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Document Author(s): Christos Gioldasis – Barbara Monaco – Silvia Zampese – Fabio Tomasi

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List of abbreviations and terms

ADAS	Advanced Driver Assistance Systems
AI	Artificial Intelligence
AIOps	Artificial Intelligence for IT Operations
ALPR	Automatic License Plate Recognition
API	Application Programming Interface
AR	Augmented Reality
ARAS	Advanced Rider Assistance Systems
AV	Autonomous Vehicle
AVAS	Acoustic Vehicle Alerting System
BaaS	Backend-as-a-Service
BLE	Bluetooth Low Energy
BRT	Bus Rapid Transit
CAN	Controller Area Network
CAV	Connected and Automated Vehicle
CCPA	California Consumer Privacy Act
C-ITS	Cooperative Intelligent Transport Systems
CoAP	Constrained Application Protocol
COVID-19	Coronavirus Disease 2019
CV	Connected Vehicle
C-V2X	Cellular Vehicle-to-Everything
DID	Decentralized Identifier
DLT	Distributed Ledger Technology
DePIN	Decentralized Physical Infrastructure Network
DRT	Demand-Responsive Transit
DSRC	Dedicated Short-Range Communications

E57	A file format for storing point clouds (ASTM E2807)
EMV	Europay, Mastercard, and Visa (standard for chip cards)
ERP	Enterprise Resource Planning
ETA	Estimated Time of Arrival
ETL	Extract, Transform, Load
EV	Electric Vehicle
FaaS	Function-as-a-Service
FPS	Frames Per Second
GBFS	General Bikeshare Feed Specification
GDPR	General Data Protection Regulation
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPRS	General Packet Radio Service
GTFS	General Transit Feed Specification
GTFS-Flex	GTFS extension for demand-responsive services
GTFS-RT	GTFS Realtime
GTT	Green Traffic light Time / Traffic Signal Priority
HD Map	High-Definition Map
HMI	Human-Machine Interface
HTTP/HTTPS	Hypertext Transfer Protocol (Secure)
I2V	Infrastructure-to-Vehicle
I3S	Indexed 3D Scene Layer (Esri standard)
ICT	Information and Communication Technology
IMU	Inertial Measurement Unit
INSPIRE	Infrastructure for Spatial Information in Europe

IoT	Internet of Things
IP	Internet Protocol
IR-PCS	Infrared Passenger Counting System
ITS	Intelligent Transport Systems
ITSO	Integrated Transport Smartcard Organisation (UK standard)
JSON	JavaScript Object Notation
KML	Keyhole Markup Language
KPI	Key Performance Indicator
LAS/LAZ	LiDAR Data Exchange Format (compressed)
LEZ	Low Emission Zone
LiDAR	Light Detection and Ranging
LoRaWAN	Long Range Wide Area Network
LPWAN	Low-Power Wide-Area Network
MaaS	Mobility-as-a-Service
MAP	Map Data (in C-ITS context)
MDS	Mobility Data Specification (for micromobility)
MEMS	Micro-Electro-Mechanical Systems
ML	Machine Learning
MLOps	Machine Learning Operations
MMaaS	Mobile Mapping as a Service
MQTT	Message Queuing Telemetry Transport
NB-IoT	Narrowband IoT
NFC	Near Field Communication
NeTEx	Network Timetable Exchange (CEN standard)
NTCIP	National Transportation Communications for ITS Protocol

OBD-II	On-Board Diagnostics II
O-D Matrix	Origin-Destination Matrix
OGC	Open Geospatial Consortium
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
OTA	Open Travel Alliance / Over-The-Air (updates)
PaaS	Platform-as-a-Service
PCI-DSS	Payment Card Industry Data Security Standard
PET	Privacy-Enhancing Technology
PII	Personally Identifiable Information
PLY	Polygon File Format (for 3D models)
PNT	Positioning, Navigation, and Timing
PPP	Precise Point Positioning
QGIS	Quantum GIS (Open Source GIS software)
RBAC	Role-Based Access Control
RFID	Radio-Frequency Identification
RFP	Request for Proposal
REST	Representational State Transfer
ROI	Return on Investment
RSU	Roadside Unit (in C-ITS)
RTK	Real-Time Kinematic
RTPI	Real-Time Passenger Information
SaaS	Software-as-a-Service
SAREF	Smart Appliances Reference Ontology
SDV	Software-Defined Vehicle
SE	Secure Element

SIRI	Service Interface for Real-time Information (CEN standard)
SLA	Service Level Agreement
SOAP	Simple Object Access Protocol
SPAT	Signal Phase and Timing (in C-ITS)
SSD	Solid-State Drive
SSI	Self-Sovereign Identity
SSL/TLS	Secure Sockets Layer / Transport Layer Security
TEE	Trusted Execution Environment
TOD	Transit-Oriented Development
ToF	Time-of-Flight (Camera/Sensor)
UI/UX	User Interface / User Experience
UWB	Ultra-Wideband
V2B	Vehicle-to-Building
V2G	Vehicle-to-Grid
V2I	Vehicle-to-Infrastructure
V2X	Vehicle-to-Everything
VRU	Vulnerable Road User
W3C	World Wide Web Consortium
WCAG	Web Content Accessibility Guidelines
WFS	Web Feature Service
Wi-Fi	Wireless Fidelity
WP	Work Package (in project context)
XAI	Explainable Artificial Intelligence
XML	eXtensible Markup Language
XYZ	A simple text format for 3D point clouds
ZEZ	Zero Emission Zone

Abstract

This document presents a strategic technology roadmap for smart mobility, developed to guide the selection and adaptation of ICT solutions for pilot testing. Within the context of the SMARTMOBAIR project, this document plays a dual operational role. First, it provides technical support for the validation of the technologies implemented in the project's pilot actions, ensuring that the chosen solutions are fit for purpose and aligned with the specific needs of each pilot case. Second, it establishes a structured technical reference to inform future decisions related to the reinforcement, scaling, and further implementation of the pilots. In this way, the roadmap serves both immediate pilot requirements and longer-term technical planning, offering a coherent pathway from initial deployment to sustainable, large-scale operation. Based on an analysis of the core mobility technologies that are employed in the pilot cases, the roadmap charts their evolution from standalone tools toward an integrated, data-driven ecosystem. It identifies key trends, enabling conditions, and deployment barriers across short, medium, and long-term horizons. The analysis culminates in actionable recommendations for deploying interoperable, secure, and equitable mobility solutions that support continuous data acquisition and evidence-based decision-making, providing a clear pathway for pilot implementation and future scalability.

The roadmap is also intended to support Sustainable Urban Mobility Planning processes. In line with the SUMP cycle, the analysis can inform the preparation and analysis phase by clarifying data needs, digital gaps and enabling conditions; support strategy development by linking technology choices to scenarios, objectives and indicators; guide measure planning by identifying scalable and interoperable solutions; and strengthen implementation and monitoring by enabling continuous data collection, evaluation and adaptive management. In this perspective, SMARTMOBAIR technologies should not be considered as stand-alone innovations, but as operational enablers of evidence-based, inclusive and adaptive SUMP implementation.

Executive Summary

This document presents a consolidated technology roadmap, developed to guide partners in adapting the most promising ICT solutions for smart mobility systems within the project's pilot actions. Informed by a detailed analysis of the core mobility technologies that are employed in the pilot cases, the roadmap charts their evolutionary pathways, identifies key enablers and barriers, and provides strategic recommendations for decision-makers in order to maximize the exploitation of these technologies for a wider implementation of the technologies tested in the pilot action. Its overarching goal is to establish a robust methodology for continuous, automated, near real-time data acquisition and analysis, forming the foundation for data-driven urban mobility planning and management.

1. Core Vision: Toward an Integrated Mobility Data Fabric

The analysis underscores a necessary shift from isolated technological deployments toward a unified and intelligent urban mobility ecosystem. The envisioned future is built on a "Mobility Data Fabric," where vehicles, infrastructure, and user journeys are seamlessly interconnected. This integrated approach enables proactive and predictive management of transport networks, seamless multimodal travel through unified user identity and payment, and more equitable and resilient services designed with data-driven insights.

2. Key Evolutionary Trends

Across all technology domains, three consistent and overlapping trajectories emerge. In the short term (0–3 years), the focus is on establishing foundations: deploying core technologies, mandating open data standards, setting clear data governance, and launching integrated pilots. The medium term (3–7 years) will see technologies grow smarter, with embedded AI enabling prediction and optimization, alongside deeper physical-digital fusion that supports dynamic management and full Mobility-as-a-Service integration. In the long term (8+ years), the ecosystem is expected to become cognitive and self-regulating, with infrastructure communicating bidirectionally with connected and automated vehicles, serving as a distributed energy resource, and managing itself through autonomous operations.

3. Critical Enablers and Cross-Cutting Dependencies

Success depends on several foundational enablers. Universal adoption of open standards and APIs, such as GTFS-RT, DATEX II, and OpenAPI, is essential to avoid vendor lock-in and foster innovation. Equally important is establishing unified data governance through clear ownership models, sharing agreements, and Mobility Data Trusts to balance innovation with privacy and public interest. As connectivity and automation increase, implementing robust cyber-physical security and privacy-by-design principles will be vital for system resilience and public trust. Finally, shifting from high upfront capital expenditure to operational "as-a-Service" models, such as Mobility Hub or Data Platform as a Service, can improve scalability and align costs more closely with delivered value.

4. Major Barriers to Large-Scale Deployment

Significant challenges remain. Technologically, fragmentation, legacy system integration, and ensuring reliability in complex environments pose considerable hurdles. Financially, high initial costs, uncertain returns on advanced capabilities, and ongoing expenses for data management create adoption risks. Regulatory and social barriers include the lack of clear frameworks for new services like dynamic pricing or autonomous vehicles, public concerns over privacy and surveillance, and the potential to widen existing digital and mobility divides.

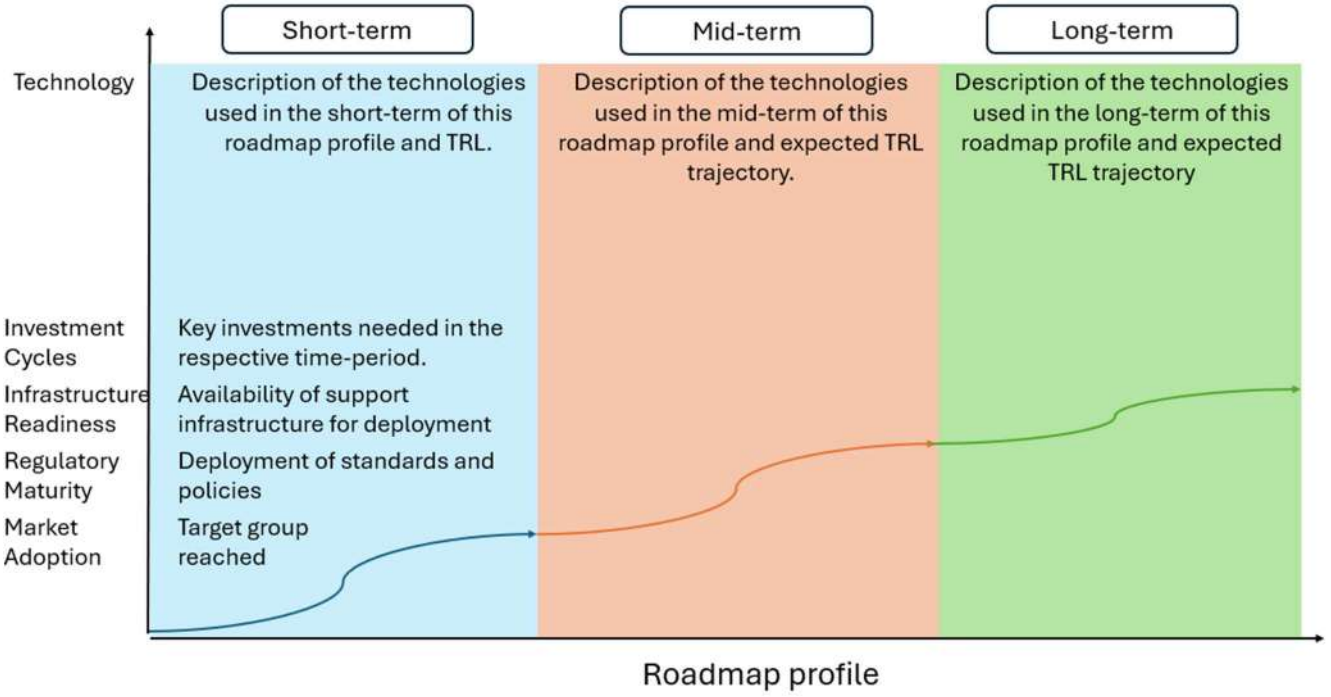
5. Strategic Recommendations for Decision-Makers

To guide the project and pilot actions effectively, several strategic actions are recommended. First, adopt a systems approach by procuring and piloting technologies as interconnected components of a broader Mobility Data Fabric, with open standards mandated in all new procurements. Second, lead with strong data governance, establishing pilot-level agreements and models that can scale, treating mobility data as critical public infrastructure. Third, focus on equity and adoption by designing inclusive pilots that serve non-smartphone users and ensure equitable geographic deployment. Fourth, build in-house capacity through training in data analytics and systems thinking to reduce long-term vendor dependency. Finally, phase implementation for learning, starting with clear interoperability and user-experience goals before advancing to more complex predictive capabilities.

6. Enabling environment

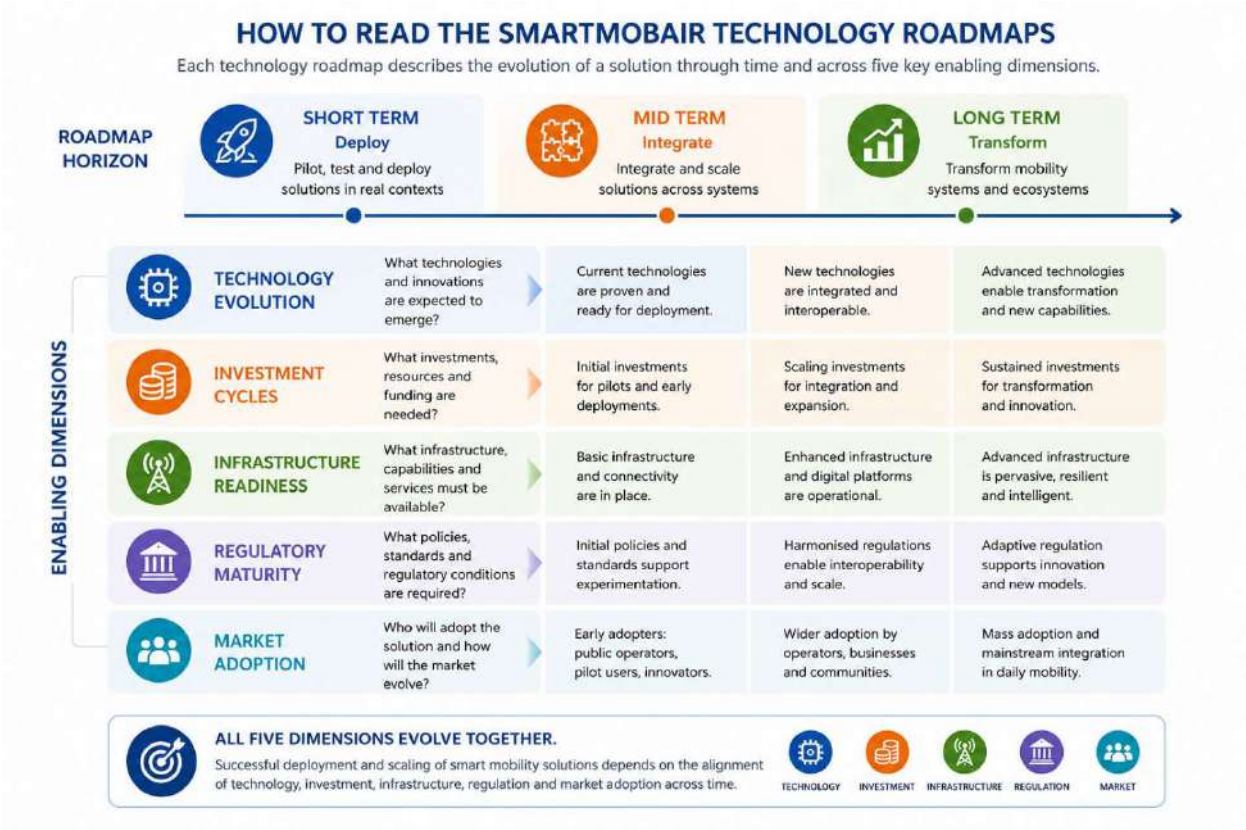
Beyond the specific technology deployments and strategic actions outlined above, the successful translation of pilot results into scalable, sustainable mobility solutions depends critically on the enabling environment, incl. the constellation of investment flows, infrastructure readiness, regulatory frameworks, and market dynamics within which technologies must operate.

The factsheets are accompanied by graphical visuals that represent a simplified version of the roadmap. The forthcoming graphical roadmaps illustrate how the technology emerges in time horizon, in parallel with the enabling dimensions evolve across the short-, medium-, and long-term horizons. The figure following presents the logic of the graphical roadmap.



This roadmap offers a practical yet visionary framework for technological decision-making within the project. By aligning pilot actions with the outlined pathways—emphasizing interoperability, intelligence, and integration—partners can deploy solutions that deliver immediate pilot benefits while consciously constructing the components of a more efficient, sustainable, and equitable future mobility system. The ultimate outcome is not

merely a set of tested technologies, but a proven, repeatable methodology for continuous data-driven innovation in urban mobility.



The figure illustrates the analytical structure used throughout the SMARTMOBAIR technology roadmap. Each roadmap assesses the evolution of a technology across three time horizons—short-term, mid-term, and long-term—while simultaneously considering five enabling dimensions: technology evolution, investment cycles, infrastructure readiness, regulatory maturity, and market adoption. Together, these dimensions provide a comprehensive framework for understanding not only how technologies may evolve over time, but also the conditions required for their successful deployment, scaling, and long-term integration within smart mobility ecosystems.

0. Introduction

Smart and sustainable mobility has emerged as one of the defining challenges for European cities and regions in the twenty-first century. The need to reduce greenhouse gas emissions, improve air quality, enhance accessibility, increase transport efficiency, and strengthen territorial resilience is driving a profound transformation of mobility systems across Europe. At the same time, rapid advances in digital technologies, data analytics, artificial intelligence, cloud computing, sensing infrastructures, and communication networks are creating unprecedented opportunities to redesign the way mobility services are planned, operated, monitored, and governed.

Mobility systems are increasingly recognised as complex socio-technical systems in which infrastructure, vehicles, digital technologies, institutions, regulatory frameworks, service providers, and users interact continuously. Consequently, the transition towards sustainable mobility cannot be understood solely as a technological process. Rather, it represents a broader transformation involving organisational practices, governance arrangements, investment priorities, business models, planning methodologies, and citizen behaviours. The future of mobility will therefore be determined not simply by the deployment of new technologies, but by the ability of cities and regions to integrate technological innovation into coherent and adaptive mobility ecosystems capable of responding to evolving societal, environmental, and economic needs.

This transformation is closely aligned with the ambitions of the **European Green Deal** and the **Sustainable and Smart Mobility Strategy**, which identify digitalisation and innovation as essential enablers of the transition towards climate-neutral transport systems. Transport remains one of the most difficult sectors to decarbonise and continues to generate significant environmental and social externalities, including greenhouse gas emissions, air pollution, congestion, noise, safety risks, and inefficient use of public space. Achieving European climate objectives therefore requires not only cleaner vehicles and alternative fuels, but also more intelligent and integrated mobility systems capable of optimising the movement of people and goods through the effective use of data and digital technologies.

Within this broader European context, the **Adriatic-Ionian region** presents both significant challenges and unique opportunities. The region is characterised by a highly heterogeneous territorial structure that includes metropolitan areas, medium-sized cities, coastal settlements, tourist destinations, rural territories, islands, and cross-border functional areas. These territories exhibit different levels of economic development, institutional capacity, technological maturity, infrastructure provision, and investment capability. Nevertheless, many of them share common mobility challenges, including traffic congestion, seasonal mobility peaks, fragmented transport services, limited multimodal integration, insufficient availability of mobility data, and difficulties in deploying innovative solutions at scale.

Unlike more homogeneous territorial systems, the Adriatic-Ionian region requires mobility solutions capable of operating across diverse governance contexts and varying levels of technological readiness. This diversity makes the region particularly suitable for testing innovative approaches while simultaneously increasing the importance of transferability, interoperability, and institutional learning. In such a context, transnational cooperation becomes more than a mechanism for exchanging experiences; it becomes an essential condition for accelerating innovation, reducing implementation risks, strengthening institutional capacities, and supporting the diffusion of successful solutions across territories facing similar challenges.

The **SMARTMOBAIR project** was conceived precisely to address these challenges. Through a transnational cooperation framework involving multiple countries and territories, the project aims to support the deployment, validation, monitoring, and future uptake of **Intelligent Transport System (ITS)** solutions capable of improving urban and regional mobility across the Adriatic-Ionian area. The project recognises that while innovative technologies are becoming increasingly available, significant barriers continue to limit their widespread adoption. These barriers include limited awareness of technological opportunities, insufficient understanding of implementation requirements, fragmented data ecosystems, regulatory constraints, institutional inertia, and uncertainty regarding future technological developments.

The **six pilot actions** implemented within SMARTMOBAIR constitute an important opportunity to test and validate innovative mobility solutions under different territorial conditions. However, the strategic value of the project extends beyond the pilots themselves. Pilot actions generate evidence, experience, knowledge, and lessons learned, but their long-term impact depends on the ability to translate these results into strategic guidance capable of supporting future investments, planning processes, and policy decisions. This requires moving beyond the evaluation of individual technologies and developing a broader understanding of how mobility systems may evolve over time.

It is within this perspective that **technology roadmapping** assumes a central role. Technology roadmapping is widely recognised as a strategic foresight instrument capable of supporting decision-making under conditions of uncertainty. Public authorities, transport operators, infrastructure managers, and mobility planners are increasingly required to make decisions whose consequences may extend over decades, while the technological landscape continues to evolve at an accelerating pace. Investments in digital infrastructures, communication networks, data platforms, sensing technologies, and intelligent mobility services must therefore consider not only current technological maturity but also future development trajectories, enabling conditions, and potential risks.

Technology roadmaps help address this challenge by providing structured insights into the evolution of technological systems. Rather than attempting to predict the future, they explore plausible development pathways, identify key enabling technologies, highlight critical dependencies, assess barriers and opportunities, and support the alignment of short-term actions with long-term strategic objectives. In doing so, roadmapping contributes to reducing uncertainty and strengthening the capacity of organisations to make informed decisions in rapidly evolving environments.

Within SMARTMOBAIR, the roadmap is not intended as a catalogue of technologies nor as a simple inventory of available solutions. Instead, it serves as a strategic framework that supports both the implementation of the project pilots and the future scaling of their results. The roadmap provides a structured understanding of how the technologies adopted within the pilot actions may evolve over time, how they interact with one another, and how they can contribute to broader mobility transformations. Its function is therefore twofold: supporting immediate implementation needs while simultaneously creating a knowledge base capable of informing future mobility strategies and investment decisions across the Adriatic-Ionian region.

The roadmap builds upon the analytical activities previously conducted within SMARTMOBAIR, including the assessment of regional mobility conditions, the identification of drivers and barriers affecting smart mobility deployment, and the development of factsheets describing adoptable mobility technologies. These activities established a detailed understanding of the current technological landscape and the specific requirements emerging from the pilot territories. The present deliverable advances this work by transforming static

technology assessments into dynamic and forward-looking perspectives focused on technological evolution, system integration, implementation pathways, and enabling conditions.

To complement the technical analysis, this deliverable includes a Policy Brief as Annex 1. While the Technology Roadmap provides a technical and forward-looking reference for project partners, mobility operators and practitioners, the Policy Brief translates its main findings into concise, actionable messages for policymakers and other non-technical stakeholders.

Beyond the analysis of individual technologies, the roadmap adopts a portfolio perspective that considers the collective contribution of multiple technological domains to the future development of mobility systems. The technologies examined in this report address different functions, ranging from data collection and infrastructure monitoring to service integration, user interaction, mobility management, and system governance. While each technology follows its own development trajectory, their combined evolution reveals broader patterns that extend beyond individual applications. Considering these technologies as part of an integrated portfolio allows decision-makers to better understand complementarities, interdependencies, and opportunities for system-wide transformation, moving from isolated technological deployments towards coordinated mobility ecosystems.

A fundamental premise underlying this roadmap is that the future of mobility will be shaped less by individual technologies than by their capacity to interact within integrated ecosystems. Historically, mobility innovations have often been deployed as isolated solutions addressing specific operational problems. Vehicle tracking systems improved fleet monitoring. Passenger counting systems supported demand assessment. Geographic information systems enhanced planning activities. Ticketing systems simplified payment processes. Today, however, the value generated by these technologies increasingly depends on their ability to exchange information, operate through common standards, and contribute to shared digital environments.

This evolution is progressively leading towards new mobility paradigms characterised by interoperability, continuous data exchange, integrated digital platforms, predictive analytics, and adaptive management capabilities. Concepts such as **Mobility-as-a-Service**, digital twins, connected infrastructure, cooperative intelligent transport systems, and data-driven mobility governance are becoming increasingly central to future mobility visions. In this emerging environment, mobility data itself is evolving into a strategic infrastructure asset. The ability to collect, manage, integrate, analyse, and exploit data is becoming as important as the physical infrastructure through which people and goods move.

Consequently, the technologies analysed within this roadmap should not be interpreted as independent innovation pathways. GPS tracking systems, geospatial platforms, cloud infrastructures, IoT architectures, passenger counting systems, geofencing solutions, mobile applications, API management platforms, and other technologies examined in this report collectively contribute to the development of integrated mobility ecosystems. Their combined evolution enables the transition from fragmented and reactive mobility systems towards increasingly connected, intelligent, predictive, and user-centred mobility environments.

While each roadmap has been developed independently to reflect the specific characteristics, maturity levels, and implementation contexts of the technology considered, several common trajectories emerge across the portfolio. Recurring themes such as interoperability, integration, data sharing, predictive analytics, digitalisation of infrastructure, and increasing automation appear consistently across multiple technological domains. These shared trajectories reveal broader transformations affecting mobility systems as a whole and provide the foundation for a cross-cutting interpretation of the roadmap results. Understanding these common patterns is

essential for moving from technology-specific analyses towards a systemic perspective on the future evolution of mobility ecosystems.

At the same time, technological evolution alone cannot guarantee successful deployment. The adoption and scaling of smart mobility solutions depend on a broader enabling environment that includes investment capacity, infrastructure readiness, regulatory maturity, institutional capabilities, market dynamics, stakeholder engagement, and public acceptance. Understanding these dimensions is essential not only for identifying what technologies may become available in the future, but also for understanding under which conditions they can generate tangible value for territories and communities.

Against this background, the SMARTMOBAIR Technology Roadmap seeks to provide a shared strategic reference for project partners, public authorities, mobility operators, planners, policy makers, and other stakeholders involved in the development of future mobility systems. By combining technology assessment, foresight, implementation-oriented analysis, and strategic reflection, the roadmap offers a structured perspective on how mobility technologies may evolve and how such evolution can support more integrated, resilient, sustainable, and data-driven mobility systems.

Ultimately, the challenge addressed by this roadmap is not the deployment of smart mobility technologies as isolated innovations, but the capacity to orchestrate them into coherent mobility ecosystems capable of continuously learning, adapting, and responding to changing societal, environmental, and economic conditions. The technologies analysed in the following chapters should therefore be regarded not merely as individual solutions, but as interconnected components of a broader transition in which data, infrastructure, services, and governance progressively converge to create more sustainable, resilient, intelligent, and adaptive mobility systems across the Adriatic-Ionian region. Understanding this transition is the fundamental purpose of the roadmap and the basis upon which future mobility strategies, investments, and policy decisions can be developed.

1. Methodology

This deliverable employs a structured methodology designed to transform the technological profiles from D.1.4.2 ("Factsheets on Adoptable Smart Mobility Technologies") into actionable, forward-looking strategic roadmaps. The methodology also draws on experience gained in previous projects, including the report on future trends in connected and automated vehicle infrastructures developed within the Interreg Med Urban Transport framework. The methodology aims to be systematic, transparent, and tailored to ensure the outputs are both pragmatic and visionary for long-term strategic planning. The development process for each technology roadmap comprised four core phases.

1.1 Foundational Analysis and Scoping

This initial phase established the basis for each roadmap, grounded in the project's prior work and contextual realities:

- Input from D.1.4.2: The detailed factsheets from Deliverable D.1.4.2 provided the essential "current state" description, core application, and baseline technical characteristics for each technology.
- Contextual Grounding: Findings from earlier SMARTMOBAIR deliverables, specifically the review of available data and the analysis of regional drivers and barriers (D.1.1.2, D.1.1.3), ensured that each roadmap was scoped with an understanding of the Adriatic-Ionian region's unique mobility challenges, institutional capacities, and infrastructural preconditions.

In addition to the project deliverables and stakeholder inputs, the scoping phase considered the strategic relevance of the identified technologies in relation to the broader mobility transformation challenges affecting the Adriatic-Ionian region. Particular attention was given to technologies capable of supporting data-driven decision-making, multimodal integration, operational efficiency, accessibility, environmental sustainability, and future interoperability requirements. This ensured that the roadmap remained closely aligned with both the implementation needs of the SMARTMOBAIR pilot actions and the longer-term mobility objectives emerging across the region.

1.2 Multi-Layer Roadmapping and Factsheet Development

The core of the methodology involved populating a standardized roadmap factsheet template for each technology. This template structured the analysis across three interconnected analytical layers to ensure a comprehensive assessment:

- Temporal Layer (Evolution Pathway & Sequencing): This layer defines the strategic trajectory of the technology. For each of the three time horizons, Short-Term (0-3 years), Medium-Term (3-7 years), and Long-Term (8+ years), a narrative trajectory was developed. This describes the expected functional evolution, key use cases, and the sequence of deployment milestones, moving from pilot integration to full ecosystem symbiosis.
- Technology Layer (Key Enablers & Dependencies): This layer identifies the technical foundations required for the evolution outlined in the Temporal Layer. It catalogues the Key Enabling Technologies and, in a dedicated table, outlines the specific technical dependencies and corresponding R&D priorities for each time horizon. This pinpoints critical innovations and standards needed for progression.

- Contextual Layer (Conditions & Barriers): This layer examines the external ecosystem required for successful deployment. A dedicated table analyses the parallel evolution of Governance & Regulatory Needs and Market & Industry Evolution across the three time horizons. A dedicated subsection then synthesizes the overarching Technological, Financial, and Regulatory/Social barriers to large-scale deployment.

The three analytical layers were not considered independently but were interpreted as mutually reinforcing dimensions of technological evolution. The expected trajectory of each technology was assessed in relation to the enabling technologies required for its development and the contextual conditions necessary for its successful deployment. This integrated perspective allowed the roadmap to capture not only technological change, but also the broader ecosystem transformations accompanying such change. By combining technological, organisational, market, and regulatory considerations within a single analytical framework, the roadmap provides a more comprehensive understanding of how smart mobility solutions may evolve and generate value over time.

1.3 Synthesis, Validation and Guidance Formulation

The third phase synthesized the insights from the multi-layer analysis into clear guidance for project partners and pilot decision-makers:

- Implications for Decision-Makers: For each time horizon, a table pairs concrete Recommended Actions with their Expected Impacts, translating strategic vision into practical steps for authorities and operators.
- Risk Assessment: A dedicated subsection identifies the key implementation risks (e.g., vendor lock-in, equity gaps, privacy erosion) and proposes targeted mitigation strategies, promoting resilient and responsible deployment.
- Internal Coherence Review: Each completed roadmap was reviewed to ensure internal consistency between the projected evolution, the stated dependencies, and the identified actions, guaranteeing a logical and credible pathway.

Beyond the assessment of individual technologies, this phase aimed to translate technological insights into practical guidance capable of supporting planning, procurement, implementation, and governance decisions. Particular attention was devoted to identifying actions that could facilitate future scalability, interoperability, and long-term sustainability beyond the duration of the pilot actions themselves.

1.4 Assessment of the Enabling Environment

Technological evolution alone does not determine deployment success. The diffusion and long-term sustainability of smart mobility solutions depend equally on the surrounding enabling environment. For this reason, the roadmap extends beyond technology assessment and examines the institutional, infrastructural, regulatory, financial, and market conditions required to support large-scale implementation.

The final phase incorporated a structured assessment of the enabling environment for technology deployment. This dimension was organized across four interrelated categories, each examined across the three time horizons:

- Investment cycles: Analysis of the primary focus, type, and intensity of investments required to support technology adoption and scaling at each stage.

- Infrastructure readiness: Evaluation of the primary enablers, readiness levels, and key build-out needs necessary to create a supportive physical and digital infrastructure base.
- Regulatory maturity: Assessment of the primary focus areas, current status, and key milestones in the regulatory landscape affecting deployment and interoperability.
- Market absorption capacity: Examination of the adoption phase, value migration patterns, and key players shaping market dynamics and user uptake.

These four dimensions were synthesized to provide a holistic view of the conditions that either facilitate or constrain the deployment of smart mobility solutions across the pilot lifecycle.

Finally, the methodology incorporated a review of good practices drawn from relevant smart mobility initiatives, standards, and prior pilot implementations. These practices served as benchmarks for identifying proven approaches in areas such as interoperability, data governance, security, user engagement, and equitable service delivery.

The outcomes of the development of the roadmap are presented in a factsheet format, that is presented in Table 1.

This four-phase methodology ensures that the resulting roadmaps are grounded in current technology assessments, attuned to regional contexts, and structured to provide direct, actionable value for the SMARTMOBAIR pilot actions and the broader policy and planning community in the Adriatic-Ionian region.

1.5 Cross-Technology Analytical Framework

The technology roadmaps developed within SMARTMOBAIR primarily focus on the evolution of individual technologies and their specific implementation pathways. However, smart mobility systems are increasingly characterised by the interaction and convergence of multiple technologies operating within shared digital, organisational, and regulatory environments. As a result, understanding future mobility transformations requires not only the analysis of individual technologies, but also the examination of the relationships, complementarities, and interdependencies emerging across the broader technology portfolio.

To support this broader perspective, an additional cross-technology analytical framework was applied to the roadmap results. The objective of this framework was to identify common patterns of evolution, recurring enabling factors, and shared strategic implications across the different technology domains considered within the roadmap. Rather than replacing the individual technology analyses, this framework complements them by providing a higher-level interpretation capable of revealing systemic transformations that may not be immediately visible when technologies are assessed separately.

The framework was structured around four analytical levels.

At the first level, individual technologies were examined according to their specific functions, maturity levels, and anticipated development trajectories. This level corresponds to the detailed roadmap factsheets presented in the following chapter.

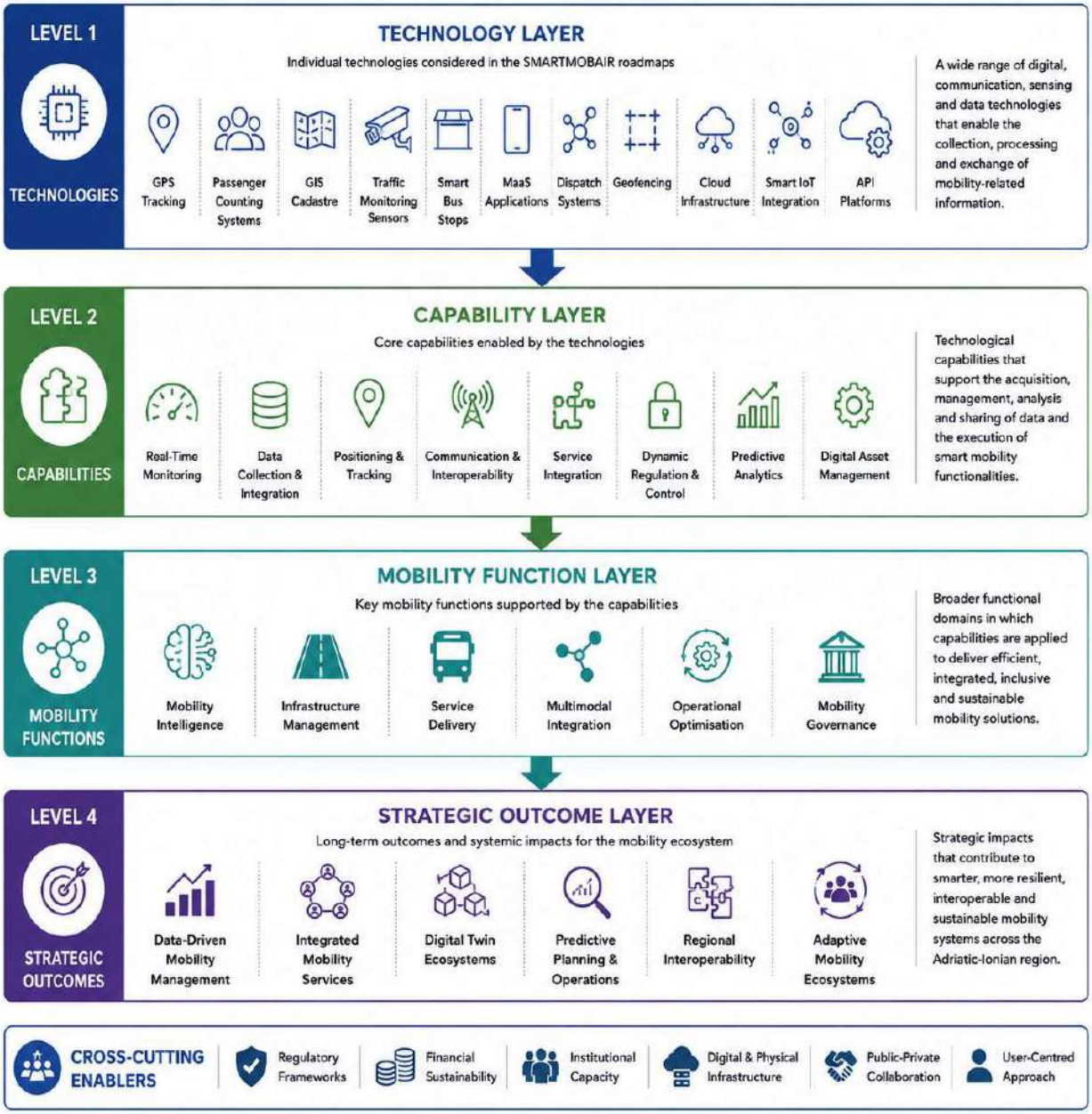
At the second level, technologies were grouped according to the capabilities they enable. Examples include real-time monitoring, data collection, communication and interoperability, service integration, predictive analytics, digital infrastructure management, and dynamic access regulation. This perspective makes it possible to identify common functionalities supported by different technological solutions.

At the third level, these capabilities were analysed in relation to broader mobility functions, such as mobility intelligence, infrastructure management, service delivery, multimodal integration, operational optimisation, and mobility governance. This step supports a transition from technology-centred analysis towards a system-oriented understanding of mobility transformation.

Finally, at the fourth level, the resulting mobility functions were interpreted in terms of strategic outcomes relevant for public authorities and mobility stakeholders. These outcomes include the development of data-driven mobility management systems, integrated mobility services, predictive planning capabilities, enhanced interoperability, and the emergence of more resilient and adaptive mobility ecosystems.

This analytical process made it possible to identify a number of recurring trajectories that cut across multiple technology domains. Themes such as interoperability, integration of data sources, increasing reliance on digital platforms, predictive decision-making, automation, and ecosystem convergence emerged consistently throughout the roadmap portfolio. These common patterns provide the basis for the cross-cutting analysis presented in the subsequent chapters of this report and contribute to a more comprehensive understanding of the future evolution of smart mobility systems in the Adriatic-Ionian region.

Next figure presents the conceptual structure of the cross-technology analytical framework applied in the roadmap development process.



SMARTMOBAIR Cross-Technology Analytical Framework. *The framework illustrates how individual technologies contribute to specific capabilities, which are subsequently aggregated into broader mobility functions and ultimately generate strategic outcomes for smart mobility systems. This analytical structure supports the identification of common trajectories and systemic transformations emerging across the technology portfolio.*

The analytical framework described above informed the development of a standardised roadmap factsheet structure applied consistently across all technologies considered within SMARTMOBAIR. The factsheet was designed to integrate the different analytical dimensions explored throughout the methodology, combining technology evolution, enabling factors, implementation conditions, risks, governance aspects, and strategic implications within a single assessment framework. This approach ensures comparability across technologies while maintaining sufficient flexibility to capture the specific characteristics and development trajectories of each solution. The structure of the roadmap factsheet adopted throughout this report is presented in Table 1.

The roadmap factsheet should be interpreted as an integrated assessment tool rather than a purely descriptive technology profile. Each section contributes to understanding a different dimension of technological evolution, ranging from future development trajectories and enabling technologies to governance requirements, market dynamics, implementation barriers, and decision-making implications. By bringing these dimensions together within a single framework, the factsheet supports a holistic understanding of how individual technologies may contribute to broader mobility system transformations over time.

Table 1 illustrates the common roadmap factsheet structure adopted throughout the report.

D.1.5.1 - SMARTMOBAIR technology roadmap

Table 1 Technology roadmap factsheet

Technology Roadmap Profile		
Technology name		
Description (current)		
Roadmap Horizon		
Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)		
Strategic Objective		
Temporal Layer: Evolution Pathway & Sequencing		
Short-Term Trajectory:		
Medium-Term Trajectory:		
Long-Term Trajectory:		
Technology Layer: Key Enabling Technologies		
Key Enabling Technologies		
	Dependencies	R&D Priorities
Short-term		
Medium-term		
Long-term		
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution
Short-term		
Medium-term		
Long-term		
Barriers		
Implications for Decision-Makers		

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	Recommended Actions	Expected Impacts
Short-term		
Medium-term		
Long-term		
Risk Assessment		
Enabling Environment for Technology Deployment		
Investment cycles		
	Primary Focus	Investment Type	Intensity
Short-term			
Medium-term			
Long-term			
Infrastructure readiness		
	Primary Enabler	Readiness Level	Key Build-Out
Short-term			
Medium-term			
Long-term			
Regulatory Maturity		
	Primary Focus	Status	Key Milestone
Short-term			
Medium-term			
Long-term			
Market absorption capacity		
	Adoption Phase	Value Migration	Key Players
Short-term			
Medium-term			
Long-term			
Good practices		

D.1.5.1 - SMARTMOBAIR technology roadmap

To develop the pathways an extensive literature review took place. The following table presents the **EU-funded projects concerning mobility** that were examined per pathway.

Project	Link	Technology Pathway(s)	Description
SPINE	cordis.europa.eu/project/id/101096664	GPS Tracking / Telematics; Smart Bus Stops / Real-Time Info; Trip Booking & Payment Apps; Dispatch & Planning Software; Driver Communication / OBU; Passenger Counting; Micromobility Apps & Vehicles; Traffic Volume Measurement; GIS / Digital Twin Cadastre; Smart IoT Integration	Smart Public transport Initiatives for climate-Neutral cities in Europe (SPINE) integrates public transport with shared mobility, micromobility, and active modes using data-driven tools. It develops travel time analysis and green wave visualization for traffic signal coordination across 11 cities with 39 partners. The project runs from 2023 to 2026 with €17M funding.
MOLIERE	cordis.europa.eu/project/id/101004275	GPS Tracking / Telematics; Trip Booking & Payment Apps; API Management / Data Exchange; NFC / Contactless	MObiLIty sERvices Enhanced by GALILEO & Blockchain (MOLIERE) integrates GALILEO geopositioning with blockchain technology for a secure, decentralized Mobility Data Marketplace. It covers MaaS platforms, data aggregation, privacy-preserving analytics, and payment transactions.
BIO-INTEL-MOB	cordis.europa.eu/project/id/101239638	GPS Tracking / Telematics; Dispatch & Planning Software; Micromobility Apps & Vehicles; Geofencing & Access Control; Smart IoT Integration	BIO-INTEL-MOB is an AI-driven, citizen-centric framework for climate-neutral peri-urban mobility integrating IoT sensors, AI cameras, satellite imagery, and predictive models. It optimizes traffic flow, emissions reduction, and multimodal transfers, running from 2026 to 2029.
CIVITAS Initiative	civitas.eu	Smart Bus Stops / Real-Time Info; Passenger Counting; Geofencing & Access Control	CIVITAS is a long-standing EU initiative supporting clean urban mobility through demonstration projects, research, and knowledge sharing. It maintains an extensive knowledge bank of case studies, policy briefs, and best practices on dynamic passenger information systems, accessibility, and service reliability.
ELIPTIC	cordis.europa.eu/project/id/636012	Smart Bus Stops / Real-Time Info	Electrification of Public Transport in Cities (ELIPTIC) explored smart infrastructure integration for electric buses and trams, including intelligent monitoring and alert systems for transport assets. It demonstrated how real-time feedback improves operational safety and energy efficiency.
GAIA-X	gaia-x.eu	Trip Booking & Payment Apps; API Management / Data Exchange; Cloud Infrastructure	GAIA-X develops a federated, sovereign cloud ecosystem for secure data sharing across Europe, with emphasis on interoperability, transparency, and data governance. It provides

			foundational infrastructure for mobility data platforms requiring trust, compliance, and cross-border data exchange.
PANOPTIS	cordis.europa.eu/project/id/769129	Driver Communication / OBU; Traffic Volume Measurement; GIS / Digital Twin Cadastre; Mobile Data Collection (LiDAR)	PANOPTIS increases resilience of transport infrastructure under extreme weather, landslides, and earthquakes. It combines climate scenarios, structural simulation tools, and multi-sensor networks (drone, satellite, ground-based) to provide early warning and risk assessment.
FF2020	cordis.europa.eu/project/id/101006828	Driver Communication / OBU; GIS / Digital Twin Cadastre; Mobile Data Collection (LiDAR)	Flying Forward 2020 develops Urban Air Mobility (UAM) infrastructure integrated within the geospatial digital infrastructure of cities. It includes governance frameworks, regulatory tools, and an Identity of Things scheme for managing drones and air taxis in urban environments.
DUET	cordis.europa.eu/project/id/870697	GIS / Digital Twin Cadastre	Digital Urban European Twins (DUET) developed digital twins integrating GIS, transport, and real-time data to support urban mobility planning and policy testing. It enables simulation of transport scenarios and supports evidence-based decision-making through interactive dashboards.
SynchroniCity	cordis.europa.eu/project/id/732240	API Management / Data Exchange; Cloud Infrastructure; Smart IoT Integration	SynchroniCity established common data models and APIs across multiple European cities to enable cross-platform service interoperability. It validated the importance of standardized, scalable API frameworks for urban data marketplaces and replicable smart city solutions.
FIWARE	www.fiware.org	API Management / Data Exchange	FIWARE provides an open-source framework of standardized APIs (NGSI-LD) enabling real-time, interoperable data exchange across mobility systems and smart city platforms. It has been widely adopted in European deployments for IoT, transport, and urban data management.
CIPURSE	osptalliance.org/cipurse	NFC / Contactless	CIPURSE is an open security standard for NFC-based transit ticketing enabling interoperability across operators and vendors. It is widely referenced in EU research and deployments for secure, scalable fare collection systems

1.6 Alignment with the Sustainable Urban Mobility Planning cycle

The SMARTMOBAIR technology roadmap has been developed as a complementary technical and strategic tool for Sustainable Urban Mobility Planning that provides evidence, technological insight and implementation-oriented guidance that can support several phases of the SUMP cycle.

In the Preparation and Analysis phase, the roadmap helps public authorities and mobility stakeholders identify relevant data sources, technological gaps, interoperability needs and enabling conditions required to understand the current mobility situation. In the Strategy Development phase, it supports the assessment of future scenarios by clarifying how emerging ICT solutions may affect mobility patterns, service integration, accessibility, environmental performance and governance requirements. In the Measure Planning phase, the roadmap can guide the selection of coherent technology-enabled measure packages, including procurement requirements, open standards, data governance provisions, financing needs and implementation responsibilities. Finally, in the Implementation and Monitoring phase, the roadmap supports the continuous monitoring, evaluation and adaptation of mobility measures, shared indicators and feedback loops between pilot implementation, policy learning and SUMP revision.

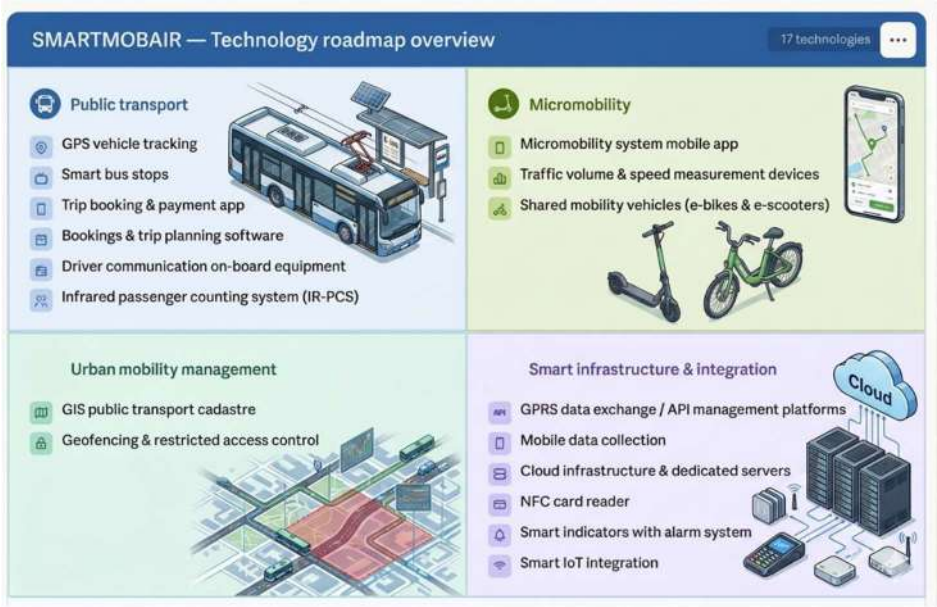
The table below summarises the main links between the SMARTMOBAIR roadmap and the SUMP planning cycle.

SUMP phase	Relevant SUMP function	Contribution of the SMARTMOBAIR roadmap
Phase 1 – Preparation and Analysis	Understanding resources, planning context, problems and opportunities	Identification of technological gaps, data needs, interoperability requirements and enabling conditions for smart mobility deployment
Phase 2 – Strategy Development	Building scenarios, vision, objectives, indicators and targets	Assessment of technology trends and their potential contribution to future mobility scenarios, strategic objectives and measurable indicators
Phase 3 – Measure Planning	Selecting measures, defining responsibilities, financing and adoption pathways	Support to the selection of scalable ICT-enabled measures, procurement specifications, investment priorities and governance arrangements
Phase 4 – Implementation and Monitoring	Managing implementation, monitoring impacts, adapting and learning	Support to continuous data collection, pilot evaluation, adaptive management, upscaling and SUMP revision or update

2. Technology roadmap

This section presents the factsheets including the technology roadmaps according to the methodology outlined in Section 1. In line with D.1.4.2 they grouped into **four categories**:

- Public transport
- micromobility
- urban mobility management
- smart mobility infrastructure & integration (horizontal domain).



2.1. Public transport

This section presents the technology roadmaps regarding public transport.

2.1.1. GPS vehicle tracking

D.1.5.1 - SMARTMOBAIR technology roadmap

Technology Roadmap Profile
Technology name
GPS Tracking
Description (current)
GPS (Global Positioning System) vehicle tracking is a technology that uses satellite-based navigation to determine and monitor the real-time location of vehicles. By installing GPS tracking devices in vehicles, fleet operators, businesses, and individuals can collect data on vehicle position, speed, route history, and idle time. These devices communicate location data to a central system via cellular or satellite networks, allowing users to view and analyze vehicle activity through a web or mobile application. GPS tracking enhances fleet management by improving route efficiency, monitoring driver behavior, reducing fuel consumption, and increasing vehicle security. It also supports geofencing capabilities, alerting users when a vehicle enters or exits predefined areas. In many cases, this technology integrates with other systems such as dispatch software, telematics platforms, and maintenance tracking tools.
Roadmap Horizon
Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)
Strategic Objective
To evolve GPS tracking from a discrete fleet management tool into the foundational, ubiquitous data layer for a fully integrated, predictive, and automated mobility ecosystem. It aims to optimize the movement of all vehicles (passenger and freight), enhance urban traffic flow efficiency, and provide the critical real-time positional data backbone for Cooperative Intelligent Transport Systems (C-ITS) and Mobility-as-a-Service (MaaS).
Temporal Layer: Evolution Pathway & Sequencing
Short-Term Trajectory: Enhanced Telematics & Basic C-ITS Integration
Deployment of low-cost, multi-constellation (GPS, Galileo, GLONASS) GNSS devices with integrated inertial sensors for improved urban canyon accuracy. Standardized integration with basic on-board diagnostics (OBD-II) and CAN-bus data for comprehensive vehicle health and performance monitoring. Initial integration with city traffic management centers via standardized data feeds (e.g., using DATEX II, SPaT) for probe vehicle data, enabling dynamic routing and congestion monitoring. Widespread use of AI-driven analytics for predictive maintenance and driver coaching.
Medium-Term Trajectory: High-Accuracy Positioning & Predictive Network Analytics
Ubiquitous adoption of centimeter-level accuracy using Real-Time Kinematic (RTK) corrections delivered via 5G/cellular networks or Low Earth Orbit (LEO) satellites. GPS tracking data fully fused with other urban data streams (traffic signals, parking sensors, weather, event data) in city Digital Twins to enable predictive traffic management and anomaly detection. Vulnerable Road User (VRU) Protection: Integration of high-accuracy positioning with C-V2X to broadcast precise vehicle location to VRU smartphones and infrastructure, generating safety alerts. Autonomous Ready: High-integrity positioning becomes a critical input for Level 2+/3 automated vehicles, requiring guaranteed performance levels.
Long-Term Trajectory: Ubiquitous, Seamless & Cyber-Resilient Positioning Fabric

D.1.5.1 - SMARTMOBAIR technology roadmap

GPS/GNSS forms one component of a seamless resilient positioning system fused with 5G/6G cellular positioning, LiDAR/vision-based localization, and infrastructure-based beacons for 100% coverage, including indoors and underground. Tracking devices become passive, low-power "tags" integrated into all vehicles and key logistics assets, forming an Internet of Moving Things. Predictive & Prescriptive System: AI uses the historical and real-time positional fabric to not just report but prescribe system-optimal routing for all road users, managing corridor capacity dynamically. Establishment of cyber-security and spoofing/jamming detection as a standard, regulated feature of all commercial tracking systems.		
Technology Layer: Key Enabling Technologies		
Key Enabling Technologies		
Multi-Constellation GNSS Receivers, Inertial Measurement Units (IMUs), Cellular & Satellite IoT Communication Modules (NB-IoT, LTE-M, SatIoT), High-Accuracy Correction Services (RTK, PPP), AI/ML for Predictive Analytics & Anomaly Detection, C-V2X & DSRC Communication Modules, Cyber-Physical Security Modules for Anti-Spoofing		
	Dependencies	R&D Priorities
Short-term	Ubiquitous and affordable cellular IoT coverage. Development of open APIs for vehicle data (e.g., extended SANDAG MDM).	Standardized "Probe Data" specifications for cities. Low-cost, energy-efficient IMU-GNSS fusion algorithms. Privacy-preserving data aggregation techniques.
Medium-term	Deployment of 5G NR with precise timing & positioning features. Widespread adoption of city Digital Twin platforms.	AI models for network-wide traffic prediction using fused data. R&D into low-cost, mass-producible RTK/PPP solutions. Standardization of safety-critical positioning messages for V2X.
Long-term	Maturation of 6G standards for integrated sensing and communication. Legal frameworks for liability of AI-prescribed routing.	Quantum-resistant encryption for positioning signals. R&D into fully alternative positioning systems (PNT) for GNSS-denied environments. Development of systemic mobility optimization algorithms.
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution
Short-term	Mandate for all publicly-served fleets (buses, municipal vehicles) to share anonymized probe data with traffic authorities. Clear GDPR/guidelines for processing vehicle location data.	Consolidation of hardware vendors; growth of vertical-specific SaaS platforms (e.g., for cold chain, last-mile). Telecom operators enter the market with integrated "IoT connectivity + platform" bundles.
Medium-term	Type-Approval for C-ITS: Regulations requiring high-integrity positioning for new vehicle safety systems. Standards for data exchange between private fleet platforms and public traffic management.	Emergence of "Positioning-as-a-Service" companies offering guaranteed accuracy levels via hybrid networks. Traditional automotive suppliers fully integrate advanced telematics into vehicle architecture. Data marketplaces for anonymized, aggregated mobility patterns emerge.

Long-term	Regulation of PNT Resilience: Critical transport services may be required to have certified backup positioning systems. National/EU-level cybersecurity certification for tracking devices.	The tracking "device" market diminishes as functionality is embedded into vehicle electronics. Value shifts to platforms offering AI-driven insights, automation, and system integration. Major cloud/AI firms dominate the analytics layer.
Barriers		
Technological: GNSS signal vulnerability in urban canyons, tunnels, and to spoofing/jamming. Power consumption and device cost for high-accuracy solutions. Financial: High initial investment for fleet-wide hardware rollout and platform integration. Uncertain ROI for advanced predictive features. Regulatory/Social: Data privacy concerns and driver/union resistance to pervasive monitoring. Lack of universal data standards creating integration silos. Digital divide in access to advanced fleet optimization tools for SMEs.		
Implications for Decision-Makers		
	Recommended Actions	**Expected Impacts**
Short-term	1. Specify open probe data standards (e.g., based on MDS) in all public procurement for fleets. 2. Launch a pilot integrating real-time bus/taxi GPS data into the city's traffic signal control system.	Improved real-time traffic monitoring and incident detection. Measurable reduction in fuel consumption and emissions for participating fleets.
Medium-term	1. Co-develop (with industry) a "High-Accuracy Zone" blueprint for critical logistics corridors and high-risk VRU areas. 2. Establish a public-private "Mobility Data Trust" to govern the secure, standardized exchange of positioning and movement data.	Enhanced safety for VRUs at intersections. Optimized freight routing reducing urban congestion. Data-driven infrastructure planning and investment.
Long-term	1. Issue policy frameworks mandating PNT resilience for future automated mobility services. 2. Develop a "System Optimum Routing" strategy, using the positional fabric to manage demand across all modes dynamically.	Increased overall network efficiency and throughput. Enhanced resilience of transport network to disruptions (including cyber-attacks on GNSS). Foundation for fully integrated, multimodal MaaS.
Risk Assessment		
Privacy Erosion & Surveillance: Centralized, high-accuracy tracking could enable unacceptable surveillance. Mitigation: Implement strict Privacy by Design principles (e.g., data anonymization at source, edge processing), transparent data governance, and clear data retention policies. Vendor Lock-in & Fragmentation: Dependence on proprietary platforms that hinder interoperability and data portability. Mitigation: Insist on open standards and APIs (e.g., OCPI, OTA) in procurement. Support the development of open-source reference platforms for data aggregation.		

D.1.5.1 - SMARTMOBAIR technology roadmap

Equity & Accessibility Gap: Advanced fleet optimization benefits large corporations, leaving small operators behind and potentially raising service costs in underserved areas. Mitigation: Create subsidized programs or shared infrastructure (e.g., city-provided correction services) for SMEs. Include equitable service requirements in public contracts.			
Enabling Environment for Technology Deployment			
Investment cycles			
	Primary Focus	Investment Type	Intensity
Short-term	Hardware rollout and fleet integration	VC in hardware, fleet subsidies, telecom CAPEX	HIGH (device manufacturing, installation)
Medium-term	Data infrastructure and public-private trusts	Growth equity in data platforms, M&A, infrastructure funds	MEDIUM-HIGH (data platforms, correction services)
Long-term	AI platforms and system integration	Institutional investment, cloud giant acquisitions	HIGH (AI consolidation, resilience tech)
Infrastructure readiness			
	Primary Enabler	Readiness Level	Key Build-Out
Short-term	5G network expansion and IoT activation	5G coverage expanding	Cellular towers, city Digital Twin pilots
Medium-term	LEO satellite corrections + 5G positioning features	5G positioning available, LEO services emerging	High-accuracy correction networks, V2X roadside units
Long-term	6G standards + alternative PNT systems	6G pilots, terrestrial backup systems deployed	Alternative PNT infrastructure (beacons, eLoran)
Regulatory Maturity			
	Primary Focus	Status	Key Milestone
Short-term	Data privacy and public fleet sharing mandates	Data sharing rules drafted/enacted	Mandates for anonymized probe data from public fleets
Medium-term	Safety type-approval and C-ITS standards	Type-approval regulations enacted/enforced	High-integrity positioning required for new vehicles
Long-term	PNT resilience and cybersecurity certification	Cyber certification drafted/enacted	Certified backup systems for critical transport
Market absorption capacity			
	Adoption Phase	Value Migration	Key Players
Short-term	Early adopters (logistics, delivery, public fleets)	Vertical SaaS solutions (fleet management)	Hardware vendors, telecom IoT bundles, vertical SaaS
Medium-term	Early majority (SMEs, commercial fleets)	Positioning-as-a-Service, data marketplaces	Correction service providers, data aggregators

Long-term	Late majority / Commoditization	AI-driven insights, system integration platforms	Cloud/AI giants, automotive OEMs
Good practices			
GPS-based Transit Signal Priority (TSP) – Minneapolis / U.S. The city integrated GPS-based Automatic Vehicle Location (AVL) from buses with traffic signal controllers so that buses approaching intersections can request green light priority when behind schedule. This reduces delays, improves schedule adherence, and increases public transport reliability. The system demonstrates how GPS data can be used not only for tracking but also for active traffic management and priority control. Link: https://conservancy.umn.edu/items/df89275b-aaf5-4ff3-ba13-0a8e3c9167e6 **Urban Geofencing for Low-Emission and Safety Zones – Gothenburg** The city of Gothenburg implemented GPS-based geofencing for vehicles entering sensitive areas such as city centres. Vehicles automatically adjust their behaviour (e.g., reduced speed or restricted engine modes) when crossing predefined GPS boundaries. This approach improves air quality, safety, and traffic regulation while affecting around 100,000 residents in the city centre. Link: https://urban-mobility-observatory.transport.ec.europa.eu/resources/case-studies/geofencing-new-tool-make-urban-transport-safer-and-more-sustainable_en			

2.1.2. Accessible UI/UX designed real-time information platforms (Smart bus stops)

Technology Roadmap Profile
Technology name
Accessible UI/UX Designed Real-Time Information Platforms (Smart Bus Stops)
Description (current)
Accessible UI/UX designed real-time information platforms at smart bus stops provide passengers with immediate, easy-to-understand updates about public transport. These platforms are integrated into digital displays, interactive touchscreens, or mobile-accessible systems at bus stops, and are developed according to universal design and accessibility standards. The platforms deliver real-time information such as live bus arrival/departure times, route changes, service alerts, and multimodal connections. They are designed with high-contrast visuals, readable fonts, tactile or auditory feedback, language options, and user-friendly layouts. This technology aims to improve the public transport experience for all users, reduce perceived waiting times, and increase the accessibility and reliability of bus services.
Roadmap Horizon
Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)
Strategic Objective
To transform the physical bus stop from a passive waiting area into an active, inclusive, and intelligent gateway to the mobility network. The objective is to increase public transport ridership and user satisfaction by ensuring equitable access to reliable, multimodal journey information for 100% of passengers, regardless of age, disability, or digital literacy, thereby reinforcing public transport as the backbone of urban mobility.
Temporal Layer: Evolution Pathway & Sequencing

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Short-Term Trajectory: Deploying Foundational Accessibility & Basic Real-Time Data
Deployment of solar-powered or hardwired e-paper/e-ink displays at high-priority stops, showing real-time arrivals via GTFS-Realtime feeds. Implementation of mandatory accessibility features: tactile keypads, audio output via speaker or headphone jack, high-contrast static interfaces, and multiple core language options. Integration with basic city-wide service alert systems. Roll-out of companion mobile web app optimized for simplicity and low data usage. Pilot testing of demand-responsive features like "Next Bus Please" buttons for users with disabilities.
Medium-Term Trajectory: Interactive, Personalized & Multimodal Hub
Upgraded interactive screens with responsive, personalized interfaces (e.g., "show me buses to the hospital" via voice or simplified menu). Full multimodal integration: Real-time info for nearby micromobility (bike/scooter availability), ride-hailing/taxi ranks, and train connections. Ambient & Proactive Communication: Use of color-coded lighting (e.g., green for on-time) and simple icons to communicate service status at a glance. Dynamic Utility: Integration of environmental sensors (air quality, temperature) and public Wi-Fi. Stops begin to serve as public space utility poles.
Long-Term Trajectory: Autonomous, Predictive & Two-Way Communication Nodes
The platform evolves into a two-way communication node within a C-ITS ecosystem. It communicates directly with approaching autonomous shuttles and CAVs to signal passenger wait status. AI-Predictive Displays: Systems predict crowding on next vehicle and suggest alternatives; provide personalized journey advice based on anonymized aggregate user patterns. Full Digital & Physical Integration: Seamless blending with personal devices via ultra-low-energy Bluetooth/UWB, pushing tailored journey info directly to smartphones or AR glasses. Infrastructure as a Service: The stop becomes a modular platform hosting cellular small cells, edge computing for city IoT, and emergency response systems.
Technology Layer: Key Enabling Technologies
Key Enabling Technologies
Low-Power Display Technologies (E-paper, E-ink, LCD), Real-Time Data Processing & Integration Middleware, Accessible Human-Machine Interface (HMI) Standards & Tools, IoT Sensors (Occupancy, Environmental, Audio Beacon), Edge Computing Units, C-V2X / DSRC Communication Modules, AI for Personalization & Predictive Analytics

	Dependencies	R&D Priorities
Short-term	Reliable, standardized real-time data feeds (GTFS-RT) from all transport operators. Stable power and connectivity (4G/5G, fiber) at stop locations.	Development of low-cost, vandal-resistant interactive panels with tactile/audio features. R&D into ultra-low-power display tech for off-grid locations. Standardized accessibility API for transport apps.
Medium-term	Ubiquitous urban IoT networks and open city data platforms (Digital Twin). Maturation of voice UI and simple gesture recognition.	R&D into context-aware interfaces that adapt to time of day, weather, or major events. Development of interoperable multimodal data standards (beyond GTFS). Energy-harvesting solutions for higher-power interactive displays.

Long-term	Mature V2X ecosystem and deployment of CAVs. Widespread adoption of personal AR/mobility assistants.	AI models for privacy-preserving personalization at public kiosks. R&D into "self-healing" public displays and robust edge computing architectures. Standardized protocols for infrastructure-to-vehicle (I2V) communication.
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution
Short-term	Mandate universal design standards (based on WCAG) in all public transport infrastructure procurement. Establish clear public data publishing mandates for transport operators.	Growth of specialized "Smart City Furniture" manufacturers. Traditional advertising display firms pivot to offer integrated transport info modules. Software startups offer white-label real-time passenger information (RTPI) platforms.
Medium-term	Develop "Mobility Hub" zoning and street design regulations that formalize the role and specifications of smart stops. Create procurement frameworks for integrated multimodal data platforms.	Emergence of "Mobility Experience as a Service" providers who manage the entire user interface layer across physical and digital touchpoints for a city. Consolidation in the software market around a few dominant RTPI platform providers.
Long-term	Establish national/EU regulations defining smart street furniture as critical digital public infrastructure, with requirements for uptime, security, and interoperability with CAVs.	The market shifts from hardware to intelligence and integration. Large tech or telecom firms may offer the stop as a node in their urban sensing network. Public agencies may take ownership of the platform layer, treating real-time info as a utility.
Barriers		
Technological: High upfront cost and maintenance of durable, weather/ vandal-resistant hardware. Connectivity and power challenges at remote stops. Rapid obsolescence of display and computer hardware. Financial: Significant capital expenditure for city-wide roll-out. Ongoing OPEX for connectivity, energy, and content/software updates. Uncertain monetization models (e.g., advertising vs. public funding). Regulatory/Social: Procurement processes often favor lowest cost over lifecycle value and accessibility. Digital literacy gaps can persist despite accessible design. Potential for the "digital divide" to manifest physically if deployment is uneven across neighborhoods.		
Implications for Decision-Makers		
	Recommended Actions	Expected Impacts
Short-term	1. Adopt a mandatory accessibility and open data specification for all new transport information contracts.	Reduced perceived wait times and anxiety. Measurable increase in ridership among elderly and disabled communities. Improved data on passenger wait times and stop usage.

	2. Launch a pilot corridor with fully accessible smart stops, measuring change in ridership and user satisfaction.	
Medium-term	1. Develop an equity-focused deployment strategy prioritizing underserved neighborhoods. 2. Issue a tender for an integrated multimodal passenger information platform that powers both physical stops and mobile apps.	Increased share of multimodal journeys (e.g., bus+micromobility). Improved operational efficiency for the transport authority (crowding management). Enhanced public perception of transit as modern and user-centric.
Long-term	1. Integrate smart stop planning into CAV and C-ITS deployment strategies. 2. Explore new public-private governance models (e.g., a joint venture) to manage the stops as a sustainable, upgradable network asset.	Creation of a resilient, future-proof data and communication layer for urban mobility. The bus stop becomes a proven, trusted node for delivering broader city services and information.

Risk Assessment

Equity & Exclusion: Deployment may cluster in wealthy or central areas, exacerbating transport inequality. Mitigation: Implement an equity-first deployment map using socio-economic and mobility desert indices. Maintain high-quality basic information (printed schedules) at all stops.
Technological Lock-in & Obsolescence: Commitment to a proprietary hardware/software system that becomes outdated or limits future integration. Mitigation: Specify modular, open-architecture hardware and insist on open data APIs and ownership of data generated. Use phased procurement.
Privacy in Public Spaces: Interactive kiosks and sensors could collect detailed data on user behavior. Mitigation: Implement strict "anonymous by design" principles for data collection (e.g., aggregate footfall only). Clearly post privacy policies and provide obvious opt-out for any personalized features.

Enabling Environment for Technology Deployment

Investment cycles

	Primary Focus	Investment Type	Intensity
Short-term	Pilot corridors and foundational hardware deployment	Public infrastructure funds, vendor contracts for displays	MEDIUM-HIGH (hardware, installation)
Medium-term	City-wide rollout and software platform integration	Municipal bonds, public-private partnerships (PPP)	HIGH (system-wide expansion)
Long-term	Modular upgrades, AI integration, and network maintenance	Operational expenditure (OPEX), asset management funds	MEDIUM (sustained maintenance, upgrades)

Infrastructure readiness

	Primary Enabler	Readiness Level	Key Build-Out
Short-term	Reliable power and 4G/5G connectivity at stops	Variable, requires targeted upgrades	Fiber/cellular backhaul to stop locations

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Medium-term	City-wide IoT networks and open data platforms	Pilots and early deployment	Integrated data backbone for multimodal info
Long-term	V2X infrastructure and edge computing nodes	Deployed in key corridors	Stops as intelligent roadside units (RSUs)
Regulatory Maturity			
	Primary Focus	Status	Key Milestone
Short-term	Universal design and accessibility standards	Mandated in public procurement	WCAG-aligned requirements in all contracts
Medium-term	Mobility hub zoning and data integration	Regulatory frameworks developed	Formal classification of smart stops as public infrastructure
Long-term	National standards for smart street furniture	Standards enacted	Stops classified as critical digital public infrastructure
Market absorption capacity			
	Adoption Phase	Value Migration	Key Players
Short-term	Early adopters (major cities, transit agencies)	Smart city furniture and display hardware	Specialized display manufacturers, transit agencies
Medium-term	Early majority (secondary cities, regional authorities)	Integrated passenger information platforms	Mobility experience platform providers, system integrators
Long-term	Late majority / Ubiquitous deployment	Intelligence and data analytics services	Large tech firms, telecom operators, public utilities
Good practices			
London Countdown System Transport for London's Countdown system provides real-time bus arrival information via displays, apps, and SMS, designed with accessibility in mind (clear layouts, audio options, multiple formats). It significantly reduced perceived waiting times and improved user confidence in public transport. Link: https://tfl.gov.uk/info-for/media/press-releases/2013/april/tfl-delivers-live-bus-arrival-information-on-digital-signs **Barcelona Smart Bus Stops** Barcelona has deployed smart bus shelters with interactive screens, USB charging, Wi-Fi, and real-time multimodal information. The system emphasizes universal accessibility and integrates environmental and city service data. Link: https://buspas.com/barcelona-tests-ai-powered-smart-bus-stops-to-tackle-passenger-crowding/			

2.1.3. Trip booking and payment customer's APP

Technology Roadmap Profile

D.1.5.1 - SMARTMOBAIR technology roadmap

Technology name
Trip booking and payment customer's APP
Description (current)
The app allows the user who intends to use the on-demand transport service to book one or more trips and pay for them via the app or via electronic payment systems (credit card, PayPal, etc.). The booking can be made days in advance. Given the nature of the service under study, which is developed in an extra-urban context, the possibility of allowing the booking of the trip even a few minutes before boarding is being evaluated. The application allows the user to enter the origin and destination addresses of the desired trip as well as the departure times. The software can propose the actual times of the trip and keep the user updated on the arrival times and significant changes to the service. The possibility of having the user make the payment when booking the ride or when using the service is being evaluated.
Roadmap Horizon
Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)
Strategic Objective
To transform fragmented, inefficient rural and peri-urban transport into a viable, reliable, and user-centric alternative to private car ownership. The app aims to increase the accessibility and utilization of public and shared transport in low-density areas, reduce average user wait times, and serve as the primary digital interface for integrating flexible, on-demand services with fixed-route networks into a seamless regional Mobility-as-a-Service (MaaS) ecosystem.
Temporal Layer: Evolution Pathway & Sequencing
Short-Term Trajectory: Foundational Service & Basic Reliability
Deployment of a standalone, user-friendly app for booking and paying for specific on-demand shuttle or ride-pooling services in pilot zones. Core features: address-based booking (days/hours in advance), real-time driver tracking, e-ticketing, and in-app payment. Evaluation of "flash booking" (minutes before) in low-demand periods. Integration with basic telematics for Estimated Time of Arrival (ETA) accuracy. Focus on overcoming digital literacy barriers with simple UI, offline capability for booking, and telephone-based support fallback.
Medium-Term Trajectory: Integrated Multimodal Platform & Dynamic Optimization
The app evolves into a regional multi-modal journey planner and booker. Users can plan and book trips combining on-demand shuttles, fixed-route buses, and train services in a single transaction. Implementation of AI-driven dynamic routing and pooling: The system optimally matches multiple trip requests in real-time, maximizing vehicle occupancy and efficiency. Introduction of flexible fare products (subscriptions, capped daily/weekly fares, bundled mobility packages). Advanced user features: Loyalty programs, saved frequent trips, and integration with personal calendars.
Long-Term Trajectory: Proactive, Autonomous & Ecosystem-Integrated MaaS
The app becomes a proactive mobility assistant, using learned preferences and calendar data to suggest optimal trip times and modes, and can auto-book regular journeys. Full integration with a CAV-ready transport ecosystem, booking journeys that may involve a mix of traditional buses, autonomous on-demand shuttles, and micromobility.

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Seamless cross-border/regional interoperability: A single user identity and wallet work across multiple transport authorities and private operators. The platform acts as a two-sided marketplace, allowing community drivers or smaller operators to offer services under a regulated framework, filling ultra-niche demands.		
Technology Layer: Key Enabling Technologies		
Key Enabling Technologies		
Mobile Application Development Platforms (iOS/Android), Geocoding & Mapping APIs (e.g., Google Maps, HERE, OpenStreetMap), Real-Time Routing & Matching Algorithms, Backend-as-a-Service (BaaS) / Cloud Platforms, Payment Gateway APIs & Digital Wallet Systems, AI/ML for Demand Prediction & Dynamic Pooling, API Standards for MaaS Integration (e.g., OCPI, OTA)		
	Dependencies	R&D Priorities
Short-term	Stable mobile connectivity (4G/5G) in target areas. Willingness of transport operators to provide real-time vehicle location data (GTFS-RT).	R&D into efficient algorithms for sparse demand pools in rural areas. Development of ultra-lightweight app versions for low-end smartphones. Standardized API for basic on-demand service booking and status.
Medium-term	Availability of open, standardized APIs from all regional transport modes (trains, buses). Mature digital identity and secure payment frameworks.	Advanced AI for multi-modal journey chaining with dynamic reliability buffers. R&D into privacy-preserving user profiling for personalized offers. Development of standardized "Mobility Wallet" protocols.
Long-term	Mature regulatory frameworks for CAVs and MaaS data governance. Widespread adoption of decentralized digital identity (e.g., SSI).	AI for long-horizon demand shaping (e.g., incentivizing off-peak travel). R&D into interoperable booking protocols for autonomous vehicle fleets. Development of robust simulation tools to model system-wide impacts of flexible services.
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution
Short-term	Establish "experimental service" regulations allowing flexible routing and on-demand pickup points. Define data sharing requirements between the app provider and public authorities for service monitoring.	Emergence of specialized software vendors for Demand-Responsive Transit (DRT) and rural MaaS. Private ride-hailing/taxi firms may offer white-label booking engines to public authorities.
Medium-term	Develop integrated ticketing and tariff regulations that allow revenue sharing across multiple operators booked via one app. Establish "Mobility Data Trusts" to govern the secure, ethical use of trip data for planning.	Rise of "Mobility Integrator" companies that operate the customer-facing app and manage the multi-operator backend, contracted by public transport authorities. Consolidation of smaller DRT software firms.
Long-term	Enact national/regional MaaS legislation defining roles, liabilities, and consumer protections. Regulate	The market may bifurcate: Public Utility Model where the app is a publicly-owned or regulated platform, and Private Ecosystem Model led by global tech/mobility

	algorithmic fairness and non-discrimination in dynamic pricing and service allocation.	giants. Data analytics services become a major value center.
Barriers		
Technological: Patchy mobile network coverage in rural areas hindering real-time functionality. High development and maintenance cost of robust, multi-platform apps. Complexity of integrating legacy booking and fare systems of different operators. Financial: Achieving economic viability with low user density and high per-trip subsidy requirements. High user acquisition costs in car-dependent communities. Uncertainty of sustainable business models for the app platform itself. Regulatory/Social: Resistance from existing taxi or fixed-route bus operators. Deep-seated car culture and low awareness/trust in new mobility services. Digital exclusion of elderly or low-income populations without smartphones or banking access.		
Implications for Decision-Makers		
	Recommended Actions	Expected Impacts
Short-term	1. Subsidize or procure a unified booking/payment app for all pilot on-demand services, mandating open data standards. 2. Launch digital literacy and promotional campaigns in pilot areas to drive adoption.	Measurable increase in ridership on pilot services. Reduced cash handling and administrative overhead for operators. First dataset on latent demand patterns in underserved areas.
Medium-term	1. Issue a tender for a Regional MaaS Platform integrator, requiring full multi-modal planning, booking, and payment. 2. Use trip data from the app to restructure and right-size fixed-route networks, replacing low-ridership lines with optimized on-demand zones.	Increased share of trips made by integrated public/ shared transport. Improved cost-efficiency of the overall transport network. Enhanced social inclusion through better connectivity for non-drivers.
Long-term	1. Establish a public-led governance entity for the regional MaaS ecosystem, overseeing the platform, data, and equitable service standards. 2. Integrate mobility credits or subsidies directly into the app's wallet system to target support efficiently.	Reduction in private car dependency and associated congestion/emissions in regional centers. Creation of a resilient, data-driven, and user-responsive transport system adaptable to future CAV integration.
Risk Assessment		
Market Fragmentation & Lock-in: Proliferation of incompatible operator-specific apps, confusing users and preventing integration. Mitigation: Early public leadership in defining open technical standards (APIs) and procuring for an interoperable regional platform. Digital Divide & Service Equity: The service becomes exclusive to tech-savvy users, leaving vulnerable populations further marginalized. Mitigation: Mandate universal access requirements (telephone booking, cash payment options via agents, community access points) as part of service contracts. Design app with extreme usability focus.		

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Data Monopoly & Privacy: The platform operator accumulates sensitive data on mobility patterns, creating commercial and surveillance risks. Mitigation: Establish a public or joint data trust with strict governance. Enforce data minimization and purpose limitation principles. Ensure users have full transparency and control over their data.			
Enabling Environment for Technology Deployment			
Investment cycles			
	Primary Focus	Investment Type	Intensity
Short-term	Pilot service deployment and app development	Public subsidies, VC in DRT software	MEDIUM (software development, pilot operations)
Medium-term	Regional platform integration and scaling	Public-private partnerships, M&A activity	HIGH (platform consolidation, expansion)
Long-term	AI-driven MaaS ecosystem and governance entity	Institutional investment, public-led digital utility funds	MEDIUM-HIGH (sustained operation, AI R&D)
Infrastructure readiness			
	Primary Enabler	Readiness Level	Key Build-Out
Short-term	4G/5G mobile coverage in rural/extra-urban areas	Expanding, with gaps	Targeted network densification in service zones
Medium-term	Open MaaS APIs and digital identity frameworks	Emerging standards (e.g., OCPI, OTA)	Regional API gateway and interoperability layer
Long-term	CAV integration and decentralized identity systems	Pilots and early deployment	Seamless regional and cross-border interoperability layer
Regulatory Maturity			
	Primary Focus	Status	Key Milestone
Short-term	Experimental service regulations for DRT	Drafted/enacted in pilot regions	Flexible routing and on-demand pickup authorized
Medium-term	Integrated ticketing and revenue-sharing rules	Frameworks developed	Multi-operator payment and settlement system operational
Long-term	National MaaS legislation and algorithmic fairness	Legislation enacted	Consumer protections and non-discrimination rules in place
Market absorption capacity			
	Adoption Phase	Value Migration	Key Players
Short-term	Early adopters (tech-savvy users, pilot zones)	Standalone DRT booking apps	Specialized DRT software vendors, private ride-hailing firms
Medium-term	Early majority (regional commuters)	Regional MaaS integrator platforms	Mobility integrator companies, public transport authorities

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Long-term	Late majority / Mainstream adoption	AI-driven insights, ecosystem governance	Global tech/mobility giants, public-led mobility utilities
Good practices			
Whim - Helsinki The Whim app in Helsinki is a leading MaaS platform integrating journey planning, booking, and payment across public transport, taxis, and micromobility. It offers subscription packages and pay-as-you-go options, simplifying multimodal travel. Link: https://www.ecodesigncircle.eu/resources-for-you/117-whim **Uber Transit** Uber Transit integrates public transport ticketing and trip planning within the Uber app in several cities. It enables users to compare and book multimodal trips, bridging private and public mobility services. Link: https://www.uber.com/us/en/transit/			

2.1.4. Bookings managing software and trip planning software

Technology Roadmap Profile
Technology name
Bookings managing software and trip planning software
Description (current)
The application allows the user or customer to plan the desired trip using the addresses and times of origin and destination of the trip as input data. The user who has booked a ride can check the position of the bus in real time and consult any updates regarding the status of the trip of interest. The user/driver (transport company) interface proposes an optimized itinerary, provides drivers with turn-by-turn driving instructions and automatically updates their programs, minimizing distractions on the road.
Roadmap Horizon
Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)
Strategic Objective
To evolve from a reactive booking and dispatch tool into a proactive, self-optimizing "central nervous system" for on-demand and flexible transport networks. The objective is to maximize overall system efficiency, by increasing average vehicle occupancy, reducing dead mileage, and improving passenger wait-time reliability, while providing a seamless, predictable experience for both passengers and operators.
Temporal Layer: Evolution Pathway & Sequencing
Short-Term Trajectory: Operational Integration & Basic Efficiency
Deployment of a unified software platform that integrates a passenger-facing booking/tracking app with a driver-facing dispatch/navigation app. Core function: Real-time matching of trip requests to vehicles, with optimization focused on minimizing detour and wait time for the next trip. Automated schedule updates pushed to drivers via simple turn-by-turn navigation, reducing manual radio dispatch.

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Provision of basic real-time passenger updates (vehicle on map, ETA). Operators use backend dashboard for manual override and basic performance reporting.
Medium-Term Trajectory: Predictive Optimization & Multimodal Orchestration
Implementation of AI-driven predictive analytics that forecasts demand (based on history, weather, events) and pre-positions vehicles. Shift from single-trip to multi-passenger, multi-stop dynamic routing in real-time, with algorithms balancing passenger convenience, vehicle capacity, and energy efficiency. The platform evolves into a multimodal orchestrator, capable of planning and managing trips that involve a transfer between an on-demand vehicle and a fixed-route bus or train, with held connections. Advanced driver interface: Integrates real-time road hazard alerts, priority signal (GTT) information, and suggests optimal safe stopping points.
Long-Term Trajectory: Autonomous Fleet Management & System-Wide Co-Optimization
The platform becomes the fleet-agnostic "brain" for a mixed fleet of human-driven and autonomous vehicles (AVs), managing assignments based on capability, cost, and service requirements. Two-way C-ITS integration: The software receives live traffic signal phasing, intersection safety warnings, and road condition data to optimize routing. It broadcasts vehicle intentions to infrastructure. System-wide co-optimization: The platform manages the entire regional flexible transport network, dynamically allocating resources (vehicles, drivers) across different service zones and operators to meet aggregate demand at the lowest systemic cost. Self-learning algorithms continuously improve based on outcomes, and can run "what-if" simulations for service planning.
Technology Layer: Key Enabling Technologies
Key Enabling Technologies
Dynamic Routing & Matching Algorithms (e.g., Dial-a-Ride Problem solvers), Real-Time Passenger Information (RTPI) & Tracking Systems, Mobile Driver Telematics & In-Cab Navigation Interfaces, AI/ML for Demand Prediction & Anomaly Detection, Cloud/Edge Computing for Real-Time Optimization, C-V2X / I2V Communication Modules, API Middleware for Multimodal Integration (e.g., OCPI, SIRI)

	Dependencies	R&D Priorities
Short-term	Reliable, low-latency vehicle location data (GPS). Stable cellular connectivity for drivers and backend.	R&D into robust, real-time matching algorithms that work with sparse, unpredictable rural/extra-urban demand. Development of low-distraction, voice-first driver interfaces. Standardized API for vehicle location and status reporting.
Medium-term	Availability of rich contextual data (traffic, events, weather) via city APIs. Mature AI/ML toolkits for time-series forecasting.	Advanced algorithms for dynamic ride-pooling with complex constraints (fare, wheelchair access, luggage). R&D into privacy-preserving demand prediction at the trip origin/destination level. Integration of energy consumption models into routing.

Long-term	Mature V2X communication standards and deployed roadside units. Regulatory clarity for mixed AV/human-driven fleets. High-fidelity urban/regional digital twins.	AI for strategic fleet positioning and long-horizon resource allocation across a network. R&D into federated learning models that improve system performance across operators without sharing raw data. Development of open simulation environments for testing optimization strategies.
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution
Short-term	Establish service level agreements (SLAs) and data sharing mandates between software providers, transport operators, and public authorities for performance monitoring.	Growth of specialized SaaS providers for Demand-Responsive Transit (DRT) and paratransit. Traditional taxi dispatch software firms pivot to on-demand public transport. Market is fragmented with many niche solutions.
Medium-term	Develop interoperability standards for booking and dispatch data to enable multi-operator platforms. Create regulatory sandboxes for testing dynamic pricing and advanced pooling in public services.	Consolidation occurs; leading firms become "Mobility Operating System" providers. Transport authorities move from buying software to procuring "Optimized Mobility Service Hours" where the platform provider guarantees efficiency KPIs.
Long-term	Enact regulations defining the safety and certification requirements for AI-driven dispatch systems (especially for AV integration). Establish public governance frameworks for network-wide mobility data generated by these platforms.	The platform layer becomes a critical public-interest digital infrastructure. Possible models: a regulated monopoly provider, or an open-source core platform maintained by a public consortium. Value shifts decisively to data intelligence and algorithmic advantage.
Barriers		
Technological: Computational complexity of real-time, large-scale optimization with dynamic constraints. Latency and reliability issues in areas with poor connectivity, critical for real-time updates. Financial: High initial investment and ongoing SaaS costs for advanced software. Operational resistance from drivers/operators used to traditional methods. Difficulty quantifying ROI of predictive features. Regulatory/Social: Union agreements may restrict dynamic schedule changes or new monitoring features. Passenger reluctance to accept shared rides with detours. Data silos between different transport operators and jurisdictions hinder regional optimization.		
Implications for Decision-Makers		
	Recommended Actions	Expected Impacts
Short-term	1. Mandate the procurement of integrated booking/dispatch software for any new on-demand service, requiring open data export capabilities.	Reduced operational costs through less dispatcher workload and more efficient routing. Improved

	2. Fund driver training programs on using the new in-cab technology to ensure adoption.	passenger satisfaction due to reliable tracking and ETAs. Creation of a digital record of all trips for basic analytics.
Medium-term	1. Use data from the platform to restructure subsidized transport contracts, paying for delivered passenger-km rather than fixed routes. 2. Sponsor the development of open API standards for dispatch data to break vendor lock-in and foster a competitive ecosystem.	Significant increase in vehicle productivity (more passengers per hour). Enhanced ability to serve dispersed demand with fewer vehicles. Data-driven evidence for network planning and subsidy allocation.
Long-term	1. Establish a Public Mobility Data and Optimization Unit to oversee the algorithmically-managed network, ensuring fairness, transparency, and system-wide goals. 2. Integrate this platform's control layer into the city/region's strategic traffic management and CAV readiness plans.	Creation of a resilient, adaptive public transport layer that can dynamically respond to demand shocks and infrastructure changes. Foundation for a truly integrated, efficient, and sustainable regional mobility system.

Risk Assessment
Algorithmic Bias & Equity: Optimization algorithms may inadvertently prioritize profitable or convenient trips, systematically underserving remote areas or passengers with disabilities. Mitigation: "Equity-by-design" in algorithm development, with explicit constraints and goals for geographic and demographic coverage. Establish an independent algorithmic audit process. Systemic Fragility & Over-Reliance: The transport network becomes critically dependent on a single software platform, creating a single point of failure (cyber-attack, vendor collapse). Mitigation: Insist on open standards and data portability. Develop public fallback protocols and manual override capabilities. Consider a multi-vendor or hybrid architecture for core systems. Labor Displacement & Deskilling: Increased automation of dispatch and routing can undermine driver skills and job satisfaction, leading to resistance. Mitigation: Engage driver unions early in design. Reposition the driver's role towards customer service and safety supervision, supported by technology. Use efficiency gains to improve driver working conditions, not just reduce headcount.

Enabling Environment for Technology Deployment			
Investment cycles			
	Primary Focus	Investment Type	Intensity
Short-term	Integrated dispatch software deployment	SaaS subscriptions, public service contracts	MEDIUM (software licensing, driver training)
Medium-term	Predictive analytics and multimodal orchestration	Growth equity in DRT platforms, public innovation funds	MEDIUM-HIGH (AI development, platform expansion)
Long-term	Autonomous fleet management and system-wide optimization	Institutional investment, strategic R&D	HIGH (AI consolidation, network-wide integration)
Infrastructure readiness			
	Primary Enabler	Readiness Level	Key Build-Out

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Short-term	Reliable cellular connectivity for real-time dispatch	4G/5G coverage along routes	Backend cloud infrastructure
Medium-term	Rich contextual data APIs (traffic, events) and AI toolkits	Available in major urban centers	City data platforms and open APIs
Long-term	Mature V2X and high-fidelity digital twins	Deployed and operational	Regional digital twin and C-ITS ecosystem
Regulatory Maturity			
	Primary Focus	Status	Key Milestone
Short-term	Data sharing mandates and service level agreements (SLAs)	Included in public contracts	Mandated data export and performance reporting
Medium-term	Interoperability standards for dispatch data	Emerging standards	Multi-operator platform integration enabled
Long-term	AI safety certification for dispatch systems	Regulations drafted	Certified AI dispatch for AV integration
Market absorption capacity			
	Adoption Phase	Value Migration	Key Players
Short-term	Early adopters (public DRT, paratransit operators)	Specialized DRT SaaS providers	Niche DRT software firms, traditional taxi dispatch vendors
Medium-term	Early majority (regional authorities, commercial fleets)	Mobility Operating System platforms	Leading DRT platform consolidators, system integrators
Long-term	Late majority / Regulated utility	Data intelligence and algorithmic optimization	Public consortiums, regulated monopoly providers
Good practices			
Via Mobility Platform Via provides dynamic ride-pooling and dispatch software used by cities worldwide to optimize routes and vehicle allocation in real time. Its algorithms increase vehicle occupancy while maintaining acceptable wait times. Link: https://ridewithvia.com **Padam Mobility** Padam Mobility offers AI-based demand-responsive transport solutions with real-time booking, routing, and dispatch optimization. It has been widely deployed in Europe to improve rural and peri-urban mobility efficiency. Link: https://padam-mobility.com			

2.1.5. Driver Communication On-Board Equipment

D.1.5.1 - SMARTMOBAIR technology roadmap

Technology Roadmap Profile
Technology name
Driver Communication On-Board Equipment
Description (current)
The driver can interact with the operations centre even if he cannot make reports. Through the application, it is possible to see where the bus is and carry out monitoring. Pop-up messages may appear.
Roadmap Horizon
Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)
Strategic Objective
To evolve the driver's cabin from a point of manual control into an intelligent, connected, and context-aware node within a cooperative transport ecosystem. The objective is to improve network-wide operational efficiency, reduce incident response times, and enhance driver safety and job satisfaction, thereby increasing overall public transport reliability and resilience.
Temporal Layer: Evolution Pathway & Sequencing
Short-Term Trajectory: Digital Integration & Enhanced Situational Awareness
Replacement of legacy analog radios with Integrated Multi-Mode Digital Consoles (voice, data, panic button). Deployment of driver tablets or integrated displays showing real-time schedule adherence, next stops, and priority traffic signal (GTT) status. Implementation of automated "silent alarms" (e.g., triggered by harsh braking, door obstruction, or manual trigger) sending immediate alerts with location to control centres. Basic two-way text/pop-up messaging for non-urgent instructions, reducing voice channel clutter.
Medium-Term Trajectory: Proactive Decision Support & C-ITS Integration
The console becomes a Cooperative ITS (C-ITS) onboard unit, receiving and displaying SPAT/MAP messages (Signal Phase and Timing, MAP data), road hazard warnings, and priority requests. AI-Powered Decision Support: The system analyzes schedule, traffic, and passenger load data to suggest optimal dwell times or minor route adjustments to recover delays. Enhanced Passenger Communication: Integration with passenger information systems allows drivers to trigger automated audio/visual announcements for delays or emergencies. Predictive Maintenance Interface: Real-time vehicle health data (engine, door, battery) is displayed with predictive alerts, enabling pre-emptive reporting.
Long-Term Trajectory: Autonomous-Ready Hub & Bi-Directional Ecosystem Node
The equipment evolves into the "Guardian Angel" interface for Automated Vehicles (AVs) in mixed-fleet operations. For AVs, it serves as a remote monitoring and intervention console; for human drivers, it provides augmented reality (AR) overlays for navigation and hazard detection. Full V2X Hub: Acts as a relay, sharing hyper-local data (e.g., detected pedestrians at a crossing, road surface condition) with infrastructure and other road users.

D.1.5.1 - SMARTMOBAIR technology roadmap

Biometric & Wellness Monitoring: Non-intrusive sensors monitor driver alertness and well-being, suggesting breaks or adjusting workload. Federated Communication: The unit seamlessly switches between and aggregates data from multiple networks (5G/6G, C-V2X, satellite, mesh networks) for fail-safe connectivity.		
Technology Layer: Key Enabling Technologies		
Key Enabling Technologies		
Digital Mobile Radio (DMR, Tetra) & IP-based Voice/Data Terminals, In-Vehicle Infotainment (IVI) or Telematics Displays/Tablets, C-V2X / DSRC On-Board Units (OBUs), IoT Sensors for Vehicle & Driver State, Edge Computing Modules within the Vehicle, AI for Contextual Alert Prioritization & Predictive Suggestions, Augmented Reality (AR) Head-Up Displays (HUDs)		
	Dependencies	R&D Priorities
Short-term	Ubiquitous and reliable 4G/5G mobile coverage along routes. Standardized vehicle data APIs (e.g., from CAN bus) for integration.	Development of intuitive, low-distraction human-machine interfaces (HMIs) for in-motion use. Standardized protocols for secure, priority data/voice over public networks. Low-cost, ruggedized tablet hardware.
Medium-term	Deployment of roadside C-ITS infrastructure (RSUs). Maturity of open in-vehicle platform standards (e.g., SDV concepts).	AI for intelligent alert filtering to avoid driver overload. R&D into secure V2X message handling and display. Integration of real-time passenger count and origin-destination data into decision support.
Long-term	Maturation of 6G and integrated sensing & communication. Legal frameworks for driver monitoring and data use. Widespread AV deployment.	R&D into adaptive interfaces that change based on automation level (L0-L4). Biometric sensing for wellness that respects privacy. Development of resilient, multi-path communication stacks for guaranteed uptime.
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution
Short-term	Update public service vehicle regulations to mandate digital, location-aware emergency communication systems. Standardize minimum data sets (location, status) to be shared by all operators with traffic management centres.	Consolidation among traditional radio/telematics suppliers adding software layers. Entry of consumer electronics and automotive Tier 1 suppliers into the public transport cabin market with tablet-based solutions.
Medium-term	Mandate C-ITS readiness for new public transport vehicle procurements. Develop data sharing agreements between transit agencies, road operators, and emergency services for integrated incident management.	Rise of "Connected Cabin" platform providers offering an integrated app ecosystem for drivers (safety, operations, info). Telecom operators offer "Managed Mobile Workforce" solutions bundling devices, connectivity, and security.

Long-term	Establish cyber-security certification requirements for all connected on-board vehicle systems. Regulate the safety and liability aspects of AI-driven recommendations to drivers.	The market splits: Mission-Critical Systems (for safety/comms) supplied by specialized industrial firms, and Productivity/UX Systems supplied by tech firms. The cabin system becomes a standardized, open platform for third-party mobility service apps.

Barriers
Technological: Legacy vehicle integration complexities and long refresh cycles (10-15 years). Ensuring system resilience and uptime in all conditions (tunnels, rural areas). Balancing information richness with driver cognitive load and distraction risks. Financial: High capital cost for fleet-wide retrofitting. Ongoing costs for cellular data subscriptions and software updates. Difficulty justifying ROI for advanced safety/optimization features beyond basic communication. Regulatory/Social: Union concerns over increased monitoring and "electronic leash" perception. Data privacy issues related to driver tracking and biometrics. Lack of interoperability standards leading to vendor lock-in.

Implications for Decision-Makers		
	Recommended Actions	Expected Impacts
Short-term	1. Specify and procure a modern digital driver communication system as part of any new vehicle purchase or major refurbishment. 2. Integrate the system's data feed into the city's traffic management centre for real-time network monitoring.	Improved response time to incidents and emergencies. Reduced radio traffic and clearer communication. Better schedule adherence through direct driver feedback.
Medium-term	1. Mandate C-ITS OBU integration in upcoming vehicle tenders to enable GTT and hazard warnings. 2. Launch a "Driver Hub" pilot with AI decision support on a high-frequency route, measuring impact on punctuality and driver stress.	Increased operational efficiency through proactive adjustments. Enhanced safety via collision and hazard warnings. Foundation for dynamic, network-aware operations.
Long-term	1. Develop a regional strategy for a federated connected vehicle ecosystem, where public transport units are key data providers. 2. Establish ethical guidelines and agreements with labour unions for the use of driver wellness and performance data.	Public transport becomes a core, reliable component of a cooperative and automated mobility system. Improved driver retention and job satisfaction through better tools and safety. Creation of a rich, real-time data layer for hyper-accurate urban digital twins.

Risk Assessment
Driver Distraction & Interface Overload: Poorly designed systems can bombard drivers with alerts, compromising safety. Mitigation: Adhere to strict human-factors design principles and involve drivers in UX testing. Implement context-aware prioritization that suppresses non-critical alerts during complex driving tasks.

D.1.5.1 - SMARTMOBAIR technology roadmap

Cybersecurity Threats: A connected vehicle becomes a potential entry point for attacks on fleet or traffic management systems. Mitigation: Design with a "secure by design" philosophy, including air-gapped critical safety functions. Implement continuous threat monitoring and regular, secure over-the-air (OTA) updates. Workforce Resistance & Erosion of Trust: Perceived as surveillance, leading to low adoption or sabotage. Mitigation: Co-create the system's features and policies with driver unions. Ensure transparency on what data is collected, how it is used, and who owns it. Focus on benefits to driver safety and job support.			
Enabling Environment for Technology Deployment			
Investment cycles			
	Primary Focus	Investment Type	Intensity
Short-term	Digital radio and tablet retrofitting	Fleet CAPEX, public vehicle replacement funds	MEDIUM-HIGH (hardware procurement, installation)
Medium-term	C-ITS OBU integration and AI decision support	Vehicle OEM integration, public innovation grants	MEDIUM (system integration, pilot programs)
Long-term	AV-ready consoles and wellness monitoring	Strategic fleet modernization, institutional investment	MEDIUM-HIGH (next-generation platform deployment)
Infrastructure readiness			
	Primary Enabler	Readiness Level	Key Build-Out
Short-term	Ubiquitous 4G/5G coverage along transit routes	Expanding coverage	Cellular network densification
Medium-term	Roadside C-ITS units (RSUs)	Deployed on key corridors	RSU network expansion
Long-term	6G and integrated sensing & communication	Pilots and early standards	Resilient, multi-path communication networks
Regulatory Maturity			
	Primary Focus	Status	Key Milestone
Short-term	Mandated digital emergency communication	Regulations updated	Location-aware emergency systems required in new vehicles
Medium-term	C-ITS readiness mandates	Included in vehicle procurement	OBU integration required for new public transport vehicles
Long-term	Cybersecurity certification for in-vehicle systems	Standards enacted	Certified secure by design for all connected systems
Market absorption capacity			
	Adoption Phase	Value Migration	Key Players
Short-term	Early adopters (major transit agencies)	Integrated digital radio and telematics	Traditional radio suppliers, telematics vendors

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Medium-term	Early majority (regional transit operators)	Connected Cabin platforms	Tier 1 automotive suppliers, telecom managed workforce providers
Long-term	Late majority / Fleet-wide standardization	Mission-critical systems vs. productivity platforms	Specialized industrial firms, large tech companies

Good practices
iBus System London London's iBus system equips drivers with real-time communication, tracking, and automated announcements, integrated with traffic signal priority. It enhances operational control and passenger information while reducing driver workload. Link: https://tfl.gov.uk/info-for/media/press-releases/2013/may/tfl-launches-countdown-digital-sign-service--offering-real-time-bus-arrival-information-in-public-spaces **EBSF Driver Interface Systems** Within EBSF, buses were equipped with onboard driver terminals integrating real-time information, navigation, and communication with control centers. These systems reduced manual dispatching and improved coordination and service reliability. Link: https://cordis.europa.eu/project/id/218647

2.1.6. Infrared Passenger Counting System (IR-PCS)

Technology Roadmap Profile
Technology name
Infrared Passenger Counting System (IR-PCS)
Description (current)
Infrared Passenger Counting Systems (IR-PCS) are technologies used to automatically count passengers entering and exiting vehicles. They use infrared sensors, usually installed above vehicle doors, to detect movement and direction when a person passes through. These sensors track the number of boardings and alightings without collecting personal information. By providing accurate passenger data, IR-PCS supports better planning and management of public transport services. The data can help operators adjust routes and frequencies based on demand, measure vehicle occupancy, and generate reports for performance and funding. Infrared systems are cost-effective, simple to install, and reliable in typical boarding conditions. They can also be combined with other systems, such as GPS tracking or ticketing, to provide more detailed insights into passenger behavior and mobility patterns.
Roadmap Horizon
Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)
Strategic Objective

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To transform passenger counting from a periodic, manual sampling tool into a continuous, automated, and intelligent data fabric that drives real-time operational decisions, long-term network optimization, and equitable service planning. The objective is to increase the efficiency of public transport resource allocation, reduce overcrowding incidents, and create a verifiable, data-driven basis for funding and service contracts.
Temporal Layer: Evolution Pathway & Sequencing
Short-Term Trajectory: Ubiquitous Deployment & Data Integration
Fleet-wide deployment of reliable, low-cost IR-PCS on all buses/trams, moving beyond pilot routes. Seamless data fusion: Automated integration of count data with vehicle location (GPS) and timetable data (GTFS) to create a spatio-temporal map of passenger demand. Focus on data validation and cleansing to achieve >95% accuracy, addressing challenges like simultaneous boardings/alightings. Generation of automated occupancy reports for operators and basic real-time "load" indicators for control centres.
Medium-Term Trajectory: Predictive Analytics & Real-Time Operational Tools
Shift from historical reporting to predictive demand modeling. AI uses historical count data, fused with external data (events, weather, land use), to forecast passenger loads for upcoming trips/shifts. Real-time decision support: Control centres and dispatchers use live occupancy data to trigger dynamic short-turns, bus bridging, or frequency adjustments during disruptions. Passenger-facing information: Real-time crowding levels (e.g., "green/yellow/red") are published in journey planner apps, allowing users to make informed choices. Integration with fare system data (while remaining anonymous) to distinguish fare-paying passengers from others (e.g., children, officers), refining demand metrics.
Long-Term Trajectory: Multimodal Origin-Destination Inference & System-Wide Optimization
IR-PCS data, combined with network-wide analytics, enables the inference of origin-destination (O-D) matrices without tracking individuals, by analyzing boarding/alighting patterns across the network over time. The system becomes a key sensor for Digital Twins, providing continuous validation data for simulating public transport flows and testing "what-if" scenarios for network changes. Automated Service Quality Auditing: Continuous measurement of KPIs like denied boardings (overcrowding) and passenger wait times at stops, directly tied to service contracts and funding. Enhanced sensing fusion: IR sensors are part of a multi-modal door sensor suite (e.g., combining with low-resolution 3D ToF cameras) to detect luggage, prams, or bicycles, providing richer context for dwell time prediction and accessibility planning.
Technology Layer: Key Enabling Technologies
Key Enabling Technologies
Infrared (IR) Beam Sensor Arrays, On-Board Data Loggers & Edge Processors, Cellular IoT (4G/5G) or Wi-Fi for Data Offloading, Data Fusion & ETL (Extract, Transform, Load) Platforms, AI/ML for Demand Prediction & Anomaly Detection, Advanced O-D Matrix Estimation Algorithms, Low-Power, High-Durability Sensor Design

	Dependencies	R&D Priorities

Short-term	Ubiquitous and affordable onboard connectivity (e.g., 4G) for data transmission. Adoption of standardized data schemas (e.g., SIRI-PM for passenger monitoring) by operators and vendors.	R&D into sensor algorithms for high-accuracy counting in complex boarding scenarios (groups, high volume). Development of low-power, wireless sensor designs for easy retrofitting on older vehicles.
Medium-term	Mature cloud/edge computing platforms for real-time analytics. Availability of open city data (events, weather) via APIs.	AI models for short-term demand forecasting at the trip/stop level. R&D into privacy-preserving data fusion techniques with ticketing data. Development of real-time data dashboards with actionable insights for controllers.
Long-term	High-fidelity urban digital twin platforms. Advanced computational methods for network-wide O-D estimation.	Advanced algorithms for inferring O-D matrices from network-wide count data. R&D into multi-sensor fusion at doors (IR + simple vision) to classify boarding "events" (e.g., person with bike). Development of self-diagnosing and calibrating sensors to minimize maintenance.
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution
Short-term	Include mandatory automated passenger counting and data reporting in new public service contracts and vehicle procurements. Define minimum data quality and accuracy standards for funded services.	Growth of specialized "Passenger Analytics" SaaS companies that aggregate and analyze count data across fleets. Traditional vehicle manufacturers start offering IR-PCS as a factory-fitted standard option.
Medium-term	Mandate the publication of anonymized historical passenger load data (as open data) to enable third-party innovation and academic research. Develop KPIs based on crowding data for performance-based contracting.	Market consolidation. Leaders emerge providing end-to-end "Demand Intelligence Platforms", from hardware to predictive analytics. Telecom operators offer bundled "IoT for Transit" packages (sensors + connectivity + basic cloud).
Long-term	Establish passenger counting data as critical public infrastructure, with governance models for its use in regional transport modeling and funding allocation.	Hardware becomes a low-margin commodity; value shifts entirely to software, AI insights, and consulting services. Public transport authorities may develop in-house data science units to own the analytics capability, reducing vendor dependency.
Barriers		
Technological: Accuracy degradation in high-density, chaotic boarding scenarios. Sensor durability and maintenance in harsh vehicle environments. Integration complexity with legacy fleet management systems. Financial: Upfront capital cost for fleet-wide sensor installation, especially for smaller operators. Ongoing costs for data connectivity and platform subscriptions. Perceived low ROI when service changes are politically, not data, driven.		

Regulatory/Social: Union concerns over data being used for punitive performance monitoring of drivers (e.g., dwell time). Public misunderstanding, potentially viewing sensors as surveillance, despite anonymity. Bureaucratic inertia in adopting data-driven decision-making processes.		
Implications for Decision-Makers		
	Recommended Actions	Expected Impacts
Short-term	1. Launch a fleet-wide IR-PCS deployment program, prioritizing high-ridership and problem corridors first. 2. Create a centralised passenger data repository and train planning staff in basic data analysis.	Elimination of costly and inaccurate manual passenger surveys. Data-driven evidence for initial service adjustments (e.g., adding trips on chronically crowded routes).
Medium-term	1. Integrate real-time occupancy data into the traffic management centre to enable dynamic operational responses (e.g., holding a crowded bus for a connecting train). 2. Publish crowding levels in public journey apps to empower passenger choice and manage demand.	Improved passenger experience through reduced severe overcrowding. More efficient resource use (e.g., avoiding running empty buses). Increased transparency and trust in service management.
Long-term	1. Base long-term network redesigns and major investments (e.g., BRT corridors) on robust O-D matrices derived from count data. 2. Shift to performance-based funding models for operators, using verified passenger load and service quality data as key metrics.	Creation of a more equitable, responsive, and financially sustainable public transport network. Ability to model and mitigate the mobility impacts of major urban developments with high precision.
Risk Assessment		
Data Inaccuracy Leading to Poor Decisions: Systematic under/over-counting could lead to harmful service cuts or misplaced investments. Mitigation: Implement rigorous, ongoing calibration and validation routines (e.g., periodic manual audits). Use data quality scores to weight the influence of data in decisions. Privacy Erosion & Function Creep: While anonymous, the detailed spatial-temporal data could be de-anonymized or combined with other datasets to track individuals. Pressure to use sensors for security surveillance. Mitigation: Enforce strict data anonymization and aggregation policies at the source. Establish a clear, public data governance charter that prohibits repurposing for surveillance. Equity Paradox: Optimization based purely on passenger counts can lead to service rationalization in low-ridership, socially necessary areas. Mitigation: Balance efficiency metrics with mandatory accessibility and coverage metrics in service planning. Use the data to identify and better serve latent demand in underserved communities.		
Enabling Environment for Technology Deployment		
Investment cycles		

	Primary Focus	Investment Type	Intensity
Short-term	Fleet-wide sensor deployment and data integration	Public fleet CAPEX, grants for modernization	MEDIUM-HIGH (hardware, installation)

Medium-term	Predictive analytics platforms and real-time tools	SaaS subscriptions, public data platform funds	MEDIUM (software, cloud infrastructure)
Long-term	Multimodal analytics and digital twin integration	Institutional investment, in-house data science units	MEDIUM (sustained analytics, R&D)
Infrastructure readiness			
	Primary Enabler	Readiness Level	Key Build-Out
Short-term	Onboard connectivity (4G/5G) for data transmission	Available on modern fleets	Cloud data repository and ETL pipelines
Medium-term	Cloud/edge computing platforms and city data APIs	Widely available	Integrated demand intelligence platform
Long-term	High-fidelity urban digital twins	Deployed in leading cities	Calibrated simulation models for network planning
Regulatory Maturity			
	Primary Focus	Status	Key Milestone
Short-term	Mandated automated counting in service contracts	Included in new procurements	Minimum data quality standards defined
Medium-term	Open data mandates for anonymized load data	Policies enacted	Historical occupancy published as open data
Long-term	Performance-based funding tied to crowding KPIs	Regulatory framework established	Funding linked to verified passenger load metrics
Market absorption capacity			
	Adoption Phase	Value Migration	Key Players
Short-term	Early adopters (large transit agencies)	Hardware and basic reporting platforms	Specialized sensor manufacturers, vehicle OEMs
Medium-term	Early majority (regional and mid-sized operators)	End-to-end Demand Intelligence Platforms	Passenger analytics SaaS providers, telecom IoT bundles
Long-term	Late majority / Standard equipment	AI insights and data science consulting	In-house public authority units, specialized analytics firms
Good practices			
CIVITAS Dynamic Passenger Information Systems CIVITAS projects integrate passenger counting and real-time data into dynamic passenger information systems to support service optimization. These systems improve planning accuracy, service reliability, and passenger experience through data-driven decision-making. Link: https://civitas.eu/mobility-solutions/increasing-the-accessibility-of-bus-stops-and-the-attractiveness-of-public **Real-Time Passenger Information System (RTPIS) implementation**			

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Peer-reviewed research on RTPIS demonstrates how passenger counting, GPS tracking, and real-time analytics can optimize fleet management and provide accurate arrival predictions. Such systems improve operational efficiency and make public transport more attractive and reliable. Link: https://arxiv.org/abs/1206.0447

2.2. Micromobility

This section presents the technology roadmaps regarding micromobility.

2.2.1. Micromobility System Mobile App

Technology Roadmap Profile
Technology name
Micromobility System Mobile App
Description (current)
A mobile/web application that provides real-time tracking and analytics for shared e-bikes. It optimizes vehicle distribution, reduces congestion, and supports data-driven decision-making for cities and operators. The mobile app allows users to locate docking stations and securely lock and unlock conventional and electric bicycles. The system can also accommodate certain types of electric scooters. Users located more than 700 metres from a station can reserve an available docking position for up to one hour. The application supports secure bicycle parking and enables users who are more than 700 metres from a station to reserve an available docking position for up to one hour. Stations can also be organised according to predefined criteria. The app enhances service accessibility and operational efficiency for dock-based micro-mobility systems.
Roadmap Horizon
Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)
Strategic Objective
To transform shared micromobility from a standalone service into a fully integrated, efficient, and equitable component of the public transport ecosystem, contributing to a measurable reduction in private car use for short urban trips.
Temporal Layer: Evolution Pathway & Sequencing
Short-Term Trajectory: Managed Fleet Operations, Basic MaaS Integration
Deployment and optimization of pilot technologies (e.g., fleet telematics, user apps) within pilot zones. Achieve basic data exchange with public transport APIs for journey planning. Implement and test regulatory sandboxes for geofenced parking and speed compliance.
Medium-Term Trajectory: Dynamic Corridor & Geofencing, Predictive Fleet AI, Full MaaS Fulfillment

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Implement AI-driven predictive rebalancing using historical and real-time data from integrated city systems (traffic lights, event calendars). Micromobility becomes a standard routing option in public transport trip planners, with integrated ticketing and payment. Deployment of smart docking stations with occupancy sensing and opportunistic charging.		
Long-Term Trajectory: Autonomous Rebalancing, Symbiotic Infrastructure & Energy Grid		
Integration with CAV corridors and traffic management systems, where micromobility vehicles act as connected probes providing hyper-local data. Exploration of lightweight autonomous vehicles for overnight fleet rebalancing. Vehicle-to-Grid (V2G) capabilities where e-bike/e-scooter batteries support local grid stability.		
Technology Layer: Key Enabling Technologies		
Key Enabling Technologies		
IoT Fleet Telematics, Mobile User Applications, Micromobility Data Specification (MDS), AI/ML Predictive Analytics, Smart Docking Infrastructure, V2X Communication Modules		
	Dependencies	R&D Priorities
Short-term	Stable 4G/5G coverage, adoption of open data standards (e.g., MDS, GTFS-Flex) by operators and cities.	Standardized Impact Metrics, Foundational AI for Single-Operator Optimization, Low-Power, Cost-Effective IoT Sensors
Medium-term	Ubiquitous low-power urban IoT networks, mature AI tools for urban mobility, standardized payment and identity APIs.	Advanced AI for Multi-Operator & City-Wide Optimization, Integrated V2X Communication Prototypes, Interoperable Battery & Charging Ecosystems
Long-term	Mature V2X ecosystem, high-accuracy urban digital twins, advanced battery and charging standards.	Robust V2X Systems, AI for Autonomous Fleet Management, Behavioral & Systemic Modeling Tools
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution
Short-term	Establish clear data-sharing agreements and "Mobility Data Trusts" between operators and cities.	Market consolidates among private operators, with new B2B SaaS firms specializing in operations software and regulatory compliance. Niche firms emerge to help operators comply with city data-sharing mandates and reporting rules. Cities launch basic data portals to aggregate operator information for multi-modal journey planning.
Medium-term	Develop city ordinances that mandate integration into MaaS platforms for operating licenses. Update street design manuals to include physical and digital micromobility infrastructure.	New "Mobility Integrator" companies operate white-label super-apps for cities, managing the customer interface while operators focus on fleet service.

		A robust market for third-party "Fleet Optimization as a Service" and advanced urban analytics sold to city governments emerges. Governed Mobility Data Trusts are established to enable secure, standardized data exchange and explore anonymized data value
Long-term	National/regional regulations for safety and communication standards of light electric vehicles, including potential automated functions.	Micromobility evolves into a regulated public utility, with public agencies managing integration, pricing, and data as part of the core transit network. Major automotive and energy firms integrate micromobility into their portfolios, using fleets as distributed energy assets. Companies provide integrated "Mobility Zones," bundling smart infrastructure, priority lanes, and management software as a single product.
Barriers		
Technological: Fragmented data standards, high cost of durable IoT hardware. Financial: High upfront capital for smart physical infrastructure; uncertain ROI for advanced features. Regulatory/Social: Public resistance to sidewalk clutter; liability frameworks for automated operations; equity of access.		
Implications for Decision-Makers		
	Recommended Actions	Expected Impacts
Short-term	Mandate MDS compliance in all new micromobility permits. Launch a pilot for integrated journey planning with one operator.	Increased mode share for micromobility, reduced average vehicle rebalancing time.
Medium-term	Co-invest with operators in smart docking/parking zones in high-demand areas. Develop a city-specific "Micromobility Integration Strategy."	Increased First/last-mile connection to transit hubs, reduced user complaints about parking/availability.
Long-term	Issue a tender for a city-wide, multi-operator management and data platform incorporating AI rebalancing.	Reduced congestion and emissions on key corridors, increased resilience of local energy grid
Risk Assessment		
Technology Lock-in: Over-reliance on a single vendor's proprietary system. Mitigation: Insist on open standards. Equity Gap: Advanced services only deployed in high-income areas. Mitigation: Link deployment mandates to equitable geographic coverage. Data Privacy: Centralized tracking raises surveillance concerns. Mitigation: Implement Privacy by Design principles and transparent data governance.		

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Enabling Environment for Technology Deployment			
Investment cycles			
	Primary Focus	Investment Type	Intensity
Short-term	Fleet telematics and app development	VC in micromobility startups, private operator CAPEX	HIGH (fleet expansion, software development)
Medium-term	Smart docking infrastructure and MaaS integration	Public-private partnerships, infrastructure funds	MEDIUM-HIGH (smart hubs, platform integration)
Long-term	Autonomous rebalancing and V2G capabilities	Institutional investment, energy utility partnerships	MEDIUM (R&D, specialized automation fleets)
Infrastructure readiness			
	Primary Enabler	Readiness Level	Key Build-Out
Short-term	4G/5G coverage in urban areas	Widely available	Geofencing enforcement infrastructure
Medium-term	Low-power IoT networks and smart docking stations	Pilot deployments	City-wide smart parking hub network
Long-term	V2X ecosystem and urban digital twins	Emerging in leading cities	Integrated C-ITS and charging grid infrastructure
Regulatory Maturity			
	Primary Focus	Status	Key Milestone
Short-term	Data sharing mandates (MDS) and permit systems	Enacted in leading cities	Standardized data reporting required for operating permits
Medium-term	MaaS integration ordinances and street design updates	Frameworks under development	Mandatory integration into public transport apps
Long-term	National safety and communication standards for LEVs	Drafting stage	Regulatory classification as regulated public utility
Market absorption capacity			
	Adoption Phase	Value Migration	Key Players
Short-term	Early adopters (tech-savvy urban users, tourists)	Standalone micromobility apps	Private operators (Lime, Tier), B2B compliance software firms
Medium-term	Early majority (commuters, transit users)	Integrated MaaS platforms, fleet optimization services	Mobility integrators, third-party analytics providers
Long-term	Late majority / Mainstream urban transport	Regulated mobility utility, distributed energy services	Public agencies, automotive OEMs, energy utilities
Good practices			
Lime			

Lime's app enables users to locate, unlock, and pay for e-scooters and e-bikes while providing real-time fleet data and geofencing compliance. Cities use Lime's data dashboards to optimize fleet distribution and reduce congestion. Link: https://www.li.me **Beryl** Beryl provides an integrated app for bike/scooter sharing with features like parking compliance, real-time availability, and user incentives. It supports city authorities with detailed operational analytics for planning and regulation. Link: https://beryl.cc

2.2.2. Traffic Volume and Speed Measurement Devices

Technology Roadmap Profile
Technology name
Traffic Volume and Speed Measurement Devices
Description (current)
Traffic volume and speed measurement technology encompasses a range of different systems and sensors that enable the collection of data on the number of vehicles, their speeds, vehicle types, direction of movement and other traffic parameters. These devices are essential for traffic planning, increasing safety and enforcing law enforcement. The goal of such a system is to continuously collect data on traffic flows of cyclists and other vehicles moving along the cycle path and use them for analysis and forecasts in order to make the best possible decisions in the field of traffic regulation and management, as well as promotion for the purpose of tourism. Technologies include inductive loops, piezoelectric sensors, radar, lidar, thermal cameras, and acoustic arrays, deployed as permanent installations or temporary, mobile units.
Roadmap Horizon
Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)
Strategic Objective
To evolve from discrete, point-based data collectors into a pervasive, intelligent sensing network that provides a real-time, multi-modal "heartbeat" of the transport network. The objective is to enable proactive traffic management that reduces congestion, improves road safety (particularly for Vulnerable Road Users) by reducing incidents, and supports data-driven policy and infrastructure investments for sustainable mobility.
Temporal Layer: Evolution Pathway & Sequencing
Short-Term Trajectory: Multi-Modal Detection & Network Densification
Technology Shift: Move from single-mode (vehicular) to multi-modal sensors capable of reliably counting and classifying cars, trucks, motorcycles, bicycles, and pedestrians at the same location. Network Expansion: Strategic deployment of cost-effective, wireless IoT sensors (e.g., radar, thermal) to fill critical gaps in the measurement network, especially on secondary roads, bike lanes, and pedestrian crossings.

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Data Integration: Aggregation of point data into a centralized Traffic Data Lake with standardized formats (e.g., DATEX II), providing a unified view for analysis. Basic Safety Applications: Use speed/volume data for dynamic speed display signs and identification of high-risk corridors.
Medium-Term Trajectory: Real-Time Network Analytics & Predictive Management
Edge Intelligence: Sensors with embedded AI perform real-time analytics at the edge (e.g., detecting near-miss events, classifying aggressive driving, identifying wrong-way cyclists). Predictive Traffic Modeling: AI fuses historical and real-time volume/speed data with events, weather, and work zones to predict congestion and safety hotspots 30-60 minutes in advance. Dynamic Policy Enforcement: Data directly feeds adaptive traffic control systems and dynamic lane management (e.g., reversible lanes, bus/taxi lane access based on congestion). Mobility-as-a-Service (MaaS) Integration: Real-time network performance data (speeds on key corridors) becomes a critical input for multi-modal journey planners to suggest reliable routes.
Long-Term Trajectory: Cooperative Sensing Fabric & Proactive System Optimization
V2X-Enhanced Sensing: Fixed sensors evolve into Cooperative ITS Roadside Units (RSUs), bi-directionally exchanging data with connected vehicles (CVs) to validate and enhance measurements, creating a hyper-accurate, composite picture of traffic. Federated & Mobile Sensing: Fixed sensor data is fused with probe data from fleets (buses, taxis) and connected private vehicles to create a seamless, city-wide traffic state map without requiring sensors on every street. System-Wide Prescriptive Control: The system moves from prediction to prescription, automatically suggesting or enacting network-wide interventions (e.g., coordinated signal timing, dynamic rerouting via navigation apps, variable pricing) to optimize for overarching goals (safety, emissions, throughput). Infrastructure Health Monitoring: Sensors double-duty to monitor road surface condition (via vibration/acoustic data) and infrastructure stress.
Technology Layer: Key Enabling Technologies
Key Enabling Technologies
Multi-Modal Detection Sensors (Radar, Lidar, Thermal, Acoustic), Wireless IoT Communication Protocols (LoRaWAN, 5G, NB-IoT), Edge Computing & AI Accelerator Modules, Data Fusion & Digital Twin Platforms, V2X Communication (C-V2X, DSRC) Roadside Units (RSUs), Standardized Traffic Data Formats (DATEX II, SENSORIS)

	Dependencies	R&D Priorities
Short-term	Ubiquitous and affordable power/connectivity at deployment sites. Standardized data schemas for multi-modal counts (bikes, pedestrians).	R&D into low-cost, ruggedized multi-modal sensors with low power consumption. Algorithm development for accurate classification in mixed traffic (e.g., bike vs. scooter). Development of self-calibrating sensors to reduce maintenance.
Medium-term	Maturity of AI-at-the-edge toolkits and hardware. Availability of high-quality contextual data feeds (weather, events).	AI models for predictive traffic state estimation and anomaly detection (e.g., stalled vehicle). R&D into privacy-preserving data aggregation from high-

		resolution sensors. Cyber-security frameworks for distributed IoT traffic networks.
Long-term	Widespread deployment of V2X-enabled vehicles and roadside units. Legal frameworks for data sharing between public and private entities (e.g., probe data from private nav companies).	Sensor fusion algorithms for combining fixed, mobile, and connected vehicle data. R&D into "collective perception" where RSUs build a shared environmental model. Development of explainable AI (XAI) for prescriptive control actions to ensure operator trust.
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution
Short-term	Develop national/regional specifications for multi-modal traffic data collection to ensure comparability. Mandate open data publication of non-sensitive historical traffic volume/speed data.	Growth of specialized "Smart Infrastructure" IoT sensor firms. Traditional traffic equipment manufacturers pivot to offer AI-enabled, multi-modal sensor suites. Emergence of Traffic Data as a Service (TDaaS) startups aggregating data from various sources.
Medium-term	Establish public-private data sharing agreements to incorporate commercial fleet and navigation app probe data into public traffic models. Create regulatory frameworks for dynamic traffic management (e.g., legally defining dynamic lanes).	Market consolidates around providers of end-to-end "Traffic Intelligence Platforms" (sensors, comms, analytics, visualization). Major cloud providers (AWS, Azure, Google) offer vertically integrated traffic management solutions.
Long-term	Enact regulations defining traffic data as critical national infrastructure, with associated security and resilience requirements. Develop liability frameworks for AI-driven traffic control decisions.	The sensing hardware becomes a utility; value is entirely in the data, analytics, and control algorithms. Potential for a publicly owned or regulated traffic data utility model to prevent private monopolies on network state information.
Barriers		
Technological: Accuracy and reliability in adverse weather (snow, heavy rain). High cost and complexity of maintaining a dense, city-wide sensor network. Power and connectivity challenges in remote or scenic tourist areas. Financial: Significant capital expenditure for network deployment and periodic technology refresh. Ongoing OPEX for data management, analytics, and maintenance. Difficulty quantifying direct ROI for advanced predictive capabilities. Regulatory/Social: Public perception of surveillance, especially with cameras/lidar. Privacy concerns around high-resolution tracking, even of anonymous vehicles. Bureaucratic silos between road agencies, traffic police, and tourism/promotion bodies hindering integrated data use.		
Implications for Decision-Makers		
	Recommended Actions	Expected Impacts

Short-term	1. Develop a multi-modal traffic data strategy identifying key corridors for bikes and vehicles, and procure modular, multi-classification sensors. 2. Establish an open traffic data portal publishing volumes, speeds, and basic safety metrics.	Evidence-based identification of safety blackspots and congestion pinch points. Improved tourism planning through data on seasonal traffic flows to scenic areas.
Medium-term	1. Integrate real-time traffic data feeds into the city's Digital Twin and traffic control center for live monitoring and AI-assisted decision-making. 2. Pilot dynamic management schemes (e.g., time-of-day bike lane usage, summer tourist traffic routing) based on predictive analytics.	Measurable reduction in peak-hour congestion and travel time variability. Enhanced safety through proactive intervention at predicted high-risk locations and times.
Long-term	1. Co-invest with vehicle OEMs/navigation providers in a federated traffic data ecosystem to achieve comprehensive coverage. 2. Implement policy levers (e.g., dynamic pricing, access regulations) informed by the system-wide optimization model, with clear public communication.	Optimization of the entire transport network for multi-objective outcomes (safety, efficiency, emissions, equity). Establishment of a resilient, data-driven foundation for the era of connected and automated mobility (CAM).

Risk Assessment
Data Bias & Incomplete Picture: Sensors may be disproportionately deployed on major roads, creating a biased dataset that overlooks neighborhood cut-through traffic or informal paths. Mitigation: Develop an equity-focused sensor deployment plan and supplement with mobile data collection (e.g., temporary counts) in underrepresented areas. Over-Reliance on Automation & Deskilling: Traffic managers may become overly dependent on AI recommendations, losing situational awareness and manual override skills. Mitigation: Design systems for human-in-the-loop control, where AI provides recommendations but humans make final decisions, backed by continuous training. Privacy & Mission Creep: High-fidelity data, especially from cameras, could be repurposed for mass surveillance or law enforcement beyond traffic safety. Mitigation: Enforce strict data governance policies with purpose limitation. Use privacy-enhancing technologies (PETs) like anonymization at source and aggregation. Implement transparent oversight and public reporting on data use.

Enabling Environment for Technology Deployment			
Investment cycles			
	Primary Focus	Investment Type	Intensity
Short-term	Multi-modal sensor deployment and network densification	Public infrastructure CAPEX, grant programs	MEDIUM-HIGH (sensors, installation)
Medium-term	Edge AI integration and predictive analytics platforms	Smart city innovation funds, SaaS subscriptions	MEDIUM (AI development, platform scaling)

Long-term	V2X RSU deployment and federated sensing networks	Infrastructure renewal funds, public-private data partnerships	HIGH (city-wide sensing fabric, system integration)
Infrastructure readiness			
	Primary Enabler	Readiness Level	Key Build-Out
Short-term	Power and connectivity at sensor locations	Variable, requires targeted upgrades	Wired/wireless backhaul to traffic cabinets
Medium-term	Edge computing nodes and city data platforms	Pilots in major corridors	Distributed AI processing at intersections
Long-term	V2X roadside units and digital twin platforms	Deployed in testbeds	City-wide cooperative sensing and communications network
Regulatory Maturity			
	Primary Focus	Status	Key Milestone
Short-term	Multi-modal data collection standards	National/regional specifications emerging	Standardized formats for bike/pedestrian counts
Medium-term	Public-private data sharing frameworks	Early agreements with navigation providers	Probe data integrated into public traffic models
Long-term	Traffic data as critical infrastructure designation	Under consideration	Security and resilience requirements mandated
Market absorption capacity			
	Adoption Phase	Value Migration	Key Players
Short-term	Early adopters (large cities, road authorities)	Smart infrastructure IoT sensors	Specialized sensor firms, traditional traffic equipment suppliers
Medium-term	Early majority (regional authorities, mid-sized cities)	End-to-end Traffic Intelligence Platforms	Major cloud providers, system integrators
Long-term	Late majority / Ubiquitous deployment	Data analytics and control algorithms	Public data utilities, cloud/AI platform firm
Good practices			
Vivacity Labs Vivacity Labs deploys AI-powered sensors that detect and classify vehicles, cyclists, and pedestrians in real time. Their systems support safety analysis (e.g., near-miss detection) and data-driven traffic management. Link: https://vivacitylabs.com **TomTom** TomTom collects anonymized probe vehicle data to measure traffic speed, congestion, and travel times globally. Cities use this data for planning, performance monitoring, and real-time traffic management.			

Link: https://www.tomtom.com/traffic-index

2.2.3. Shared mobility vehicles (e-bikes and e-scooters)

Technology Roadmap Profile
Technology name
Shared mobility vehicles (e-bikes and e-scooters)
Description (current)
An e-bike/e-scooter system in a city consists of a connected network of electric bicycles/e-scooters integrated with a digital platform for shared use. It enhances urban mobility by offering a sustainable, efficient, and flexible transportation option.
Roadmap Horizon
Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)
Strategic Objective
To evolve shared micromobility from a disruptive, standalone service into a fully regulated, seamlessly integrated, and equity-focused component of the urban transport ecosystem. The objective is to increase the mode share of sustainable micromobility for trips under 5km, reduce private car usage for short urban trips, and create a safe, orderly, and universally accessible service that complements public transit and active travel networks.
Temporal Layer: Evolution Pathway & Sequencing
Short-Term Trajectory: Regulation, Integration & Fleet Management
Regulatory Framing: Cities implement permit systems mandating data sharing (MDS/GBFS), geofenced parking, speed limits, and equitable service areas. Basic Multimodal Integration: Shared e-bikes/scooters appear as a routing layer in public transport journey planners, with basic payment integration (single app, separate checkout). Fleet Management Maturity: Operators deploy AI-driven predictive rebalancing to meet demand and comply with parking rules. Swappable battery systems become standard to reduce dead-mileage for charging. Safety & Enforcement: Pilot camera-based sidewalk riding detection and mandatory in-app rider safety tutorials.
Medium-Term Trajectory: Physical & Digital Infrastructure Fusion
Infrastructure Integration: Deployment of smart docking/parking hubs with occupancy sensing, opportunistic charging, and integration into street furniture (e.g., smart lampposts). These become designated Mobility Hubs co-located with transit stops. Seamless MaaS: Full Mobility-as-a-Service (MaaS) integration with unified identity, booking, and payment across public transport, micromobility, and taxis. Dynamic pricing packages (e.g., monthly "all-access" pass) emerge. Vehicle-to-Infrastructure (V2I): E-scooters/e-bikes become connected probes, providing hyper-local data on road surface conditions, near-miss hotspots, and air quality to city dashboards.

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Advanced Safety Systems: Introduction of acoustic vehicle alerting systems (AVAS) for quiet vehicles and on-board ADAS (e.g., blind-spot warnings, automatic emergency braking).		
Long-Term Trajectory: Autonomous Operations & Energy Grid Symbiosis		
Autonomous Rebalancing & Maintenance: Lightweight autonomous utility robots or self-riding vehicles perform overnight fleet rebalancing, charging, and minor repairs, drastically reducing operational costs and congestion. Symbiotic Energy Infrastructure: Fleet batteries form a distributed energy resource. Vehicle-to-Grid (V2G) and Vehicle-to-Building (V2B) capabilities allow parked vehicles to support local grid stability and power public infrastructure. Full C-ITS Integration: Micromobility is fully integrated into the Cooperative Intelligent Transport System (C-ITS), receiving and broadcasting SPAT/MAP messages and intersection collision warnings via C-V2X. Material & Circular Economy: Vehicles are designed for full circularity with modular, repairable components and standardized batteries, minimizing waste.		
Technology Layer: Key Enabling Technologies		
Key Enabling Technologies		
IoT Fleet Telematics & Swappable Battery Systems, Geofencing & Compliance Technology, AI/ML for Predictive Rebalancing & Demand Forecasting, Smart Docking & Charging Infrastructure, C-V2X Communication Modules, Lightweight Autonomous Navigation Systems, Advanced Rider Assistance Systems (ARAS)		
	Dependencies	R&D Priorities
Short-term	Ubiquitous 4G/5G coverage. Widespread adoption of open data standards (MDS, GBFS) by operators and cities. Stable regulatory frameworks.	Standardized safety and impact metrics. Low-cost, durable IoT and battery sensors. AI for single-operator fleet optimization in complex urban environments.
Medium-term	Deployment of public smart street furniture with power/data. Mature digital identity and payment APIs. Development of city digital twins.	AI for multi-operator, city-wide fleet optimization. Interoperable battery & charging ecosystems. V2X communication prototypes for lightweight vehicles.
Long-term	Mature V2X ecosystem and communication standards. Advanced battery tech (solid-state). Regulatory frameworks for light autonomous vehicles.	AI for autonomous fleet management and maintenance. Robust V2G/V2B systems and business models. Advanced materials for longer-lasting, recyclable vehicles.
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution
Short-term	Establish clear data-sharing agreements and "Mobility Data Trusts" between operators and cities. Define liability frameworks for accidents and data breaches.	Market consolidation among private operators. Emergence of B2B SaaS firms specializing in fleet management, compliance, and analytics software.
Medium-term	Develop ordinances mandating integration into MaaS platforms for operating licenses. Update street design	Rise of "Mobility Integrator" companies operating white-label super-apps for cities. Growth of third-party "Fleet Optimization as a Service" providers.

	manuals to include physical and digital micromobility infrastructure (docks, lanes).	
Long-term	Enact national/regional regulations for safety, communication, and automated operations of light electric vehicles. Treat micromobility as a regulated public utility with service obligations.	Micromobility becomes a core public transport service, often operated under franchise by private firms or public agencies. Automotive and energy firms deeply integrate micromobility into portfolios as distributed energy assets.
Barriers		
Technological: Battery lifecycle and range limitations. Durability and vandalism of vehicles. High cost of smart physical infrastructure. Financial: High upfront capital for fleets and charging networks. Uncertain profitability leading to operator churn. Municipal costs for enforcement and infrastructure. Regulatory/Social: Public resistance to sidewalk clutter and rider behavior. Safety conflicts with pedestrians and cyclists. Equity gaps in service deployment and digital literacy requirements.		
Implications for Decision-Makers		
	Recommended Actions	Expected Impacts
Short-term	1. Mandate MDS/GBFS compliance in all operating permits. 2. Designate and enforce parking/corridor geofences in partnership with operators.	Increased mode share for micromobility. Reduced sidewalk clutter and improper parking. Data-rich understanding of trip patterns.
Medium-term	1. Co-invest with operators in smart mobility hubs at key transit stations. 2. Issue an RFP for a city-wide integrated MaaS platform including micromobility.	Increased first/last-mile connectivity to transit. Reduced vehicle rebalancing traffic and emissions. Seamless user experience across modes.
Long-term	1. Develop a "Micromobility Master Plan" integrating dedicated lanes, charging grid, and C-ITS. 2. Establish a public or public-private entity to oversee the integrated system as a sustainable mobility utility.	Significant reduction in private car use for short trips. Enhanced resilience of local energy grid. Safe, orderly, and equitable access to lightweight electric mobility.
Risk Assessment		
Market Consolidation & Monopoly: A single operator or platform gains dominant market power, reducing competition and city leverage. Mitigation: Promote open standards and interoperability to lower barriers to entry. Consider multi-operator permits and non-exclusive contracts. Equity and Accessibility Divide: Service clusters in high-income, high-density areas, exacerbating transport poverty. Mitigation: Link permits to equitable service area requirements and subsidized pricing tiers. Co-locate hubs with social housing and key services. Public Space Conflict and Safety Deterioration: Proliferation of vehicles leads to pedestrian conflicts and discourages walking/cycling. Mitigation: Enforce strict riding and parking regulations with fines and penalties. Invest in dedicated, protected infrastructure (cycle lanes) to separate modes.		
Enabling Environment for Technology Deployment		

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Investment cycles			
	Primary Focus	Investment Type	Intensity
Short-term	Fleet deployment and regulatory compliance	Private operator CAPEX, VC funding	HIGH (vehicle procurement, market expansion)
Medium-term	Smart docking hubs and MaaS platform integration	Public infrastructure funds, PPPs	MEDIUM-HIGH (physical infrastructure, software integration)
Long-term	Autonomous rebalancing fleet and V2G infrastructure	Institutional investment, energy utility CAPEX	MEDIUM (specialized robotics, grid integration)
Infrastructure readiness			
	Primary Enabler	Readiness Level	Key Build-Out
Short-term	4G/5G coverage and swappable battery networks	Expanding coverage	Charging stations, operator depots
Medium-term	Smart docking stations with opportunistic charging	Pilot deployments	Mobility hubs at transit stations and key corridors
Long-term	V2X roadside units and grid-interactive charging infrastructure	Emerging standards and pilots	City-wide charging grid and C-ITS integration
Regulatory Maturity			
	Primary Focus	Status	Key Milestone
Short-term	Permit systems with data sharing and geofencing mandates	Enacted in leading cities	MDS/GBFS compliance required
Medium-term	MaaS integration ordinances and street design updates	Frameworks under development	Mandatory inclusion in public transport journey planners
Long-term	National safety, communication, and automated operations regulations	Drafting stage	Regulatory framework for autonomous rebalancing and V2G
Market absorption capacity			
	Adoption Phase	Value Migration	Key Players
Short-term	Early adopters (young urban users, tourists)	Private micromobility operators	Lime, Tier, Dott, Voi
Medium-term	Early majority (commuters, transit users)	Fleet optimization software, MaaS platforms	Mobility integrators, B2B SaaS firms
Long-term	Late majority / Regulated public utility	Distributed energy services, integrated mobility-as-a-utility	Public transit agencies, automotive OEMs, energy utilities
Good practices			
Tier Mobility			

Tier operates shared e-scooter and e-bike systems integrated with public transport apps and MaaS platforms. It uses swappable batteries and geofencing to improve sustainability and compliance. Link: https://www.tier.app **Nextbike** Nextbike operates large-scale bike-sharing systems across Europe with app-based access and integration into local transport networks. Its systems support station-based and hybrid models for better urban coverage. Link: https://www.nextbike.net

2.3. Urban mobility management

This section presents the technology roadmaps regarding urban mobility management.

2.3.1. GIS Public Transport Cadastre

Technology Roadmap Profile
Technology name
GIS Public Transport Cadastre
Description (current)
GIS (Geographic Information System) Public Transport Cadastre is a digital, map-based system that collects, manages, and displays geographic data related to public transport infrastructure and services. It includes information such as routes, stops, stations, service areas, etc. By integrating spatial and attribute data, this system helps authorities, planners, and the public to visualise, analyse, and improve public transport networks for better accessibility, planning, and decision-making.
Roadmap Horizon
Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)
Strategic Objective
To evolve the GIS Public Transport Cadastre from a static registry of assets into a dynamic, real-time "Central Nervous System for Urban Mobility," integrating the physical, operational, and demand layers of transport. The objective is to enable proactive, evidence-based planning that increases public transport mode share, improves service accessibility for 100% of residents, and optimizes infrastructure investments by reducing planning errors and cost overruns.
Temporal Layer: Evolution Pathway & Sequencing
Short-Term Trajectory: Foundation of a Unified Digital Twin & Open Data
Consolidation & Standardization: Create a unified, cloud-based geospatial database integrating all disparate datasets (routes, stops, signals, sidewalks) using common standards (GTFS, INSPIRE). Mandate GTFS static data publication by all operators.

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Basic Digital Twin: Develop a 2.5D/3D foundational Digital Twin of the transport network, incorporating terrain, buildings, and cadastral parcels for basic visual analysis and public engagement. Field Data Collection Modernization: Equip inspectors with mobile GIS apps for real-time field updates, enabling instantaneous corrections to the live cadastre (e.g., new bus shelter installed, pothole reported). Public Portal Launch: Release an interactive public web map showing routes, stops, and real-time service status (via GTFS-RT), building public trust and data literacy.
Medium-Term Trajectory: Real-Time Operational Intelligence, Predictive Mobility Analytics & Multi-Modal Integration
Live Data Integration: Fully integrate real-time data feeds—vehicle locations (AVL), passenger counts, traffic signal status, roadworks—transforming the cadastre into a live operational dashboard. Predictive Analytics Layer: Embed AI/ML models to simulate and predict impacts of service changes, land-use developments, or disruptions on ridership, accessibility, and network performance. Multi-Modal & Land-Use Fusion: Systematically integrate data on cycling networks, micromobility zones, and pedestrian flows to enable true multi-modal corridor planning. Link deeply with land-use and zoning data to model transit-oriented development (TOD) potential. Automated Compliance & Change Detection: Use satellite/AI imagery analysis to automatically detect unauthorized encroachments on transport corridors or changes in infrastructure, triggering alerts.
Long-Term Trajectory: Autonomous, Prescriptive & Ecosystem-Integrated Platform
Prescriptive Planning AI: The system evolves to offer prescriptive recommendations for network design, stop placement, and infrastructure upgrades based on multi-objective optimization (equity, efficiency, sustainability, cost). CAV & C-ITS Ready Cadastre: The cadastre becomes the authoritative digital map (HD Map) layer for Connected and Automated Vehicles (CAVs), containing lane-level geometry, traffic rules, and permanent landmarks with centimeter accuracy. Blockchain for Asset Lifecycle: Implement blockchain-based registries for high-value transport assets (e.g., bridges, stations), recording installation, inspection, maintenance, and ownership history immutably. Federated National/Regional Cadastre: Local cadastres interoperate seamlessly in a federated system, enabling regional journey planning, cross-border infrastructure projects, and macro-scale mobility trend analysis.
Technology Layer: Key Enabling Technologies
Key Enabling Technologies
Cloud-Native Geospatial Databases (PostGIS, cloud data warehouses), Digital Twin Platforms & 3D GIS (Cesium, Esri ArcGIS Urban), Real-Time Data Streaming & Integration Pipelines (Apache Kafka, FME), AI/ML for Spatial Analytics & Predictive Modeling, Mobile GIS & Field Data Collection Applications, High-Definition (HD) Mapping Tools for CAV, Blockchain for Asset Provenance & Data Integrity

	Dependencies	R&D Priorities
Short-term	Political mandate for data sharing across agencies. Ubiquitous high-speed internet for cloud access. Adoption of GTFS/INSPIRE by all relevant entities.	Automated data validation and cleansing tools. Low-cost mobile field data collection kits. Development of simple, public-facing API standards for cadastre data.

Medium-term	Maturity of city-wide IoT sensor networks providing real-time feeds. Advanced cloud computing/AI services accessible to public sector.	AI models for predictive ridership and land-use interaction. Semi-automated feature extraction from satellite/LiDAR imagery. Interoperability frameworks for fusing transport, utility, and land-use data models.
Long-term	Legal frameworks for digital twins as legal documents. Standardization of HD map formats for CAVs (e.g., OpenDRIVE, Lanelet2). Widespread use of decentralized identifiers (DIDs).	AI for generative network design. Privacy-preserving spatial analytics on sensitive data. Blockchain protocols for secure, distributed asset registries across jurisdictions.
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution
Short-term	Enact "Open Transport Data" legislation requiring publication of core cadastre data in GTFS/GeoJSON. Establish inter-agency data-sharing agreements with clear ownership and update protocols.	Growth of specialized GIS consultancies for public sector digitization. Traditional engineering firms expand into digital asset management services. Open-source GIS (QGIS) gains market share in budget-constrained authorities.
Medium-term	Legally recognize the Digital Twin Cadastre as the authoritative record for infrastructure planning and dispute resolution. Develop national standards for transport asset data models (based on Transmodel/NeTEx).	Emergence of "Transportation Digital Twin as a Service" providers from major cloud & GIS platforms. Data integration platform vendors become key partners. Traditional CAD/BIM software firms deepen GIS integration.
Long-term	Regulate liability and updates for CAV-grade HD maps derived from the public cadastre. Establish international treaties for cross-border cadastre data exchange in federated models.	The cadastre platform becomes critical national digital infrastructure. The market bifurcates: public utility model (state-owned platform) vs. regulated private consortium. Value shifts to AI analytics, simulation services, and ecosystem orchestration.
Barriers		
Technological: Legacy data silos in incompatible formats and systems. High cost and complexity of creating and maintaining a high-accuracy, complete 3D digital twin. Ensuring data freshness and synchronization across multiple contributing sources. Financial: Significant upfront investment in software, cloud infrastructure, and skills training. Ongoing costs for data acquisition, updates, and system maintenance. Difficulty quantifying direct ROI for advanced capabilities. Regulatory/Social: Bureaucratic resistance to data sharing and process change. Legal complexities around data ownership, privacy (e.g., depicting private land), and liability for decisions based on cadastre data. Digital divide in public access and engagement.		
Implications for Decision-Makers		
	Recommended Actions	Expected Impacts

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Short-term	1. GIS Public Transport Cadastre project with a mandate to consolidate all existing datasets. 2. Publish GTFS static feeds and a basic public web map to establish transparency and build an open data culture.	Elimination of data conflicts between departments. Faster response to public information requests. Foundation for third-party app development (journey planners).
Medium-term	1. Integrate the cadastre with real-time operational systems (AVL, passenger counts) to create a live management dashboard. 2. Use the cadastre's predictive analytics to pilot new service lines or redesign existing ones based on simulated outcomes.	Data-driven optimization of routes and schedules, improving efficiency and ridership. Proactive identification and resolution of accessibility gaps.
Long-term	1. Formalize the cadastre as the legally recognized "source of truth" for all transport infrastructure planning and asset management. 2. Issue the cadastre's data as a certified HD Map layer to support the safe deployment of CAVs and advanced C-ITS services.	Drastic reduction in planning errors and cost overruns for infrastructure projects. Positioning the city/region as a leader in data-driven governance and future-ready mobility.

Risk Assessment
Data Quality Risk: Poor underlying data renders the sophisticated cadastre useless or misleading. Mitigation: Implement rigorous, ongoing data quality assurance processes and clear metadata on accuracy, source, and date. Start with critical "core" datasets and expand only with validated data. Vendor Lock-in & Technological Obsolescence: Heavy reliance on a single proprietary GIS platform or cloud provider creates long-term dependency and cost. Mitigation: Adopt open standards and open-source components where possible. Ensure data portability and use modular, API-first architecture. Develop in-house expertise. Digital Exclusion & Democratic Deficit: If the primary interface is complex or requires high digital literacy, planning decisions may become less democratic, excluding vulnerable communities. Mitigation: Invest in inclusive public engagement tools (e.g., simplified map interfaces, community workshops using cadastre visuals). Ensure the public portal is accessible and available in multiple languages.

Enabling Environment for Technology Deployment			
Investment cycles			
	Primary Focus	Investment Type	Intensity
Short-term	Data consolidation, cloud migration, and public portal	Public sector CAPEX, grant programs	MEDIUM-HIGH (software, cloud infrastructure, data migration)
Medium-term	Real-time data integration and predictive analytics	Innovation funds, SaaS subscriptions	MEDIUM (AI development, platform scaling, IoT integration)

Long-term	HD mapping for CAV and federated national system	Strategic infrastructure funds, institutional investment	MEDIUM-HIGH (HD mapping, interoperability, long-term maintenance)
Infrastructure readiness			
	Primary Enabler	Readiness Level	Key Build-Out
Short-term	Cloud infrastructure and high-speed internet	Widely available	Centralized geospatial data warehouse
Medium-term	City-wide IoT sensor networks and real-time data feeds	Expanding deployment	Real-time integration pipelines and APIs
Long-term	HD mapping standards and CAV communication infrastructure	Emerging standards	Federated regional/national data exchange platform
Regulatory Maturity			
	Primary Focus	Status	Key Milestone
Short-term	Open transport data legislation	Drafted or enacted in leading regions	Mandated GTFS/GeoJSON publication by operators
Medium-term	Digital twin as legal authoritative record	Frameworks under development	Legal recognition for planning and dispute resolution
Long-term	HD map standards for CAV and cross-border data treaties	Early standardization	Certified public HD map layer for automated vehicles
Market absorption capacity			
	Adoption Phase	Value Migration	Key Players
Short-term	Early adopters (large cities, national transport agencies)	GIS consultancies, open-source GIS tools	Esri, QGIS, specialized geospatial consultants
Medium-term	Early majority (regional authorities, mid-sized cities)	Transportation Digital Twin as a Service	Major cloud platforms (AWS, Azure), GIS vendors (Esri), system integrators
Long-term	Late majority / National digital infrastructure	AI analytics, simulation services, ecosystem orchestration	Public utilities, regulated private consortia, cloud/AI firms
Good practices			
Horizon 2020 DUET DUET developed digital twins integrating GIS, transport, and real-time data to support urban mobility planning and policy testing. It enables simulation of transport scenarios and supports evidence-based decision-making. Link: https://cordis.europa.eu/project/id/870697 **Europe's Rail Joint Undertaking**			

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A European Union public–private partnership focused on advancing research and innovation in rail transportation which involves considerable work on integrated mobility data platforms and digital twins for transport infrastructure. Link: https://rail-research.europa.eu/

2.3.2. Geofencing and restricted access control

Technology Roadmap Profile
Technology name
Geofencing and Restricted Access Control
Description (current)
Geofencing is a location-based technology that uses GPS, RFID, Wi-Fi, or cellular data to create a virtual geographic boundary. When a device or vehicle enters or exits this boundary, a pre-programmed action is triggered—like sending a notification, opening a gate, or logging a data point. Restricted access control is a security method that limits entry or usage of a physical space, or resource to only authorized individuals, vehicles. Access control is a method of regulating who or what can view or use resources in a given environment.
Roadmap Horizon
Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)
Strategic Objective
To evolve geofencing and access control from a tool for static zone enforcement into a dynamic, adaptive, and equitable "Urban Mobility Operating System" layer. This system will intelligently manage demand, space, and emissions in real-time, reducing urban traffic congestion, cutting transport-related emissions in controlled zones, and ensuring safe, prioritized access for essential services and sustainable modes.
Temporal Layer: Evolution Pathway & Sequencing
Short-Term Trajectory: Standardized Deployment & Basic Enforcement
Regulatory & Technical Foundation: Cities implement Low Emission Zones (LEZs) and pedestrian priority zones using fixed geofences with clear rules. Deploy hybrid systems (ALPR cameras + retractable bollards) for physical and digital enforcement. Data Standardization: Develop and adopt open API standards (e.g., extending MDS or GBFS) for geofence definition, permission management, and data exchange between city systems and private fleets (e.g., micromobility, freight). Basic Dynamic Control: Implement time-based rules (e.g., school zones active 7-9am, 2-4pm; night-time delivery windows). Public Communication & Onboarding: Launch public awareness campaigns and mandatory in-app registration/consent for services operating within zones.
Medium-Term Trajectory: Dynamic, Multi-Modal & Integrated Management
Context-Aware Dynamic Geofencing: Zones become adaptive, automatically activating, deactivating, or modifying rules based on real-time data (air quality spikes, major event congestion, emergency vehicle routing). Multi-Modal Priority & Pricing: System implements dynamic pricing and access prioritization. Public transport, shared EVs, and cargo bikes get free/cheaper access; solo combustion vehicles face higher fees or are denied entry during peak pollution/congestion.

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Seamless MaaS Integration: Access control is fully integrated into MaaS platforms. User trips are pre-authorized, and fees are automatically calculated and settled within a mobility wallet. Automated Logistics Management: Freight and delivery geofencing manages curbside access, assigning dynamic loading bays and time slots to reduce double-parking and conflicts.		
Long-Term Trajectory: Predictive, Autonomous & Symbiotic Urban Control		
Predictive & Prescriptive Zoning: AI uses predictive models to pre-emptively adjust zone boundaries and rules hours or days in advance based on forecasts for demand, weather, and events, optimizing the entire network. CAV-Centric Access Control: The system communicates directly with Connected and Automated Vehicles (CAVs) via C-V2X, providing dynamic access permissions, speed advisories, and routing instructions. Physical barriers become obsolete for enforcement against compliant vehicles. Micro-Zoning & Personal Permissions: Hyper-local, temporary "micro-geofences" can be created for micro-events (e.g., a street repair, a pop-up market), with permissions pushed directly to affected users' navigation apps. Symbiotic Urban Management: The access control system is fused with energy grid demand and public space utilization data, managing vehicle access to support grid stability (via managed EV charging/discharging) and optimize the use of street space for multiple functions.		
Technology Layer: Key Enabling Technologies		
Key Enabling Technologies		
High-Accuracy GNSS/GPS & Hybrid Positioning (GNSS+IMU+5G), Automatic License Plate Recognition (ALPR) & Computer Vision, C-V2X / DSRC Communication for Direct Vehicle Signaling, IoT Sensor Networks & Smart Bollards/Gates, Dynamic Policy Management Engines, AI/ML for Predictive Traffic & Demand Modeling, Blockchain/DLT for Secure, Transparent Permission Ledgers		
	Dependencies	R&D Priorities
Short-term	Ubiquitous cellular connectivity (4G/5G). Political consensus to implement zones. Adoption of open geofence data standards by vehicle/device OEMs.	Low-latency, high-reliability zone detection algorithms for mixed GPS environments (urban canyons). Standardized digital permit formats and APIs. Development of low-cost, hybrid ALPR+IoT enforcement nodes.
Medium-term	Widespread vehicle telematics and connected car APIs. Mature city-wide digital twin for simulation. Legal frameworks for dynamic road pricing.	AI for real-time multi-objective optimization of zone rules (balancing congestion, emissions, equity). Privacy-preserving anonymity in movement-based authorization. Interoperability protocols between different enforcement systems (city vs. private parking).
Long-term	High penetration of V2X-enabled vehicles. Legal recognition of digital enforcement (replacing physical barriers). Advanced city-scale simulation tools.	AI for predictive zoning and conflict resolution between competing urban needs. Secure, decentralized identity and permission systems using DLT. Fail-operational enforcement systems for safety-critical zones.
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution

Short-term	Enact local ordinances defining zones, rules, fees, and exemptions (e.g., for residents, disabled). Establish clear data governance for location data collected.	Emergence of specialized "Smart Zoning" software vendors. Traditional traffic enforcement and parking management companies pivot to offer geofencing solutions.
Medium-term	Develop regional/national frameworks for interoperability of zones and digital permits (e.g., a national LEZ permit registry). Legislate principles for dynamic pricing to prevent perceived unfairness.	Market consolidation into "Urban Access Management" platform providers. Navigation and mapping companies (Google, HERE) become essential partners for zone dissemination and in-app compliance.
Long-term	Establish legal equivalence between digital and physical enforcement. Create regulatory bodies to oversee algorithmic fairness in dynamic access and pricing systems.	The system becomes regulated public infrastructure. Value shifts from enforcement to optimization and data services. Potential for public-private utilities to manage the city's "digital curb" and access rights.
Barriers		
Technological: GNSS inaccuracy in urban canyons leading to false triggers. High cost of city-wide, resilient enforcement infrastructure (cameras, comms). Cybersecurity vulnerabilities in a system controlling physical access. Financial: High upfront CAPEX for enforcement hardware and software integration. Ongoing OPEX for maintenance, data management, and customer support. Political difficulty in implementing fees/pricing. Regulatory/Social: Strong public and business resistance to perceived restrictions and "pay-to-enter" schemes. Equity concerns about penalizing lower-income drivers. Privacy fears over pervasive location tracking. Additionally, the current legislative framework is not yet equipped to support dynamic, flexible systems—for road transit, for example. In Italy, any change in zoning currently requires a city ordinance, highlighting the need for legal evolution to enable smart, dynamic traffic management. Furthermore, questions of accountability arise when decisions are automatically determined by artificial intelligence, necessitating clear frameworks for responsibility and governance.		
Implications for Decision-Makers		
	Recommended Actions	Expected Impacts
Short-term	1. Start with a clear, limited pilot zone (e.g., a school street, a small LEZ) to test technology and build public acceptance. 2. Mandate that all shared mobility operators use standardized geofencing APIs for compliance.	Measurable improvement in air quality and safety in the pilot zone. Establishment of a working model for public-private compliance.
Medium-term	1. Develop a city-wide "Dynamic Curb and Access Management Strategy" that integrates geofencing for freight, loading, parking, and pedestrian zones. 2. Integrate access control data with the traffic management center for holistic network optimization.	Reduced congestion and double-parking in commercial areas. Increased efficiency of freight and service deliveries. Data-driven basis for expanding or modifying zones.

Long-term	1. Establish a transparent, independent governance body to oversee algorithmic rules and pricing models for dynamic zones. 2. Phase out physical barriers in favor of digital enforcement as CAV penetration increases, reclaiming street space.	Transformation of city centers into safer, cleaner, and more people-centric spaces. Creation of a flexible urban management tool that can adapt to future mobility paradigms.

Risk Assessment
Digital Divide & Social Inequity: The system may disproportionately impact those who cannot afford newer, compliant vehicles or lack smartphones for digital permits. Mitigation: Implement grace periods, exemptions, and subsidized permits for vulnerable groups. Provide non-digital permit alternatives (e.g., windshield stickers verified by ALPR). Conduct robust equity impact assessments before zone implementation. Systemic Fragility & Cyber-Physical Risk: A cyber-attack could disable enforcement, paralyze access for emergency vehicles, or create chaotic traffic conditions. Mitigation: Design a defense-in-depth architecture with air-gapped safety-critical components. Implement manual override protocols and physical fallbacks. Conduct regular penetration testing and have a comprehensive incident response plan. Mission Creep & Surveillance: Location data collected for access control could be repurposed for mass surveillance or law enforcement beyond its original intent, eroding public trust. Mitigation: Enforce strict purpose limitation and data minimization via legislation and technical design. Implement privacy-preserving analytics (e.g., aggregate data only). Establish independent oversight and public audit of data use.

Enabling Environment for Technology Deployment			
Investment cycles			
	Primary Focus	Investment Type	Intensity
Short-term	Enforcement infrastructure (cameras, bollards) and pilot zones	Public infrastructure CAPEX, municipal budgets	HIGH (hardware, installation, pilot deployment)
Medium-term	Dynamic policy engines and MaaS integration	Smart city innovation funds, PPPs	MEDIUM-HIGH (software platforms, system integration)
Long-term	Predictive AI and V2X-enabled access control	Institutional investment, technology partnerships	MEDIUM (AI R&D, V2X infrastructure, governance bodies)
Infrastructure readiness			
	Primary Enabler	Readiness Level	Key Build-Out
Short-term	ALPR cameras, GNSS coverage, cellular networks	Deployed in major cities	Zone boundary enforcement infrastructure
Medium-term	City-wide IoT and connected vehicle telematics	Expanding coverage	Dynamic policy management platforms
Long-term	V2X roadside units and high-accuracy positioning networks	Pilots and early deployment	Direct vehicle communication infrastructure
Regulatory Maturity			
	Primary Focus	Status	Key Milestone

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Short-term	Local ordinances for LEZs and restricted zones	Enacted in leading cities	Legal framework for geofenced enforcement
Medium-term	Interoperable digital permit frameworks	Regional/national standards emerging	Cross-jurisdictional permit recognition
Long-term	Algorithmic fairness and digital enforcement equivalence	Under consideration	Legal equivalence between digital and physical enforcement
Market absorption capacity			
	Adoption Phase	Value Migration	Key Players
Short-term	Early adopters (major cities with LEZs)	Smart zoning software, enforcement hardware	Specialized software vendors, traffic enforcement firms
Medium-term	Early majority (secondary cities, regional authorities)	Urban Access Management platforms	Mapping and navigation companies (Google, HERE), platform consolidators
Long-term	Late majority / Regulated public infrastructure	Optimization services, data analytics, digital curb management	Public utilities, regulated private operators, cloud/AI firms
Good practices			
London Ultra Low Emission Zone London's ULEZ uses geofencing and camera-based enforcement to restrict high-emission vehicles from entering central areas. It has significantly reduced NO_2 levels and accelerated fleet transition to cleaner vehicles. Link: https://tfl.gov.uk/modes/driving/ultra-low-emission-zone **Vianova** Vianova provides geofencing tools that help cities manage micromobility parking, speed limits, and restricted zones. Its platform enables real-time regulation and data-driven urban mobility policies. Link: https://www.vianova.io			

2.4. Smart mobility infrastructure and integration

This section presents the technology roadmaps regarding Smart mobility infrastructure and integration.

2.4.1. GPRS data exchange/API management platforms

Technology Roadmap Profile
Technology name
GPRS data exchange/API management platforms

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Description (current)
GPRS (General Packet Radio Service) data exchange platforms enable the transmission of mobile data over cellular networks, particularly in scenarios where low-bandwidth, wide-area connectivity is sufficient. These platforms are commonly used in smart mobility applications to transmit small packets of data from mobile units, like vehicles, traffic sensors, or parking meters, to centralized servers or cloud systems. API (Application Programming Interface) management platforms sit on top of these data exchange layers, enabling standardized, secure, and scalable communication between different software systems. They provide developers and system integrators with tools to access, publish, secure, and monitor APIs that are used to share mobility-related data across various stakeholders, including transportation authorities, service providers, and application developers. Together, GPRS data exchange and API management platforms support the real-time collection and dissemination of data such as GPS location, vehicle diagnostics, fare transactions, and traffic conditions. They are especially valuable in environments where devices need to remain connected over long distances without requiring high-speed internet.
Roadmap Horizon
Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)
Strategic Objective
To evolve from a disparate collection of data pipes and APIs into a unified, intelligent, and sovereign "Data Fabric for Mobility," providing seamless, secure, and efficient data exchange across the entire ecosystem. The objective is to reduce system integration costs, increase the velocity of mobility service innovation by enabling new data products, and ensure reliable, real-time data flow even in remote or challenging environments to support equitable service deployment.
Temporal Layer: Evolution Pathway & Sequencing
Short-Term Trajectory: Standardization, Consolidation & Basic Governance
Protocol & Standard Adoption: Widespread adoption of lightweight, efficient protocols (e.g., MQTT, CoAP) over LPWAN (NB-IoT, LTE-M) for IoT sensors, moving beyond basic GPRS. Mandate OpenAPI specifications for all public mobility APIs. API Gateway Consolidation: Cities and major operators deploy centralized API management platforms (e.g., Kong, Apigee) to act as a single point of entry, providing security, rate limiting, and analytics for all mobility data feeds. Developer Ecosystem Activation: Launch public developer portals with sandbox environments, standardized authentication (OAuth 2.0), and clear documentation to lower the barrier for third-party app development. Basic Data Governance: Implement API usage policies, SLAs for data availability, and rudimentary data quality monitoring.
Medium-Term Trajectory: Intelligent Orchestration & Federated Data Mesh
Transition to Data Mesh Architecture: The ecosystem evolves from a centralized API gateway to a decentralized data mesh, where each domain (e.g., traffic management, public transit, parking) owns and exposes its data products via standardized APIs, managed by a federated governance layer. AI-Powered API Orchestration: Introduction of intelligent API gateways that can perform real-time data transformation, enrichment, and routing based on context (e.g., merging GTFS-RT with weather data on-the-fly for a journey planner). Edge-to-Cloud Continuum: Edge API management emerges, allowing data processing and API calls to be executed on vehicle ECUs or roadside units, reducing latency and bandwidth usage for time-critical applications (e.g., collision warnings).

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Automated Compliance & Monetization: Platforms support automated compliance checks (e.g., GDPR data masking) and sophisticated API monetization models (e.g., pay-per-call, tiered subscriptions) to create sustainable data marketplaces.		
Long-Term Trajectory: Sovereign, Cognitive & Self-Healing Data Fabric		
Cognitive Data Fabric: The platform incorporates cognitive AI that understands data semantics, automatically discovers and connects relevant data sources across the mesh, and suggests new data products or integrations to solve emerging mobility challenges. Decentralized Sovereign Identity & Access: API access control moves to decentralized identity frameworks (e.g., SSI, verifiable credentials), allowing users and devices to control and consent to data sharing granularly without a central authority. Self-Healing & Predictive Networks: The data exchange layer becomes predictive and resilient, using AI to anticipate network congestion or device failures, automatically rerouting data flows and pre-fetching/caching critical data to ensure uninterrupted service. Quantum-Resistant & Post-Quantum Cryptography: Integration of quantum-safe encryption protocols into all API communications and data storage to prepare for future threats, ensuring long-term security of mobility data.		
Technology Layer: Key Enabling Technologies		
Key Enabling Technologies		
Low-Power Wide-Area Network (LPWAN) Technologies (NB-IoT, LTE-M, LoRaWAN), API Management & Gateway Platforms (Open Source & Commercial), Lightweight IoT Protocols (MQTT, CoAP), Data Mesh Architecture & Governance Tools, Edge Computing & Edge API Management, AI/ML for API Analytics, Orchestration, and Anomaly Detection, Decentralized Identity (SSI) & Verifiable Credentials, Post-Quantum Cryptography Libraries		
	Dependencies	R&D Priorities
Short-term	Reliable, affordable cellular IoT coverage expansion. Industry consensus on core mobility data schemas (GTFS, SENSORIS, DATEX II).	Development of ultra-low-power, long-range communication modules for remote sensors. Standardized API design patterns for mobility data (e.g., pagination, filtering, error handling).
Medium-term	Widespread adoption of 5G standalone (SA) with network slicing for IoT. Legal frameworks for data product ownership and liability in a data mesh.	AI models for automated API documentation and versioning. Interoperability protocols for seamless edge-to-cloud API orchestration. Privacy-enhancing computation techniques for secure data federation.
Long-term	Global standards for decentralized identity. Maturation of post-quantum cryptography. Development of semantic web/linked data technologies.	Cognitive AI for autonomous data discovery and integration. Self-sovereign identity protocols for machine-to-machine (M2M) communication. Development of "digital data trust" technical frameworks.
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution

Short-term	Establish "Open Mobility Data" mandates requiring core APIs to be publicly available. Develop security certification for API platforms handling sensitive mobility data.	Growth of specialized "Mobility API" management vendors. Telecom operators enhance offerings with IoT connectivity bundled with API management services.
Medium-term	Create data sovereignty and portability regulations ensuring users/agencies can move data between platforms. Establish federated governance bodies for cross-domain data mesh standards.	Emergence of "Mobility Data Mesh" consultancies and platform providers. Traditional system integrators evolve into data product developers. A vibrant marketplace for third-party mobility data products and analytics emerges.
Long-term	Legally recognize decentralized identity and smart contracts for automated data exchange agreements. Regulate algorithms used in cognitive data fabrics for fairness and transparency.	The foundational data exchange layer becomes a regulated utility or commons. Value shifts entirely to the data products, AI insights, and applications built on top. Major cloud providers offer fully managed "Sovereign Mobility Data Fabric" services.
Barriers		
Technological: Legacy systems with proprietary protocols resistant to API-fication. Ensuring low-latency, high-reliability communication for safety-critical applications. Complexity of managing thousands of APIs and microservices at scale. Financial: High initial investment in platform software, developer outreach, and security. Ongoing costs for cloud infrastructure, API monitoring, and support. Unclear business models for open data APIs. Regulatory/Social: Fragmented data privacy laws across regions complicating API design. "Data hoarding" mentality among incumbents resisting open exchange. Skill shortage in API design, data product management, and data mesh governance.		
Implications for Decision-Makers		
	Recommended Actions	Expected Impacts
Short-term	1. Procure or establish a central API management platform for the city/region and mandate its use for all new mobility data projects. 2. Publish 3-5 high-value core datasets (e.g., real-time vehicle positions, static schedules) via well-documented, reliable public APIs.	Dramatic reduction in time and cost for internal and external developers to access data. Stimulation of innovation, leading to new citizen and operational apps.
Medium-term	1. Champion the adoption of a data mesh approach within the transport authority, training domain teams to build and own data products. 2. Launch a federated data marketplace (or catalog) where internal departments and certified external partners can publish and discover data products.	Break down of internal data silos, leading to more holistic analysis and planning. Creation of new revenue streams or cost savings through efficient data reuse and external partnerships.

Long-term	1. Adopt decentralized identity standards for all API access, giving citizens and businesses control over their mobility data sharing. 2. Position the region's data fabric as critical digital infrastructure, investing in its resilience, security, and cognitive capabilities.	Establishment of a trusted, innovative data ecosystem that attracts mobility businesses and talent. Foundation for seamless integration of future technologies (CAVs, MaaS) with minimal friction.

Risk Assessment
Central Point of Failure: Over-reliance on a single API management platform or cloud provider creates systemic vulnerability. Mitigation: Design for multi-cloud/hybrid deployment and federated governance. Ensure contractual and technical exit strategies (data portability, open-source components). API Sprawl & Technical Debt: Proliferation of poorly designed, undocumented, or redundant APIs leads to unsustainable complexity and security gaps. Mitigation: Enforce strict API design and lifecycle governance from the start. Implement automated API discovery, cataloging, and deprecation tools. Data Misuse & Reputational Harm: Public APIs, if not properly secured and monitored, can be abused for scraping, fraud, or to infer sensitive patterns, damaging public trust. Mitigation: Implement robust API security (WAF, rate limiting, anomaly detection). Publish clear terms of use and ethical data guidelines. Conduct regular security and privacy impact assessments.

Enabling Environment for Technology Deployment			
Investment cycles			
	Primary Focus	Investment Type	Intensity
Short-term	API gateway deployment and developer portals	Public sector IT CAPEX, SaaS subscriptions	MEDIUM (platform licensing, integration services)
Medium-term	Data mesh architecture and federated governance	Innovation funds, M&A in data platform space	MEDIUM-HIGH (platform expansion, governance tools)
Long-term	Cognitive data fabric and decentralized identity	Institutional investment, strategic R&D	MEDIUM (AI development, quantum-safe security)
Infrastructure readiness			
	Primary Enabler	Readiness Level	Key Build-Out
Short-term	LPWAN (NB-IoT, LTE-M) and 4G coverage	Widely available in urban areas	Cellular IoT network densification
Medium-term	5G standalone with network slicing	Early deployment	Edge API management nodes
Long-term	6G and quantum-safe communication infrastructure	Research and pilots	Federated, sovereign data exchange backbone
Regulatory Maturity			
	Primary Focus	Status	Key Milestone

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Short-term	Open mobility data mandates	Enacted in leading cities	Core APIs publicly available with clear SLAs
Medium-term	Data sovereignty and portability regulations	Frameworks emerging	Federated governance bodies established
Long-term	Decentralized identity and smart contract recognition	Early legislation	Legally recognized self-sovereign identity for M2M
Market absorption capacity			
	Adoption Phase	Value Migration	Key Players
Short-term	Early adopters (large cities, national agencies)	Mobility API management platforms	API gateway vendors, telecom IoT providers
Medium-term	Early majority (regional authorities)	Mobility Data Mesh platforms, data products	Cloud providers, system integrators, data consultancies
Long-term	Late majority / Regulated data utility	AI insights, data products, orchestration services	Public data utilities, cloud/AI firms, regulated consortia
Good practices			
FIWARE Context Broker (EU-backed standard for mobility APIs) The FIWARE Foundation provides NGSI-LD APIs enabling real-time, interoperable data exchange across mobility systems. It has been widely adopted in European smart city deployments to unify IoT and transport data streams. It demonstrates scalable, standards-based API ecosystems for cities. Link: https://www.fiware.org/developers/catalogue/ **SynchroniCity IoT API Framework** The SynchroniCity established common data models and APIs across multiple cities to enable cross-platform service interoperability. It validated the importance of standardized APIs for urban data marketplaces. It supports replication of mobility data exchange solutions across regions. Link: https://synchronicity-iot.eu/			

2.4.2. Mobile data collection

Technology Roadmap Profile
Technology name
Mobile data collection
Description (current)
Mobile data collection using LiDAR and 3D spherical cameras enables the capture of highly detailed, accurate, and comprehensive information about physical environments. LiDAR (Light Detection and Ranging) systems emit laser pulses to generate precise 3D models of surroundings, capturing spatial geometry with high accuracy. Complementing this, 3D spherical cameras record full 360-degree images or videos, offering immersive visual

context to the spatial data. Together, these technologies provide a powerful solution for mapping, surveying, and analyzing complex environments in real-time.
Roadmap Horizon
Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)
Strategic Objective
To evolve mobile data collection from a periodic, project-based surveying tool into a continuous, real-time, and intelligent "Spatial Nervous System" for the built environment. This system will create and maintain a dynamic, centimeter-accurate 4D (3D + time) digital twin of urban and transport infrastructure, enabling predictive maintenance, proactive safety interventions, and seamless support for next-generation mobility.
Temporal Layer: Evolution Pathway & Sequencing
Short-Term Trajectory: Proliferation of Standardized Surveys & Foundational Digital Twins
Routine Asset Inventory: Establish mandated periodic LiDAR/imagery surveys (e.g., annual/biennial) of all critical transport corridors and assets by public authorities, creating a baseline digital inventory. Open Data & Standardization: Publish collected point clouds and spherical imagery as open data in standard formats (LAS, E57) via public portals. Adopt OGC standards (e.g., 3D Tiles, I3S) for efficient web streaming. Integration with Traditional GIS: Develop automated pipelines to extract 2D/2.5D features (lane markings, sign locations, curb heights) from point clouds and feed them into existing city GIS and asset management systems. Pilot "Crowd-Sourced" Sensing: Equip a subset of municipal fleets (e.g., garbage trucks, buses) with low-cost solid-state LiDAR to augment dedicated survey vehicles, increasing update frequency.
Medium-Term Trajectory: Dynamic, Real-Time Updates & AI-Driven Analytics
"Always-On" Mobile Sensing Network: A large-scale, hybrid sensing fleet (comprising dedicated vehicles, shared mobility fleets and public transport) continuously captures and streams incremental changes to the central digital twin. AI-Powered Automated Feature Extraction & Change Detection: Deploy computer vision and deep learning models to automatically identify and classify assets (potholes, faded signs, vegetation encroachment), measure wear (road surface rutting), and detect unauthorized changes (e.g., construction encroachment). Real-Time for Operational Use: Processed data feeds directly into operational systems: real-time road condition alerts for maintenance crews; updated HD maps for autonomous vehicle fleets; temporary work zone models for traffic management. Semantic & Layered Digital Twins: The digital twin evolves from a geometric model to a semantic, layered model, where objects (a traffic light) have properties (type, height, condition, interconnection) and relationships (controls a crosswalk).
Long-Term Trajectory: Predictive, Autonomous & Fully Integrated Spatial Fabric
Predictive Simulation & Prescriptive Insights: The 4D digital twin, fused with IoT sensor data and simulation engines, enables predictive analytics (e.g., simulating flood impact on roads, predicting pavement failure) and prescriptive recommendations for optimal maintenance schedules and infrastructure upgrades. Fully Autonomous Surveying & Maintenance: Autonomous ground and aerial vehicles conduct scheduled and on-demand surveys, with AI directing them to areas of predicted change or degradation. This enables a "self-auditing" city.

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Ubiquitous Embedded Sensing: Survey-grade LiDAR and cameras become smaller, cheaper, and integrated into standard urban furniture (light poles, traffic signals), providing persistent, fixed-point monitoring of critical intersections and corridors. Spatial Data Marketplace & Federation: A secure, federated spatial data marketplace allows certified public and private entities to contribute to and access the dynamic digital twin, with clear data provenance, quality scores, and usage rights managed via blockchain or similar technologies.		
Technology Layer: Key Enabling Technologies		
Key Enabling Technologies		
Solid-State LiDAR & High-Resolution Spherical Cameras, Multi-Sensor Fusion Platforms (LiDAR + Camera + IMU + GNSS), Edge Computing for Real-Time On-Vehicle Data Processing, AI/ML for Computer Vision & Point Cloud Analytics, Cloud/High-Performance Computing for Massive Data Processing, Digital Twin Platforms & 3D Geospatial Databases, Standards for Streaming 3D Data (3D Tiles, I3S), Blockchain for Data Provenance & Access Management		
	Dependencies	R&D Priorities
Short-term	Affordable, automotive-grade solid-state LiDAR. High-bandwidth, low-latency connectivity (5G) for data offloading. Political will to fund baseline surveys.	Automated calibration and synchronization of multi-sensor arrays. Compression algorithms for efficient storage/streaming of massive point clouds. Open-source tools for point cloud cleaning and basic feature extraction.
Medium-term	Maturation of AI/ML frameworks for 3D spatial data. Development of scalable digital twin platforms. Legal frameworks for liability of AI-identified defects.	AI models for real-time, on-edge change detection and classification. Semantic segmentation of complex urban scenes (separating road, sidewalk, building, vegetation). Standardized APIs for pushing change alerts to external systems.
Long-term	Ubiquitous ultra-fast connectivity (5G-Advanced/6G). Widespread autonomy in vehicle platforms. Advanced materials for robust, miniaturized sensors.	AI for predictive modeling of infrastructure decay. Federated learning to improve AI models across cities without sharing raw data. Development of "spatial data trust" architectures for secure multi-party data ecosystems.
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution
Short-term	Establish public procurement standards for mobile mapping data (accuracy, format, delivery). Develop privacy guidelines for handling imagery and point clouds (e.g., automatic blurring of faces/license plates).	Growth of specialized "Mobile Mapping as a Service" (MMaaS) providers. Traditional surveying and engineering firms invest heavily in mobile mapping fleets. AV companies spin out mapping divisions to serve broader markets.
Medium-term	Mandate regular digital twin updates as part of infrastructure asset management regulations. Create	Emergence of "Digital Twin Orchestration" platforms that integrate mobile mapping data with other IoT feeds.

	data-sharing frameworks between public authorities and private fleets (e.g., delivery robots, AVs) contributing sensor data.	AI-powered analytics firms emerge as key partners, selling insights rather than raw data.
Long-term	Legally recognize the official digital twin as the authoritative record for infrastructure dimensions and conditions. Regulate access and security for the spatial data fabric as critical national infrastructure.	The data collection hardware becomes a commodity. Value shifts to the continuous analytics, simulation, and predictive insights derived from the living digital twin. Potential for public-private "Spatial Data Utilities" to manage the core asset.
Barriers		
Technological: Immense data volumes creating storage, processing, and transmission bottlenecks. Achieving consistent accuracy and calibration across diverse, moving sensor platforms. Real-time processing of complex 3D data remains computationally intensive. Financial: Very high capital cost for high-end survey systems and processing software. Significant ongoing costs for data storage, compute, and skilled personnel. Uncertain ROI for continuous, high-frequency updates versus periodic surveys. Regulatory/Social: Major privacy concerns with persistent, high-resolution visual and spatial data collection in public spaces. Intellectual property and data ownership disputes between public funders and private surveyors. Resistance from traditional manual inspection and surveying professions.		
Implications for Decision-Makers		
	Recommended Actions	Expected Impacts
Short-term	1. Commission a high-resolution baseline mobile mapping survey of the entire primary road network and publish it as open data. 2. Invest in training for GIS/planning staff on point cloud and 3D data analysis fundamentals.	Creation of a single, accurate source of truth for all transport assets. Elimination of costly and dangerous manual measurements for basic planning tasks.
Medium-term	1. Launch a "City Scanner" program, instrumenting municipal fleets to provide continuous, incremental updates to the digital twin. 2. Develop AI-powered analytics dashboards for the public works department to prioritize maintenance based on automated defect detection.	Transition from reactive to proactive and predictive maintenance, reducing costs and improving safety. Accelerated deployment of AV services through readily available, high-fidelity HD maps.
Long-term	1. Establish a governance and business model for a shared, regional spatial data utility funded by public and private beneficiaries. 2. Integrate the dynamic digital twin as the core planning tool for all major infrastructure projects, requiring "twin-first" design and approval.	Optimization of billions in infrastructure investment through simulation and evidence-based planning. Establishment of a future-proof spatial data foundation that drives innovation across sectors (mobility, utilities, resilience).
Risk Assessment		

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Privacy Erosion & Surveillance Capitalism: The capability for persistent, detailed 3D recording could enable unprecedented mass surveillance if misused. Mitigation: Implement strict "privacy-by-design" in processing: automatic anonymization (blurring) in imagery, aggregation of point cloud data to object level only. Enforce strong data governance with independent oversight. Legislate clear purpose limitation for collected data.
Data Silos & Vendor Lock-in 2.0: Investment in proprietary sensor stacks, data formats, and platforms can create new, even more expensive silos. Mitigation: Mandate open standards and interoperability in all procurements. Develop in-house expertise in data management. Favor platforms with open APIs and data export capabilities.
Over-Reliance on Automation & "Black Box" Analytics: Blind trust in AI-detected defects or simulated futures could lead to poor decisions if models are biased or context is lost. Mitigation: Maintain human-in-the-loop validation for critical decisions (e.g., structural safety). Ensure transparency and explainability in AI analytics (XAI). Conduct regular audits of algorithmic outputs against ground truth.

Enabling Environment for Technology Deployment			
Investment cycles			
	Primary Focus	Investment Type	Intensity
Short-term	Baseline surveys and fleet instrumentation	Public infrastructure CAPEX, grant programs	HIGH (survey systems, processing infrastructure)
Medium-term	Continuous sensing fleet and AI analytics	PPPs, innovation funds	MEDIUM-HIGH (fleet expansion, AI platform)
Long-term	Autonomous surveying and spatial data utility	Institutional investment, strategic partnerships	MEDIUM (autonomous systems, federation)
Infrastructure readiness			
	Primary Enabler	Readiness Level	Key Build-Out
Short-term	5G for high-bandwidth data offload	Expanding coverage	Cloud storage and processing pipelines
Medium-term	Edge computing for on-vehicle processing	Emerging capabilities	Real-time streaming infrastructure
Long-term	6G and ubiquitous high-speed connectivity	Pilots and standards	Federated spatial data marketplace
Regulatory Maturity			
	Primary Focus	Status	Key Milestone
Short-term	Privacy guidelines for imagery and point clouds	Drafted/enacted	Mandatory blurring of faces/license plates
Medium-term	Digital twin update mandates for asset management	Emerging regulations	Regular infrastructure surveys mandated
Long-term	Legal recognition of digital twin as authoritative record	Frameworks under development	Official digital twin for planning and dispute resolution
Market absorption capacity			

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	Adoption Phase	Value Migration	Key Players
Short-term	Early adopters (large cities, transport agencies)	Mobile Mapping as a Service (MMaaS)	Specialized survey firms, engineering consultants
Medium-term	Early majority (regional authorities)	Digital Twin Orchestration platforms	Cloud providers, AI analytics firms, platform vendors
Long-term	Late majority / Spatial data utility	Predictive analytics, simulation services	Public spatial data utilities, regulated private operators

Good practices
Mobile Mapping Systems Research (LiDAR + 360° imaging) The Mobile Mapping Systems field demonstrates the integration of LiDAR, GNSS, and imaging for accurate spatial data capture. Peer-reviewed studies confirm its effectiveness for road asset management and HD mapping. It underpins modern digital twin development. Link: https://doi.org/10.1016/j.isprsjprs.2019.05.012 **HERE HD Live Map** HERE Technologies offers continuously updated HD maps using vehicle-based sensors and cloud processing. It integrates probe data and LiDAR inputs for real-time mapping. It supports automated driving and advanced traffic management systems. Link: https://www.here.com/platform/hd-live-map

2.4.3. Cloud infrastructure and dedicated servers

Technology Roadmap Profile
Technology name
Cloud infrastructure and dedicated servers
Description (current)
This architecture enables the centralized management using a secure cloud infrastructure or optionally dedicated servers. It allows real-time monitoring, configuration, and maintenance of the network while applying granular access policies that ensure only authorized users can access specific data or controls. It collects, processes, and stores data from other devices within a network and it is used to constantly monitor the system, enabling analysis and rapid response to potential problems
Roadmap Horizon
Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)
Strategic Objective
To evolve cloud and server infrastructure from a siloed, application-specific back-end into a unified, resilient, and intelligent "Mobility Data Brain." This central nervous system will ingest, process, and orchestrate all mobility data in real-time, enabling seamless interoperability, advanced AI-driven insights, and robust security, thereby reducing system integration costs and accelerating the deployment of new smart mobility services.
Temporal Layer: Evolution Pathway & Sequencing

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Short-Term Trajectory: Consolidation, Hybrid Cloud & Foundational Security
Architecture Standardization: Move from fragmented, vendor-specific servers to a city-adopted hybrid cloud strategy, using private cloud/on-prem for sensitive operational data and public cloud for scalable analytics and public APIs. Centralized Data Lake Ingestion: Establish a unified data ingestion layer (e.g., using Apache Kafka) to collect and normalize data streams from all mobility sources (GPS, counters, payments) into a central Mobility Data Lake. Zero-Trust Security Foundation: Implement a zero-trust architecture across the entire infrastructure, with mandatory identity and device verification for all access requests, replacing basic role-based access control. Basic Observability: Deploy comprehensive monitoring, logging, and alerting (MLOps) to track system health, performance (uptime, latency), and data pipeline integrity.
Medium-Term Trajectory: Edge-Cloud Continuum & AI-Enabled Platform
Distributed Edge Processing: Shift from centralized processing to an edge-cloud continuum. Critical, low-latency processing (e.g., real-time traffic signal adjustment, immediate fraud detection) occurs at the edge (on-roadside units or vehicles), while complex analytics run in the cloud. AI Ops & Automated Management: Utilize AI for IT Operations (AIOps) to predict and automatically remediate infrastructure failures, optimize resource allocation, and manage security patches. "Mobility-as-Code" Platform: Expose core mobility functions (routing, payment, identity) as managed APIs and serverless functions (FaaS), allowing developers to build new services without managing servers. This creates a true Platform-as-a-Service (PaaS) for mobility. Sovereign & Federated Cloud: Implement sovereign cloud capabilities or data residency controls to comply with strict regional data laws, while enabling secure data federation with neighboring municipalities or private partners.
Long-Term Trajectory: Cognitive, Self-Healing & Quantum-Resilient Fabric
Cognitive Data Fabric: The infrastructure evolves into a cognitive layer that understands data semantics, automatically connects related data streams, and proactively surfaces insights or predicts system needs (e.g., auto-scaling before a major public event). Fully Autonomous Infrastructure Management: Self-healing, self-optimizing systems manage the entire stack, from physical servers to application deployments, with human oversight only for strategic decisions. Post-Quantum & Homomorphic Encryption: Integration of post-quantum cryptography to secure all data at rest and in transit. Experimentation with homomorphic encryption to allow computation on encrypted data, enabling privacy-preserving analytics from sensitive sources. Decentralized Physical Infrastructure Networks (DePIN): Exploration of blockchain-coordinated, decentralized server and sensor networks, where contributors (e.g., businesses with spare compute, citizens with home IoT) can securely support the public mobility data fabric, enhancing resilience and reducing central costs.
Technology Layer: Key Enabling Technologies
Key Enabling Technologies
Hybrid & Multi-Cloud Management Platforms, Data Ingestion & Streaming Platforms (Apache Kafka, Apache Pulsar), Containerization & Orchestration (Kubernetes, Docker), Serverless & Function-as-a-Service (FaaS) Platforms, AIOps & Observability Suites, Zero-Trust Network Access (ZTNA) & Confidential Computing, Edge Computing Nodes & Gateways, Post-Quantum Cryptography Libraries

	Dependencies	R&D Priorities

Short-term	High-reliability, high-bandwidth internet backbone. Political mandate for data consolidation across city departments.	Development of lightweight data normalization schemas for diverse mobility data. Open-source blueprints for zero-trust architectures in public sector IT. Cost-optimization tools for hybrid cloud deployments.
Medium-term	Widespread 5G deployment for reliable edge connectivity. Maturation of AI/ML tooling for operational data. Legal clarity on liability for AI-driven automated decisions in public infrastructure.	AI models for predictive infrastructure scaling and failure prevention. Standardized APIs for edge-to-cloud orchestration in mobility contexts. Privacy-enhancing computation techniques for secure multi-party data analysis.
Long-term	Commercial availability of post-quantum cryptographic standards. Development of viable decentralized compute/storage markets. Advances in neuromorphic or other post-von Neumann computing architectures.	Cognitive AI for autonomous data management and insight generation. Frameworks for resilient, city-scale DePINs. R&D into energy-efficient, high-density computing for sustainable urban data centers.
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution
Short-term	Establish a city-wide cloud and data governance policy defining ownership, access, security standards, and vendor lock-in mitigation. Create cyber-insurance and liability frameworks for cloud-based public services.	Consolidation of city IT contracts with hyperscale cloud providers (AWS, Azure, Google Cloud) offering specialized government clouds. Rise of "GovTech" system integrators specializing in public sector cloud migration.
Medium-term	Develop inter-municipal data sharing and cloud co-op agreements to achieve economies of scale. Regulate algorithmic transparency and auditability for AI-driven public infrastructure management.	Emergence of "Mobility Cloud" specialists within larger cloud providers, offering pre-integrated PaaS for transport. Growth of niche AIOps and observability firms focused on critical infrastructure.
Long-term	Legislate digital infrastructure as a public utility, with associated reliability and access obligations. Create international standards and treaties for cross-border mobility data processing and quantum-safe security.	The underlying compute/storage layer becomes a low-margin commodity utility. Value migrates to the software, platform services, and AI intelligence layers. Potential for publicly owned or co-operative cloud entities to ensure digital sovereignty.
Barriers		
Technological: Immense complexity in integrating legacy on-prem systems with modern cloud-native architectures. Ensuring consistent ultra-low latency for safety-critical applications (e.g., CAV coordination). Managing and securing exponentially growing data volumes. Financial: High and unpredictable ongoing OPEX for cloud services and data egress. Significant upfront investment in skills training and organizational change management. Difficulty in transitioning from CapEx to OpEx budgeting models in public sector.		

Regulatory/Social: Deep concerns over data sovereignty and foreign jurisdiction when using global cloud providers. Public distrust of centralized data repositories perceived as vulnerable to hacking or misuse. Resistance from internal IT departments and legacy vendor ecosystems.		
Implications for Decision-Makers		
	Recommended Actions	Expected Impacts
Short-term	1. Appoint a Chief Data/Cloud Officer and develop a Cloud-First & Data Consolidation Strategy for all mobility IT projects. 2. Migrate 2-3 non-critical but data-intensive mobility systems (e.g., public bike counter data) to a pilot hybrid cloud environment as a learning exercise.	Reduction in server maintenance costs and improved scalability for pilot systems. Establishment of internal cloud expertise and clearer understanding of true costs.
Medium-term	1. Issue an RFP for a city-wide "Mobility Data Platform" based on PaaS principles, requiring open APIs and sovereign data controls. 2. Mandate the use of the central platform's APIs for all new mobility-related software procurements.	Drastic reduction in integration time and cost for new services. Creation of a unified data asset that enables cross-modal optimization and innovative citizen apps.
Long-term	1. Develop a "Digital Infrastructure Resilience Plan" that includes sovereign cloud capabilities, edge failover, and post-quantum readiness. 2. Treat the mobility data and compute layer as a strategic public asset, investing in its long-term evolution, security, and openness.	Creation of a resilient, future-proof foundation that attracts innovation and investment in smart mobility. Ensured digital sovereignty and public control over critical urban data and functions.
Risk Assessment		
Vendor Lock-in & Strategic Dependency: Over-reliance on a single cloud provider's proprietary services and pricing models, leading to loss of control and escalating costs. Mitigation: Adopt a multi-cloud or hybrid strategy from the outset. Insist on open standards, containerization, and data portability in all contracts. Develop strong in-house architecture and vendor management skills. Catastrophic Systemic Failure: A major outage or cyber-attack on the central cloud infrastructure could paralyze multiple critical mobility services simultaneously. Mitigation: Design for high availability across geographically dispersed zones. Implement comprehensive disaster recovery and business continuity plans with regular testing. Maintain critical fallback operational capabilities that can function in a degraded, offline mode. Democratization & Equity Deficit: If advanced APIs and compute resources are only accessible to well-funded private developers, public innovation and equitable service development could be stifled. Mitigation: Create a public "Civic Tech Sandbox" with free tier access to the platform's core APIs and compute resources for accredited researchers, nonprofits, and startups. Provide grants and technical support for projects targeting underserved communities.		
Enabling Environment for Technology Deployment		
Investment cycles		
	Primary Focus	Investment Type	Intensity

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Short-term	Hybrid cloud migration and data lake consolidation	Public sector IT CAPEX, cloud migration services	MEDIUM-HIGH (cloud contracts, integration)
Medium-term	Edge-cloud continuum and AIOps deployment	Innovation funds, managed services	MEDIUM (edge nodes, AIOps platforms)
Long-term	Cognitive data fabric and DePIN exploration	Institutional investment, strategic R&D	MEDIUM (AI development, quantum-safe upgrades)
Infrastructure readiness			
	Primary Enabler	Readiness Level	Key Build-Out
Short-term	High-bandwidth internet backbone and data centers	Widely available	Centralized Mobility Data Lake
Medium-term	5G for edge connectivity and network slicing	Expanding deployment	Edge computing nodes at roadside and hubs
Long-term	Sovereign cloud capabilities and quantum-safe networks	Pilots and emerging standards	Federated, resilient compute fabric
Regulatory Maturity			
	Primary Focus	Status	Key Milestone
Short-term	Cloud governance and data sovereignty policies	Drafted/enacted	City-wide cloud and data governance framework
Medium-term	Algorithmic transparency and auditability regulations	Emerging frameworks	AI-driven public infrastructure oversight
Long-term	Digital infrastructure as public utility designation	Under consideration	Reliability and access obligations legislated
Market absorption capacity			
	Adoption Phase	Value Migration	Key Players
Short-term	Early adopters (large cities, transit agencies)	Hyperscale government clouds, GovTech integrators	AWS, Azure, Google Cloud, specialized integrators
Medium-term	Early majority (regional authorities)	Mobility Cloud PaaS, AIOps specialists	Cloud providers, mobility platform vendors
Long-term	Late majority / Regulated utility	Platform services, AI intelligence layer	Public cloud utilities, co-operative ent
Good practices			
GAIA-X Federated Cloud Infrastructure The GAIA-X initiative develops a federated, sovereign cloud ecosystem for secure data sharing. It emphasizes interoperability, transparency, and European data governance. It is highly relevant for mobility data platforms requiring trust and compliance. Link: https://gaia-x.eu/			

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Microsoft Azure Digital Twins Platform Microsoft Azure provides tools for building digital twins and integrating real-time data streams. It enables advanced analytics and simulation for urban mobility systems. It is widely adopted in public-sector smart infrastructure projects. Link: https://azure.microsoft.com/en-us/products/digital-twins/

2.4.4. NFC card

Technology Roadmap Profile
Technology name
NFC card reader
Description (current)
NFC card readers use short-range wireless communication (typically within 4 cm) to exchange data with NFC-enabled cards, smartphones, or wearables.
Roadmap Horizon
Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)
Strategic Objective
To evolve NFC from a simple payment and access token into a universal, secure, and intelligent "Key to the City", a foundational digital identity layer for inclusive, multi-modal mobility. The objective is to increase the adoption of public and shared transport among digitally excluded populations, create a seamless, tap-and-go experience across all modes, and establish a privacy-centric alternative to smartphone-dependent mobility services.
Temporal Layer: Evolution Pathway & Sequencing
Short-Term Trajectory: Universalization & Backend Modernization
Interoperable Card Standard: Cities mandate and issue a universal NFC mobility card (or mandate interoperability between all operator cards) that works across public transport, bike-share, and car-share systems. EMV & Open-Loop Adoption: NFC readers are upgraded to accept contactless bank cards (EMV) and mobile wallets (Apple/Google Pay) as a default, reducing the need for proprietary cards and simplifying tourist/occasional user access. Backend-as-a-Service (BaaS) for Fare Logic: Migration from monolithic backend systems to cloud-based fare calculation and authorization services, enabling faster integration for new operators and dynamic fare products (e.g., daily/weekly caps). Enhanced Anti-Fraud: Implementation of advanced card authentication protocols and real-time backend checks to combat cloning and replay attacks.
Medium-Term Trajectory: Context-Aware & Multi-Purpose Smart Tokens
Dynamic, Multi-Modal Fare Capping: The NFC system evolves to support seamless multi-modal journey capping. A user tapping a bike, then a bus, then a train is automatically charged the optimal daily or weekly fare cap across all operators. NFC as a Secure Digital Identity Carrier: The NFC chip is used to store verifiable credentials (e.g., proof of eligibility for concession fares, disability status for priority access) that can be validated offline by readers, enhancing privacy and service personalization.

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Integration with MaaS Wallets: NFC taps become one input into a broader Mobility-as-a-Service (MaaS) wallet. The physical card or phone can be linked to a digital account for managing subscriptions, top-ups, and journey history via an app or website. Offline-First & Resilient Design: Readers are designed for extended offline operation, caching transactions and permissions to ensure service continuity during network outages, critical for reliability.		
Long-Term Trajectory: Ambient NFC Authentication, Decentralized Identity & Sustainable Tokenization		
NFC "Everywhere" – Ambient Authentication: NFC readers become ubiquitous and miniaturized, embedded into everyday surfaces (door handles, steering wheels, bike frames). Authentication becomes ambient and passive as a user approaches with a token. Biometric-NFC Hybrid Tokens: NFC cards or wearables integrate on-device biometric sensors (e.g., fingerprint). A tap requires biometric verification on the token itself, combining the convenience of contactless with the security of two-factor authentication, eliminating the risk of lost-card fraud. Decentralized Identity & Self-Sovereign NFC: NFC tokens become carriers for decentralized identifiers (DIDs). Users control what personal data (e.g., age, residency) is shared with each reader via their token, without a central database, maximizing privacy. Energy-Harvesting & Sustainable Tokens: Development of battery-free or energy-harvesting NFC tokens that draw power from the reader's field, eliminating waste from battery replacement and enabling new form factors (e.g., flexible, embedded in clothing).		
Technology Layer: Key Enabling Technologies		
Key Enabling Technologies		
NFC Forum-compliant Chipsets & Readers (Type 4/5 Tags, Host Card Emulation), EMV Contactless & Open-Loop Payment Standards, Secure Element (SE) & Trusted Execution Environment (TEE) for Mobile Devices, Cloud-based Fare Calculation & Clearinghouse Platforms, Verifiable Credentials & W3C Decentralized Identity Standards, On-Token Biometric Sensors (Fingerprint, ECG), Energy-Harvesting Circuits for Passive NFC		
	Dependencies	R&D Priorities
Short-term	Widespread merchant acceptance of contactless payments (EMV). Agreement among local transport operators on a common technical standard (e.g., Calypso, ITSO).	R&D into low-cost, ruggedized NFC readers for outdoor micromobility use. Standardized APIs for backend fare calculation and clearing between operators. Enhanced anti-cloning protocols for MIFARE/DESfire cards.
Medium-term	Legal frameworks for digital identity and verifiable credentials in public services. Maturation of offline-capable, syncing transaction protocols.	Algorithms for real-time, multi-operator best-fare calculation. Privacy-preserving protocols for offline verification of eligibility credentials. Ultra-low-power NFC reader designs for solar-powered stations.
Long-term	Commercialization of viable energy-harvesting NFC. Widespread adoption of decentralized identity standards. Public acceptance of biometrics in everyday objects.	Integration of biometric sensors directly into NFC inlays. Development of standard protocols for decentralized identity via NFC. R&D into recyclable/biodegradable NFC token materials.
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution
Short-term	Mandate open-loop payment acceptance (EMV contactless) in all new fare collection system	Consolidation of fare system vendors offering EMV-ready, cloud-native platforms. Payment networks

	procurements. Establish data sharing and revenue settlement agreements between transport operators for interoperable cards.	(Visa/Mastercard) become key partners in transport ticketing.
Medium-term	Legislate principles for inclusive digital mobility, ensuring NFC card options remain available and subsidized as smartphone-centric services grow. Regulate the security and privacy standards for verifiable credentials on mobility tokens.	Emergence of "Mobility Identity & Payment as a Service" providers managing the universal token backend. Smartcard manufacturers pivot to producing multi-application, identity-enabled tokens.
Long-term	Legally recognize decentralized identity tokens as valid for concession verification and service access. Regulate the environmental lifecycle and recyclability of physical NFC tokens.	The physical reader hardware becomes a low-cost commodity. Value shifts to the identity, security, and data services layer. Potential for publicly owned "Mobility Identity Utility" issuing and managing the foundational tokens.
Barriers		
Technological: Limited read range and speed compared to other RF technologies (e.g., BLE). Vulnerability to certain relay and eavesdropping attacks despite encryption. Power and connectivity requirements for readers in remote/outdoor locations. Financial: Cost of replacing legacy magnetic stripe or closed-loop RFID systems with NFC/EMV-compliant infrastructure. Transaction fees associated with open-loop bank card payments cutting into operator revenue. Regulatory/Social: Complexity of creating fair revenue-sharing models between multiple operators in an interoperable system. Risk of excluding the very elderly or vulnerable if physical cards are phased out for biometric/smartphone solutions. Persistent consumer perception of contactless payments as less secure.		
Implications for Decision-Makers		
	Recommended Actions	Expected Impacts
Short-term	1. Launch a universal NFC mobility card program (or an interoperability framework) that works on all public transport and publicly subsidized shared mobility services. 2. Begin the phased upgrade of validators/readers to accept EMV contactless bank cards and mobile wallets.	Measurable increase in ridership/convenience for occasional users and tourists. Significant reduction in cash handling costs and fraud from cloned proprietary cards.
Medium-term	1. Implement automatic multi-modal fare capping using the universal card/EMV tap as the identifier. 2. Pilot an NFC-based verifiable credential system for concession fares (e.g., youth, senior), replacing paper passes with enhanced privacy.	Simplification of the fare system, boosting ridership among low-income users who benefit from caps. Improved efficiency and reduced fraud in administering concession programs.

Long-term	1. Develop a strategy for "ambient authentication" in mobility, embedding NFC into the fabric of vehicles and infrastructure. 2. Establish a circular economy program for NFC tokens, ensuring old cards are collected and recycled, and promote battery-free token options.	Creation of the most accessible, seamless, and inclusive mobility payment system, serving as a global benchmark. Alignment of mobility technology with broader sustainability and digital sovereignty goals.

Risk Assessment
Vendor Lock-in & Fragmentation: Procuring closed, proprietary NFC systems from a single vendor can hinder future interoperability and innovation. Mitigation: Insist on open standards (NFC Forum, EMV) and modular architecture in procurement. Support the development of open-source reference implementations for backend fare logic. Digital Divide Reinforced: Over-focusing on smartphone-based NFC (Apple/Google Pay) could marginalize low-income, elderly, or disabled users who rely on physical cards. Mitigation: Maintain and promote affordable, rechargeable physical card options as a permanent, parallel channel. Ensure top-up locations are widespread and accessible. Systemic Fraud & Security Breach: A large-scale breach of card credentials or a flaw in a widely deployed card model could undermine public trust in the entire transport payment system. Mitigation: Implement continuous security monitoring and threat intelligence. Adopt a layered security approach combining secure elements, dynamic cryptography, and real-time backend analytics. Have a clear, public breach response and card replacement plan.

Enabling Environment for Technology Deployment			
Investment cycles			
	Primary Focus	Investment Type	Intensity
Short-term	Reader upgrades and universal card issuance	Public transit CAPEX, operator investments	MEDIUM-HIGH (hardware, backend modernization)
Medium-term	Multi-modal fare capping and credential pilots	Innovation funds, MaaS integration budgets	MEDIUM (software, clearinghouse platforms)
Long-term	Ambient authentication and biometric tokens	Institutional investment, R&D partnerships	LOW-MEDIUM (next-gen token development)
Infrastructure readiness			
	Primary Enabler	Readiness Level	Key Build-Out
Short-term	EMV contactless acceptance network	Widely available	Cloud-based fare calculation backend
Medium-term	Offline-capable transaction protocols	Emerging standards	Resilient, sync-capable reader network
Long-term	Energy-harvesting NFC and ambient readers	Research and pilots	Ubiquitous ambient authentication infrastructure
Regulatory Maturity			

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	Primary Focus	Status	Key Milestone
Short-term	Open-loop payment mandates for transit	Enacted in leading cities	EMV acceptance required in new procurements
Medium-term	Inclusive mobility and digital identity legislation	Frameworks emerging	Physical card options mandated alongside digital
Long-term	Decentralized identity and token lifecycle regulation	Under consideration	Legal recognition of self-sovereign mobility identity
Market absorption capacity			
	Adoption Phase	Value Migration	Key Players
Short-term	Early adopters (major transit agencies)	EMV-ready fare collection platforms	Fare system vendors, payment networks
Medium-term	Early majority (regional operators)	Mobility Identity & Payment as a Service	Identity platform providers, smartcard manufacturers
Long-term	Late majority / Universal adoption	Identity, security, and data services	Public mobility identity utilities, platform firms
Good practices			
CIPURSE Open Standard (OspT Alliance) An open security standard for NFC-based transit ticketing enabling interoperability across operators and vendors. Widely referenced in EU research and deployments for secure, scalable fare systems. Link: https://osptalliance.org/cipurse/ **HID Global – Transit Ticketing Solutions** A commercial NFC ticketing platform supporting secure smart cards, mobile credentials, and interoperable transit systems. Used globally for integrated fare collection and identity-based mobility access. Link: https://www.hidglobal.com/solutions/transportation-ticketing			

2.4.5. Smart Indicators with Alarm System

Technology Roadmap Profile
Technology name
Smart Indicators with Alarm System
Description (current)
This system includes integrated visual and acoustic indicators at the docking stations that provide real-time feedback to users and signal alarm conditions in the event of tampering or misuse. The indicators serve both as a user guidance mechanism and as a deterrent for theft and vandalism.
Roadmap Horizon

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Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)
Strategic Objective
To transform smart indicators from a simple alarm system into an intelligent, proactive communication and security layer for shared mobility infrastructure. The objective is to reduce asset theft and vandalism costs, increase user satisfaction and perceived safety at hubs, and evolve stations into interactive community nodes that enhance the overall urban experience.
Temporal Layer: Evolution Pathway & Sequencing
Short-Term Trajectory: Standardization & Deployment of Smart Indicator and Alarm Systems
Mandatory Feature in New Deployments: Include integrated visual (LED) and acoustic indicators as a standard requirement in all new micromobility docking station and hub procurements. Standardized Alert Protocols: Define and implement clear, universal signal patterns: green for available/ok, amber for transaction in progress/low battery, red/flashing + siren for tamper/theft. This ensures user understanding across different operators. Basic Integration with Ops Center: Alarms trigger immediate alerts in the operator's fleet management platform, showing station ID and type of alarm (tamper, forced removal). Public Awareness Campaigns: Educate users on what the signals mean and that alarms are active, serving as a public deterrent.
Medium-Term Trajectory: Context-Aware Communication & Proactive Response
Ambient & Contextual Indicators: Systems use ambient lighting to show station status from a distance (e.g., a soft glow for available bikes). Indicators provide contextual user feedback via light sequences (e.g., pulsing blue for successful check-in, rapid red for improper docking). Two-Way Communication & Diagnostics: Stations gain simple audio output for voice guidance (e.g., "Please reposition the bike") and basic diagnostic lights to guide users or maintenance staff (e.g., a specific LED pattern indicates a faulty lock mechanism). Integrated Surveillance & Evidence Collection: Alarms activate on-board, low-power cameras or acoustic sensors to capture short-duration, event-triggered footage/audio for law enforcement, stored securely with privacy filters (e.g., blurred faces). Automated External Alerting: High-priority tamper alarms are automatically forwarded to nearby security patrols (via app) or local law enforcement based on predefined thresholds and location.
Long-Term Trajectory: Intelligent, Adaptive & Community-Integrated Systems
Predictive Threat Detection: Using historical tamper data, time of day, and local event feeds, the system enters a heightened alert state proactively, increasing indicator brightness or activating a deterrent sound when high risk is predicted. Biophilic & Urban-Fabric Design: Indicators evolve into architectural elements. Lighting becomes subtle, using biophilic patterns that contribute to urban aesthetics. Acoustic alerts use localized directional sound or non-alarming tones to minimize noise pollution while remaining effective. Public Safety & Community Hub: Stations double as public safety points. A dedicated button or gesture can activate a silent alarm connected to city emergency services, with the station providing location and live ambient audio/video. Self-Healing & Vandal-Resistant Design: Incorporation of self-healing materials for surfaces and redundant, mesh-connected indicator systems where if one light/sensor is damaged, others take over its function and report the fault.
Technology Layer: Key Enabling Technologies
Key Enabling Technologies

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Multi-Color, High-Brightness Programmable LEDs, Solid-State Speakers & Directional Audio Systems, Tamper & Vibration Sensors (MEMS, Piezoelectric), Low-Power, Event-Triggered Imaging/Acoustic Sensors, Secure Edge Computing for Local Decision-Making, Mesh Networking for Inter-Station Communication, Predictive Analytics & Anomaly Detection AI, Self-Healing Materials & Vandal-Resistant Enclosures		
	Dependencies	R&D Priorities
Short-term	Reliable power and network connectivity at docking locations. Agreement on signal standards among operators/cities.	Development of ultra-low-power LED drivers and controllers. Standardized communication protocol between dock sensor and indicator system. Tamper-sensor fusion algorithms to reduce false positives.
Medium-term	Maturation of low-cost, privacy-aware edge sensing (e.g., thermal cameras, lidar for presence). Legal frameworks for use of automated evidence collection.	AI for contextual alarm filtering (distinguishing vandalism from accidental bumps). On-edge privacy filtering for event-triggered imaging/audio. Energy-harvesting designs to power indicators from solar or kinetic energy.
Long-term	Advances in smart materials and self-healing polymers. Widespread deployment of public safety IoT networks.	Predictive AI models for vandalism/hotspot forecasting. Development of aesthetic, integrated urban furniture designs that house intelligent indicators. Protocols for inter-infrastructure emergency communication (e.g., station to nearby smart light pole).
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution
Short-term	Include minimum security and user feedback standards (including indicators/alarms) in micromobility permitting and public infrastructure contracts.	Emergence of "Smart Docking" specialists within the micromobility hardware sector. Traditional street furniture manufacturers begin integrating basic IoT indicators.
Medium-term	Develop privacy guidelines and evidence handling procedures for alarm-triggered sensor data. Establish SLAs for response times with security/law enforcement linked to automated alerts.	Growth of "Security-as-a-Service" for Mobility Infrastructure, where a third party monitors alarms and coordinates response. Integration firms specialize in connecting dock alarms to city-wide security operations centers.
Long-term	Regulate public safety functionalities of street furniture, including liability and maintenance responsibilities. Develop urban design codes that encourage integrated, aesthetically pleasing smart indicators.	Hardware becomes a low-margin component of larger "Mobility Hub as a Service" offerings. Value shifts to the intelligence, analytics, and integrated security response services. Potential for public-private partnerships to own and operate the secure hub network.
Barriers		

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Technological: Ensuring reliability and durability of lights/speakers in all weather conditions and against intentional damage. Power consumption for always-on or frequently activated systems. False alarms from environmental factors (e.g., strong wind, debris impact).
Financial: Added unit cost per docking station for quality indicators, sensors, and secure comms. Ongoing maintenance costs for replacing damaged components. Uncertain ROI on advanced features beyond basic deterrence.
Regulatory/Social: Potential for noise complaints if acoustic alarms are too frequent or loud. Privacy concerns if cameras or microphones are perceived as surveillance overreach. Risk of "alarm fatigue" where operators or the public begin to ignore alerts.

Implications for Decision-Makers		
	Recommended Actions	Expected Impacts
Short-term	1. Specify and mandate the inclusion of smart indicator/alarm systems in all new micromobility docking infrastructure tenders. 2. Develop a public guide explaining the light/sound signals to build user familiarity and amplify the deterrent effect.	Immediate reduction in opportunistic theft and vandalism at equipped stations. Improved user experience through clear transactional feedback.
Medium-term	1. Integrate station alarm feeds into the city's existing security or traffic management center for coordinated monitoring. 2. Pilot a program linking high-frequency alarm zones with increased lighting or mobile security patrols.	Data-driven deployment of security resources, increasing effectiveness. Stronger partnership between mobility operators and public safety agencies.
Long-term	1. Develop design guidelines for "Next-Gen Mobility Hubs" that integrate intelligent indicators seamlessly into attractive, multi-functional public spaces. 2. Explore a shared, city-owned smart infrastructure layer for alarms and public communication that any mobility operator can plug into.	Transformation of micromobility points from utilitarian fixtures into valued, secure, and intelligent components of the urban landscape. Reduced duplication of systems and lower barriers to entry for new operators.

Risk Assessment

Over-Engineering & Diminishing Returns: Investing in overly complex indicator systems that rarely provide value beyond basic lights, leading to wasted resources and maintenance headaches. Mitigation: Start with a lean, robust set of core signals (success, fault, tamper). Pilot advanced features (audio, cameras) only in high-risk areas and measure impact before wide rollout.
Privacy Violation & Public Backlash: Deployment of sensors (cameras, mics) for security, even if event-triggered, can be seen as intrusive mass surveillance. Mitigation: Implement privacy by design: no continuous recording, on-edge processing to detect events without storing raw video/audio, clear public signage about data use. Establish a citizen oversight panel for the system.

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System Failure Leading to Loss of Trust: If indicators malfunction (e.g., show green for a broken dock) or alarms fail during an incident, user confidence in the entire system can collapse. Mitigation: Design for high reliability and redundancy (e.g., dual LED arrays). Implement continuous self-diagnostics and remote testing. Have a rapid response protocol for repairing faulty stations.			
Enabling Environment for Technology Deployment			
Investment cycles			
	Primary Focus	Investment Type	Intensity
Short-term	Hardware integration and alarm standardization	Private operator CAPEX, public infrastructure contracts	MEDIUM (sensors, LEDs, speakers)
Medium-term	Event-triggered sensing and automated alerting	Innovation funds, security integration budgets	LOW-MEDIUM (cameras, edge processing)
Long-term	Predictive threat detection and community integration	Strategic infrastructure investment	LOW (AI analytics, urban design integration)
Infrastructure readiness			
	Primary Enabler	Readiness Level	Key Build-Out
Short-term	Reliable power and connectivity at docking stations	Variable, requires targeted upgrades	Station-level IoT connectivity
Medium-term	City-wide security monitoring and response networks	Existing in major cities	Integration with public safety operations
Long-term	Mesh networking and self-healing infrastructure	Emerging capabilities	Inter-connected smart street furniture network
Regulatory Maturity			
	Primary Focus	Status	Key Milestone
Short-term	Security standards in micromobility permitting	Enacted in leading cities	Mandatory indicator/alarm requirements
Medium-term	Privacy guidelines for event-triggered sensing	Frameworks emerging	Clear rules for camera/audio use and data handling
Long-term	Public safety infrastructure liability frameworks	Under consideration	Defined responsibilities for emergency functionality
Market absorption capacity			
	Adoption Phase	Value Migration	Key Players
Short-term	Early adopters (micromobility operators, transit agencies)	Smart docking hardware	Micromobility OEMs, street furniture manufacturers
Medium-term	Early majority (regional operators, cities)	Security-as-a-Service for mobility infrastructure	Security monitoring firms, system integrators

Long-term	Late majority / Standard equipment	Intelligence, analytics, integrated response	Mobility Hub as a Service providers, public-private partnerships
Good practices			
ELIPTIC Project (Electrification of Public Transport in Cities) EU project exploring smart infrastructure integration, including intelligent monitoring and alert systems for transport assets. Demonstrates how real-time feedback improves operational safety and efficiency. Link: https://www.eliptic-project.eu/ **"Smart Street Furniture Systems for Urban Safety" (Sustainable Cities and Society)** Peer-reviewed research examining integrated lighting, sensors, and alarm systems in public infrastructure to enhance safety and user interaction. Highlights the role of visual/acoustic indicators in smart mobility hubs. Link: https://doi.org/10.1016/j.scs.2020.102355			

2.4.6. Smart IoT integration

Technology Roadmap Profile
Technology name
Smart IoT integration
Description (current)
Integrated IoT infrastructure connects each hardware unit to a centralized cloud management platform. This integration allows remote monitoring, data collection, device control, and system diagnostics in real time.
Roadmap Horizon
Short-Term (0-3 years), Medium-Term (3-7 years), Long-Term (8+ years)
Strategic Objective
To evolve Smart IoT Integration from a collection of connected devices into a unified, intelligent, and autonomous "Central Nervous System" for urban mobility infrastructure. This system will not only monitor and report but also predict, optimize, and self-heal, enabling a reduction in operational costs, an increase in infrastructure uptime, and serving as the foundational data layer for a fully integrated, city-wide mobility ecosystem.
Temporal Layer: Evolution Pathway & Sequencing
Short-Term Trajectory: Standardization, Consolidation & Basic Intelligence
Protocol & Platform Unification: Cities mandate the use of open, lightweight IoT protocols (e.g., MQTT, CoAP) and adopt a single, central IoT platform or enforce interoperability standards to manage all public mobility assets, breaking down vendor-specific silos. Comprehensive Asset Digital Twin: Each physical asset (dock, charger, sensor) has a digital twin in the cloud, storing its real-time status, configuration, and maintenance history, enabling centralized lifecycle management.

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Rule-Based Automation & Alerts: Implementation of basic rule engines to automate responses (e.g., send a maintenance ticket if a dock is offline for >1 hour; trigger a rebalancing alert if occupancy >90%). Unified Operational Dashboard: Creation of a single pane of glass for infrastructure managers, aggregating data from all IoT-connected mobility systems (bikes, scooters, EV chargers, smart parking) into one actionable view.
Medium-Term Trajectory: Predictive Analytics, Edge Intelligence & Ecosystem Integration
Predictive Maintenance & AIOps: Deployment of AI/ML models to analyze sensor data (vibration, power cycles, error logs) to predict hardware failures before they occur, scheduling maintenance proactively. Shift to Edge-Cloud Continuum: Intelligence moves to the edge. IoT gateways at hubs or on vehicles perform local analytics, filtering data and making immediate control decisions (e.g., load balancing power between chargers) to reduce latency and bandwidth. Open Ecosystem via API Marketplace: The IoT platform exposes its capabilities via a secure API marketplace. Third-party developers can build applications that consume real-time infrastructure data (e.g., an app showing real-time charger availability) or send commands (e.g., reserve a specific dock). Dynamic Resource Optimization: The system orchestrates resources in real-time. For example, it dynamically adjusts pricing at parking/charging spots based on demand, or redirects users to less congested hubs via integrated signage or apps.
Long-Term Trajectory: Autonomous, Cognitive & Self-Sovereign Infrastructure
Cognitive IoT & Autonomous Management: The system evolves into a cognitive layer that understands system-wide goals (e.g., "maximize micromobility utilization," "ensure 99.9% charger uptime"). It autonomously makes and executes complex decisions, learning from outcomes to improve over time. Decentralized & Self-Sovereign Infrastructure Networks: IoT infrastructure operates as a decentralized physical infrastructure network (DePIN). Participants (e.g., businesses hosting docks, private EV chargers) can securely contribute resources to the public network and be compensated via tokenized incentives, governed by smart contracts. Self-Healing & Resilient Design: Infrastructure components are equipped with self-diagnostic and self-repair capabilities (e.g., a dock with a redundant lock mechanism that engages if the primary fails). The network automatically re-routes around failed nodes. Infrastructure-as-a-Service (IaaS) Model: The city's IoT-managed mobility infrastructure becomes a shared utility. Private mobility operators no longer deploy their own hardware but lease smart "docking/charging/parking-as-a-service" from the public network, drastically reducing street clutter and fragmentation.
Technology Layer: Key Enabling Technologies
Key Enabling Technologies
IoT Connectivity Protocols (MQTT, CoAP, LoRaWAN, NB-IoT), IoT Platform & Digital Twin Suites, Edge Computing & AI Accelerator Modules, Predictive Analytics & AIOps Software, API Management & Marketplace Platforms, Blockchain / DLT for DePIN Coordination & Smart Contracts, Secure Over-the-Air (OTA) Update Mechanisms

	Dependencies	R&D Priorities
Short-term	Ubiquitous and affordable LPWAN/cellular IoT coverage. Political mandate for municipal IoT platform consolidation.	Development of standardized data models for mobility assets (e.g., based on SAREF). Open-source reference

		architectures for municipal IoT. Security-by-design frameworks for large-scale IoT deployments.
Medium-term	Maturation of edge AI toolkits and hardware. Legal frameworks for data sharing and liability in automated systems. Widespread 5G deployment.	AI models for failure prediction in harsh outdoor environments. Federated learning techniques to improve AI across cities without sharing raw data. Interoperability protocols for cross-vendor, cross-domain IoT orchestration.
Long-term	Commercial viability of decentralized compute/storage networks. Advances in materials science for self-healing components.	Cognitive AI for goal-based system optimization. Trustless coordination protocols for public DePINs. Energy-harvesting and ultra-low-power designs for perpetual IoT devices.
Contextual Layer: Conditions & Barriers		
	Governance & Regulatory Needs	Market & Industry Evolution
Short-term	Establish a city IoT strategy and governance body to oversee platform selection, data standards, and security. Mandate cybersecurity certification for any IoT device deployed on public infrastructure.	Growth of "Smart City IoT" platform vendors (both large tech and specialized firms). Traditional infrastructure manufacturers (lights, poles, benches) embed IoT modules to become "smart."
Medium-term	Develop "Right to Repair" and interoperability regulations for public IoT hardware to avoid vendor lock-in. Create incentive models for private property owners to host public mobility IoT assets.	Market consolidation around vertical "Mobility Infrastructure IoT" platforms. Emergence of specialized "IoT Analytics as a Service" firms selling insights to cities. System integrators focus on connecting IoT data to business outcomes.
Long-term	Legislate digital infrastructure as a public utility with universal access principles. Regulate algorithmic governance and transparency in autonomous public systems.	The IoT platform layer becomes a regulated public utility or open commons. Value shifts entirely to the applications, AI services, and ecosystem services built on top. New economic models emerge around shared infrastructure networks and data marketplaces.
Barriers		
Technological: Extreme heterogeneity of devices, protocols, and data formats creating integration nightmares. Ensuring security across millions of often simple, low-power devices is a monumental challenge. Managing the lifecycle (updates, decommissioning) of a vast IoT fleet. Financial: High upfront cost for sensors, connectivity, platform licensing, and integration services. Ongoing OPEX for data storage, analytics, and security monitoring. Difficulty in proving ROI for advanced predictive capabilities. Regulatory/Social: Lack of clear data ownership and liability frameworks for automated actions taken by IoT systems. Public distrust of pervasive sensing and automated control of public assets. Risk of creating a "digital divide" in neighborhoods with poor connectivity, limiting IoT deployment.		
Implications for Decision-Makers		

D.1.5.1 - SMARTMOBAIR technology roadmap

	Recommended Actions	Expected Impacts
Short-term	1. Select and deploy a city-standard IoT platform for all mobility-related infrastructure projects. 2. Develop a "Mobility IoT Device Catalog" with approved, interoperable hardware that meets security and data standards.	Elimination of data silos and reduced integration costs for new projects. Creation of a unified operational view, improving response times to outages.
Medium-term	1. Launch a predictive maintenance pilot for a high-value asset class (e.g., EV chargers) using the IoT platform's data. 2. Open a secure API portal with real-time infrastructure status feeds to spur third-party app development.	Significant reduction in maintenance costs and downtime for piloted assets. Innovation boom as developers create new services using open infrastructure data.
Long-term	1. Develop a business case and governance model for a "Shared Urban Mobility Grid," a publicly managed DePIN for docking, charging, and sensing. 2. Establish an "IoT Infrastructure Resilience" fund to invest in self-healing technologies and cyber-physical security.	Transformation of mobility infrastructure from a cost center into a resilient, revenue-generating, innovation-enabling public utility. Ensured long-term sustainability and adaptability of the city's digital-physical fabric.

Risk Assessment
Catastrophic Systemic Cyber-Attack: A breach in the central IoT platform could allow an attacker to disable city-wide mobility infrastructure, causing chaos and safety risks. Mitigation: Implement a "defense in depth" strategy with network segmentation, zero-trust principles, and air-gapped critical controls. Conduct regular red team exercises. Have manual override and fallback procedures for all automated systems. Vendor Lock-in & Technological Obsolescence: Heavy reliance on a single vendor's proprietary IoT platform can lead to escalating costs and an inability to adopt new innovations. Mitigation: Adopt open standards and insist on data portability in all contracts. Favor open-source core components. Develop in-house expertise to manage and evolve the platform independently. Algorithmic Bias & Inequitable Service: Optimization algorithms might prioritize efficiency over equity, leading to better maintenance and service in affluent areas while neglecting underserved neighborhoods. Mitigation: Bake equity metrics explicitly into system goals and AI training data. Implement continuous equity impact audits of automated decisions. Ensure transparent public reporting on infrastructure performance across all districts.

Enabling Environment for Technology Deployment			
Investment cycles			
	Primary Focus	Investment Type	Intensity
Short-term	Platform consolidation and device standardization	Public sector IT CAPEX, platform licensing	MEDIUM-HIGH (IoT platform, integration services)

Medium-term	Predictive maintenance and edge AI deployment	Innovation funds, AIOps investments	MEDIUM (edge nodes, AI models)
Long-term	Cognitive IoT and DePIN infrastructure	Institutional investment, strategic R&D	MEDIUM (autonomous systems, decentralized networks)
Infrastructure readiness			
	Primary Enabler	Readiness Level	Key Build-Out
Short-term	LPWAN (LoRaWAN, NB-IoT) and 4G/5G coverage	Expanding coverage	Centralized IoT platform and digital twin registry
Medium-term	Edge computing nodes and API marketplaces	Emerging deployment	Distributed intelligence at infrastructure sites
Long-term	DePIN networks and self-healing components	Pilots and research	Federated, autonomous IoT fabric
Regulatory Maturity			
	Primary Focus	Status	Key Milestone
Short-term	IoT cybersecurity certification mandates	Drafted/enacted	Security standards for public IoT devices
Medium-term	Right to repair and interoperability regulations	Emerging frameworks	Vendor lock-in mitigation requirements
Long-term	Algorithmic governance and public utility designation	Under consideration	Transparency rules for autonomous public systems
Market absorption capacity			
	Adoption Phase	Value Migration	Key Players
Short-term	Early adopters (large cities, transit agencies)	Smart City IoT platforms	IoT platform vendors, telecom providers
Medium-term	Early majority (regional authorities)	Mobility Infrastructure IoT platforms, analytics as a service	Cloud providers, specialized analytics firms
Long-term	Late majority / Regulated utility	Applications, AI services, ecosystem services	Public IoT utilities, platform cooperative
Good practices			
SynchroniCity (EU Horizon 2020 Project) A large-scale EU project developing interoperable IoT platforms and data marketplaces for smart cities, including mobility applications. Demonstrates standardized IoT integration across multiple cities. Link: https://synchronicity-iot.eu/ **"Internet of Things for Smart Cities" (IEEE Communications Magazine)**			

D.1.5.1 - SMARTMOBAIR technology roadmap

A foundational peer-reviewed article outlining IoT architectures, interoperability, and real-time data integration for urban systems. Widely cited in smart mobility IoT design. Link: https://ieeexplore.ieee.org/document/6740844

3. Cross-Cutting Insights and Strategic Implications

3.1 Technology Portfolio and System Perspective

The technology roadmaps presented in Chapter 2 were developed individually in order to capture the specific characteristics, maturity levels, development trajectories, implementation requirements, and enabling conditions associated with each technology. This technology-specific perspective is essential for understanding the opportunities, challenges, and future evolution pathways of individual solutions. However, the future transformation of mobility systems cannot be fully understood through the analysis of individual technologies alone.

Smart mobility is increasingly evolving towards integrated ecosystems in which multiple technologies interact, exchange data, support common functions, and collectively contribute to broader mobility objectives. Technologies that may appear independent when examined separately often become highly interconnected when deployed within operational mobility environments. As a result, the value generated by a mobility system is increasingly determined not only by the performance of individual technological components, but also by the quality of the interactions established between them.

The technology portfolio analysed within SMARTMOBAIR reflects this systemic perspective. The technologies considered in the roadmap span a broad range of mobility functions, including data collection, positioning and tracking, infrastructure monitoring, passenger information, service integration, operational management, payment systems, geospatial planning, access regulation, and digital infrastructure management. Together, these technologies address the different layers required to support the transition towards more intelligent, connected, and adaptive mobility systems.

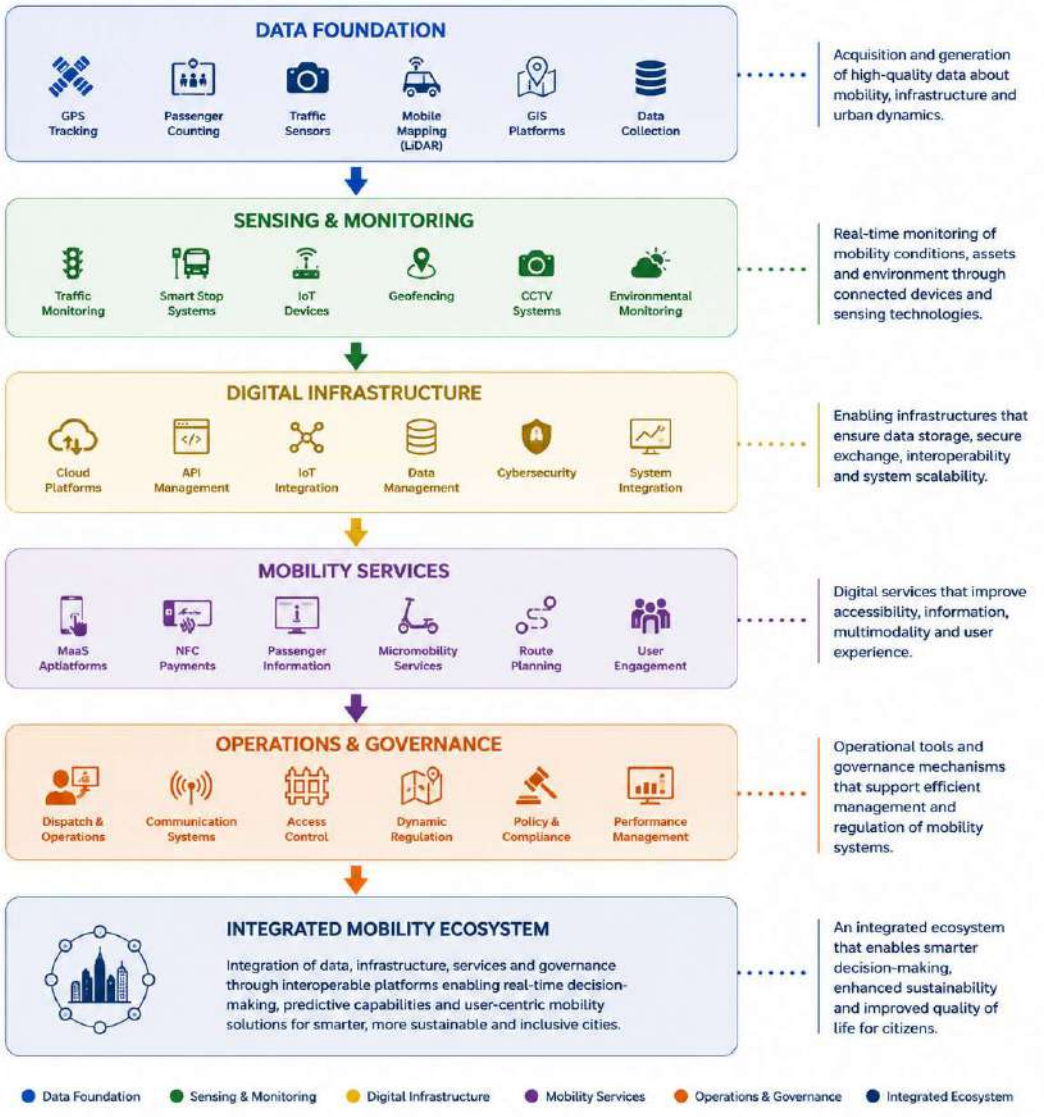
At a functional level, the roadmap portfolio can be interpreted as a combination of complementary technology domains. A first group of technologies provides the foundations for data acquisition and situational awareness, including GPS tracking systems, passenger counting solutions, traffic monitoring devices, mobile mapping technologies, and geospatial platforms. These technologies contribute to the generation of increasingly rich and dynamic representations of mobility conditions and infrastructure performance. A second group focuses on digital infrastructures and interoperability, including cloud environments, API management platforms, and IoT integration solutions that enable data exchange and system connectivity. A third group addresses user-facing mobility services, including mobility applications, smart passenger information systems, payment solutions, and shared mobility platforms. Finally, additional technologies support operational management, mobility governance, and dynamic regulation through dispatch systems, communication tools, geofencing mechanisms, and intelligent control systems.

Although these technology domains perform different functions, their evolution reveals a common direction. Across the portfolio, technologies are progressively moving from isolated and application-specific solutions towards increasingly integrated digital environments characterised by interoperability, real-time information exchange, predictive capabilities, and platform-based service delivery. This evolution reflects a broader shift from fragmented mobility systems towards coordinated mobility ecosystems capable of combining data, infrastructure, services, and governance mechanisms within a common operational framework.

The portfolio perspective also highlights the growing importance of convergence across technological domains. Data generated by sensing technologies increasingly feeds planning tools, operational platforms,

passenger information systems, and regulatory mechanisms. Infrastructure management systems become interconnected with mobility services. User-facing applications become gateways to integrated mobility ecosystems. Digital platforms progressively act as coordination layers linking multiple actors, technologies, and services. Consequently, the boundaries between traditionally separate mobility functions become increasingly blurred, giving rise to more integrated and adaptive mobility environments.

Understanding these interdependencies is essential for interpreting the roadmap results. The future mobility systems emerging from the SMARTMOBAIR technology portfolio are not characterised by the dominance of a single technology or innovation pathway. Rather, they are shaped by the progressive integration of complementary technologies that collectively support new forms of mobility management, service provision, infrastructure operation, and decision-making. The portfolio perspective therefore provides a bridge between the individual roadmaps presented in Chapter 2 and the broader transformation patterns discussed in the following sections of this report.



SMARTMOBAIR Technology Portfolio and System Perspective *illustrates how the different technology domains contribute to the development of increasingly integrated mobility ecosystems.*

3.2 Emerging Mobility Transformation Patterns

While the roadmap factsheets presented in Chapter 2 describe the evolution of individual technologies, a broader analysis of the SMARTMOBAIR technology portfolio reveals a number of recurring transformation patterns that extend across multiple technology domains. Although the technologies considered in the roadmap differ in terms of functions, maturity levels, deployment contexts, and implementation requirements, their development trajectories exhibit significant commonalities. These shared trends provide valuable insights into the broader direction of mobility system evolution and help explain how individual technological innovations collectively contribute to wider transformations in mobility planning, management, and service provision.

A first recurring pattern concerns **the growing strategic importance of data**. Across virtually all technology domains analysed within the roadmap, data emerges as the primary resource underpinning future mobility systems. Technologies such as GPS tracking, traffic monitoring devices, passenger counting systems, mobile mapping solutions, geospatial platforms, cloud infrastructures, API management systems, and IoT integration architectures all contribute to the generation, processing, exchange, and exploitation of mobility-related information. While these technologies serve different operational purposes, their long-term evolution points towards increasingly integrated data ecosystems capable of supporting real-time situational awareness, evidence-based planning, predictive analytics, and adaptive management processes. In this context, mobility data progressively evolves from a by-product of transport operations into a strategic infrastructure asset that supports decision-making across multiple organisational and territorial levels.

A second transformation pattern concerns **the evolution of mobility services from isolated applications towards interconnected digital ecosystems**. Traditionally, mobility services have often been organised around individual modes, operators, or technological solutions, resulting in fragmented user experiences and limited integration between transport options. The roadmap indicates a progressive shift towards more integrated service environments enabled by mobility applications, smart passenger information systems, digital payment solutions, shared mobility platforms, booking systems, and multimodal journey planning tools. The future trajectory of these technologies increasingly emphasises seamless user experiences, integrated service delivery, unified access mechanisms, and platform-based mobility models. This evolution reflects a broader transition from technology-centred solutions towards user-centred mobility ecosystems in which different services operate as interconnected components of a common mobility environment.

A third recurring pattern involves **the transformation of mobility management practices from reactive approaches towards predictive and increasingly proactive decision-making models**. Several roadmap technologies, including passenger counting systems, traffic monitoring devices, geofencing solutions, dispatch platforms, IoT infrastructures, and digital planning tools, progressively incorporate advanced analytical capabilities based on artificial intelligence, machine learning, and real-time data processing. These developments allow mobility systems to move beyond the simple observation of current conditions towards the anticipation of future events and operational needs. The resulting shift from monitoring to prediction creates opportunities for dynamic traffic management, predictive maintenance, demand forecasting, adaptive service planning, and more efficient allocation of mobility resources. Consequently, future mobility systems are expected to become increasingly capable of anticipating disruptions, identifying emerging trends, and responding proactively to changing mobility conditions.

Underlying all these developments is a fourth and perhaps most pervasive transformation pattern: the growing importance of interoperability and system integration. Interoperability appears consistently throughout the roadmap portfolio as a prerequisite for unlocking the full value of smart mobility technologies. Whether considering data exchange platforms, cloud infrastructures, mobility applications, geospatial systems, intelligent transport solutions, or operational management tools, future developments increasingly depend on the ability of technologies to communicate through common standards, shared data models, and interoperable digital architectures. In this sense, interoperability should not be regarded as a technical feature of individual technologies, but as a foundational condition for the emergence of integrated mobility ecosystems. Without interoperability, data remains fragmented, services remain disconnected, and opportunities for coordinated management remain limited.

Taken together, these transformation patterns suggest that the future evolution of mobility systems will be characterized less by the deployment of individual technologies and more by the progressive convergence of multiple technological domains into integrated digital environments. Data collection technologies increasingly feed analytical platforms; digital infrastructures support service integration; operational management systems rely on real-time information flows; and governance mechanisms become increasingly informed by continuous streams of mobility data. The resulting convergence progressively blurs traditional boundaries between infrastructure management, service provision, planning, regulation, and user interaction, creating increasingly connected and adaptive mobility ecosystems.

The patterns identified across the SMARTMOBAIR portfolio therefore point towards a common vision of future mobility systems. These systems are expected to be increasingly data-driven, interconnected, predictive, and adaptive. Rather than being defined by individual technological innovations, they will be characterised by the capacity to integrate data, infrastructure, services, and governance mechanisms into coordinated mobility ecosystems capable of continuously learning, evolving, and responding to changing societal, environmental, and operational conditions. Understanding these broader transformation patterns is essential for interpreting the individual roadmaps and for identifying the strategic implications discussed in the following section.

3.3 Strategic Implications for the Adriatic-Ionian Region

The transformation patterns identified across the SMARTMOBAIR technology portfolio have implications that extend beyond the evolution of individual technologies. Collectively, they provide insights into the broader direction of mobility system development and highlight a number of strategic considerations that are particularly relevant for the Adriatic-Ionian region. These considerations emerge not from a single roadmap, but from the convergence of technological trajectories observed across the entire portfolio.

A first implication concerns the growing strategic importance of mobility data. Across the technologies analysed in this report, data increasingly emerges as the primary resource enabling planning, operations, monitoring, optimization, and service integration. The future competitiveness and effectiveness of mobility systems will therefore depend not only on the availability of physical infrastructure but also on the ability to collect, manage, share, and exploit mobility-related information. In this sense, data infrastructures are becoming a critical component of mobility systems, supporting functions that were traditionally associated with physical assets alone. The capacity to generate high-quality, interoperable, and trustworthy data is likely to become an increasingly important determinant of mobility system performance.

A second implication concerns the role of interoperability. The roadmap analysis consistently highlights the growing interdependence between technologies, services, operators, and governance mechanisms. As mobility systems become more connected, the ability of different technological components to exchange information and operate within common digital environments becomes increasingly important. Interoperability therefore evolves from a technical requirement into a strategic condition for future mobility development. The effectiveness of many emerging solutions will depend less on the performance of individual technologies than on their capacity to interact within broader ecosystems characterised by common standards, shared data models, and coordinated governance arrangements.

The roadmap also suggests a gradual evolution in the role of mobility management. Traditional approaches have often relied on periodic data collection, retrospective analysis, and reactive decision-making processes. The technologies considered within SMARTMOBAIR indicate a progressive transition towards **real-time awareness, predictive capabilities, and increasingly adaptive operational models**. This transformation has implications not only for transport operations but also for planning practices and institutional decision-making processes. Future mobility systems are likely to rely on continuous information flows and dynamic management approaches that enable more responsive and evidence-based interventions.

From a territorial perspective, these developments are particularly relevant for the Adriatic-Ionian region. The diversity of territorial contexts represented within SMARTMOBAIR demonstrates that technological innovation cannot be separated from local implementation conditions. Differences in institutional capacity, digital maturity, infrastructure readiness, market development, and governance structures will continue to influence the pace and character of mobility transformation across the region. At the same time, the common challenges faced by many territories suggest significant opportunities for **knowledge transfer, mutual learning, and wider replication** of successful solutions.

The pilot actions implemented within SMARTMOBAIR should therefore be viewed not only as individual demonstrations of technological solutions but also as building blocks within a broader regional learning process. Their value lies not solely in the validation of specific technologies, but in the generation of evidence regarding implementation pathways, enabling conditions, organisational requirements, and potential barriers to deployment. The experiences gained through the pilots contribute to a shared knowledge base that can support future mobility initiatives throughout the Adriatic-Ionian area.

Taken together, the roadmap findings indicate that future mobility systems are likely to become increasingly integrated, data-driven, and adaptive. While individual technologies will continue to evolve along distinct trajectories, their collective impact will depend on the extent to which they contribute to the creation of connected mobility ecosystems capable of combining data, infrastructure, services, and governance mechanisms within coherent operational frameworks. For the Adriatic-Ionian region, the strategic challenge is therefore not simply the adoption of innovative technologies, but the ability to create the conditions that enable these technologies to function as components of a broader and more resilient mobility system.

4. Concluding remarks

The technology roadmaps presented in this report, together with the cross-cutting analysis developed in Chapter 3, highlight a common direction of evolution across the SMARTMOBAIR technology portfolio. While individual technologies differ in terms of functions, maturity levels, and implementation pathways, their trajectories collectively point towards increasingly integrated, data-driven, interoperable, and adaptive mobility systems. The following concluding remarks synthesise the main findings emerging from the roadmap analysis and their significance for the future development of smart mobility in the Adriatic-Ionian region.

This SMARTMOBAIR Technology Roadmap provides a **practical guide for moving from planning to action**. By analyzing key smart mobility technologies, we have outlined clear, step-by-step paths for their development and use in the Adriatic-Ionian region.

The roadmaps show a common pattern for how these technologies can grow. The first step is to make different systems work together through shared data standards and to test them fairly in pilot projects. The next phase involves adding smarter tools, like AI, to improve efficiency and create smoother travel options across different transport modes. Looking further ahead, the goal is a more connected and efficient system where infrastructure and vehicles communicate to optimize traffic, energy use, and maintenance on their own.

The technology roadmaps collectively reveal a profound and accelerating paradigm shift in how mobility systems are conceived, built, and operated. The current state—characterized by fragmented, proprietary, and reactive technologies serving isolated modes—is giving way to a fundamentally new architecture. This emerging paradigm is defined by convergence: data streams from GPS trackers, passenger counters, traffic sensors, and micromobility fleets no longer reside in silos but flow into unified Mobility Data Lakes. Physical infrastructure—bus stops, docking stations, traffic signals, and vehicles—becomes intelligent and communicative. User interfaces—whether smartphone apps, NFC cards, or smart bus stop displays—seamlessly interconnect across modes. The strategic objective that unifies all 17 roadmaps is the transformation of mobility **from a collection of discrete services into a coherent, intelligent, and adaptive fabric** woven into the urban environment.

This shift is not merely technological but structural. In the short-term horizon, the focus is on foundational consolidation: mandating open data standards, deploying interoperable hardware, and establishing regulatory frameworks that mandate data sharing and accessibility. These foundational investments are prerequisites for the medium-term transformation, where predictive analytics, edge intelligence, and multimodal integration begin to deliver tangible efficiency gains and user experience improvements. The long-term horizon envisions something far more ambitious: a cognitive, self-optimizing, and resilient mobility ecosystem where autonomous vehicles, infrastructure, and users interact seamlessly within a trusted, sovereign data framework. Across all roadmaps, this three-horizon structure remains consistent, demonstrating a shared understanding of the sequential dependencies that must be respected for successful transformation.

Perhaps the most significant insight emerging is **the blurring boundary between physical and digital infrastructure**. Historically, transport planning focused on concrete, steel, and asphalt, roads, bridges, bus shelters. The roadmaps reveal a future where these physical assets are increasingly indistinguishable from their digital counterparts. A smart bus stop is simultaneously a physical shelter and a data node, hosting

environmental sensors, passenger counting devices, real-time information displays, and V2X communication units. A geofenced low-emission zone is both a regulatory boundary and a dynamic digital policy enforced through connected vehicle telematics and camera networks. The GIS Public Transport Cadastre evolves from a static map of infrastructure into a living digital twin that mirrors the physical network in real-time, becoming the authoritative record for planning, maintenance, and even legal dispute resolution.

This convergence carries profound implications for governance and investment. Infrastructure investment decisions can no longer be separated from digital investment. Procurement must specify not only physical durability but also data interoperability, cybersecurity, and upgradeability. The concept of "infrastructure" itself expands to include data platforms, API gateways, and cloud services as core assets deserving of public investment and oversight. Several roadmaps explicitly recognize this shift by proposing that digital infrastructure—the mobility data fabric, the geospatial cadastre, the IoT platform—should be designated as critical public infrastructure or even a regulated utility. This framing elevates digital systems from operational support tools to foundational assets whose resilience and accessibility are matters of strategic public importance.

Across every technology pathway, a consistent trajectory emerges: the migration of intelligence from the center to the edge, and from historical reporting to predictive action. In the short-term, intelligence is primarily rule-based—alerts triggered by thresholds, reports generated from aggregated data. By the medium-term, artificial intelligence and machine learning become pervasive, enabling demand forecasting, predictive maintenance, dynamic routing, and real-time optimization. Fleet operators no longer simply track vehicles; they anticipate demand and preposition assets. Traffic managers no longer merely monitor congestion; they predict it and prescribe interventions. Passenger counting systems no longer just report ridership; they infer origin-destination patterns and inform network design.

The long-term horizon envisions intelligence becoming cognitive and autonomous. Systems will not only predict but also prescribe, learning from outcomes to continuously improve. They will manage mixed fleets of human-driven and autonomous vehicles, orchestrate multimodal journeys without user intervention, and optimize network-wide performance against complex goals—balancing efficiency, equity, sustainability, and resilience. This evolution demands new capabilities in AI research, edge computing infrastructure, and, critically, in governance. The roadmaps consistently highlight the need for algorithmic transparency, equity audits, and human-in-the-loop oversight to ensure that autonomous systems serve public values rather than narrow efficiency metrics. Intelligence, in this future, is not merely a technical capability but a governed resource subject to democratic accountability.

A striking feature of these roadmaps is the persistent and intentional focus on equity and inclusion. Each technology pathway explicitly addresses the risk of digital divide and proposes mitigation strategies. Smart bus stops must be designed with universal accessibility—tactile interfaces, audio output, high-contrast visuals—to serve users regardless of age, disability, or digital literacy. Trip booking apps must maintain telephone-based and cash-based alternatives alongside smartphone functionality. Micromobility permits must include equitable geographic coverage requirements, ensuring that shared services do not cluster only in affluent neighborhoods. NFC physical cards must remain available as a permanent alternative to smartphone-based payment, ensuring that those without bank accounts or smartphones are not excluded from the mobility system.

This commitment to equity is not merely ethical but strategic. A mobility system that excludes significant portions of the population—elderly, low-income, disabled, digitally disconnected—cannot achieve its objectives of reducing private car dependency or increasing public transport ridership. Moreover, the roadmaps recognize that equity must be designed in from the start, not retrofitted. Algorithmic optimization models must include equity constraints. Deployment strategies must prioritize underserved neighborhoods. Data governance must ensure that the insights derived from mobility data benefit all communities, not just those with the highest digital engagement. The roadmaps thus offer a model for technology development that places social inclusion alongside efficiency and innovation as core design principles.

Underpinning all technological evolution is a profound governance challenge: who owns the data, who controls the infrastructure, and who ensures the system serves the public interest? The roadmaps consistently identify data sovereignty, vendor lock-in, and public trust as critical risks requiring active mitigation. Short-term solutions include open data mandates, open API standards, and modular procurement that prevents proprietary lock-in. Medium-term strategies involve the establishment of Mobility Data Trusts—governed entities that manage data sharing between public and private actors under clear rules. Long-term visions propose sovereign cloud frameworks (such as GAIA-X) and decentralized identity systems that give individuals control over their own mobility data.

The concept of **infrastructure as a public utility** emerges repeatedly, particularly in the long-term horizons of cloud infrastructure, IoT platforms, and GIS cadastre roadmaps. This framing suggests that foundational digital assets—the data platforms, connectivity networks, and spatial registries upon which all mobility services depend—should be subject to public oversight, accessibility requirements, and resilience standards akin to those applied to roads, water, and electricity. This does not necessarily imply direct public ownership; public-private partnerships, regulated private consortia, and open-source commons are all viable models. But it does imply that these systems cannot be left solely to market forces. Their criticality to mobility, safety, and social participation demands governance frameworks that ensure continuity, equity, and accountability.

The roadmaps were developed in a context of accelerating uncertainty, climate change intensifying extreme weather events, cybersecurity threats evolving rapidly, geopolitical shifts affecting technology supply chains and data governance, and the unpredictable pace of autonomous vehicle deployment. Across all 17 pathways, resilience emerges as a central design principle. Infrastructure must be hardened against physical and cyber threats. Systems must include manual overrides and fallback mechanisms for when connectivity fails or algorithms err. Positioning systems must be resilient against spoofing, jamming, and GNSS outages, with alternative PNT (Positioning, Navigation, and Timing) sources becoming standard in critical applications.

The long-term horizon consistently incorporates quantum-resistant cryptography, anticipating that today's encrypted data will be vulnerable to tomorrow's quantum computers. Decentralized physical infrastructure networks (DePIN) and federated cloud architectures offer pathways to resilience through distribution, avoiding single points of failure. Self-healing infrastructure—systems that can detect damage, reroute around failures, and even repair themselves—shifts from science fiction to engineering roadmap. This emphasis on resilience reflects a maturation in smart mobility thinking: the recognition that digital systems, for all their benefits, introduce new vulnerabilities that must be systematically addressed, not as an afterthought but as a foundational requirement.

Finally, for decision-makers, whether in public authorities, private enterprises, or civil society, the roadmaps offer both a vision and a set of actionable priorities. The short-term actions recommended across the 17

pathways coalesce into a coherent agenda: mandate open data standards in all procurements; establish centralized API management platforms to reduce integration costs; deploy baseline infrastructure (sensors, connectivity, digital twins) in pilot corridors; require universal accessibility and equity provisions in permits and contracts; and build internal data literacy and governance capacity. These are not speculative investments but proven foundations that enable all subsequent innovation.

The roadmaps can act as a practical bridge between smart mobility innovation and Sustainable Urban Mobility Planning. In particular they can guide mobility planners in :

• embed technology choices within existing or forthcoming SUMP objectives, avoiding stand-alone digital investments that are not linked to measurable mobility, environmental and social goals;

• use the roadmaps during the preparation and analysis phase to identify data gaps, interoperability requirements and the digital infrastructure needed to support evidence-based planning;

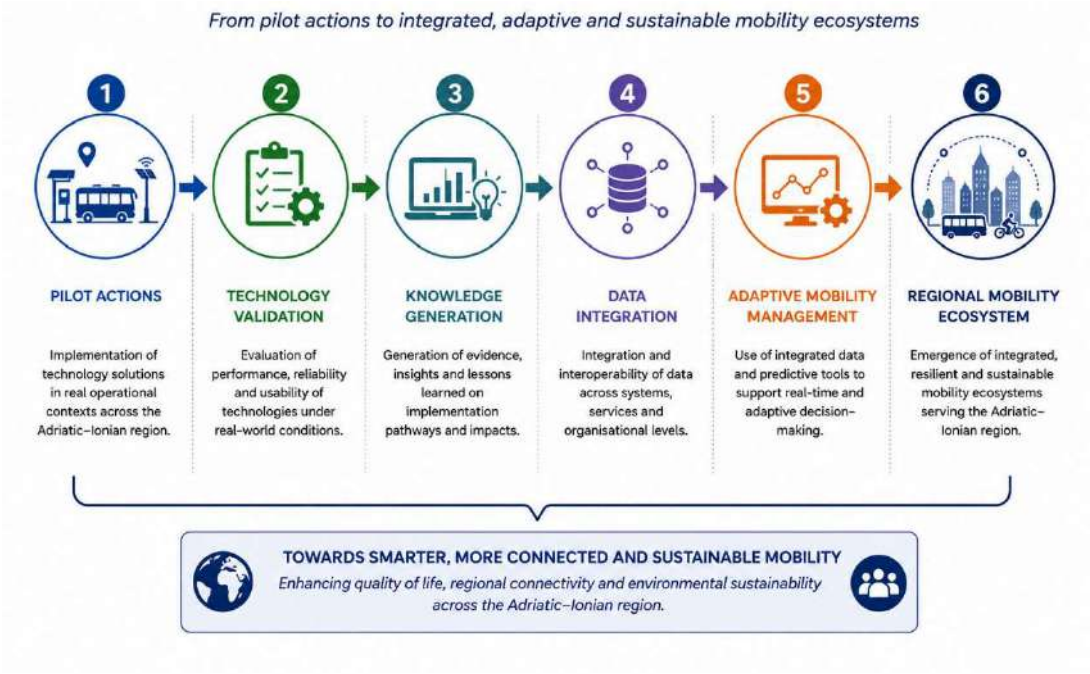
• translate pilot results into SUMP indicators and monitoring schemes, ensuring that data generated by ITS solutions in real time can be used to assess accessibility, modal shift, congestion, emissions, safety and service quality;

• include open standards, data sharing, cybersecurity, privacy-by-design and accessibility requirements in procurement procedures for smart mobility solutions;

• design implementation pathways that move progressively from pilot testing to scalable and transferable solutions, combining technical feasibility with institutional capacity, financial sustainability and stakeholder acceptance.

The medium-term requires a shift from pilot to scale. Cities and regions must move from fragmented, operator-specific solutions to unified platforms—MaaS integrators, digital twins, mobility data trusts—that orchestrate the entire ecosystem. Performance-based contracting, where operators are paid for outcomes (passenger-kilometers, service reliability) rather than inputs (vehicle-hours), aligns incentives with public goals. Cross-sectoral collaboration becomes essential, as mobility data fuses with energy, land use, and public safety systems. The long-term calls for strategic positioning: designating digital infrastructure as critical public assets, establishing governance frameworks for algorithmic accountability, and building the sovereign data capabilities that will underpin future competitiveness and resilience.

The roadmaps make clear that the transition to smart, sustainable, equitable mobility is not predetermined. It will require **sustained investment**, **good governance**, and **a commitment to values** that extend beyond efficiency. But the technologies, the standards, and the good practices exist. What is needed now is the collective will to build the mobility future that these roadmaps envision—a future where movement is seamless, inclusive, resilient, and in harmony with the broader goals of sustainable urban life.



SMARTMOBAIR Pathway to Regional Mobility Transformation. *The figure illustrates the progressive pathway through which the technologies assessed within SMARTMOBAIR contribute to broader mobility system transformation. Starting from pilot implementation and technology validation, the process generates operational knowledge and evidence that support data integration, adaptive mobility management, and the development of increasingly connected and interoperable mobility ecosystems. The pathway highlights how individual technological solutions can collectively contribute to the long-term transition towards more sustainable, resilient, and data-driven mobility systems across the Adriatic-Ionian region.*

Annex 1 - Policy Brief

Executive Message

Smart mobility is no longer defined by the technologies that cities deploy, but by their capacity to **govern technological change**. As mobility systems become increasingly connected, data-driven and multimodal, the ability to integrate digital innovation within **coherent governance frameworks** has become the decisive factor for achieving sustainable, resilient and people-centred mobility.

This challenge is particularly relevant across the **Adriatic-Ionian (ADRION) region**, where diverse territorial conditions, fragmented mobility systems and varying institutional capacities require coordinated policy responses that extend beyond individual technological solutions. The experience generated through SMARTMOBAIR demonstrates that technological innovation creates **lasting public value** only when supported by effective governance, **interoperable data ecosystems**, institutional capacity and collaborative decision-making.

Building on these lessons, this Policy Brief translates the evidence generated by SMARTMOBAIR into a **strategic framework for future policymaking**. Rather than advocating specific technologies, it identifies the **enabling conditions** that allow innovation to strengthen public transport, promote integrated and inclusive mobility services, reinforce institutional capacity and accelerate the transition towards climate-neutral and safe mobility systems.

The ambition of this Policy Brief is to support municipalities, regional authorities and policymakers in transforming innovation into **long-term public value**. By placing governance alongside technology, it provides a strategic reference for future policies and investments that can contribute to a more integrated, resilient and sustainable mobility ecosystem across the ADRION region.

1. Why Smart Mobility Matters in the ADRION Region

The transition towards **sustainable, resilient and climate-neutral mobility** has become a **strategic priority** for European territories. While the European Green Deal, the Sustainable and Smart Mobility Strategy and the New EU Urban Mobility Framework establish a common policy direction, achieving these objectives ultimately depends on the capacity of **local and regional authorities** to translate ambition into **effective planning, coordinated governance and long-term investment**.

For the **Adriatic-Ionian (ADRION) region**, this transition presents both significant opportunities and complex challenges. The region encompasses a diverse territorial landscape characterised by medium-sized cities, dispersed settlements, coastal areas, islands and cross-border functional spaces, where mobility systems operate under highly heterogeneous geographical, demographic and socio-economic conditions. Seasonal tourism, uneven urbanisation patterns and varying levels of institutional and digital maturity further increase the complexity of planning and managing sustainable mobility solutions across the region.

Despite this diversity, **common structural challenges** can be observed throughout the ADRION area. Public transport systems often remain fragmented, multimodal integration is still limited and private vehicle dependency continues to dominate many urban and peri-urban contexts. At the same time, **public authorities** frequently face **fragmented mobility data**, legacy digital infrastructures and **limited institutional capacity** to fully exploit technological innovation as a driver of strategic planning and policy development. These constraints reduce the effectiveness of transport planning, hinder coordinated investment decisions and limit the ability to monitor and evaluate policy outcomes over time.

The transition towards smart mobility in the ADRION region requires coordinated governance frameworks capable of integrating technological innovation, institutional capacity and evidence-based decision-making to address shared territorial challenges.

Digital technologies have the potential to transform this landscape. **Intelligent Transport Systems (ITS)**, connected infrastructure, real-time monitoring, data platforms and digital mobility services offer new opportunities to improve the efficiency, accessibility and sustainability of transport systems. Yet experience increasingly shows that **technology alone does not deliver better mobility outcomes**. The real challenge is enabling public authorities to integrate these technologies within **coherent governance frameworks**, where data, infrastructure, services and institutional processes operate as components of a single, interoperable mobility ecosystem.

This represents a fundamental shift in the role of public authorities. **Smart mobility** is no longer primarily about deploying innovative technologies; it is about strengthening the **institutional capacity** to govern increasingly complex mobility systems. **Interoperability**, **data governance**, **stakeholder collaboration** and **evidence-based decision-making** become **strategic enablers** that allow municipalities to improve planning, optimise investments, coordinate mobility services and continuously adapt policies to changing territorial needs.

Within this context, the **SMARTMOBAIR project** contributes to the implementation of European mobility objectives by generating practical evidence on the deployment of smart mobility solutions across the ADRION region. Through **pilot actions**, **technology assessment**, **stakeholder engagement** and **transnational cooperation**, the project explores how digital innovation can support more integrated, sustainable and user-centred mobility systems while strengthening the capacity of public authorities to plan and manage future mobility transitions. Building upon these experiences, this Policy Brief identifies the **strategic priorities** and **policy recommendations** that can support municipalities and regional authorities in accelerating the transition towards more resilient, integrated and data-driven mobility systems across the Adriatic-Ionian region.

2. Strategic Insights Emerging from SMARTMOBAIR

The SMARTMOBAIR project confirms that the transition towards **smart and sustainable mobility** cannot be understood solely as a process of technological innovation. Across the different pilot experiences, territorial contexts and stakeholder perspectives, a consistent message emerged: the effectiveness of smart mobility solutions depends less on the availability of digital technologies than on the capacity of **public authorities** to integrate them within **coherent governance frameworks**, supported by institutional capacity, strategic planning and cross-sector collaboration.

While the pilot actions addressed different mobility challenges and tested diverse technological applications, they revealed a **common set of enabling conditions** that transcend individual solutions and are relevant for municipalities throughout the Adriatic-Ionian region. These conditions represent the project's most significant policy legacy, demonstrating that successful innovation is determined not only by technical performance but also by the organisational, institutional and governance environment in which technologies are deployed.

A first lesson concerns the evolving role of public authorities. The project demonstrates that municipalities are increasingly required to move beyond their traditional role as infrastructure providers or service regulators, assuming instead the role of system orchestrators capable of coordinating multiple actors, integrating heterogeneous sources of information and aligning technological investments with long-term policy objectives. In this context, **governance becomes the primary driver of innovation**, creating the institutional conditions necessary for technologies to deliver measurable public value.

Closely connected to this transformation is the strategic importance of **mobility data**. Throughout the project, data emerged not simply as a technical resource supporting operational management, but as a strategic public asset capable of improving planning, monitoring and policy evaluation. However, the value of mobility data depends fundamentally on **interoperability**. Fragmented information systems and isolated digital applications limit the capacity of public authorities to generate comprehensive knowledge of mobility patterns and to support coordinated decision-making. Developing interoperable data ecosystems should therefore be recognised as a strategic policy objective rather than a purely technological challenge.

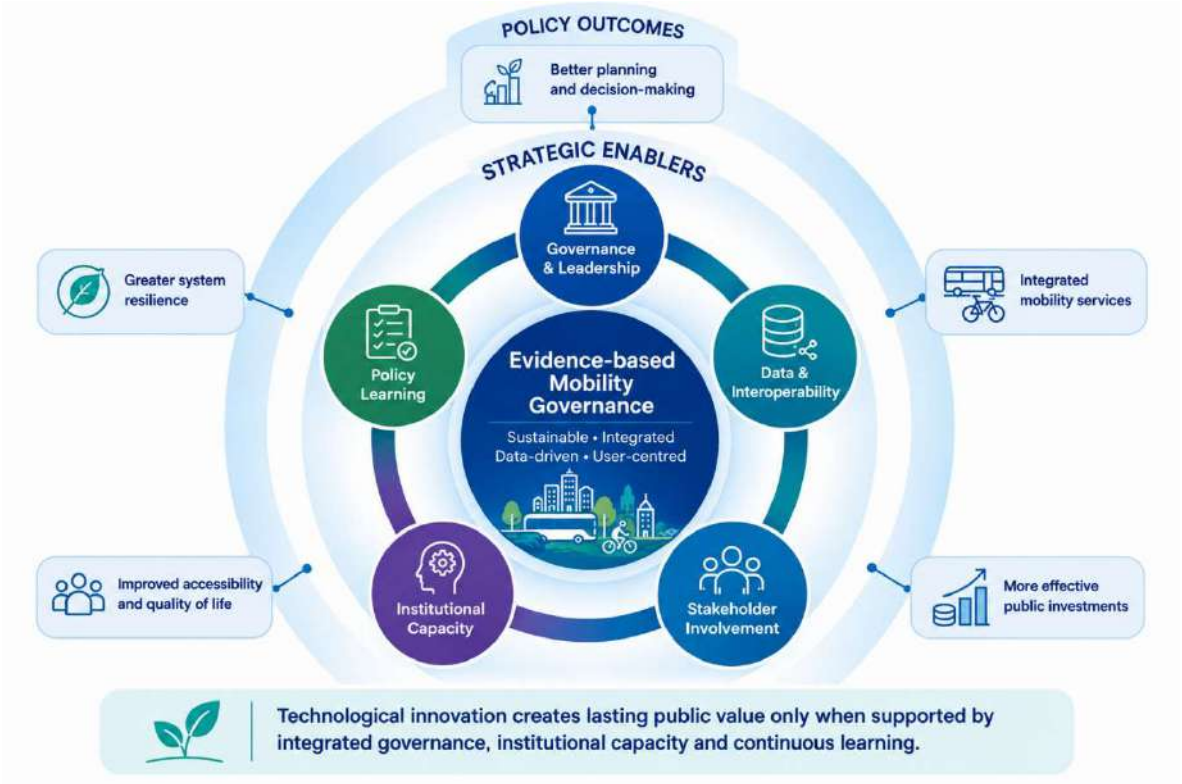
The project also demonstrates the broader value of **pilot actions** within the policy cycle. Beyond validating innovative technologies, pilot implementations provide an opportunity to test governance arrangements, identify operational barriers, strengthen institutional learning and reduce uncertainty before larger-scale investments are undertaken. In this perspective, pilot projects should be regarded as instruments for **evidence generation**, enabling public authorities to design more robust policies and make better-informed investment decisions based on practical experience rather than assumptions.

Another recurring lesson emerging from SMARTMOBAIR concerns the importance of **collaboration**. The complexity of contemporary mobility systems requires the active involvement of municipalities, transport operators, technology providers, research organisations and civil society. The project illustrates how stakeholder engagement not only improves the quality and acceptability of mobility solutions but also facilitates knowledge exchange, institutional coordination and the long-term sustainability of innovation processes. Collaborative governance therefore represents a structural prerequisite for effective smart mobility rather than a complementary activity supporting project implementation.

Finally, the experience gained throughout SMARTMOBAIR highlights the critical role of **institutional capacity**. Digital transformation requires new technical competences, organisational capabilities and strategic leadership

within public administrations. Investments in digital infrastructure alone are insufficient if local authorities lack the capacity to manage complex data ecosystems, evaluate technological options, coordinate procurement processes or monitor policy outcomes over time. Strengthening institutional capabilities should therefore be considered a strategic investment in its own right, enabling municipalities to scale innovation, adapt to evolving mobility needs and maximise the long-term benefits of technological change.

Taken together, these insights suggest that the future of smart mobility in the ADRION region will depend not on the deployment of individual technologies, but on the ability to build **integrated governance ecosystems** in which digital innovation, institutional capacity and **evidence-based decision-making** reinforce one another. This systemic perspective provides the foundation for the strategic priorities presented in the following chapter, where the lessons emerging from SMARTMOBAIR are translated into policy directions and recommendations for municipalities, regional authorities and other public stakeholders.



The SMARTMOBAIR experience demonstrates that the successful transition towards smart mobility depends on a set of mutually reinforcing strategic enablers. Effective governance, interoperable data ecosystems, institutional capacity, stakeholder collaboration and continuous policy learning enable public authorities to transform technological innovation into integrated, evidence-based and resilient mobility systems that generate long-term public value.

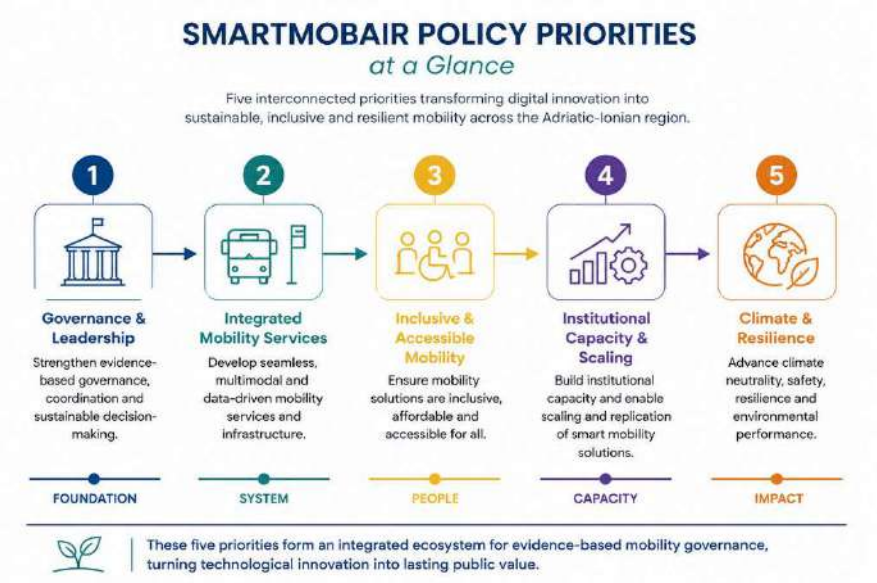
3. Strategic Priorities for ADRION Policymakers

Building upon the strategic insights emerging from SMARTMOBAIR, this chapter translates the project's evidence into a set of **policy priorities** aimed at supporting the long-term transformation of mobility systems across the ADRION region. Rather than prescribing individual technological solutions, these priorities identify the strategic areas where public authorities can create the conditions for more integrated, resilient and evidence-based mobility governance.

The proposed priorities reflect the common challenges and opportunities observed throughout the project and are closely aligned with the technology pathways identified in **the SMARTMOBAIR Technology Roadmap**. Together, they provide a **coherent policy framework** that supports municipalities and regional authorities in strengthening institutional capacity, guiding investment decisions and accelerating the transition towards sustainable, digital and user-centred mobility systems.

Where **Sustainable Urban Mobility Plans** are in place, these priorities can be embedded within the whole SUMP cycle, helping public authorities connect long-term mobility objectives with investment choices, implementation and performance monitoring.

Although presented as distinct priorities, they should not be considered as independent actions. Their effectiveness depends on their combined implementation, recognising that governance, digital transformation, service integration, institutional capacity and sustainability are mutually reinforcing dimensions of a **comprehensive smart mobility strategy**.



Strategic Priority 1 - Strengthen Evidence-Based Mobility Governance

Transforming mobility data into better public decisions

Key Policy Message

The digital transformation of urban mobility requires a corresponding transformation in the way public authorities govern mobility systems. As transport networks become increasingly connected, data-rich and multimodal, effective governance is no longer based solely on infrastructure planning or service regulation, but on the ability to **integrate evidence**, coordinate stakeholders and translate information into strategic decisions. Strengthening evidence-based mobility governance enables municipalities to **anticipate mobility needs**, improve investment prioritisation and ensure that technological innovation contributes to **long-term public value** rather than isolated digital solutions.

Policy Challenge

Across the ADRION region, municipalities are progressively adopting digital technologies to improve transport management and public services. Nevertheless, the availability of data has not always been matched by equivalent advances in governance practices. Mobility information often remains fragmented across institutions, transport operators and digital platforms, while planning processes continue to rely on disconnected datasets and limited analytical capacity. As a result, public authorities frequently encounter difficulties in developing integrated mobility policies, assessing the effectiveness of interventions and adapting planning decisions to evolving mobility patterns.

Addressing these challenges requires recognising mobility data as a strategic public asset. Establishing interoperable governance frameworks, strengthening institutional coordination and embedding evidence within policy processes are essential conditions for improving the effectiveness, transparency and resilience of mobility systems.

Policy Objective	**Expected Outcome**
Strengthen governance frameworks that integrate interoperable mobility data, institutional coordination and evidence-based decision-making throughout the mobility planning cycle.	Better-informed policy decisions, more efficient allocation of public resources, stronger coordination among mobility actors and continuous monitoring of policy performance.

SMARTMOBAIR Technology Roadmap Evidence

The SMARTMOBAIR Technology Roadmap identifies data interoperability, digital integration and Intelligent Transport Systems as fundamental enablers of contemporary mobility governance. Across the four technology clusters analysed within the roadmap—**Public Transport Systems, Micromobility, Infrastructure, and System Integration**—a consistent conclusion emerges: technological innovation generates sustainable benefits only when supported by governance models capable of integrating heterogeneous data sources, coordinating multiple stakeholders and embedding digital evidence within strategic planning processes.

The experiences generated through the SMARTMOBAIR pilots reinforce this perspective. Beyond validating technological applications, the pilots demonstrated how integrated data ecosystems improve operational awareness, support policy evaluation and facilitate cooperation between public authorities and mobility stakeholders. Collectively, these findings indicate that investments in digital technologies should be accompanied by equivalent investments in governance capacity, interoperability and institutional learning if they are to generate durable policy outcomes.

Policy Recommendations

Recommendation	Governance Level
Integrate mobility data governance within Sustainable Urban Mobility Planning (SUMP) and other strategic planning instruments.	Local / Regional
Adopt interoperable data standards and shared digital architectures that facilitate information exchange across public authorities and transport operators.	National / Regional
Establish permanent governance mechanisms that promote data sharing and interoperability among local authorities, mobility providers, infrastructure managers and other relevant stakeholders.	Local / Regional
Define clear responsibilities for mobility data ownership, access, quality, security and ethical use across the organisations involved.	Local
Promote transnational cooperation to harmonise governance approaches, indicators and good practices across ADRION territories.	Interregional / EU

Expected Impacts

Strengthening governance capacity enables public authorities to transform fragmented mobility data into strategic knowledge that supports integrated planning, informed investment decisions and adaptive mobility management. This progression illustrates how evidence-based governance acts as the foundation for resilient, efficient and user-centred mobility systems.

👉 **Watch out for:** Data silos between departments that prevent effective interoperability and integrated decision-making.

Strategic Priority 2 - Accelerate the Digital Transformation of Public Transport

Making public transport more connected, reliable and attractive

Key Policy Message

Public transport remains the cornerstone of sustainable urban mobility, yet its competitiveness increasingly depends on the capacity to integrate digital technologies that improve **operational efficiency**, **service quality** and **passenger experience**. Digital transformation should therefore be understood not as the simple deployment of intelligent technologies, but as a strategic process that enables public transport systems to become more reliable, accessible, responsive and seamlessly connected with other mobility services. Strengthening the digital maturity of public transport is essential for **reducing car dependency** and supporting the transition towards integrated and low-carbon mobility systems.

Policy Challenge

Many public transport systems across the ADRION region continue to face structural challenges associated with fragmented service provision, limited operational integration and growing competition from private car use. Although digital technologies capable of improving service management and passenger information are increasingly available, their deployment often remains partial and disconnected from broader mobility strategies. Limited interoperability between operators, inconsistent digital service provision and unequal access to real-time information reduce the attractiveness of public transport and constrain the development of integrated multimodal mobility.

Accelerating digital transformation therefore requires coordinated investment in intelligent transport systems, interoperable digital platforms and passenger-oriented services that enhance both operational performance and the overall user experience.

Policy Objective	**Expected Outcome**
Accelerate the digital transformation of public transport through interoperable Intelligent Transport Systems, integrated passenger information services and data-driven operational management.	More reliable, efficient and attractive public transport services, increased multimodal integration and greater public transport use.

SMARTMOBAIR Technology Roadmap Evidence

The SMARTMOBAIR Technology Roadmap identifies the digital transformation of public transport as one of the principal pathways towards more sustainable mobility systems. Technologies such as real-time passenger information, fleet monitoring, predictive operations, intelligent ticketing, passenger counting systems and integrated mobility platforms improve both operational management and service quality.

The project demonstrates that these technologies deliver the greatest benefits when implemented within integrated digital ecosystems that connect operators, infrastructure managers and public authorities. The experience emerging from SMARTMOBAIR highlights that digitalisation is most effective when centred on the passenger experience while simultaneously strengthening the operational capacity of transport authorities through continuous data collection and performance monitoring.

Policy Recommendations

Recommendation	Governance Level
Prioritise investment in interoperable Intelligent Transport Systems supporting real-time public transport operations.	Local / Regional
Promote integrated passenger information systems providing seamless multimodal travel information across operators and modes.	Regional / National
Support the deployment of common digital platforms enabling data exchange among transport operators and public authorities.	Local / Regional
Encourage procurement strategies that favour open standards, interoperability and long-term scalability of digital solutions.	National / Regional
Promote continuous monitoring of service quality through data-driven performance indicators and passenger feedback mechanisms.	Local

Expected Impacts

The digital transformation of public transport strengthens the efficiency, reliability and attractiveness of mobility services by integrating intelligent transport systems, real-time information and data-driven operational management. When embedded within interoperable digital ecosystems, these technologies enhance the passenger experience, support multimodal integration and reinforce the role of public transport as the backbone of sustainable urban mobility.

👉 **Watch out for:** Vendor lock-in through proprietary systems that reduce interoperability and future flexibility.

Strategic Priority 3 - Promote Inclusive and Integrated Mobility Services

Connecting people, places and mobility services

Key Policy Message

Sustainable mobility systems are ultimately measured by their ability to provide **accessible, seamless and user-centred services** for all citizens. Digital innovation should therefore support the integration of transport modes, mobility operators and user information into a **coherent mobility ecosystem** that simplifies travel, reduces barriers to access and promotes **equitable mobility opportunities**. Inclusive and integrated mobility services are essential to increase public transport attractiveness, encourage behavioural change and ensure that the benefits of digital transformation are shared across different population groups and territorial contexts.

Policy Challenge

Across the ADRION region, mobility services continue to be characterised by fragmentation between transport modes, operators and administrative jurisdictions. Users frequently encounter disconnected information systems, separate ticketing arrangements and inconsistent service integration, limiting the overall attractiveness and usability of sustainable transport alternatives. These barriers particularly affect older adults, persons with disabilities, occasional users and residents of peripheral or rural areas, where mobility choices are often more limited.

Overcoming these challenges requires shifting from the optimisation of individual transport services towards the integration of the entire mobility experience. This involves combining digital technologies, interoperable platforms and inclusive service design to ensure that mobility systems are accessible, understandable and responsive to the needs of diverse users.

Policy Objective	**Expected Outcome**
Promote integrated and inclusive mobility services through interoperable digital platforms, multimodal coordination and user-centred service design.	Improved accessibility, seamless multimodal travel, greater user satisfaction and increased use of sustainable mobility services.

SMARTMOBAIR Technology Roadmap Evidence

The SMARTMOBAIR Technology Roadmap highlights system integration as a fundamental prerequisite for the future evolution of smart mobility. Technologies supporting integrated passenger information, multimodal journey planning, digital ticketing, shared mobility platforms and connected transport services enable users to access different transport options through a single, coherent mobility ecosystem.

The SMARTMOBAIR experience further demonstrates that successful integration extends beyond technological interoperability. Pilot activities underline the importance of designing services around user needs, ensuring accessibility, simplifying travel experiences and fostering cooperation among transport operators and public authorities. Inclusive-by-design approaches are also required to prevent digital exclusion, ensuring that essential information, ticketing and mobility services remain accessible to users with limited digital skills, restricted connectivity or no access to smart devices. This integrated perspective enhances the usability of sustainable mobility solutions while contributing to greater social inclusion and territorial cohesion.

Policy Recommendations

Recommendation	Governance Level
Promote Mobility-as-a-Service (MaaS) approaches that integrate public transport, shared mobility and active mobility services.	Local / Regional
Develop interoperable passenger information and ticketing systems across transport operators and administrative boundaries.	Regional / National
Apply universal and inclusive-by-design principles, maintaining accessible non-digital alternatives for people with disabilities, older adults and users at risk of digital exclusion.	Local
Encourage coordinated mobility planning that connects urban, peri-urban and rural mobility services.	Local / Regional
Support partnerships between public authorities, transport operators and digital service providers to deliver integrated mobility ecosystems.	Regional / EU

Expected Impacts

Integrated mobility services place users at the centre of the mobility ecosystem by connecting transport modes, digital platforms and mobility providers into a seamless travel experience. Through interoperability, accessibility and user-centred service design, public authorities can improve mobility choices, foster social inclusion and increase the uptake of sustainable transport across diverse territorial contexts.

👉 **Watch out for:** Digital exclusion of users with limited digital access, connectivity or skills.

Strategic Priority 4 - Strengthen Governance and Institutional Capacity for Scaling-up Innovation

Building the capabilities needed to sustain and replicate innovation

Key Policy Message

The long-term success of smart mobility depends not only on technological innovation, but also on the capacity of public institutions to govern, **scale and sustain innovation** over time. Municipalities require organisational capabilities, strategic leadership and collaborative governance mechanisms that enable them to move from isolated pilot initiatives towards **systematic policy implementation**. Strengthening institutional capacity is therefore essential to ensure that successful mobility solutions can be **replicated, adapted and embedded** within long-term territorial development strategies.

Policy Challenge

Across the ADRION region, many municipalities have demonstrated a growing willingness to experiment with innovative mobility solutions. However, limited administrative capacity, fragmented governance arrangements and restricted access to specialised technical expertise often constrain the transition from pilot implementation to large-scale deployment. As a result, valuable experiences generated through demonstration projects frequently remain isolated, reducing their potential contribution to long-term policy development.

Scaling innovation requires more than financial investment. Public authorities need institutional structures capable of coordinating stakeholders, managing increasingly complex digital ecosystems, adapt to disruptive technological innovation, evaluating policy impacts and integrating innovation into strategic planning and investment programmes. Building these capabilities represents a prerequisite for achieving durable and transferable mobility transformation.

Policy Objective	**Expected Outcome**
Strengthen institutional capacity and collaborative governance mechanisms to enable the replication, adaptation and long-term integration of innovative mobility solutions.	Stronger public institutions, greater implementation capacity, improved policy continuity and increased scalability of successful mobility initiatives.

SMARTMOBAIR Technology Roadmap Evidence

The SMARTMOBAIR Technology Roadmap demonstrates that technological pathways alone are insufficient to achieve systemic mobility transformation. Across all technology clusters, successful implementation depends on governance arrangements capable of supporting strategic planning, stakeholder coordination, knowledge transfer and organisational learning.

The project further highlights that pilot actions generate value beyond technological validation by strengthening institutional experience, improving cooperation among public authorities at different levels of governance, involving actively stakeholders and creating practical knowledge that can support future policy development. These findings underline the importance of investing in institutional capacity alongside digital infrastructure, ensuring that innovation can be replicated across different territorial contexts and sustained beyond individual project lifecycles.

Policy Recommendations

Recommendation	Governance Level
Establish permanent governance structures supporting the long-term implementation of smart mobility strategies.	Local / Regional
Invest in continuous capacity-building programmes covering digital governance, innovative procurement, mobility planning, policy evaluation and the responsible use of artificial intelligence and other emerging technologies.	Local / National
Promote Communities of Practice and transnational knowledge exchange to facilitate peer learning and replication of successful approaches.	Interregional / EU
Integrate pilot results into local and regional planning instruments, ensuring continuity beyond project implementation.	Local / Regional
Encourage governance models that strengthen cooperation between public authorities, academia, technology providers and civil society.	Local / Regional

Expected Impacts

Strengthening institutional capacity enables public authorities to move from isolated pilot initiatives to long-term policy transformation. By investing in governance, knowledge transfer, organisational learning and collaborative networks, municipalities can replicate successful solutions, scale innovation across different territorial contexts and embed smart mobility within strategic planning and investment processes.

👉 **Watch out for:** Loss of institutional knowledge and momentum once pilot funding and project resources come to an end.

Strategic Priority 5 - Digital solutions for climate neutral and safe urban mobility

Supporting climate resilience and safer mobility through digital innovation

Key Policy Message

Achieving climate-neutral and safe mobility requires more than the deployment of low-emission technologies. It calls for an **integrated policy approach** that combines digital innovation, sustainable transport planning, intelligent infrastructure and behavioural change to improve **environmental performance** while enhancing road safety and urban liveability. Smart mobility should therefore be recognised as a strategic instrument for supporting the broader transition towards resilient, climate-neutral and **people-centred cities**.

Policy Challenge

Cities across the ADRION region are increasingly exposed to the combined impacts of climate change, urban congestion, air pollution and road safety challenges. At the same time, the transition towards cleaner mobility systems is often constrained by fragmented planning processes, limited integration between transport and environmental policies and insufficient use of digital technologies to optimise mobility management.

Addressing these challenges requires coordinated policies capable of reducing transport-related emissions while improving the safety, efficiency and resilience of urban mobility systems. Intelligent transport solutions, connected infrastructure and real-time mobility management can significantly contribute to these objectives, provided they are integrated within broader sustainability strategies and supported by long-term governance commitments.

Policy Objective	**Expected Outcome**
Integrate smart mobility solutions into climate-neutral and safe urban mobility strategies through intelligent infrastructure, sustainable transport planning and data-driven mobility management.	Reduced greenhouse gas emissions, improved road safety, more resilient transport networks and healthier urban environments.

SMARTMOBAIR Technology Roadmap Evidence

The SMARTMOBAIR Technology Roadmap identifies intelligent transport systems, connected infrastructure, digital traffic management, active mobility solutions and integrated mobility services as complementary pathways supporting the transition towards climate-neutral and safe urban mobility. Rather than acting independently, these technologies create the greatest value when implemented as part of coordinated mobility ecosystems that optimise transport demand, improve operational efficiency and encourage sustainable travel behaviour.

The experience gained through SMARTMOBAIR demonstrates that digital innovation contributes not only to improving transport performance, but also to wider environmental and social objectives. Enhanced traffic management, integrated mobility services, real-time information and data-driven planning support lower emissions, more efficient resource use and safer mobility environments while increasing the overall resilience of urban transport systems.

Policy Recommendations

Recommendation	Governance Level
Integrate digital mobility solutions within Sustainable Urban Mobility Plans (SUMPs) and local climate strategies.	Local / Regional
Promote intelligent traffic management systems that optimise network performance while reducing emissions and congestion.	Local / Regional
Prioritise investments in infrastructure supporting active mobility, public transport and low-emission transport modes.	Local / National
Use mobility data and digital monitoring tools to assess environmental performance, safety indicators and policy impacts.	Local
Foster cross-sector cooperation between transport, environmental, energy and urban planning authorities to support integrated climate-neutral mobility policies.	Regional / National

Expected Impacts

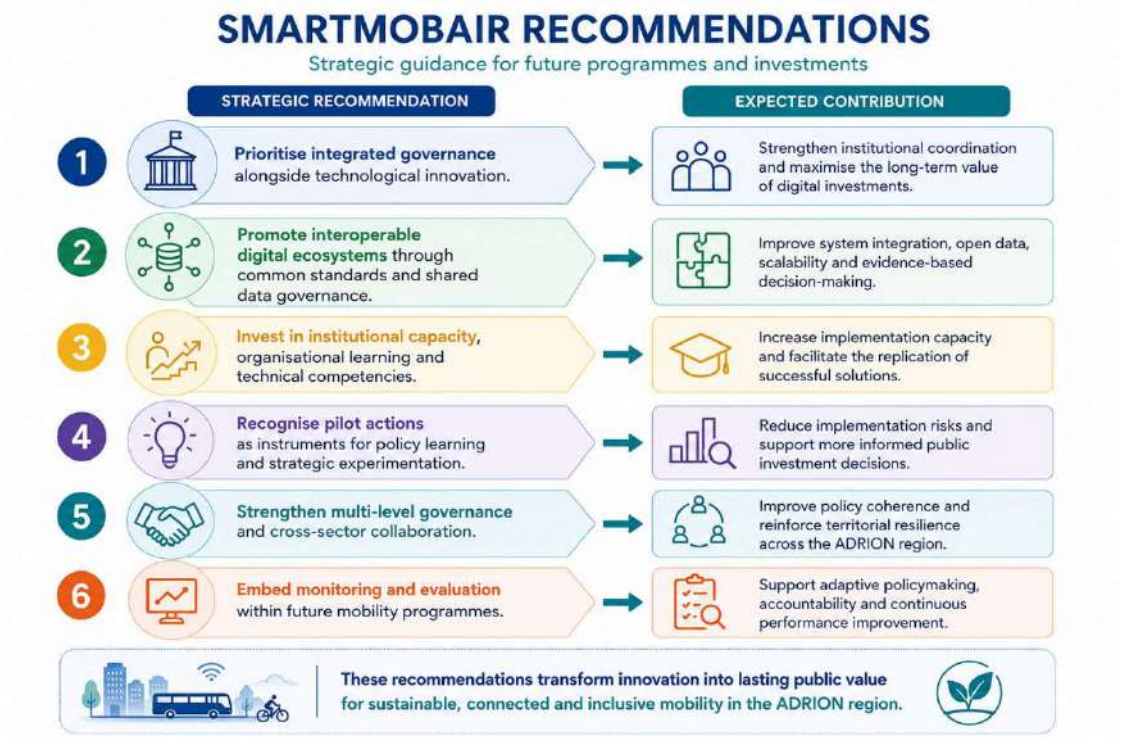
Smart mobility supports the transition towards climate-neutral and safe cities by integrating intelligent transport systems, sustainable mobility planning and digital governance within a common strategic framework. Coordinated policies that combine technological innovation, resilient infrastructure and evidence-based decision-making enable public authorities to reduce transport emissions, improve road safety and enhance the quality of urban life.

👉 **Watch out for:** Relying on technology alone without accompanying governance and behavioural changes needed to achieve climate objectives.

4. Recommendations for Future Programmes and Investments

The SMARTMOBAIR experience demonstrates that the transition towards smart and sustainable mobility cannot be achieved through technological innovation alone. While digital solutions are becoming increasingly mature and accessible, their long-term effectiveness depends on the capacity of public authorities to integrate them within coherent governance frameworks, strengthen institutional capabilities and translate project-based experimentation into enduring policy practice. The evidence generated throughout the project suggests that future mobility programmes should increasingly adopt a **systemic perspective**, recognising that governance, interoperability, organisational learning and stakeholder collaboration are as critical to successful implementation as the technologies themselves.

This perspective has important implications for the design of future investment programmes across the ADRION region. Supporting pilot actions remains essential for testing innovative approaches and reducing implementation risks, but their value should be measured not only by the technologies deployed, but also by their contribution to **institutional learning**, policy innovation and territorial capacity building. Future programmes should therefore create stronger mechanisms for transferring knowledge, scaling successful experiences and embedding innovation within strategic planning processes, ensuring continuity beyond individual project lifecycles.



Building upon these strategic directions, future mobility initiatives should increasingly promote integrated policy frameworks that **connect digital innovation with sustainable urban planning, climate objectives and territorial cohesion** and include a coherent data governance plan. Investments should encourage open and interoperable digital architectures, strengthen collaboration across governance levels and facilitate the exchange of knowledge between municipalities, regions, research organisations and technology providers. Equally important, future programmes should continue supporting the development of institutional capabilities that enable public authorities to govern increasingly complex mobility ecosystems and adapt to evolving societal and environmental challenges.

Supporting Implementation through European and National Funding

The successful implementation and scaling-up of smart mobility initiatives can be supported through a combination of European, national and regional funding instruments. Depending on the type of intervention, public authorities may consider:

Funding source	Typical focus
European Regional Development Fund (ERDF)	Digital infrastructure, urban innovation and sustainable mobility investments
Cohesion Fund	Sustainable transport infrastructure and connectivity projects
Horizon Europe	Research, innovation and pilot actions for emerging mobility solutions
Interreg Programmes	Territorial cooperation, knowledge exchange and transferability of good practices
National and Regional Programmes	Local implementation, capacity building and scaling-up of smart mobility initiatives

Public authorities should align project proposals with the objectives and eligibility criteria of the relevant funding programmes, while combining financial investments with governance, institutional capacity and long-term planning.

The strategic priorities presented in this Policy Brief provide a framework for supporting this transition. Rather than identifying individual technological solutions, they define the enabling conditions through which **innovation can generate long-term public value**. By strengthening governance, institutional capacity, interoperability and evidence-based decision-making, the ADRION region can accelerate the development of mobility systems that are more integrated, inclusive, resilient and climate-neutral, while reinforcing territorial cooperation and improving the quality of life of its citizens.

In this perspective, the legacy of SMARTMOBAIR extends beyond the pilot actions implemented during the project. Its principal contribution lies in providing a strategic reference for future policymaking, demonstrating how technological innovation, when supported by effective governance and institutional collaboration, can become a catalyst for the **long-term transformation of mobility systems** across the Adriatic-Ionian region.