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White Paper

Evidence Based Policy Recommendations and Roadmap for Large-Scale Deployment of Digital Transport Ecosystems

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Abstract

Freight transport and logistics operations remain shaped by fragmented information flows and document-centric procedures, in which multiple actors exchange data through heterogeneous systems and, in many cases, paper-based documentation. KEYSTONE addresses these constraints by introducing standardized, Plug & Play solutions that combine an Application Programming Interface (API) standard with a web application to enable interoperable data sharing between logistics stakeholders and enforcement authorities. This White Paper consolidates evidence generated through the two pilot deployments and the associated evaluation activities, translating operational findings into evidence-based recommendations for transport operators, policy makers, and enforcement authorities. It identifies multi-layered restrictions, gaps, and opportunities that influence the transition from pilot-scale interoperability to large-scale deployment, and it provides concrete roadmaps for the road and intermodal ecosystems, grounded in pilot outcomes and lessons learnt, to support the standardisation of transport operations within a truly digital and resilient transport ecosystem.

Introduction

The KEYSTONE project supports the digital transformation of freight transport by enabling interoperable, Plug & Play data exchange across the logistics chain. By combining a standardized API approach with a web application, it responds to persistent challenges linked to fragmented information flows, uneven digital maturity, and the need to ensure regulatory compliance without disrupting transport operations. The project therefore focuses on creating the technical and organisational conditions for reliable, standardised data sharing between private stakeholders and enforcement authorities in both road and intermodal contexts.

In line with this, KEYSTONE aims to enable a seamless intermodal exchange of transport information, strengthen collaboration among operators, terminals and public authorities, and reduce compliance related costs through automated and secure data-sharing mechanisms. The project also targets wide scale uptake by promoting solutions that can be replicated across different operational environments while remaining aligned with regulatory requirements and standardisation needs at European level.

This White Paper translates the evidence produced through the pilot deployments into stakeholder-specific recommendations and a concrete roadmap for adoption. It frames the restrictions, gaps, and opportunities identified during implementation and evaluation as actionable guidance for transport operators, policy makers, and enforcement authorities, with the aim of supporting large-scale deployment.

Background and context

The need for a digital transport ecosystem

Freight transport and logistics operations are still heavily formed by fragmented information flows and document-centric processes, where multiple actors (operators, terminals, shippers, forwarders, and authorities) share data via heterogeneous systems and, in many cases, paper-based documentation. Sector discussions highlight that the paper documents, fragmented information, and siloed systems translate into practical inefficiencies which causes weaker planning capabilities, delays and uncertainty, higher administrative costs, and avoidable emissions. In this view, the need for a digital transport ecosystem is operational and systemic, because transport chains can only function efficiently when data can move with the same continuity as goods (Maurin et al., 2024).

The problem becomes more acute in intermodal and international contexts, where a single transport mission requires the synchronized contribution of multiple actors and the alignment of heterogeneous procedures and datasets. Research indicates that digitalization can mitigate key operational barriers, but only when stakeholders can rely on interoperable data exchange rather than isolated solutions (Vural et al., 2020).

Creating such an ecosystem is not merely a technical integration challenge. Platform and data ecosystem studies emphasize that governance roles, boundary resources such as APIs, and rules for participation are central to coordinating multiple sides in a sustainable way (Schreieck et al., 2016). Inter-organizational data partnerships must simultaneously strike a balance between innovation and regulatory compliance, necessitating governance structures that cover risk management, accountability, and data protection (V.D Broek & V.Veenstra, 2018).

In light of this, Task 5.4 translates pilot-based evidence into policy recommendations and a workable roadmap addressing multi-layer gaps in interoperability, governance, and compliance.

Methodology

The methodology is designed as an evidence to action pipeline that transforms what is learned in the pilot deployments into implementable guidance for practitioners, authorities, and policy makers. It follows a sequential logic: consolidate and interpret pilot results; validate insights through KPI-based and sustainability-oriented assessment; complement the evidence base with structured process evaluation inputs (including questionnaire-based evidence) support systematic review of implementation progress, coordination mechanisms, outcomes achieved, and scalability conditions; translate the evidence into structured multi-level recommendations addressing regulatory and technological gaps for a fully digital transport ecosystem; and package and promote these outputs through a White Paper and a concrete roadmap for adoption, supported by targeted dissemination.

Recommendations are organised through a multi-level framework reflecting the multi-actor nature of digital transport ecosystems and the need to align private operational requirements with public-sector priorities. The framework structures restrictions, gaps, and opportunities in a coherent manner, ensuring recommendations remain actionable and relevant across interconnected governance scales.

Results from pilot deployments

Pilot deployments overview and objectives

The implementation overview is structured around two complementary perspectives to assess both pilots. The first focuses on how the each pilot progressed against its objectives, including the overall implementation experience, achievements, milestones, and adherence to the planned timeline. The second examines the enabling conditions for delivery, looking at preparation and coordination, stakeholder involvement and alignment, and the effectiveness of the technical implementation and API-based integration, together with the adequacy of technical support provided during deployment.

The pilot deployments provide empirical evidence of how standardized API-based exchange and digital tools can support compliance verification without disrupting transport flows. Across both pilots, the benefits of digitalisation emerged clearly only when upstream data were complete, timely and consistent, reinforcing the need for standardised data formats and validation steps at the point of entry.

The pilots also highlighted the importance of operational adaptability across contexts, and the need for interoperability resilience, including fallback options when preferred formats are temporarily unavailable in Electronic Consignment Note (eCMR)/Electronic Freight Transport Information (eFTI) related exchanges. Finally, both pilots underscored the importance of user engagement and cross-organisational collaboration, noting that successful digital innovation depends on alignment with established workflows and on reducing not increasing operational friction.

Pilot 1 (Road transport digital ecosystem) demonstrates the data-sharing concept through API standardisation in a digital environment for road transport in a monomodal road transportation scenario with port interaction, including an extra-EU shipment management scenario with eCMR sharing. Based on pilot findings and interview with Pilot 1 leader (Figure 1), the implementation profile is consistently strong, with top ratings for objectives achievement, stakeholder involvement and alignment, and technical integration (K-API), confirming that the pilot met its intended goals through proactive collaboration and seamless end-to-end data exchange. The remaining dimensions - progress against plan, preparation and coordination, and technical support effectiveness - are rated highly, indicating only minor timing deviations and limited fine-tuning needs during deployment.

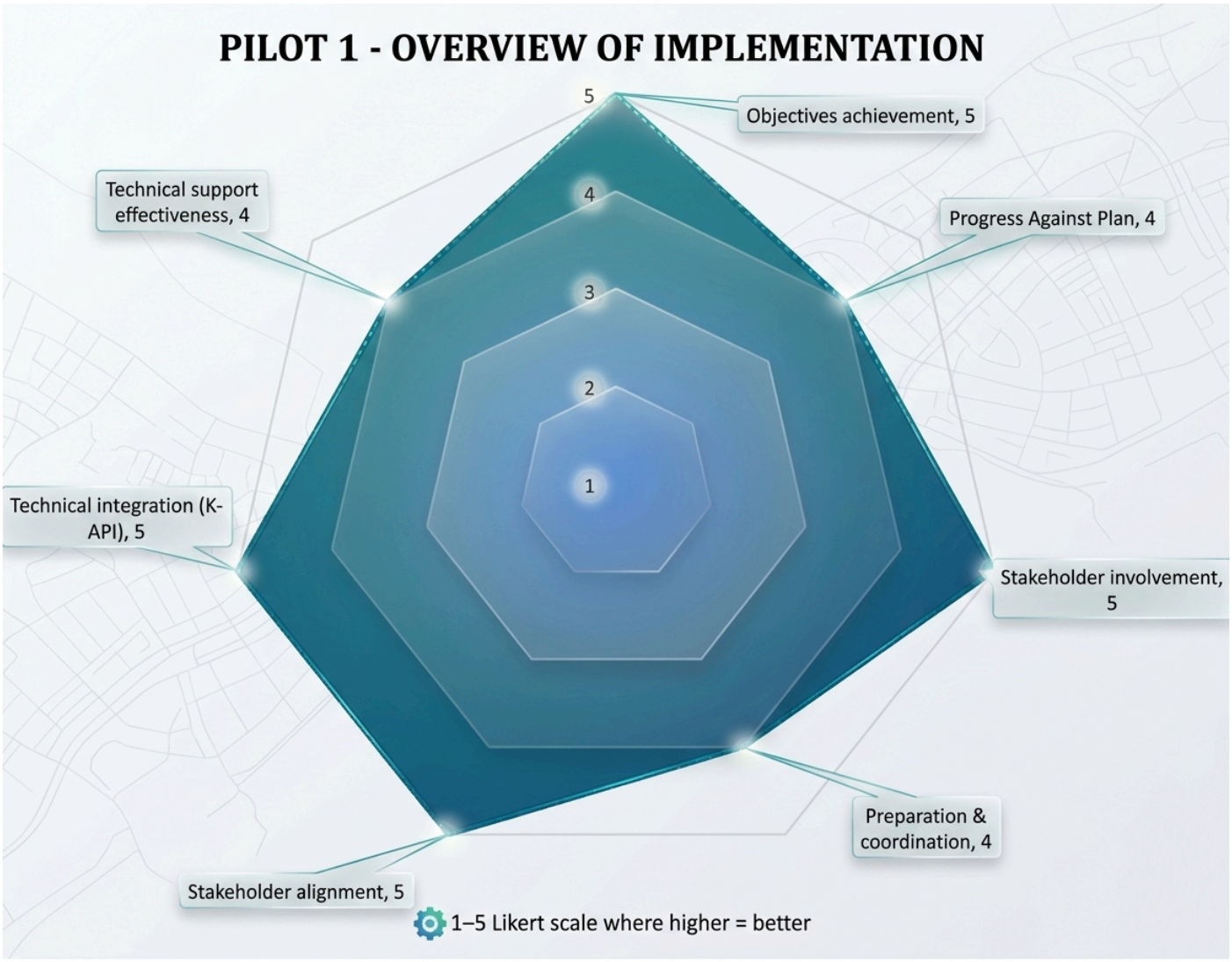

Figure 1: Pilot 1 Road Transport Digital Ecosystem – Implementation performance overview (*based on interviews with Pilot 1 leader*)

Pilot 2 (Intermodal digital ecosystem) demonstrates the data-sharing concept through API standardisation in a digital environment for intermodal transport, enabling coordinated data exchange across rail-road operations and enforcement checks. Based on pilot findings and interview with Pilot 2 leader (Figure 2), the pilot achieved its objectives at the highest level and reported equally strong stakeholder involvement and alignment, reflecting sustained engagement across the participating actors. Technical integration (K-API), preparation and coordination, progress against plan, and technical support were all assessed positively at a high level, indicating stable interoperability performance with only minor optimisation needs.

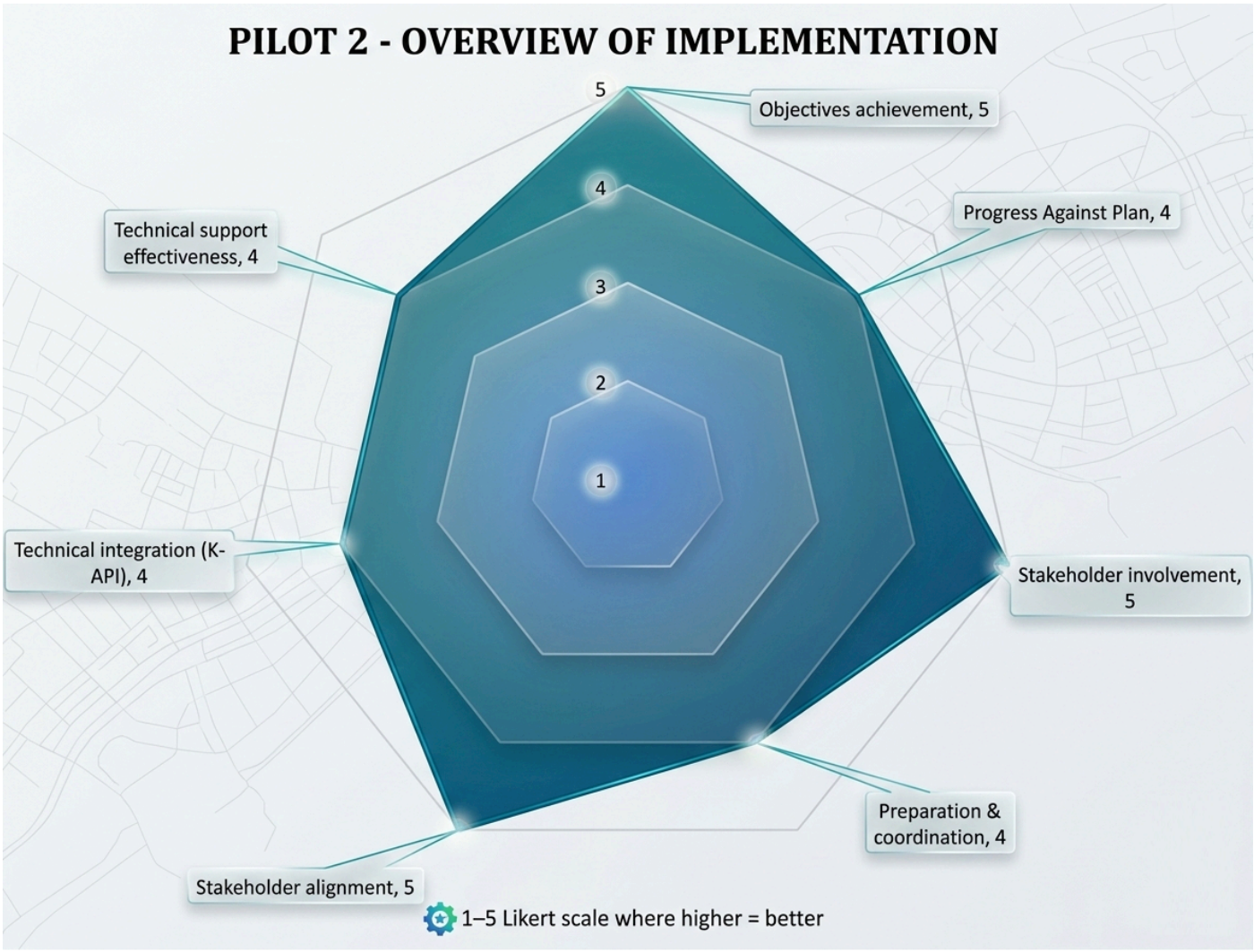

Figure 2: Pilot 2 Intermodal digital ecosystem - Implementation performance overview (*based on interviews with Pilot 2 leader*)

Multi-layered restrictions, gaps, and opportunities for large-scale deployment

Our analysis identifies that, as reported by the pilot leaders under process evaluation questionnaire (PEQ), across both pilots, the outcomes highlight the key restrictions, gaps, and opportunities which must be considered when moving from pilot-scale interoperability to a standardised EU-wide digital transport ecosystem including interaction with the Port Community System (PCS). A first restriction, identified under PEQ (Barriers and Challenges), shows concerns regarding the sensitivity of end-to-end digital processes to data quality and early-stage alignment. In both pilots, implementation benefits materialised when upstream data were complete, timely, and consistent; even minor inconsistencies at entry for example, missing reference data or timing misalignments propagated across connected systems and required rapid corrective actions. While both pilots highlighted that barriers remained minor and were resolved effectively via joint troubleshooting, this confirms the need for systematic validation and alignment practices to avoid recurring disruptions during scale-up.

A second set of gaps, also identified under PEQ (Risks and Mitigation Strategies), concerns interoperability issues during onboarding and system connection phases. **Pilot 1** highlights that scaling to additional ports is primarily constrained by the heterogeneity of PCS and the need to align different PCS data formats, even when API-based exchange is standardised. **Pilot 2** also points to remaining interoperability issues during the connection phase between the terminal operating system and the web application, which required additional technical coordination during testing. These observations, highlight a broader ecosystem gap: standardised exchange mechanisms can function well within a given configuration, but replication remains vulnerable to local infrastructure variation and the practical frictions of connecting heterogeneous legacy environments.

At the same time, both pilots, as identified by the pilot leaders under PEQ, demonstrate concrete opportunities to enable adoption at scale, provided scale-up pathways are matched to context. **Pilot 1** explicitly assesses replication across EU ports as highly feasible with minimal adaptation, because the systems are already based on standardised APIs, and it reports low effort for replication requiring only minor technical configuration. This supports a scale-out opportunity focused on ports where the integration logic can be reused with limited local tailoring.

Pilot 2 identified in PEQ, assesses scaling as moderately feasible, not because the model lacks value, but because full integration with national road security/enforcement systems is difficult in a real environment; however, it identifies a pragmatic expansion route through ports and major logistics nodes (interports and rail/road terminals) to begin capturing benefits for drivers and transport companies, while deferring more complex national enforcement integration to later stages.

Across both pilots, the evidence also indicates, particularly (Supporting Activities and Engagement), in PEQ that sustained adoption depends on strong cooperation, clear operational roles, and engagement of enforcement actors, with supporting activities (coordination calls, joint testing, and field demonstrations) repeatedly described as essential to progress: this suggests that scalability is as much organisational as technical, and that governance of collaboration must be treated as part of the deployment model.

Concrete roadmap of actions based on pilot outcomes

Roadmap for Pilot 1 Road transport digital ecosystem (P1)

The following roadmap is derived from implementation and adoption evidence reported during Pilot 1 and Pilot 2, including findings from the PEQ, the lessons learned documented in D4.3, and the KPI and sustainability evidence provided in D5.2. Together, these sources capture integration readiness, data-quality dependency, interoperability constraints, and the importance of early authority validation. The phased ordering reflects an analytical synthesis that translates these pilot observations into a practical scale-up sequence.

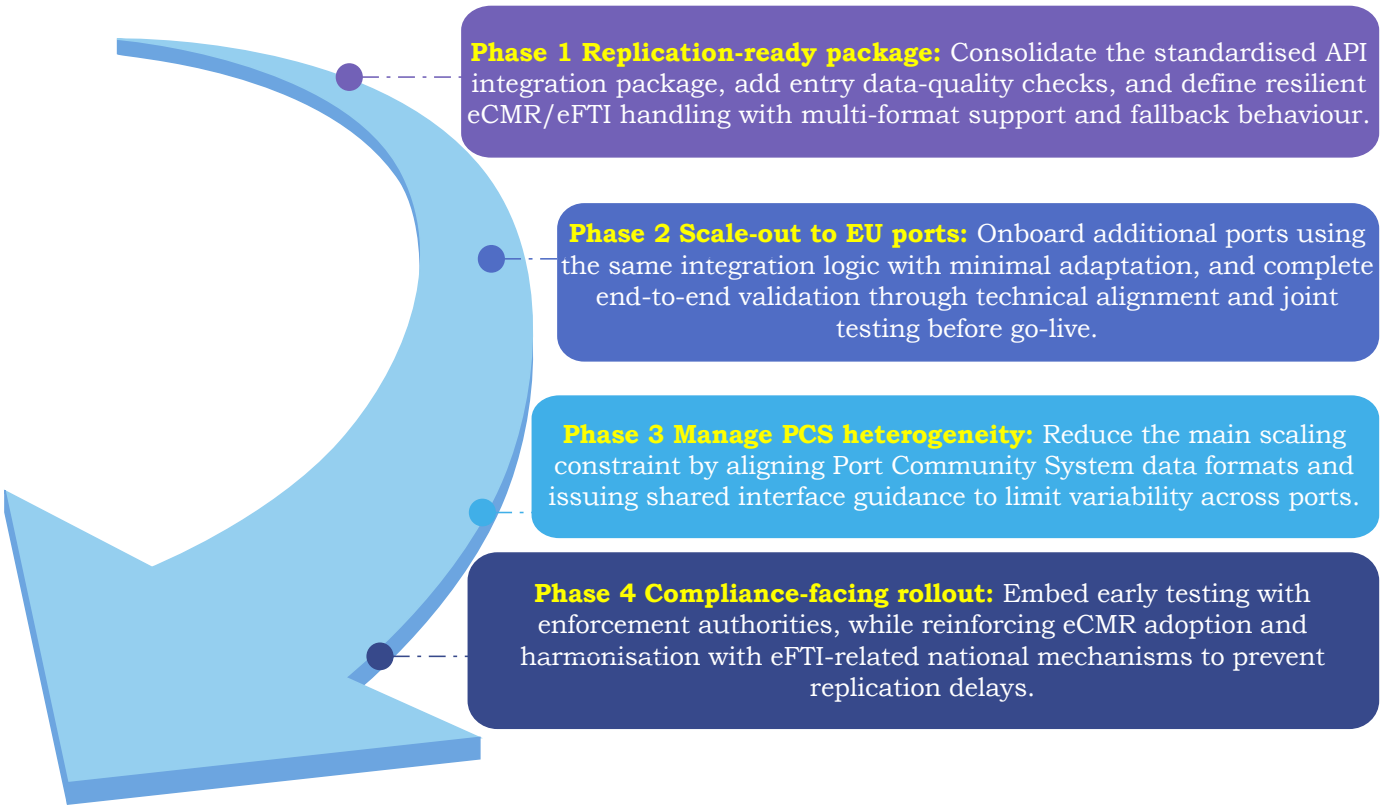

Figure 3: Concrete roadmap for Pilot 1 (Road transport digital ecosystem)

The roadmap for scaling the **Pilot 1** model follows a phased approach that first establishes a replication-ready foundation (Phase 1) and then progressively expands deployment across additional EU ports. Lessons derived from the pilot, shows that stable operations depend on consolidating a reusable standardised API integration package, complemented by systematic data-quality checks at entry and resilient eCMR/eFTI handling to ensure stable operations, even when preferred formats or components are temporarily unavailable. The second phase (Scale-out to EU ports) shifts the focus from pilot validation to wider deployment; it builds on the pilot evidence that the same integration logic could be transferred to comparable port contexts, with replication expected to rely mainly on technical configuration and alignment rather than entirely new development. To ensure that this process remains robust, each new deployment should undergo a structured end-to-end validation cycle, combining technical alignment sessions with joint testing before transition to live operations.

As part of Phase 3, the roadmap then addresses the main structural constraint identified for replication, namely heterogeneity across PCS. This is managed by prioritising alignment of PCS data formats and issuing shared interface guidance to reduce variability across different implementations. Finally the fourth phase brings the compliance-facing dimension of deployment to the forefront; phase 4 (Compliance-facing roll-out) emphasises earlier integration testing with enforcement authorities as a standard rollout step, ensuring that compliance-related data can be accessed and validated under operational conditions from the outset. In parallel, it supports broader eCMR adoption and stronger harmonisation with eFTI-related national mechanisms, so that replication does not stall because of uneven implementation conditions across contexts.

Roadmap for Pilot 2 Intermodal digital ecosystem (P2)

The following roadmap for Pilot 2 sets out a structured pathway for transforming the pilot experience into a repeatable and scalable intermodal deployment model. Building on the lessons learned during implementation, it identifies the main steps needed to strengthen operational stability, support phased expansion, improve public-private interoperability, and prepare for broader institutional integration. The roadmap is therefore designed to guide their gradual replication across more complex logistics environments.

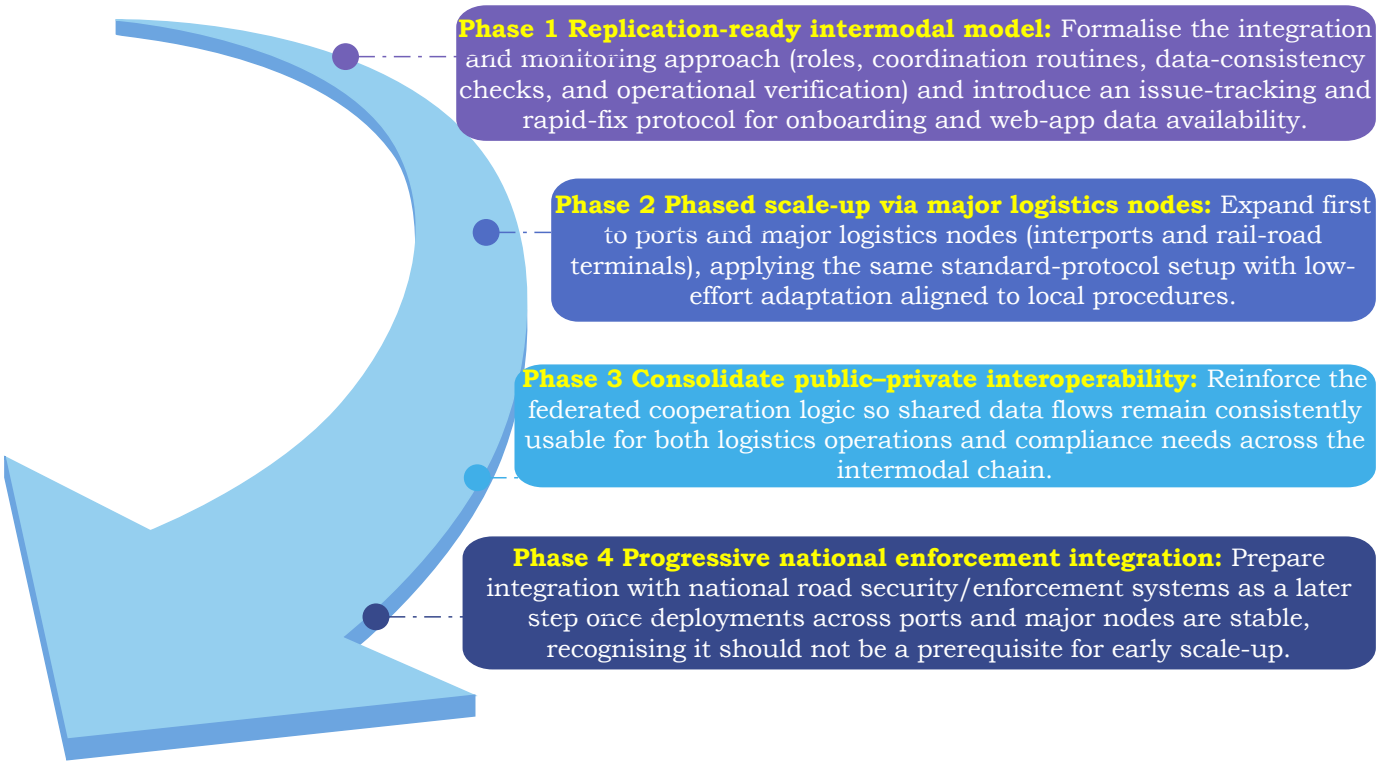

Figure 4: Concrete roadmap for Pilot 2 (Intermodal digital ecosystem)

The roadmap for **Pilot 2** focuses on making the intermodal deployment model repeatable and scalable while recognising the higher complexity of public private integration in real operating environments. Lessons emerging from the pilot highlight the need to formalise roles, coordination routines, data-consistency checks, and operational verification steps, while also introducing a structured issue-tracking and rapid-fix protocol to manage onboarding frictions (such as connection-stage interoperability constraints and data availability timing during web-app use).

On this basis, the proposed scale-up pathway expands first to ports and major logistics nodes (Phase 2), such as interports and rail road terminals, using the same standard protocol setup and low-effort adaptation aligned with local procedures. As deployments grow, pilot lessons support federated public-private interoperability to ensure data flows remain consistently usable for both logistics operations and compliance needs across the intermodal chain (Phase 3). Finally, reflecting the pilot's stated constraint that full national road security/enforcement integration is difficult outside the pilot setting, the roadmap treats this as a longer-term step to be pursued progressively once deployments across ports and major nodes are stable (Phase 4).

Evidence-based recommendations

The recommendations below are derived from pilot findings and interviews with pilot leaders, translating these implementation insights into actionable guidance for the large-scale deployment of digital transport ecosystems.

Table 1: Evidence-Based Recommendations for Key Stakeholders

Stakeholder category	Evidence-based recommendations for pilot models P1 and P2
Transport Operators	• Prioritise early technical alignment and integration readiness by aligning IT teams early, agreeing data models, and validating end-to-end flows before operational test windows. **[P1-P2]** • Institutionalise joint troubleshooting and coordinated API testing as a repeatable onboarding practice, reflecting the effectiveness of joint debugging and data model harmonisation in restoring stable exchanges. **[P1]** • Prioritise operational data quality and consistency through validation checks at entry (identifiers, references, timing/ETA fields) to prevent inconsistencies propagating across connected systems. **[P1-P2]** • Embed enforcement/authority touchpoints in rollout through joint demonstrations and controlled validation sessions, reflecting the proven value of coordinated test days and direct engagement with authorities. **[P1-P2]** • Design for practical resilience in eCMR/eFTI-related exchanges, including multi-format handling and robust fallback behaviour when preferred formats or components are temporarily unavailable. **[P1]**
Policy Makers	• Accelerate standardisation and harmonisation pathways that reduce heterogeneity across local infrastructures, including alignment of Port Community System data formats and onboarding interfaces. **[P1]** • Promote earlier enforcement involvement in integration testing and validation. Pilot 1's forward-oriented guidance explicitly calls for "earlier integration testing with enforcement authorities," reflecting that enforceability and compliance verification are core to adoption and should be validated early in deployment cycles.**[P1]** • Support broader eCMR uptake and alignment with eFTI-related harmonisation mechanisms, including collaboration with national alignment platforms to reduce fragmentation and uncertainty. **[P1]** • Enable phased integration strategies in complex contexts, avoiding full national road security/enforcement integration as a precondition and supporting staged deployment across ports and major logistics nodes. **[P2]** • Reinforce continuity and federation-oriented interoperability ambitions so that pilot results translate into stable governance and implementation conditions for long-term uptake. **[P2]**
Enforcement Authorities	• Integrate enforcement needs early in deployment and testing by participating in joint validation sessions to confirm that the required compliance data are available, consistent, and usable in operational conditions. **[P1-P2]** • Institutionalise procedures for remote, real-time compliance verification using standardised digital information (e.g., ETA and electronic transport documentation), so that routine checks can be performed without unnecessary physical stops and with improved planning of control activities. **[P1-P2]** • Treat data quality and data alignment as an enforcement prerequisite by requiring consistent identifiers and validated data at entry points, recognising that even minor

	inconsistencies can propagate across connected systems and reduce the reliability of compliance verification. **[P1-P2]** • Operational resilience should be required for eCMR/eFTI-related checks so that compliance verification can continue without disruption, even when preferred formats or technical components are temporarily unavailable. To support this, interoperability arrangements should allow for the handling of multiple formats and include clearly defined fallback procedures, ensuring that enforcement activities can continue without reverting to paper-based processes. **[P1-P2]** • Support phased scale-up where full national enforcement integration is complex, prioritising initial deployment in ports and major logistics nodes (e.g., interports and rail-road terminals) to realise benefits early, while preparing progressive integration steps for broader national systems over time. **[P2]**

Conclusion

The pilot deployments demonstrate that a digital transport ecosystem based on standardized API-enabled exchange can be implemented effectively in both road-port and intermodal contexts when supported by strong coordination, high stakeholder engagement, and stable technical integration. In both pilots, stakeholder involvement and alignment were consistently rated at the highest level, indicating that multi-actor cooperation and shared understanding are decisive enablers of successful deployment. Technical integration and support were assessed positively, confirming the feasibility of implementing interoperable data flows in real operational environments, while acknowledging that minor timing and optimisation issues may still arise during execution.

At the same time, the evidence highlights that large-scale deployment depends on addressing cross-context constraints that extend beyond local pilot success. Data quality and early alignment are critical, as small inconsistencies at entry can propagate across connected systems. Replication is also sensitive to heterogeneity in local infrastructures, particularly where differences in port and terminal systems require additional alignment during onboarding and connection phases.

The roadmaps and recommendations presented in this White Paper respond directly to these findings by prioritising replication-ready integration packages, structured end-to-end validation, resilience in eCMR/eFTI-related exchanges, and early involvement of enforcement authorities. By linking pilot evidence to stakeholder-specific recommendations, this White Paper provides a practical pathway to move from validated pilots to scalable implementation conditions, supporting the standardisation of transport operations and the development of a digital and resilient transport ecosystem at European scale.

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