Pilot

The governance baseline analysis in section 5.3.2 reveals a clear gap between the current situation and what the CARMONY Interlinked Orchestrator needs in order to function effectively. Therefore, this section translates the baseline analysis into five core governance requirements and a set of operational conditions that must be established before deployment in the forthcoming phases of the CARMONY project.

REQUIREMENT 1: Advisory operation in authority boundaries

For this set of use cases and pilot, it is also recognized that all outputs of the CARMONY Interlinked Orchestrator must be advisory in nature. The orchestrator may provide early warnings, predictive analyses, traffic impact assessments, and coordination proposals, but it must not issue binding instructions or override the authority of any decision-maker.

This reflects the Luxembourg accountability baseline: CITA holds statutory road authority for motorway traffic management, PTA governs scheduled public transport obligations, Sales Lentz operates within contractual constraints, and logistics actors have operational interests but no authority over public infrastructure. The current D4.1 baseline also states that operational stakeholders reject binding external orchestration because each actor's legal and operational accountability remains domain-specific.

What this means in practice:

- Recommendations to CITA are evaluated exclusively by CITA operators against internal regulations and procedures.
- Recommendations with public transport implications must transit the PTA before reaching Sales Lentz operational controllers.
- Logistics-oriented messages should be structured as advisory push notifications, not routing commands.
- No actor should feel obligated to follow an orchestrator recommendation in order to comply with their governance obligations.

REQUIREMENT 2: Explainability, traceability and auditability

The Luxembourg pilot requires a high level of explainability because it has been noticed that actors like CITA cannot rely on black-box recommendations. Each orchestrator's output must include the reason for the recommendation, data sources, expected impact, level of confidence, and available alternatives. The current requirements already identify that CITA needs explanation, data sources, expected impact, confidence level, and comparison with alternatives before trusting a recommendation.

In other words, every recommendation generated by the orchestrator must carry its data sources, the rationale for its generation, its estimated operational impact, its confidence level, and the alternatives considered. Every recommendation and the human decision that follows (or does not follow) must be logged and auditable.

Traceability is equally important from an accountability perspective. Each recommendation must be distinguishable in the audit log from the human decision that followed it. This protects operators (who can demonstrate they exercised independent judgement), supports post-incident review, and enables iterative improvement of the orchestrator's outputs over time.

The analytical framing of explainability as a governance requirement is developed further in Section 7, 2.3.

REQUIREMENT 3: Institutional hierarchy and decision chains

The orchestrator must address recommendations to the correct actor at the correct level of the decision chain. It must not bypass established institutional authority. The strategic and policy layer sets the governance envelope, CITA validates motorway measures, PTA validates scheduled public transport implications, Sales Lentz manages operational fleet decisions

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within its contractual boundaries, and logistics actors receive information but do not exercise road authority.

This is the initial list of priority conflicts that have been identified in the baseline that require explicit governance rules:

- Emergency response vs congestion reduction: all stakeholders agree emergency access unconditionally takes precedence.
- Freight continuity vs managed lane access: the A3 carpool lane benefits public transport (Sales Lentz) but not logistics (C4L). Lane eligibility rules must be defined by CITA/MMTP.
- Local optimisation vs network-wide optimization: actions rational for one actor may be suboptimal at the network level. Trade-offs must be made transparent.
- Environmental objectives vs logistics efficiency: not operationally acute today, but priority rules must be established in advance.

REQUIREMENT 4: Multimodal real-time coordination and data-sharing protocols

The Luxembourg baseline identifies the absence of a real-time operational platform through which CITA, Sales Lentz, logistics actors, and other relevant stakeholders can share situational awareness and coordinate responses. It also identifies that logistics actors are currently passive during congestion events and that predictive governance is limited because cross-actor information is not systematically available.

The orchestrator should therefore support multimodal situational awareness, but only within data-sharing protocols that respect GDPR, cybersecurity, commercial confidentiality, and institutional mandates.

Phase	Focus	Governance condition	Example outputs
1. Information	Shared situational awareness; early warnings	Open data sharing; basic bilateral agreement	Congestion alerts; cross-border incident notifications
2. Advisory	Tested recommendation functions for specific use cases	Formal data agreements; governance protocols; operator training	Speed reduction proposals for A3 (UC6); cross-border routing suggestions (UC5)
3. Coordinated	Multi-actor coordination support; predictive management	Full governance framework; co-operation agreements; audit mechanisms in place	Multimodal disruption coordination; managed lane optimisation (UC4)

Table 8: Suggested phases for requirement 4 within Luxembourg pilot

REQUIREMENT 5: Cross-border governance mechanism

The A13 use case requires a specific governance mechanism connecting Luxembourg and German road authorities. The baseline indicates that current cross-border coordination relies partly on bilateral personal contacts and lacks a real-time operational protocol. This is insufficient for predictive orchestration, early warning, and impact assessment.

In other words, the A13 corridor requires a dedicated governance arrangement engaging both Luxembourg (CITA/MMTP) and German (Autobahn GmbH) road authorities within a structured coordination framework. Reliance on bilateral personal contacts is insufficient for the predictive and real-time coordination functions that CARMONY is intended to support.

For instance, CITA identified earlier warning and traffic impact prediction as the most realistic and useful contributions that CARMONY could make in the cross-border context. Delivering even this requires three specific governance conditions:

- Aggregation of situational awareness across a national boundary where data flows are currently fragmented.
- Coordination proposals that are actionable within the respective authority frameworks of two national road operators, without requiring formal institutional alignment that does not yet exist.
- Communication in terms operationally intelligible to actors working in different administrative traditions and potentially different languages.

Governance interoperability requirements

Beyond the five core principles, the baseline analysis identifies five specific governance interoperability requirements that must be addressed through co-creation before the orchestrator can function as designed.

Requirement	Current status	What is needed
Data sharing protocols	Absent for most actor pairs	Agreed frameworks respecting GDPR, cybersecurity, commercial confidentiality, and institutional mandates
Trigger conditions and escalation hierarchies	Not defined	Agreed definitions of when and how orchestrator outputs reach which actors through which channels
Accountability rules for recommendations	Partially covered by existing structures; *not formalised for CARMONY*	Clear log distinguishing recommendation from human decision at each point in the chain
Priority rules for competing objectives	Defined in principle by authorities; not operationalised for orchestration	Explicit hierarchy for emergency, congestion, freight, environment, and public transport objectives
Logistics participation conditions	Absent	Formal governance role for freight actors without conferring authority over public infrastructure

Table 9: List of governance interoperability requirements for Luxembourg pilot.

7. Data Exchange, Multi-Level Decision Making and Regulatory Implications

This chapter synthesises the governance implications emerging from the CARMONY stakeholder engagement activities, pilot analyses, governance workshops and literature review. Building upon the governance baseline and requirements identified in previous chapters, it focuses on conditions required for the successful deployment of the Interlinked Orchestrator in complex mobility ecosystems.

The stakeholder consultations conducted in Luxembourg and Murcia reveal that the deployment of orchestration capabilities is not primarily a technological challenge. While interoperability, data integration and analytics remain important, the decisive barriers and enablers are often institutional, organisational and regulatory. The orchestrator operates in a system-of-systems environment involving public authorities, traffic managers, public transport operators, logistics actors, emergency services, technology providers and citizens. Each actor possesses distinct mandates, incentives, decision rights and accountability obligations.

For this reason, governance considerations are analysed through three complementary dimensions: data exchange between parties, decision-making across multiple levels and regulatory and legal implications. The five governance requirement dimensions identified in section 6.1 provide the analytical backbone for the three-part structure of this chapter. These dimensions reflect the recurring themes emerging from the interviews and provide a framework for understanding how orchestration systems can be deployed in a legitimate, trustworthy and sustainable manner. In addition, a section on development pathways explores scenarios of progress towards and interlinked orchestrator originating from different stakeholders.

7.1 Data Exchange

Mobility orchestration fundamentally depends on the ability to collect, process and exchange operational data across organisational boundaries. In CARMONY, the orchestrator concept relies on integrating data from multiple sources including traffic sensors, connected vehicles, public transport systems, logistics fleets, traffic management centres and infrastructure operators.

This reflects a broader transformation in transport governance where data becomes a strategic infrastructure layer. Traditionally, mobility systems were governed through physical infrastructure such as roads, signs and traffic signals. Increasingly, however, operational coordination depends on digital infrastructures and data ecosystems.

This evolution creates new governance questions regarding ownership, access rights and control.

Stakeholder interviews reveal that data-sharing willingness is strongly conditioned by governance arrangements. Public authorities tend to frame data as a public-interest resource, while private operators often consider operational data commercially sensitive.

7.1.1 Data Governance and Ownership

As documented in the pilot baselines (section 5.3), both Murcia and Luxembourg demonstrate how fragmented data ownership creates operational coordination gaps.

The consultations demonstrate that access to data cannot be taken for granted. A central governance challenge concerns ownership and stewardship, with several **questions** emerging:

- Who owns operational traffic data?

- Who owns vehicle-generated data?
- Can public authorities mandate data sharing?
- What rights do private operators retain?
- How should derived insights and predictive outputs be governed?

In ITS ecosystems, **ownership** is fragmented across actors:

- Infrastructure managers own sensor systems
- Public authorities own regulatory data
- Navigation platforms own behavioural and routing data
- Fleet operators own vehicle telemetry
- Telecom operators own communication layers
- Users generate behavioural data

This fragmentation complicates orchestration. European policy frameworks increasingly promote the idea of mobility data spaces and interoperable ecosystems. However, operational governance arrangements remain underdeveloped in practice.

Public authorities often regard mobility data as a public-interest asset capable of supporting traffic optimisation, sustainability objectives and safety improvements. Private actors, in contrast, frequently consider operational data commercially sensitive. Public transport operators, logistics providers and mobility service operators may be willing to share selected information but remain cautious about exposing data that could affect competitiveness or contractual obligations.

Public authorities	Private operators
• Congestion reduction • Emergency access • Sustainability • Safety • Equity	• Travel-time reliability • Operational efficiency • Cost optimisation • Contractual obligations • Competitive advantage

Table 10: Priorities of actors over data use and sharing

These priorities are not necessarily incompatible, but they may conflict in specific situations. For example, a logistics operator may resist rerouting recommendations that increase delivery uncertainty. Public transport operators may reject operational changes conflicting with concession agreements. Navigation providers may prioritise user-specific optimisation rather than system-wide equilibrium.

The Murcia pilot illustrates the growing importance of urban data platforms. The city has invested in FIWARE-based infrastructures, semantic models and extensive sensor networks, demonstrating how municipalities increasingly act as data orchestrators. Luxembourg highlights complementary concerns associated with public transport operations, cross-border traffic management and logistics coordination.

Together, these experiences suggest that future governance frameworks must define clear rules concerning:

- Ownership
- Access rights
- Stewardship responsibilities
- Acceptable uses of data
- Data-sharing obligations

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- Management of conflicts of interest

European policy developments provide an important reference point. The Data Governance Act, the Data Act and the emerging European mobility data spaces seek to facilitate trusted data sharing while preserving legitimate interests. CARMONY can contribute to this agenda by demonstrating how data governance principles can be operationalised in mobility orchestration contexts.

Future deployment should adopt a layered approach in which governance responsibilities are distributed according to the nature and sensitivity of the data involved. Such an approach can balance openness, innovation and trust.

Future research questions

- What governance models best balance public-interest objectives with commercial data ownership?
- Under which legal conditions can public authorities mandate operational data sharing?
- How should data ownership be defined in orchestrated mobility ecosystems?
- What incentive structures encourage voluntary data contribution?
- How can mobility data spaces avoid reinforcing market concentration?

7.1.2 Interoperability and Data Exchange Architectures

The CARMONY use cases illustrate the significant **heterogeneity** of data required for traffic orchestration. Relevant data categories include: traffic-flow measurements, congestion indicators, vehicle positioning, infrastructure sensor data, weather data, emergency-event information, public transport schedules, logistics-fleet information, cross-border traffic information, environmental and LEZ-related data, user-preference data and travel-demand patterns. These datasets differ significantly regarding frequency, granularity, format, reliability, ownership, latency and legal sensitivity. Interoperability, therefore, becomes a significant technical challenge.

Technical interoperability concerns communication protocols, APIs, semantic standards and data models. Without these foundations, systems cannot exchange information efficiently.

Murcia provides a strong example of investment in semantic interoperability through NGSI-LD and FIWARE-based architectures. Such approaches support scalability and facilitate integration across domains.

In addition, while the technical issue of interoperability is critical, the stakeholder consultations reveal a broader reality. Effective orchestration requires technical interoperability, **organisational interoperability and governance interoperability**.

Organisational interoperability concerns procedures, responsibilities and workflows. Data exchange alone does not guarantee coordinated action. Organisations must possess compatible processes for interpreting information and responding to recommendations. Several stakeholders highlighted the persistence of organisational silos despite technological advances.

Governance interoperability goes one step further. It concerns the ability of institutions with different mandates, legal responsibilities and priorities to collaborate effectively through shared information. This concept emerged strongly across both pilot sites. Luxembourg stakeholders emphasised coordination between authorities, operators and cross-border actors. Murcia

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stakeholders highlighted interactions between mobility, traffic, environmental management, emergency services and smart-city units.

The Interlinked Orchestrator should therefore be viewed as an interoperability enabler. Its success depends not only on connecting systems but also on supporting institutional coordination. Governance interoperability may ultimately prove more difficult to achieve than technical interoperability, yet it is essential for real-world deployment.

Technical interoperability	Semantic interoperability	Institutional interoperability
• APIs • Communication protocols • Standardised formats • Data architectures • Connectivity	• Shared definitions • Common event classifications • Harmonised traffic categories • Compatible operational interpretations	• Organisational procedures • Governance agreements • Decision-making compatibility • Legal frameworks

Table 11: Types of interoperability

Several stakeholders emphasised the importance of **timing and latency**, distinguishingly:

- Real-time incident detection
- Near-real-time congestion monitoring
- Daily planning information

This differentiation is crucial because orchestration systems combine strategic, tactical and operational layers. Emergency response may require second-level reaction times, while infrastructure planning operates on weekly or monthly cycles. The orchestrator therefore requires multi-speed data governance.

Future research questions

- Which interoperability standards are most suitable for cross-border orchestration?
- How can semantic interoperability between traffic-management actors be improved?
- What level of latency is acceptable for different orchestration functions?
- How can orchestration systems avoid information overload?
- How should multi-speed governance architectures be designed?

7.1.3 Data Quality, Explainability and Trust

Trust emerged as one of the most important themes across all stakeholder categories. Participants consistently indicated that recommendations would only be adopted if the underlying information is reliable, timely and understandable. This requirement is also summarized for the Luxembourg pilot in 6.3, Requirement 2.

Data quality therefore has direct governance implications. Inaccurate, incomplete or delayed information can undermine confidence and discourage adoption. Governance frameworks should define responsibilities for data quality assurance, validation and monitoring. Confidence indicators and quality metrics may also help users assess the reliability of recommendations.

The consultations reveal an important distinction between technical trust and institutional trust. Technical trust relates to the performance of systems, data quality and analytical models. Institutional trust concerns confidence that governance arrangements are fair, transparent and

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aligned with stakeholder interests. Both forms of trust are necessary for sustainable deployment.

Explainability plays a particularly important role. Stakeholders rarely demanded detailed technical explanations of algorithms. Instead, they emphasised operational explainability: understanding why a recommendation has been generated, what evidence supports it and what consequences are expected. This finding is highly relevant for future system design. Explainability should not be treated solely as an AI requirement but as a governance requirement.

Transparent recommendations can strengthen legitimacy, facilitate accountability and improve adoption. Consequently, governance frameworks should include requirements relating to traceability, auditability and communication of decision rationales.

Operational resilience also emerged as a major concern. Stakeholders repeatedly emphasised that orchestration systems must not replace operator judgement. This implies the need for:

- Human override capabilities
- Fallback procedures
- Redundant communication channels
- Graceful degradation mechanisms
- Manual operation continuity

This perspective reflects the operational culture of traffic management centres, where reliability and continuity are prioritised over automation.

Stakeholders also identified **operational overload** as a risk. PCH-CITA specifically warned against excessive alerts and low-relevance recommendations. This highlights an important challenge often overlooked in ITS literature: more data does not automatically improve decision quality. Traffic management centres already operate in highly information-intensive environments. Additional orchestration systems risk generating alert fatigue, cognitive overload, decision paralysis and reduced trust. Future systems therefore require intelligent prioritisation and contextual filtering.

Future research questions

- How should orchestration systems communicate uncertainty?
- What validation standards are required for traffic orchestration algorithms?
- Which explainability methods are operationally meaningful for traffic managers?
- How can orchestration systems remain resilient during data failures?
- What governance frameworks are appropriate for AI-supported traffic management

7.1.4 Cybersecurity, Privacy and Critical Infrastructure

The increasing integration of mobility systems creates new governance challenges associated with cybersecurity and privacy. Traffic management systems, public transport platforms and urban digital infrastructures are progressively becoming components of **critical digital infrastructure**.

Luxembourg stakeholders highlighted concerns regarding external access to operational traffic management systems and emphasised the importance of protecting critical infrastructure. Explicitly raised cybersecurity as a barrier to external system integration as mentioned in 5.3.2. Similar concerns are evident across Europe as transport systems become increasingly connected.

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Increasing connectivity expands the attack surface of mobility systems. Potential risks include:

- Manipulated traffic recommendations
- Denial-of-service attacks
- Infrastructure disruption
- False incident reporting
- Data theft
- Ransomware attacks
- Communication spoofing

Because traffic management directly affects public safety, cybersecurity becomes a core governance requirement rather than a secondary IT issue.

A governance paradox emerges. Greater interoperability creates opportunities for coordination and optimisation but simultaneously increases the attack surface of digital systems. Future governance frameworks must therefore balance openness with resilience.

Privacy considerations are equally important. Mobility data can reveal sensitive behavioural information concerning individuals and organisations. Compliance with GDPR principles remains essential. Data minimisation, purpose limitation, consent mechanisms and secure processing arrangements should be integrated into governance architectures from the outset. European GDPR frameworks provide legal safeguards, but operational implementation remains complex. Questions emerge regarding: Data minimisation, Consent mechanisms, retention periods, profiling risks, secondary use and cross-border transfer. The emerging AI Act further reinforces the need for robust governance. Depending on deployment scenarios, certain orchestration functions may fall within categories requiring enhanced transparency, human oversight and risk management. While the precise regulatory implications will depend on implementation choices, the broader direction is clear: governance frameworks must incorporate cybersecurity, privacy and accountability by design.

Finally, public acceptance of orchestration systems depends strongly on perceived legitimacy. Citizens may resist systems perceived as overly intrusive, opaque, behaviourally manipulative and commercially exploitative. Insufficiently accountable trust therefore becomes a governance resource.

Future research questions

- How can orchestration systems balance interoperability with cybersecurity isolation?
- What cybersecurity governance models are appropriate for critical traffic infrastructure?
- Which privacy-preserving approaches are operationally viable?
- How can public trust in orchestration systems be measured and strengthened?
- What governance safeguards are necessary for behavioural traffic orchestration?

7.1.5 Administrative Capacity and Organisational Readiness

One of the most novel findings emerging from the consultations concerns the importance of administrative capacity. Stakeholders repeatedly observed that governance barriers often stem from organisational limitations rather than technological shortcomings.

Several stakeholders described fragmented coordination structures. Examples include:

- Limited real-time coordination between logistics actors and road authorities
- Siloed organisational structures
- Fragmented operational responsibilities

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- Weak integration between public and private actors
- Inconsistent communication channels

These coordination gaps represent institutional rather than technical barriers.

Institutional trust emerged repeatedly as a prerequisite for orchestration. Stakeholders require confidence that:

- Recommendations are reliable
- Data is protected
- Governance is fair
- Operational autonomy is respected
- Accountability remains clear

Trust is particularly important in multi-actor ecosystems where actors possess different incentives and asymmetric information.

Municipalities and public authorities face significant challenges in recruiting specialised personnel, maintaining advanced digital systems and managing increasingly complex technology ecosystems. Procurement cycles often evolve more slowly than technological innovation, creating risks of obsolescence and dependency.

Murcia stakeholders particularly emphasised the difficulties associated with staffing, institutional learning and long-term maintenance. Similar concerns were evident in Luxembourg, where operational responsibilities constrain experimentation and increase the importance of reliability.

These findings suggest that organisational readiness should be treated as a core governance issue. Successful orchestration requires more than technical infrastructure. It also requires skilled personnel, institutional memory, training programmes and sustainable support structures.

Furthermore, cross-border coordination was often described as depending on personal contacts and informal relationships. This illustrates that operational governance frequently depends on informal institutional networks rather than purely formal architectures. Future orchestration systems must therefore complement rather than replace existing human coordination structures.

Future governance frameworks should therefore incorporate capacity-building measures, knowledge-transfer mechanisms and long-term maintenance strategies. Without such investments, even technically successful systems may struggle to achieve operational sustainability.

Future research questions

- How can orchestration systems strengthen rather than undermine institutional trust?
- What role do informal coordination networks play in traffic governance?
- How should governance frameworks manage conflicting stakeholder incentives?
- Which organisational structures best support operational interoperability?
- How can trustworthiness of orchestration systems be evaluated?

7.2 Decision-making across multiple levels

This section examines the governance conditions required to enable trusted, secure and effective data exchange across the CARMONY ecosystem. It addresses how data ownership, access rights and responsibilities should be defined among participating actors, while also

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considering the technical and organisational interoperability needed to connect heterogeneous systems.

7.2.1 Governance Architecture

Traditional traffic management is often hierarchical and infrastructure-centred. Orchestration systems instead operate through distributed coordination involving multiple autonomous actors. This creates a multi-level governance environment where decisions occur simultaneously at multiple levels.



Figure 4: Decision-making levels relevant in traffic orchestration

One of the most important unresolved questions concerns the institutional positioning of orchestration systems. Possible models include:

- Public-authority-controlled systems;
- Public-private partnerships;
- Federated coordination platforms;
- Neutral interoperability layers;
- Commercial mobility platforms.

Consulted stakeholders tend to strongly favour public-authority oversight.

Public actors repeatedly emphasised that binding decisions must remain under public authority control, that orchestrators should remain advisory, that human validation is required and that public-interest objectives must dominate. This suggests that fully autonomous orchestration models currently lack institutional legitimacy.

The evidence collected throughout the project suggests that the Interlinked Orchestrator should not be conceived as a centralised command-and-control system. Instead, it should operate as a coordination layer facilitating information exchange, recommendation generation and collaborative decision-making.

Three broad governance models can be considered. A centralised model concentrates decision authority and coordination responsibilities within a single entity. While such an

approach may simplify governance, it risks reducing institutional autonomy and creating resistance among stakeholders.

A federated model preserves autonomy by allowing actors to maintain control over their own systems and decisions. However, excessive decentralisation may reduce coordination effectiveness and limit opportunities for optimisation.

A hybrid-federated model appears most consistent with stakeholder expectations. Under this approach, coordination mechanisms and shared governance principles coexist with decentralised decision authority. The orchestrator acts as a broker, facilitator and recommender rather than a command centre.

This model aligns closely with the system-of-systems philosophy underpinning CARMONY. It recognises the distributed nature of mobility governance and the need to preserve existing institutional mandates while improving coordination.

Future research questions

- Which institutional models are most appropriate for orchestration systems?
- How can orchestration systems remain democratically accountable?
- What governance architectures best support cross-border traffic coordination?
- How should orchestration platforms interact with existing traffic-management centres?
- Can orchestration systems operate without centralised authority?

7.2.2 Multilevel Governance Dependencies, Decision Hierarchies and Authority

Traffic orchestration takes place within a multilevel governance environment. Decisions are influenced by interactions between local, regional, national and European actors, as well as by relationships among departments, agencies and private operators.

The Luxembourg pilots highlight vertical governance dependencies. National authorities, motorway operators, public transport actors and neighbouring jurisdictions all play important roles. Cross-border mobility introduces additional complexity because governance frameworks and operational practices differ between countries.

The Murcia pilots highlight horizontal governance dependencies. Stakeholders described the need for closer coordination among traffic management, transport planning, emergency services, environmental management and smart-city functions. Although digital infrastructures are becoming more integrated, organisational structures often remain fragmented.

The findings suggest that governance frameworks should explicitly address coordination across governance levels. Escalation procedures, communication protocols and conflict-resolution mechanisms should be clearly defined. Integrated coordination structures, such as Murcia's monitoring centre approach, may provide valuable reference models.

Ultimately, multilevel governance is not merely a contextual factor. It is a core design consideration for orchestration systems.

Advisory versus binding decisions

One of the clearest findings across all stakeholder groups concerns the distinction between advisory and binding measures. Stakeholders consistently support:

- Advisory recommendations;
- Decision-support systems;

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- Predictive analytics;
- Situational awareness enhancement.

However, they remain cautious regarding automated binding decisions, external operational control and delegation of authority to algorithms.

This distinction reflects deeper **governance principles**, with binding traffic measures involving:

- Legal liability;
- Public accountability;
- Safety responsibility;
- Democratic legitimacy.

As a result, public authorities insist on maintaining final authority.

Human-in-the-loop governance

Human supervision emerged as a universal requirement. Stakeholders repeatedly stated that:

- Operators must validate recommendations;
- Drivers retain safety responsibility;
- Public authorities retain override authority;
- Algorithms cannot replace human judgement.

Rather than replacing operators, orchestration systems are currently viewed as augmentation tools.

Decision Rights and Accountability

One of the central objectives of the stakeholder engagement process was to understand who decides what under routine and disruption conditions. The resulting insights have important implications for orchestrator governance.

Stakeholders consistently support decision-support functions but remain cautious regarding delegation of authority. Recommendations generated by the orchestrator are viewed as valuable inputs, yet implementation decisions should remain with actors possessing legal mandates and operational responsibilities.

This finding highlights the importance of accountability. Governance frameworks must ensure that responsibilities remain clear even when decisions are supported by advanced analytics. Ambiguity concerning accountability can undermine trust and create barriers to adoption.

A RACI-inspired governance model may help clarify roles. Such an approach distinguishes between actors responsible for implementation, accountable for outcomes, consulted during decision-making and informed about resulting actions. While specific allocations will vary across use cases, the underlying principle remains applicable across contexts.

Clear decision rights and accountability structures are essential for legitimacy, trust and operational effectiveness.

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Decision activity	Orchestrator	Traffic Management Centre	Road Authority	PT Operator	Emergency Services
Incident detection	*R*	*A*	*I*	*I*	*I*
Generate recommendation	*R*	*C*	*I*	*C*	*C*
Validate recommendation		*R*	*C*	*C*	*C*
Approve traffic measure		*A*	*A*	*I*	*C*
Implement measure		*R*	*C*	*R*	*I*
Communicate to users	*C*	*C*	*I*	*R*	*I*
Monitor outcomes	*R*	*A*	*C*	*C*	*C*

R – Responsible ; A – Accountable ; C – Consulted ; I - Informed

Table 12: RACI-Inspired Governance Model for the Interlinked Orchestrator

Future research questions

- Which traffic-management functions are appropriate for automation?
- How can progressive automation be governed safely?
- What levels of explainability are required for operational legitimacy?
- How should responsibility be allocated between humans and algorithms?
- Under what conditions can advisory systems evolve into semi-binding systems?
- How can orchestration systems align heterogeneous stakeholder incentives?
- What governance mechanisms best manage co-opetition?
- Which actors require representation in orchestration governance?

7.2.3 Human versus Automated Decision-Making

Mobility systems tend to **algorithmic governance**, which depends on: predictive analytics, automated optimisation, AI-supported recommendations and real-time behavioural steering.

This trend creates tensions between:

- Efficiency and autonomy
- Optimisation and legitimacy
- Automation and accountability

The stakeholder consultations reveal broad support for advisory systems and decision-support functions. At the same time, they reveal caution regarding automation, particularly in safety-critical contexts.

Stakeholders consistently demanded **transparency** and explainability. Operational actors require the ability to understand:

- Why recommendations are produced
- Which data sources are used
- What assumptions exist
- Which impacts are expected

This is especially important because operators remain legally accountable. Human-in-the-loop governance emerges as the preferred model for current deployment environments. Under this approach, recommendations are generated by the system but remain subject to human validation.

Over time, progressive automation may become feasible for selected functions. However, such transitions should be guided by evidence, trust and clearly defined accountability arrangements. Human oversight should remain central whenever decisions involve significant safety, legal or societal implications.

Orchestration systems may also influence user behaviour to promote the system's goals.

This behavioural influence raises **ethical and political questions** regarding legitimacy on different aspects of this influence, like nudging, behavioural steering, incentive structures, manipulation risks and public-interest optimisation.

The findings suggest that future orchestration systems should be designed to augment rather than replace human expertise. Effective human-AI collaboration depends on explainability, transparency and user confidence. Governance frameworks should therefore define the conditions under which automation may be introduced and the safeguards required to preserve accountability.

Future research questions:

- How can orchestration systems remain explainable under complex AI architectures?
- What forms of behavioural steering are socially acceptable?
- How should algorithmic accountability be implemented in mobility systems?
- Which human-machine collaboration models are operationally viable?
- How can orchestration systems preserve user autonomy?

7.2.4 Governance-by-Design

A key insight emerging from the consultations is that traffic orchestration is never value-neutral. Decisions concerning priorities, routing strategies and optimisation objectives inevitably reflect public policy choices. This perspective builds on the design-based governance framework introduced in section 6.1.

The Murcia mobility hierarchy provides a clear example. Prioritising pedestrians, cyclists and public transport before private vehicles reflects policy objectives concerning safety, sustainability and accessibility. Similar choices arise in relation to emergency corridors, environmental objectives and congestion management.

Governance-by-design refers to the deliberate integration of public values into system architecture. Rather than treating governance as an external layer applied after technical development, governance considerations are embedded directly within algorithms, optimisation functions and decision rules.

This perspective is increasingly important in debates concerning algorithmic governance and public value design. For CARMONY, it implies that optimisation objectives should be transparent, contestable and aligned with democratically legitimate priorities. Stakeholders should understand not only how recommendations are generated but also which values and objectives influence them.

Future research questions:

- What value hierarchy should govern orchestration decisions?

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- How should fairness in traffic orchestration be evaluated?
- How can orchestration systems avoid reinforcing existing inequalities?

7.3 Regulatory and Legal Implications

The deployment of traffic orchestration systems introduces a range of regulatory and legal challenges that extend well beyond the technical implementation of data-sharing and decision-support capabilities. While existing traffic management systems already operate within complex legal and institutional frameworks, orchestration introduces new forms of coordination, data exchange and decision support that challenge traditional assumptions regarding authority, accountability and operational responsibility.

A central finding emerging from both the stakeholder consultations and the broader literature is that traffic orchestration does not occur in a regulatory vacuum. Instead, orchestration systems must operate within a dense network of sector-specific regulations governing traffic management, public transport, emergency response, data protection, cybersecurity and public administration. Consequently, the successful deployment of an orchestrator depends not only on technical feasibility but also on its ability to coexist with existing legal mandates and institutional responsibilities.

7.3.1 Legal Authority and Decision-Making Competence

One of the most important regulatory questions concerns the allocation of legal authority. Traffic management decisions often involve legally binding measures such as speed restrictions, lane closures, traffic diversions, public transport priority measures and emergency management procedures. These powers are typically assigned to specific authorities through national legislation and administrative frameworks.

The stakeholder consultations conducted in Luxembourg illustrate this challenge clearly. Public authorities responsible for motorway management possess explicit legal powers to impose traffic restrictions and operational measures. Similar arrangements exist across most European jurisdictions, where traffic management responsibilities are assigned to road authorities, municipalities, police services or transport agencies. Consequently, an orchestrator cannot simply assume decision-making authority over operational measures without potentially conflicting with existing legal mandates.

This distinction has important implications for governance design. In the foreseeable future, orchestrators are likely to function primarily as advisory and coordination mechanisms rather than autonomous decision-makers. While they may generate recommendations, forecasts and optimisation proposals, final authority for implementing legally binding measures is expected to remain with competent authorities.

7.3.2 Liability and Accountability

The introduction of advanced decision-support systems raises complex questions regarding liability and accountability. Traditional traffic management systems are characterised by relatively clear responsibility structures. Decisions are made by identifiable organisations and individuals operating within established legal frameworks. The site-specific accountability structures documented in section 5.3 illustrate how these general liability challenges materialize in practice.

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Traffic orchestration complicates this picture. Recommendations may be generated through the combination of multiple data sources, predictive algorithms and optimisation models. If an orchestrator recommends a traffic management action that contributes to negative operational outcomes, determining responsibility becomes significantly more difficult.

Several potential liability scenarios may arise:

- Incorrect recommendations resulting from inaccurate data;
- Operational disruptions caused by algorithmic errors;
- Failure to detect critical incidents;
- Adverse consequences resulting from automated coordination actions;
- Conflicts between orchestrator recommendations and existing operational procedures.

Current legal frameworks provide only limited guidance regarding such situations. In practice, stakeholders consistently expressed a preference for maintaining human oversight precisely because it preserves existing accountability structures. Human validation ensures that responsibility remains attached to authorised decision-makers rather than being transferred to technical systems.

From a governance perspective, this suggests that accountability frameworks should be explicitly defined as part of orchestration deployment. RACI-based governance models, clear audit trails and transparent decision records may help address some of these challenges.

7.3.3 Data Protection and Privacy

Data governance constitutes one of the most significant regulatory dimensions of traffic orchestration. By design, orchestrators depend on the integration of information originating from multiple actors, including public authorities, mobility operators, infrastructure managers, connected vehicles and digital platforms.

Many of these datasets contain information that may be subject to privacy and data protection requirements. Vehicle trajectories, travel patterns, mobility preferences and operational fleet information can potentially reveal sensitive behavioural information concerning both individuals and organisations.

Within the European context, the General Data Protection Regulation (GDPR) provides the principal legal framework governing the processing of personal data. The GDPR establishes obligations relating to lawful processing, transparency, purpose limitation, data minimisation and accountability. These principles are directly relevant to orchestration systems, particularly where mobility data can be linked to identifiable individuals.

However, compliance with GDPR alone may not be sufficient. Stakeholder consultations repeatedly highlighted broader concerns relating to trust, transparency and acceptable use. Future orchestration frameworks will therefore require governance arrangements that extend beyond legal compliance and actively promote responsible data stewardship.

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7.3.4 Cybersecurity and Critical Infrastructure Protection

Traffic management systems increasingly form part of critical digital infrastructure. As orchestration systems create new connections between previously independent systems, they also introduce new cybersecurity risks.

The Luxembourg interviews revealed sensitivity regarding external access to operational traffic management systems. Stakeholders emphasised the need to preserve the integrity, availability and resilience of critical infrastructure while simultaneously enabling information exchange and coordination.

This creates a regulatory paradox. Effective orchestration requires interoperability and connectivity, yet increased connectivity may also increase exposure to cyber threats. Governance frameworks must therefore reconcile two potentially competing objectives: openness and resilience.

Recent European legislation, including the NIS2 Directive and related cybersecurity initiatives, reinforces the importance of risk management, incident reporting and critical infrastructure protection. Future orchestrators will likely be required to comply with increasingly stringent cybersecurity obligations, particularly when operating within critical mobility infrastructures.

7.3.5 Artificial Intelligence and Automated Decision-Making

As orchestration systems evolve, artificial intelligence is expected to play an increasingly important role in prediction, optimisation and recommendation generation. This introduces additional regulatory considerations associated with transparency, explainability and human oversight.

The European Union's AI Act provides an important reference framework. While the precise classification of orchestration functions will depend on implementation details, several aspects of traffic orchestration may potentially fall within categories requiring enhanced governance safeguards. These may include obligations relating to risk management, transparency, human oversight and accountability.

The stakeholder consultations strongly support this direction. Across multiple interviews, participants consistently emphasised the importance of maintaining human control over safety-critical decisions. This suggests that future orchestration systems are likely to evolve within a framework of human-centred automation rather than fully autonomous decision-making.

7.3.6 Cross-Border and Multi-Level Regulatory Challenges

The CARMONY pilots also highlight the importance of cross-border and multi-level governance. Traffic flows frequently extend beyond municipal, regional and national boundaries. Yet legal responsibilities, operational procedures and regulatory frameworks often remain fragmented. These regulatory fragmentation challenges are operationalized in the A13 cross-border governance requirement described in section 6.3.

Cross-border coordination introduces additional complexity because participating actors may operate under different legal systems, governance traditions and institutional arrangements. Even where technical interoperability exists, differences in liability frameworks, decision-making authority and operational protocols may hinder coordination.

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These challenges suggest that future orchestration systems will require not only technical interoperability standards but also governance and regulatory interoperability. Harmonisation efforts at European level, including mobility data spaces, Intelligent Transport Systems (ITS) initiatives and Connected Cooperative and Automated Mobility (CCAM) programmes, may play an important role in supporting such developments.

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8. Transition Towards Operational Governance and Development Pathways

This section explores how the initial governance arrangements developed within CARMONY can evolve from pilot experimentation towards sustainable operational deployment. It examines the institutional, organisational and regulatory conditions required to embed orchestration within existing mobility ecosystems and presents alternative development pathways driven by different actors and operational needs. Rather than assuming a single deployment model, the section frames mobility orchestration as a progressive process in which data integration, coordinated decision-making and automation advance as trust, accountability, interoperability and institutional readiness mature.

8.1 From Pilot Governance to Operational Governance

The transition from pilot projects to operational deployment represents one of the most significant governance challenges facing innovation initiatives and, in turn, for the objective of this task and WP4 in general. Many research projects successfully demonstrate technical feasibility yet struggle to achieve institutional integration and long-term sustainability.

There are multiple institutional barriers to tackle, including lack of trust, safety concerns, institutional conservatism, regulatory rigidity, accountability ambiguity, and fear of operational overload. These barriers suggest that technological feasibility alone is insufficient for deployment.

Stakeholders emphasised that successful deployment requires integration into organisational routines, procurement frameworks, regulations and operational procedures. Ownership arrangements, maintenance responsibilities and funding models must be defined before systems can become permanent components of mobility ecosystems.

This transition should be understood as a governance process. Technical success alone is insufficient. Institutions must adapt, governance arrangements must mature and stakeholders must develop confidence in new ways of working.

For CARMONY, this implies that governance models should be designed with long-term operational sustainability in mind. For that, the methodology and steps presented in Figure 1 in section 4, they all must be oriented to achieve that pilot governance, and the operational governance are connected stages within a broader transformation process.

8.2 Development Pathways Towards Mobility Orchestration

The stakeholder consultations conducted within CARMONY WP4 consistently indicate that the implementation of a fully operational mobility orchestrator is unlikely to occur through a single deployment initiative or institutional reform. Rather, orchestration is expected to emerge progressively through a series of evolutionary developments driven by different stakeholders, responding to distinct operational needs and governance incentives.

This finding is particularly relevant because the development of orchestration capabilities requires advances not only in data exchange but also in decision-making coordination across multiple organisations and governance levels. While significant progress is already being made in areas such as mobility data sharing, interoperability standards and digital platforms, the governance arrangements required to support coordinated decision-making remain less mature. Consequently, the pathway towards orchestration should be understood as a staged process characterised by increasing levels of data integration and progressively more coordinated decision-making.

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From a governance perspective, the maturity of orchestration systems can be analysed along two dimensions. The first concerns data exchange, evolving from basic information sharing towards shared optimisation and coordinated orchestration. The second concerns decision-making, evolving from information exchange and recommendations towards coordinated decision-making and, potentially, partial automation of operational actions. Stakeholder consultations suggest that most current mobility ecosystems remain at relatively early stages of both dimensions, while the long-term vision embodied by the Interlinked Orchestrator implies significantly higher levels of integration.

8.2.1 Analytical framework for creation of pathway scenarios

Mobility orchestrator scenarios are developed considering the dimensions of data exchange, decision making and the stakeholder triggering the orchestration development.

Data exchange maturity		Decision making maturity	
D1	Basic data sharing	**M1**	Information exchange
D2	Real-time data sharing	**M2**	Recommendations
D3	Shared situational awareness	**M3**	Coordinated decisions
D4	Shared predictive models	**M4**	Semi-automated execution
D5	Shared optimisation and orchestration	**M5**	Autonomous orchestration

Table 13: Data exchange maturity and decision-making maturity

The stakeholder interviews strongly suggest that Europe is currently between D1–D3 and M1–M2, while the full CARMONY vision is closer to D5 and M4. Few stakeholders appear comfortable with M5.

8.2.2 Public Traffic Management Pathway

One of the most plausible development pathways is driven by road authorities and traffic management organisations. In this scenario, orchestration emerges as an extension of existing traffic management functions. Initial deployment is motivated by operational challenges such as congestion management, incident response and emergency corridor coordination.

Data exchange initially focuses on traffic conditions, incidents, roadworks and infrastructure status. Over time, integration expands to include public transport operators, municipalities, emergency services and logistics actors. As interoperability improves, authorities may progressively develop shared situational awareness and predictive capabilities capable of supporting coordinated traffic management actions.

The evolution of decision-making is likely to remain cautious. Stakeholder interviews suggest strong support for information sharing, recommendations and coordinated operational responses. However, public authorities consistently emphasise the importance of retaining responsibility for legally binding traffic measures. Consequently, this pathway is likely to culminate in semi-automated decision support rather than fully autonomous orchestration.

The principal strengths of this pathway are its legitimacy, public accountability and alignment with existing institutional mandates. However, implementation may be constrained by procurement processes, institutional conservatism and limited administrative flexibility.

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8.2.3 Smart City Platform Pathway

A second pathway emerges through municipal smart-city initiatives. In this scenario, orchestration develops as an extension of integrated urban data platforms rather than traffic management systems alone.

The Murcia pilot provides valuable insights into this approach. Municipal investments in digital twins, urban platforms, sensor networks and interoperability frameworks create an environment in which orchestration capabilities can be progressively incorporated into broader urban governance structures. Initial efforts focus on integrating data across municipal departments, including traffic management, environmental monitoring, public transport and emergency services.

As interoperability increases, orchestration may support cross-department coordination and integrated urban operations. The resulting governance model is characterised by strong horizontal coordination within municipalities and close integration with smart-city governance structures.

This pathway benefits from existing digital infrastructures and may facilitate rapid experimentation. However, it also faces challenges relating to scalability, municipal capacity and the risk of developing solutions optimised primarily for local conditions rather than broader regional mobility ecosystems.

8.2.4 Public Transport-Oriented Pathway

A third pathway is driven by public transport authorities and operators seeking to improve service reliability, passenger experience and operational efficiency.

In this scenario, data exchange initially focuses on vehicle positioning, schedules, passenger demand and service performance. Integration with road authorities, municipalities and mobility platforms subsequently enables more sophisticated coordination mechanisms. The orchestrator may support dynamic priority measures, service coordination and disruption management.

Because public transport enjoys strong policy support within European mobility strategies, this pathway may benefit from favourable political conditions. However, its scope may remain limited if governance arrangements become overly focused on public transport objectives at the expense of broader mobility-system optimisation.

8.2.5 Logistics and Freight-Oriented Pathway

A fourth pathway originates within freight and logistics ecosystems. Stakeholder consultations indicate significant interest in improving travel-time reliability, reducing operational uncertainty and enhancing coordination between logistics operators and infrastructure managers.

Under this model, orchestration initially focuses on freight-related information exchange and operational optimisation. As governance arrangements mature, integration with road authorities and urban mobility systems enables broader coordination.

This pathway benefits from clear business incentives and the potential for private investment. However, concerns regarding commercial confidentiality, data ownership and public legitimacy may limit its ability to evolve into a system-wide orchestration framework without significant public-sector involvement.

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8.2.6 Mobility Platform and MaaS Pathway

Another plausible pathway is driven by mobility platforms and Mobility-as-a-Service (MaaS) providers. In many respects, digital navigation and routing platforms already perform rudimentary orchestration functions by influencing route choices and mobility behaviour through information and recommendations.

As these platforms gain access to richer mobility datasets and stronger integration with public transport systems, infrastructure operators and urban services, they may increasingly perform orchestration functions. The resulting governance model would be characterised by high levels of data availability, rapid innovation and strong user engagement.

However, stakeholder consultations highlight concerns regarding accountability, transparency, market concentration and democratic legitimacy. While such actors may possess significant technical capabilities, questions remain regarding their suitability as primary orchestrators of public mobility systems.

8.2.7 European Mobility Data Space Pathway

A final pathway emerges through European interoperability initiatives and mobility data spaces. In this scenario, the development of common standards, governance frameworks and data-sharing mechanisms precedes the emergence of orchestration capabilities.

Rather than being driven by a single operational actor, orchestration evolves through the gradual creation of interoperable mobility ecosystems capable of supporting coordinated services across jurisdictions and sectors. This pathway offers strong potential for scalability and cross-border interoperability but may progress more slowly due to the complexity of achieving consensus among diverse stakeholders.

8.2.8 Progressive automation as a Governance Pathway

While the previous sections describe alternative institutional pathways through which orchestration capabilities may emerge, stakeholder consultations suggest that the evolution of decision-making authority within orchestration systems follows a separate but equally important trajectory. Regardless of whether orchestration is initially driven by road authorities, municipalities, public transport operators, logistics actors or mobility platforms, stakeholders consistently anticipate a gradual increase in automation over time.

This finding is particularly significant because it highlights that orchestration maturity is not solely determined by data availability or interoperability. It is also determined by the degree of confidence that organisations are willing to place in automated recommendations and actions. Consequently, the development of orchestration systems can be understood as a progressive transition from human-centred decision support towards increasingly automated forms of coordination.

Importantly, stakeholder interviews reveal little support for fully autonomous orchestration in the short to medium term. Instead, respondents consistently emphasised the need for human oversight, operational accountability and institutional control. Nevertheless, several interviewees acknowledged that, as trust in orchestration systems increases, certain functions could gradually become semi-automated or conditionally automated. This suggests an evolutionary governance pathway characterised by five successive levels of automation.

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Level 1 – Information Support

At the initial stage, the orchestrator functions primarily as an information aggregation and dissemination platform. Its role is limited to collecting, integrating and visualising information originating from multiple actors and systems. Decision-making remains entirely under the control of human operators.

Typical functions at this stage include:

- Shared situational awareness;
- Real-time traffic monitoring;
- Incident reporting;
- Cross-organisational information exchange;
- Operational dashboards and visualisation tools.

Most existing traffic management centres and smart-city platforms already operate at or near this level. The governance implications are relatively limited because the orchestrator does not directly influence operational decisions. Instead, it supports human actors by reducing information asymmetries and improving awareness of system conditions.

Level 2 – Advisory Recommendations

At the second level, the orchestrator begins generating recommendations based on available data and analytical models. However, all decisions remain subject to explicit human approval.

Examples include:

- Suggested rerouting strategies;
- Public transport priority recommendations;
- Emergency corridor proposals;
- Predicted congestion mitigation actions;
- Logistics coordination suggestions.

This level corresponds closely to the current expectations expressed by most stakeholders interviewed within CARMONY. Public authorities, transport operators and traffic managers generally view the orchestrator as a decision-support tool rather than a decision-maker. Consequently, human validation remains mandatory before any operational action is implemented.

Governance requirements at this stage focus on transparency, explainability and accountability. Users must understand why recommendations are generated and retain the ability to reject them when necessary.

Level 3 – Semi-Automated Coordination

At the third level, selected coordination functions become partially automated. Human actors continue to supervise operations but no longer need to approve every routine action individually.

Typical examples might include:

- Automated information sharing between organisations;
- Dynamic coordination of predefined traffic-management procedures;
- Automatic activation of low-risk operational workflows;
- Automated dissemination of approved recommendations.

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Stakeholder consultations suggest that this level may represent a realistic medium-term objective for many orchestration initiatives. Semi-automated coordination offers significant operational benefits while preserving meaningful human oversight.

However, achieving this level requires considerably higher levels of institutional trust. Participating organisations must have confidence not only in the technical reliability of the system but also in the governance arrangements that determine how recommendations are generated and implemented.

Level 4 – Conditional Automation

At the fourth level, the orchestrator acquires the authority to implement predefined actions automatically under specific circumstances and within clearly defined operational boundaries.

Examples may include:

- Automatic adjustment of signal-control strategies;
- Automated activation of predefined traffic management plans;
- Dynamic lane-management recommendations executed under approved protocols;
- Automatic dissemination of emergency-routing instructions.

Conditional automation differs fundamentally from full autonomy because actions remain constrained by previously agreed governance rules and operational procedures. Human operators retain the ability to intervene, override, or suspend automated actions when required.

This level represents an important governance transition point. Organisations must be willing to delegate limited operational authority to the orchestrator, and regulatory frameworks must provide legal certainty regarding accountability and liability.

Level 5 – Selective Autonomous Execution

The highest level of automation involves autonomous execution of selected orchestration functions without prior human validation. Such autonomy would likely be restricted to narrowly defined operational domains where risks are low, system behaviour is predictable and governance arrangements are mature.

Potential examples include:

- Automated optimisation of traffic-signal coordination;
- Dynamic management of digital information services;
- Automated coordination of low-risk mobility incentives;
- Continuous optimisation of selected operational parameters.

Stakeholder evidence suggests that widespread adoption of this level remains unlikely in the foreseeable future, particularly in safety-critical domains such as emergency response, major traffic restrictions, or public transport service management. Nevertheless, selective autonomy may emerge in specific contexts where technical reliability, institutional trust, and regulatory maturity are sufficiently advanced.

Governance Conditions for Progression

The transition between automation levels should not be understood as a purely technological process. Instead, progression depends upon a combination of technical, organisational and institutional factors.

Five governance conditions appear particularly important:

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- **Trust**. Organisations must develop confidence in the reliability, transparency, and predictability of orchestration systems.
  - **Accountability**. Clear allocation of responsibilities is required at every automation level. Stakeholders must understand who remains accountable when automated actions contribute to operational outcomes.
  - **Explainability**. As automation increases, stakeholders require stronger justification mechanisms capable of explaining why actions are proposed or implemented.
- **Regulatory Adaptation**. Existing legal frameworks are generally designed around human decision-makers. Higher levels of automation may require regulatory adjustments to clarifying liability, oversight obligations, and acceptable levels of autonomy.
- **Institutional Learning**. Organisations require time to adapt operational procedures, develop competences, and gain experience working with orchestration technologies.

A Progressive Rather than Revolutionary Transition

Taken together, the stakeholder consultations suggest that the future evolution of mobility orchestration is likely to be progressive rather than revolutionary. Rather than moving directly towards fully autonomous coordination, organisations are expected to advance incrementally through successive levels of automation such as trust, governance maturity and regulatory clarity increase.

In this view, CARMONY should be understood as an enabling step towards progressively more coordinated and data-informed mobility governance.

8.2.9 Towards a Hybrid Evolutionary Model

The stakeholder evidence suggests that the future development of mobility orchestration is unlikely to follow any single pathway. A more plausible scenario is the coexistence of multiple parallel developments. Traffic management organisations, smart-city platforms, public transport authorities, logistics ecosystems and digital mobility platforms are all likely to develop orchestration-related capabilities independently.

Over time, increasing interoperability, common governance frameworks and shared data infrastructures may facilitate convergence between these initiatives. In such a scenario, orchestration emerges not through the creation of a single centralised platform but through the progressive integration of multiple coordination systems operating across different governance levels and mobility domains.

Perhaps the most important finding emerging from the consultations is that the principal barrier to this evolution is unlikely to be technological interoperability. Significant progress is already being made in data sharing, interoperability standards and digital infrastructure. The more difficult challenge concerns multi-level decision-making: determining who has authority to act, who remains accountable for outcomes, how conflicts between stakeholders are resolved and how public-interest objectives are balanced against organisational incentives.

Consequently, future governance research should focus not only on data exchange mechanisms, but also on the institutional arrangements required to support coordinated decision-making across increasingly interconnected mobility ecosystems.

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9. Conclusions and next steps

D4.1 presents the initial governance framework for the CARMONY Interlinked Orchestrator, developed at M15 based on a literature review, stakeholder mapping, semi-structured interviews, an Outreach Group workshop (focus group) and a site-specific governance analysis for the Murcia and Luxembourg sites. The deliverable answers to a central premise of the project, that the deployment of traffic orchestration systems is not only a technological challenge, but also a governance one.

This deliverable advances beyond the state of the art in three main aspects. The first one, it reframes traffic orchestration as a governance design problem, articulating requirements around actor roles, accountability, data exchange and multilevel decision-making rather than treating governance as a secondary consideration. The second one is that it operationalises a four-layer governance baseline model (strategic, operational, contractual and ecosystem) applied empirically to two pilot environments. The last, but not least, one, is that it introduces a progressive automation framework that defines five levels of decision-making authority, providing a structured pathway from information support towards conditional automation grounded in stakeholder evidence rather than purely technical criteria.

Across both pilot sites, one of the key findings revealed in stakeholder consultations is that governance interoperability (the ability of institutions with different mandates and legal responsibilities to coordinate effectively) presents a more fundamental barrier than technical interoperability. Data fragmentation, institutional silos and asymmetric incentives between public authorities and private operators constrain coordinated action even where adequate technical infrastructure exists. Human oversight, explainability of recommendations and operational resilience emerged as non-negotiable requirements across all stakeholder categories. The orchestrator legitimacy will depend as much on these governance conditions as on its analytical capabilities.

The regulatory challenge that traffic orchestration is facing, has to be understood as an enabler by creating predictable governance environments, clarifying responsibilities and facilitating trust among participating actors. The development of orchestration systems is likely to depend on the progressive adaptation of existing regulatory domains, with traffic management, legislation, data governance frameworks, cybersecurity regulation and AI governance mechanisms. The stakeholder evidence suggests that the most viable pathway involves a gradual evolution from advisory and recommendation-based orchestration towards more advanced coordination as trust, institutional maturity and regulatory clarity increase.

There are some governance questions remaining open at this stage and will need to be addressed in following activities. These include the allocation of legal responsibility in AI supported traffic management, the conditions under which public authorities can mandate data sharing from private operators and the regulatory mechanisms required to enable cross-border orchestration between jurisdictions with different legal frameworks. A specific risk identified concerns the potential for alert fatigue and operational overload in traffic management centres, if the orchestrator is not designed with prioritisation from the beginning. The governance framework must therefore be developed alongside the technical architecture, not after it.

D4.1 outputs serve at the intersection of several interconnected WPs within CARMONY, and the governance framework developed here is informed by and feeds into activities across multiple WPs and tasks within the project. The foundational inputs for this deliverable were delivered in WP2 (requirements and KPIs), where the outputs provided the baseline for stakeholder mapping, pilot use case analysis and the governance dimensions addressed in Chapters 5 and 6. The most direct downstream is with WP5 and specifically, for T5.3 where the contribution from EUT is explicitly testing and integrating results from WP4, which means

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that the governance requirements, actor roles and decision-making logics articulated in D4.1 must translate into concrete design choices in the orchestrator. Beyond T5.3, there has to be a role for shaping the governance architecture underlying the CARMONY data space (T5.1): decisions about data access control, stewardship responsibilities and interoperability standards cannot be made in isolation from the governance framework, as the institutional realities at both pilot sites directly constrain which architectures are viable.

For WP6 and WP7, WP6 is where the governance framework will ultimately be put to test, while in WP7, the synergies operate on two levels. First, the CARMONY Outreach Group, established under T7.3, constitutes an important external validation mechanism for the governance requirements developed in WP4. Second, T7.5 led by EUT, will develop governance recommendations, policy tools and standardisation inputs for policymakers and technicians, building directly on the regulatory analysis in Chapter 7 and the development pathways in Chapter 8.

Last but not least, next steps are mainly focussed on the coordination with WP5 and WP6 to agree on how governance models will be operationalised, tested and validated. This means defining the adequate testing conditions and scenario configurations that will allow governance hypotheses to be evaluated within the orchestrator implementation. Moreover, a definition of a governance-informed architecture for the CARMONY data space will be generated, including the allocation of data stewardship responsibilities, access control governance and the adaption of the interoperability architecture to the institutional realities identified at both pilot sites. Within WP6, the key coordination objective is agreeing on the validation criteria and methodological framework, as well as figuring out the limitations of the whole process. All this information will be presented in D4.3.

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10. Abbreviations

Term	Definition
AI	Artificial Intelligence
API(s)	Application Programming Interface(s)
C4L	Cluster for Logistics Luxembourg
CARMONY	Safe, Resilient Transport and Smart Mobility services for passengers and goods
CCAM	Connected, Cooperative and Automated Mobility
DE	Germany
DPO	Data Protection Officer
DS4M	Mediterranean Mobility Data Space
EC	European Commission
EU	European Union
GA	Grant Agreement
GPS	Global Positioning System
IP	Intellectual Property
ITS	Intelligent Transport Systems
KPI(s)	Key Performance Indicator(s)
LEZ(s)	Low Emission Zone(s)
MaaS	Mobility-as-a-Service
MINECO	Ministry of the Economy
MISTRAL	Murcia Smart Mobility Platform
PT	Public Transport
PTA	Public Transport Authority
PU	Public
R	Document, Report
RACI	Responsible, Accountable, Consulted, Informed
SAE	Automatic Exploitation Systems
SEN	Sensitive
TMC	Traffic Management Centre
TMS	Traffic Management System

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UC(s)	Use Case(s)
WP	Work Package

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Annex

Semi-structured interview guidelines

*Introduction of the project and the interview's objectives (optional and to be adapted for each interview): The purpose of this interview relies on Task 4.1, which focuses on **co-creating governance models for the Interlinked Orchestrator in each use case**, based on input from key local stakeholders through these consultative methods and activities.*

- *The Interlinked Orchestrator is designed for traffic orchestration in a **system-of-systems** context, where multiple independent actors and systems (public authorities, infrastructure operators, mobility service providers, fleets, and users) need to coordinate. In practice, "who can give orders" is context-dependent: during emergencies, authorities may have mandates, while in routine operations coordination often relies on guidelines, recommendations, and incentive structures, supported by trust, transparency and mutual benefit.*
- *Having said this, the goal of this interview is not to validate a pre-defined solution, but to **learn from your operational reality** and start shaping a governance approach that is workable, fair and effective for the use case(s) that concern you—clarifying **roles, decision rights, responsibilities, coordination flows and constraints,** identifying what would make collaboration sustainable over time.*
- *General objectives:*
  - *Confirm stakeholder role in the ecosystem and relevant use case(s).*
  - *Map "who decides what" in routine vs disruption/emergency condition.*
  - *Identify needs, constraints, and requirements that must guide governance design in WP4.*
  - *Clarify data and coordination requirements needed for orchestration to work in practice.*
  - *Understand incentives and participation conditions from stakeholders*

Stakeholder presentation and context

Role & scope

- What is your role and your organisation's mission in mobility/transport?
- What geography/network do you cover (city, corridor, cross-border segment)?

Operational responsibilities

- What do you operate/control day-to-day (TMC operations, signals, fleet ops, enforcement, booking systems, traveller info, etc.)?
- What KPIs are you accountable for (safety, emissions/LEZ compliance, travel time reliability, freight efficiency, etc.)?

Systems & interfaces

- Which systems/tools do you use (TMS, signal control, fleet management, apps, VMS, sensors, etc.)?

Use case relevance and questions

Introduction of use case(s) based mainly on D2.2

Use case(s)

- Which use case(s) do you see as relevant to you? (UC1–UC6)

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- What is the main problem you want solved in that UC?

Current process

- How is the situation managed today (routine + disruptions)?
- What fails in the current coordination model?

Actual governance mechanisms

Decision rights — routine

- In normal operations, who sets policies/guidelines? Who can recommend actions, and who chooses whether to comply?
- What is currently **advisory** (recommendations) vs **binding** (enforced)?

Decision rights — disruption/emergency

- In emergency/disruption scenarios, who has legal/operational mandate to issue binding instructions?
- What are the escalation paths (who calls whom; within what time)?

Conflict resolution

- When objectives clash (e.g., congestion vs fairness vs emissions vs freight needs), how is it resolved today?
- What conflicts do you anticipate if an orchestrator proposes actions?

Accountability & liability

- If an orchestrator recommendation leads to a negative outcome (ex. Congestion increase, safety risk, ...) who do you think should be accountable?
- Under what conditions would you accept automated recommendations influencing your operations?
- What level of human validation would you expect before actions are implemented?

Trust, transparency & explainability

- What information would you need to trust the orchestrator recommendations? (rationale, data sources, expected impacts)
- How important is explainability for operational decisions (suggested by orchestrator)
- Would transparency about how decisions are calculated increase your willingness to participate?

Triggers

- What types of events should trigger orchestration action?
- Who should define it?
- Should thresholds be fixed or can it be adjustable depending on context? How is it done?

Multi-actor coordination

- Which actors are essential for coordinates decisions in your use case or in general?
- Which actors are currently missing from coordination?

Actual data exchanges and operational constraints

Data you can provide:

- What data could you share (and at what frequency/latency)?
- What data do you need from others to do your job better?

Constraints and approvals

- What blocks data sharing today (GDPR/privacy, cybersecurity, procurement, IP, organisational policy)?
- Who must approve participation/data sharing (legal, DPO, IT security, leadership)?

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Guidance/messages
CARMONY foresees guidance that must be explicit about **mandatory vs advisory**, rationale, scope, provenance, etc.

- In your view, which messages/actions should be *mandatory* vs *advisory* in your UC?

Understanding incentives and needs

Value proposition

- What benefits would justify your participation? (operational efficiency, compliance support, fewer incidents, better user satisfaction, etc.)
- What would be "non-negotiable" for you?

Risks/concerns

- What worries you (liability, loss of control, reputational risk, fairness concerns, competitive disadvantage, costs)?
- What safeguards would you want?

Willingness to engage

- Would you join co-creation workshops? Provide test data? Validate draft cooperation agreements?

Policy priorities

If the orchestrator must prioritise between objectives (emergency response vs congestion reduction) how should priorities be defined?

- Imagine there is an accident on a highway and emergency services need fast access to the location. At the same time, traffic management policies aim to reduce congestion by limiting certain flows or rerouting vehicles away from that corridor. In such situations, **which objective should take precedence and who should define that priority?**

Additional comments

Interest in follow-up CARMONY
Participation in further activities
Knowledge about other related innovation projects

USE-CASE SPECIFIC QUESTIONS

Murcia

UC1 (LEZ + urban optimisation): LEZ restrictions, parking/transfer points, multimodal alternatives, policy goals.

- Who owns LEZ rules/exemptions and how are changes communicated?
- What data sources are "authoritative" for LEZ status and parking availability?

UC2 (critical road blockage): orchestrator as real-time crisis manager; rerouting; technical assistance access; passenger alternatives.

- Who authorises lane closures / rerouting priorities?
- How is roadside assistance coordinated today?

UC3 (emergency corridor): corridor creation, signal prioritisation, alerts to vehicles and connected VRUs.

- What minimum authority is required to clear corridors and adjust signals?
- How do you want VRU warnings handled (channels, responsibility, timing)?

Luxembourg

UC4 (A3 carpool lane + reservations): dynamic access, fairness, slot reservation; commuting + freight scenarios.

- Who sets the fairness rules for lane access and reservation eligibility?
- How would enforcement/verification work (and by whom)?

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UC5 (A13 cross-border interruption): regulatory differences, border constraints, truck restrictions/rest periods.

- Which cross-border bodies must be involved for joint decisions?
- What constraints must be “hard rules” in routing guidance?

UC6 (A3 speed reduction for jam avoidance): direct comms to connected users + dynamic speed limits via signs.

- When should the system issue binding speed changes vs advisory speed guidance?
- Who authorises variable speed limit strategies operationally?

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