Overcoming Knowledge Silos in Multimodal Transport Systems: A Knowledge Management Perspective

Preetha Ramiah[1], Alexeis Garcia-Perez[1], Zoi Petrakou[2], Paulo Cantillano-Lizana[3], Eftychia Koliou[4] and Guilia Renzi[3]

[1]Centre for Business in Society, Coventry University, UK
[2]AETHON Engineering Single Member, P.C., Greece
[3]ICOOR/ University of Modena and Reggio Emilia, Italy
[4]Smart Transportation alliance, Spain

Preetha.ramiah@coventry.ac.uk
alexeis.garcia-perez@coventry.ac.uk
z.petrakou@aethon.gr
paulo.cantillano@icoor.it
e.koliou@smart-transportation.org
Giulia.renzi@icoor.it

Abstract: Multimodal transport systems are crucial for the efficient movement of freight, but organisational and sectoral knowledge silos hinder effective coordination and decision-making. This paper applies knowledge management (KM) principles to explore how transport and logistics companies can overcome these barriers, focusing on insights from the KEYSTONE project. The project surveyed transport and logistics operators, freight terminals, and enforcement authorities across the EU and the UK. A major challenge is the lack of a unified regulatory framework for multimodal transport. Variations in the implementation of international transport conventions across Member States cause regulatory fragmentation. Additionally, differing cross-border documentation requirements—such as customs declarations, vehicle registration, and driver permits—complicate knowledge sharing and real-time coordination. Technological challenges, particularly fragmented IT environments, hinder collaboration. Non-interoperable B2A (Business-to-Authority) and B2B (Business-to-Business) systems limit seamless data sharing, creating cross-border inefficiencies. Trust concerns, such as electronic signatures and document verification, further restrict digital tool adoption. To address this, KEYSTONE proposes an Application Programming Interface (API) Reference Model and Standard using Plug & Play principles to enhance interoperability across digital systems. This model streamlines data transfer, reducing inefficiencies and enabling real-time B2A and B2B information sharing. Cross-Border Governance provides a strategic framework for managing regulatory and procedural complexities. By fostering cooperation and developing common rules for cross-border operations, this approach ensures smoother integration between national systems and addresses challenges related to differing documentation and compliance requirements. KEYSTONE's findings highlight the need for a common digital and regulatory framework to support multimodal transport operations. This paper presents the frameworks developed by the KEYSTONE consortium and discusses how it addresses both technical and regulatory barriers to knowledge sharing, helping overcome knowledge silos in multimodal transport.

Keywords: Knowledge management, DataiIntegration, Interoperability, Multimodal transport, Logistics, Digital ecosystem

1. Introduction

As of recent statistical data, road transport accounts for approximately 24.9% of the overall freight transport in the European Union, while maritime transport dominates with 67.8%. The remaining percentages are divided between rail (5.5%) and inland waterways (1.6%) (European Commission, 2024c). Multimodal transportation in logistics is a vital component of the global economy, serving as the backbone of trade and commerce. However, the movement of goods via road, rail or sea presents unique challenges, including delays at border crossings, customs clearance issues, inventory mismanagement, and communication breakdowns between international logistics operators in Multimodal Freight Transportation (Karam et al, 2023**)**. An integrated multimodal transport network is essential for companies to efficiently manage their supply chain operations at both domestic and international levels. However, the complexity of multimodal integration—particularly the involvement of diverse operators—often creates significant challenges that hinder its seamless implementation (Grancharova et al, 2021). One of the primary constraints is the lack of effective and efficient information connectivity between various transport modes, leading to operational inefficiencies. This includes fragmentation of information and the lack of standardized protocols across various logistics operators and transport modes (Sarraj et al, 2013). These disparities hinder seamless knowledge sharing, leading to inefficiencies, delays, and increased operational costs. A crucial step in addressing this issue is the development of a standardized knowledge management framework (KM) (Alavi, 2001) that integrates

disparate systems, ensuring seamless information exchange and collaboration. Such a framework would facilitate secure and efficient coordination among stakeholders while ensuring compliance with regulatory and security requirements. By reducing information gaps and improving interoperability, this approach would enhance decision-making, foster trust among transport operators, and streamline multimodal logistics operations. In the long term, these advancements promise improved efficiency, reduced administrative burdens, and greater resilience in multimodal transport networks.

Knowledge management plays a critical role in tackling these challenges by enabling the systematic collection, organization, and dissemination of information among stakeholders in the transport and logistics sector. Traditionally, KM systems in transportation agencies have been either manual or semi-automated, often lacking the scalability and flexibility required to adapt to the evolving demands of the industry (Paddeu et al., 2019). The absence of fully integrated KM frameworks limits organizations' ability to effectively manage logistics processes, optimize decision-making, and enhance coordination within multimodal transport networks. Addressing these gaps through advanced KM strategies and digital transformation is essential for improving operational efficiency and fostering innovation in the transport sector (Nakash and Bolisani, 2025).

This paper proposes a novel model to standardize and integrate existing fragmented protocols through secure API (Application Programming Interface) architectures (Kumar et al., 2023). An API Reference Model is a standardized framework that outlines how software components should interact, enabling different systems to communicate effectively through defined endpoints, data formats, and protocols. Unlike current isolated systems, our approach enables seamless authentication and verification of identity holders across borders. A distinguishing aspect of our model is its alignment with, and integration of existing European digital platforms used by enforcement authorities for regulatory information exchange in the logistics and road transport sector. By linking these systems through a unified digital architecture, we aim to reduce administrative burdens, enhance trust and operational transparency, and improve the overall efficiency and security of cross-border logistics in the EU.

This research paper explores the complex landscape of logistics interoperability by drawing on extensive qualitative data gathered from stakeholder surveys, focus groups, round table discussions and semi-structured interviews within the KEYSTONE project (KEYSTONE EU Project, 2024). Knowledge Management plays a central role in this research, as the project utilizes KM frameworks to systematically collect, organize, and disseminate critical data across stakeholders, thereby improving decision-making and collaboration in multimodal transport systems. Through the application of KM, the KEYSTONE project seeks to address the challenges of interoperability and foster a more cohesive, efficient transport network. Identifying gaps in Knowledge management for Multimodal transport

The current transport infrastructure has been designed primarily to support national economies rather than a broader European framework. The absence of unified standards in infrastructure design, traffic management, and data exchange leads to cross-border bottlenecks that hinder the efficient movement of goods (Golinska, 2013). The key gaps identified in the knowledge management infrastructure of multimodal transport include technological barriers, obstacles to digital adoption, and regulatory challenges that impede cross-border transport.

2. Technological Barriers

Multimodal transport faces significant technological barriers that hinder its efficiency and integration. One of the primary challenges is the lack of a universal technological standard for data exchange between different transport modes. The absence of standardized protocols results in non-interoperable systems, making it difficult for stakeholders—such as logistics operators, enforcement authorities, and transport providers—to seamlessly share and process information across borders. Additionally, the fragmented IT infrastructure, where various digital platforms operate in isolation, lead to inefficiencies in real time data exchange. Many of digital platforms are designed for specific transport modes or national regulations, preventing smooth intermodal coordination. The lack of integration between transport management systems, tracking technologies, and digital documentation platforms leads to inefficiencies, increased administrative burdens, and delays in operations. Cybersecurity risks also pose a significant challenge. The increasing reliance on digital platforms for real-time tracking, data sharing, and electronic documentation raises concerns about data security, privacy breaches, and cyberattacks. For instance, the Transportation Security Administration (TSA) has proposed new cybersecurity regulations for pipelines and railroads to enhance the protection of critical infrastructure, highlighting the growing sophistication of cyber threats targeting industrial machinery (WSJ,

2024). Many transport operators are hesitant to fully embrace digitalization due to the risks associated with unauthorized access, data manipulation, and potential financial losses from security breaches.

2.1 Barriers to Digital Adoption in Multimodal Transport

Even with advancements in digital tools accessibility issues continue to hinder the widespread adoption of digital solutions in multimodal transport. A key challenge is the non-acceptance of digital documents by many stakeholders. Despite legislative advancements, paper-based documentation remains dominant, as not all authorities or operators are ready to fully embrace digital alternatives. Additionally, high competition among stakeholders—not only between different transport modes but also within the same mode—discourages information sharing. Operators may be reluctant to share data if they believe it could put them at a competitive disadvantage. The cost of implementation for digital platforms also poses a barrier, particularly for smaller logistics companies that may lack the financial resources to invest in such technologies. Language barriers further complicate communication in international transport, as different Member States use platforms with varying linguistic requirements, limiting data accessibility across borders. The absence of standardized electronic documents also prevents smooth information exchange, as different stakeholders use varied formats and systems. Finally, the unreadiness of drivers—especially in an aging workforce—further delays the adoption of digital technologies, as older drivers may not be comfortable using smart devices or digital tools in their daily operations (KEYSTONE EU Project, 2024).

2.2 Regulatory Challenges

Regulatory inconsistencies across jurisdictions add another layer of complexity to the knowledge management of multimodal transport. One significant issue is the lack of obligation to use digital platforms, as not all Member States mandate the adoption of electronic documents. While some countries have embraced digital solutions, the absence of uniform legal requirements results in inconsistent enforcement practices, creating inefficiencies in data exchange and compliance (Wittenberg et al., 2024). Another major challenge is the fragmented legal framework, which imposes varying obligations on enforcement authorities regarding the acceptance of electronic documents. This inconsistency enables different implementation practices across regions, making it difficult for transport operators to adhere to a standardized approach. Furthermore, the fragmented IT environment is shaped by a variety of non-interoperable systems used for the transfer of electronic transport information and document exchange in both B2A (Business-to-Authority) and B2B (Business-to-Business) contexts. The lack of system compatibility between stakeholders prevents seamless data flow, leading to inefficiencies and delays in multimodal transport operations. Additionally, the lack of harmonization of laws across Member States creates barriers to effective cross-border cooperation. Each country follows its own regulatory framework, leading to operational inefficiencies, added administrative burdens, and delays in transport processes. Another critical issue is the absence of clear definitions of responsibilities regarding data access and management. Without standardized guidelines on who can access, share, and protect data, disputes may arise, resulting in unauthorized access, confidentiality breaches, and limited trust among stakeholders.

3. Knowledge Management in Multimodal Transport

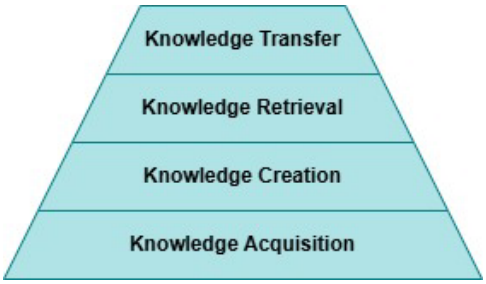

Figure 1: Knowledge management Framework

The knowledge management framework is represented as a pyramidal structure, with knowledge acquisition forming the base. Above it, knowledge creation, knowledge retrieval, and knowledge transfer are layered as shown in Figure 1 (Dalkir., 2017). Each of these pillars plays a crucial role in the effective management of knowledge within a framework, contributing to the creation, sharing, and utilization of valuable information for improved decision-making and organisational performance.

In the context of transport information, Knowledge Acquisition involves collecting data from both internal and external sources. This process includes gathering real-time data from transport networks, government bodies, or other sources, and making it available for further use within the framework. The knowledge framework must ensure this data is captured efficiently for future processing and sharing with stakeholders. This data is then processed in the Knowledge Creation phase, where raw data is transformed into actionable insights through analysis, trend identification, and collaboration with experts to develop strategies and solutions. Knowledge Retrieval ensures that this valuable information is organized, categorized, and easily accessible, enabling quick responses to changing conditions. Finally, Knowledge Transfer involves sharing the processed data and insights with relevant stakeholders, ensuring secure distribution for further analysis, policymaking, and decision-making in the transportation sector.

4. Implementing a Unified Digital and Regulatory Framework

To address the challenges discussed in Section 2, a unified digital and regulatory framework that enhances interoperability, streamlines compliance, and fosters collaboration is needed. The integration of API -based digital solutions and the establishment of common regulatory frameworks play a pivotal role in overcoming these obstacles.

4.1 Best Practices for Integrating Digital Solutions in Multimodal Transport

The integration of digital solutions in multimodal transport requires a structured approach that ensures system interoperability, data security and real-time collaboration. These best practices can be categorized into several aspects. For example, the adoption of API-based interoperability standards, including API reference models and standards, facilitates real-time data exchange between B2B and B2A platforms. This enables seamless integration across different transport management systems, reducing inefficiencies caused by incompatible IT environments. Among the best practices are:

- The adoption of an API-based interoperability standard enables seamless communication between digital platforms users, ensuring consistency in data structure, authentication, and access protocols across different transport management systems.
- Enhancing digital documentation and verification, especially regarding the electronic consignment note (eCMR) (Tomicová, Poliak and Zhuravleva, 2021), which can significantly increase data security boost efficiency, and contribute to a more streamlined, safe, and secure transport system.
- Digital integration on multiple levels (regional, national and European) is essential for ensuring efficient multimodal transport. At the European level, initiatives such as the Digital Transport and Logistics Forum (European Commission, 2025e), the DeployEMDS project for transforming European mobility data sharing (European Commission, 2025i), and the Electronic Freight Transport Information and Regulation (EU) 2020/1056 (European Union, 2025j) aim to enhance digital documentation, standardize data-sharing, and mandate electronic freight transport information systems by 2025. At the National level, adopting EU directives and developing National Digital Freight Corridors can interconnect transport data among key stakeholders. Meanwhile, regional efforts focus on cross-border cooperation to harmonise customs digitisation, enable real-time freight tracking, and streamline exchange of electronic documentation.
- Enhancing cybersecurity and data protection in logistics by promoting awareness, training, and secure IoT protocols, to safeguard operations. This aligns with the EU regulations, such as the Cyber Resilience Act (European Commission, 2025d), which aims to strengthen data security in transport and logistics networks.
- A Plug & play digital ecosystem (European Commission, 2024b) for logistics and transport promotes the development of interoperable digital platforms that seamlessly connect stakeholder data, by adopting standardized APIs and data-sharing protocols. ‘Plug and Play’ refers to a design principle that allows systems and components to connect and function together with minimal configuration, enabling stakeholders to integrate their platforms without requiring complex technical setups. This enhances operational efficiency, reduces administrative burdens, and fosters real-time collaboration across the supply chain.

4.2 Developing Common Regulatory Frameworks for Improved Compliance

Harmonizing regulatory frameworks is essential for ensuring seamless operations across transport sectors. The variations in national regulation can create inefficiencies, increase compliance costs, and create barriers for digital integration. Establishing common standards for data exchange, documentation, and enforcement, as

previously mentioned, can significantly enhance real-time information sharing, reduces cross-border delays and streamline administrative procedures. By aligning policies at the EU level and promoting stronger cooperation among member states, regulatory frameworks can support greater interoperability, improve compliance efficiency and enhance the overall resilience of the logistics sector. Furthermore, common regulations will encourage innovation and investment in digital solutions, help logistics operators meet global standards, and provide clarity that can support small and medium-sized enterprises (SMEs) in participating in global trade.

4.3 EU-Level Platforms for Unified Digital Integration

A critical component of the proposed unified digital and regulatory framework is the integration of existing EU-level platforms currently used by enforcement authorities for road transport regulation and compliance. These platforms are foundational to enabling secure, real-time data exchange and digital identity verification across borders. The following are key EU-level platforms for knowledge sharing and are integral to the proposed unified digital and regulatory framework. RESPER (Register of Road Transport Undertakings) (European Commission, 2005f) – Provides a register of professional drivers' license and qualification information, essential for verifying driver eligibility and compliance across EU member states. TACHONET (European Commission, 2024h)– Facilitates the secure exchange of digital tachograph card data between national authorities. It enables verification of driver activity, rest periods, and compliance with EU driving time regulations. ERRU (European Register of Road Transport Undertakings) (European Commission, 2024g)– Allows national authorities to share and access information on transport operators' compliance with EU rules, including infringements and penalties, supporting better enforcement coordination. By incorporating these systems through a standardized API-driven architecture, authorities and logistics operators can achieve real-time access to verified data. This will significantly reduce redundant paperwork, streamline cross-border inspections, and support compliance with social, safety, and market regulations. Their integration into the proposed plug-and-play digital ecosystem ensures that the framework is not only innovative but also grounded in existing infrastructure, enhancing feasibility and adoption potential across the EU.

5. Digital Solutions for Overcoming Knowledge Silos: The KEYSTONE Approach

To overcome these persistent challenges, the KEYSTONE project is developing digital solutions that facilitate seamless knowledge exchange, ensuring that all stakeholders have access to consistent and standardized transport data. By integrating an API Reference Model and a common regulatory framework, KEYSTONE aims to eliminate knowledge silos and enable a more efficient multimodal transport ecosystem. A major impediment identified during consultations, surveys and interviews with stakeholders in logistics and law enforcement is the lack of a unified regulatory framework for multimodal transport, with variations in the implementation of international transport conventions causing regulatory fragmentation. Additionally, differing cross-border documentation requirements further complicate knowledge sharing and real-time coordination.

To address these issues, KEYSTONE is developing frameworks that tackle both technical and regulatory barriers to knowledge sharing. These frameworks are designed to breakdown existing knowledge silos. Figure 2 illustrates the overall knowledge management framework in line with the Keystone approach.

5.1 API Reference Model and Standard: Enhancing Interoperability Through Plug and Play Principles

The KEYSTONE project actively develops solutions that significantly contribute to the KM aspect of the logistics sector and the regulatory compliance, particularly overcoming knowledge silos within multimodal systems. At the core of its developments is the creation of an API Reference Model and the subsequent API standard designed with the Digital Transport and Logistics Forum (DTLF's) Plug and Play principles at its heart as outlined in the EU Transport Policy framework (European Commission, 2024e). This approach enables seamless interoperability across diverse platforms and systems. Furthermore, KEYSTONE addresses critical aspects of cross-border governance and standardized data sharing, ensuring real-time, efficient and sustainable coordination among stakeholders. The first pivotal component of KEYSTONE's approach is the development of a comprehensive API Reference Model (Keystone EU Project, 2025), which serves as a blueprint for facilitating seamless, interoperable digital exchange within the transport and logistics sector. In essence it serves as a foundational framework to build upon the API standard. By establishing a structured approach to API standardisation, the API Reference Model strives to bridge existing gaps in data-driven operations and enable 'Plug and Play' solutions that can overcome the limitations of current legacy systems. It - streamlines connectivity, enhance scalability and ensure secure, regulatory-compliant business transactions.

This model (Refer figure 2) connects information from various regulatory platforms example, RESPER, TACHONET and ERRU based on knowledge acquisition, knowledge creation (Integrating Platforms using API standard), and knowledge retrieval (KEYSTONE's standardized Plug and Play solutions) in a seamless and efficient flow. DTLF's Plug and Play is a set of concepts and procedures designed to let individual stakeholders—from public authorities to private enterprises—seamlessly connect and share data through a common digital platform. It removes barriers associated with intricate knowledge and technical expertise needed for setting up, configuring software components and integrating, by providing standardized, predefined settings and agreements, which simplify the process of linking disparate legacy systems and ensures interoperability across the transport and logistics ecosystem. Therefore, with these principles incorporated, the API reference model and the derived API standard are structures that provide single, predefined connection endpoints for each data-sharing need a stakeholder may have. This simplifies the definitions of the proper data-providing/consuming APIs, streamlines the integration process, and reduces the need for manual setups. Through this system, the Knowledge Hub and the Authority can efficiently exchange data in a standardized and secure manner for cross-border transport. In the context of logistics data sharing, the KEYSTONE project adopts Plug and Play design principles to meet the diverse needs of individual end-users, fostering a user-centric, inclusive, and easily accessible environment, as specified in the DTLF Interim Report (European Commission, 2024a). That is why it is the first pivotal step towards eliminating data silos and ensuring that data is shared in a consistent, interoperable format, contributing to the knowledge management aspect in the logistics field and data-driven decision-making.

Regarding the components, the API reference model includes robust technical specifications that define data formats -using JSON (JavaScript Object Notation), a lightweight data-interchange format that is easy for humans to read and write, and easy for machines to parse and generate, commonly used in communication protocols that follow REST (Representational State Transfer) principles, which use standard HTTP methods (GET, POST, PUT, DELETE) for interaction and allow web-based systems to communicate in a scalable, stateless manner (Neumann et al., 2021). Security is also a core element, ensuring that all data exchanged remains confidential and intact through measures such as HTTPS (Hypertext Transfer Protocol Secure) encryption. In this way the model is designed to standardize not only technical aspects but also to serve as a cornerstone for effective knowledge management in multimodal transport ensuring safety and security. Additionally, the model provides a scalable, simple architectural blueprint that defines API components—endpoints, requests, and responses—based on stakeholder needs and current digital standards.

The overarching goals of the API Reference Model are multifaceted. It established standardized data exchange protocols that enhance safety within the transport ecosystem while fostering collaboration and interoperability among diverse systems used by organisations and authorities. It aims to reduce compliance costs for involved stakeholders of all sizes and legacy capacities, optimise resource utilisation, boost digitalisation, transparency and automation to a greater extent of certain operations and processes, and promote consistency, reusability, and modular integration for improved efficiency and scalability. Ultimately, this framework encourages the broad adoption of digital solutions across the transport and logistics industry.

The goal is that once the API Standard is developed based on this model, different stakeholders can connect their systems and exchange data with minimal complexity in configuration, embodying the essence of Plug and Play. Data can remain at its source and be accessible to competent authorities for cross-border checks along various transport routes, as per the KEYSTONE's scope. However, a standardized API is vital for knowledge management not only for the project's purposes but also well beyond that. By providing a consistent, secure method for querying and retrieving data across disparate systems, the API standard enables authorities and stakeholders to integrate and analyse information without needing to centralise it. This uniformity allows for real-time monitoring, comparative analysis, and the extraction of actionable insights while preserving data ownership and privacy. Ultimately, it enhances decision-making, promotes regulatory oversight, and builds a comprehensive, interoperable knowledge base that drives efficiency and sustainability in the transport sector

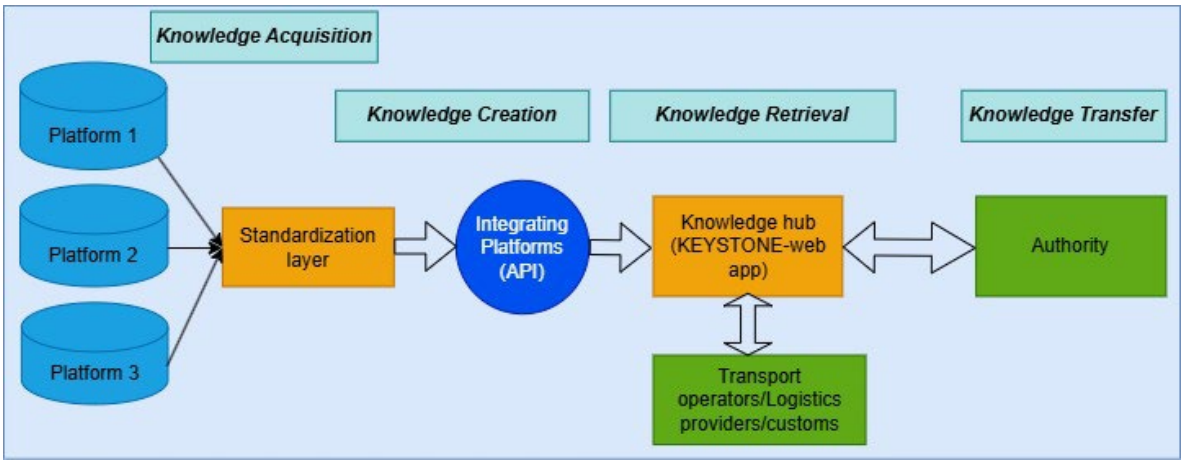

Figure 2: Knowledge Management framework explaining KEYSTONE concept (KEYSTONE EU Project, 2025)

5.2 Cross-Border Governance Framework: Addressing Regulatory and Procedural Complexities

The KEYSTONE project acknowledges that a major challenge in multimodal transport is the lack of a unified regulatory framework across the EU and the UK. To address these regulatory and procedural complexities, KEYSTONE aims to contribute to a cross-border governance framework with the development of its solutions. This framework aims to foster cooperation and develop common rules for cross-border operations, ensuring smoother integration between national systems and addressing challenges related to differing documentation and compliance requirements. The API model and the respective deriving API standard are designed to support such a framework by providing a technical mean for the exchange of regulatory information and compliance-related data. The model and consequently the standard will facilitate the definition of API endpoints and thus the creation of such standardized APIs that can handle the diverse data elements required for cross-border transport, such as those related to vehicle status, driver qualifications, and cargo details among others. The intention is that a standardized API will facilitate the verification of compliance with existing legislation by enforcement authorities and their competent agencies across the EU in a quick and secure way and without language/paper barriers.

Furthermore, to evaluate and validate these developed solutions and thus showcase in a measurable manner the value they aim to deliver, KEYSTONE develops a data exchange web-based application based on the API standard. This web application will serve as a concrete example of the effectiveness and viability of the API standard and reference model, demonstrating real-time data exchange. The backend of this system will manage requests and process data, integrating with third-party systems through standardized APIs and connectors. The emphasis on REST services for the APIs will provide a standardized external interface for data consumption by the web app and other systems, facilitating real-time information access.

The web app and the demonstrations of it are in essence a validation tool for the entire KEYSTONE endeavour. By demonstrably using the API standard and reference model to achieve real-time data exchange with integrated systems through its backend and RESTful APIs, it directly addresses regulatory complexities withing the cross-border governance framework by showcasing how standardized data exchange can streamline compliance checks and information sharing across different regulatory domains.

5.3 Standardized Data-Sharing Models for Real-Time B2A and B2B Coordination

Fragmentation in data exchange within the transport and logistics sector often arises from the use of disparate systems, leading to inefficiencies and communication barriers, issues which standardisation also aims to tackle, by ensuring flow smoothly between systems without the need for extensive custom integrations, effectively reducing said fragmentation. For Business-to-Business (B2B) exchanges, the implementation of standardized APIs facilitates real-time data sharing between logistics operators, suppliers, and customers. This immediacy enhances supply chain visibility, allowing businesses to respond swiftly to market demands and operational challenges. Additionally, it reduces manual data entry errors and streamlines processes, leading to cost savings and improved partner relationships by allowing them to coordinate in an optimised manner.

In the context of Business-to-Authority (B2A) interactions, standardized APIs enable efficient and secure data transmission between businesses and competent enforcement authorities. This capability is crucial for compliance with legal requirements, as it allows for automated reporting and real-time monitoring.

Consequently, authorities can perform their oversight functions more effectively, and businesses can ensure adherence to regulations with minimal administrative burden.

Furthermore, for both cases (B2B and B2A), automation of data exchanges is becoming feasible and easy to implement with the adoption of the API standard. As a result, manual data entry, and the use of paper documents, which are still prevalent in many cases and prone to mistakes, may become obsolete. For instance, integrating systems through standardized APIs allows for real-time updates of transport statuses, shipment tracking and more, creating a seamless flow of information. This automation not only streamlines operations but also enhances data accuracy allowing interventions and checks to be focused on targeted cases. Moreover, all parties can access up-to-date information for informed decision-making. This immediacy reduces delays associated with traditional data exchange methods and enables prompt responses to any emerging issues, significantly reducing the administrative workloads, which are a prominent issue in many cases.

By implementing a unified API Reference Model, a common regulatory framework, and a cross-border governance approach, KEYSTONE addresses long-standing challenges in multimodal transport. These solutions enable real-time data exchange, enhance regulatory compliance, and improve coordination between businesses and authorities. The standardisation of data-sharing models not only reduces inefficiencies but also fosters digital innovation, creating a resilient, transparent, and efficient logistics ecosystem. As these technologies and frameworks gain traction, they lay the foundation for a more harmonised and future-ready multimodal transport network.

6. Conclusion and Future Directions

Multimodal transport systems are essential for efficient freight movement, yet persistent knowledge silos, regulatory fragmentation, and technological barriers hinder seamless coordination. This paper has explored how knowledge management principles can address these challenges, focusing on insights from the KEYSTONE project.

A major finding is that the lack of a unified regulatory framework creates inefficiencies in cross-border operations. Variation in transport conventions, documentation requirements, and compliance standards across member states complicates coordination. Additionally, fragmented IT systems and interoperability issues in B2A and B2B interactions limit knowledge sharing. Based on knowledge management principal KEYSTONE project propose an API reference model and standard, facilitating seamless digital interoperability through plug and play principles. This approach enhances data exchange between existing platforms like RESPER, ERRU and TACHONET, reducing inefficiencies between stakeholders. To demonstrate the feasibility of this approach, KEYSTONE has also developed a web-based application as a proof-of-concept. This tool serves as a validation mechanism for the API standard and reference model, showcasing real-time data exchange and seamless integration with third-party systems using RESTful APIs. It exemplifies how such frameworks can translate into tangible solutions that improve operational workflows.

Future research should focus on advancing digital transformation strategies to address persistent interoperability and regulatory challenges in multimodal transport. While technical solutions, such as those proposed by KEYSTONE, contribute to bridging knowledge gaps and enhancing digital connectivity, further exploration is needed to refine digital ecosystems and improve real-time data exchange. One key area is the development of artificial Intelligence- driven systems that can automate logistics process and support decision making for transport operators.

Another important aspect is the development of digital governance frameworks and standardization efforts at various level to promote alignment across member states. Collaboration among policymakers, industry stakeholders, and technology providers will be crucial in achieving a fully integrated multimodal transport network.

By implementing the recommendations outlined in this paper, the transport and logistics sector can move towards a more connected, efficient, and knowledge-driven ecosystem, ultimately enhancing global trade and supply chain resilience.

Acknowledgement

This research was conducted as part of the KEYSTONE project, which has received funding from the European Commission’s Horizon Europe programme under grant agreement number 101103740 (EU HORIZON-CL5-2022-D6-02).

Ethics declaration: This research did not require ethical clearance as it does not involve human participants, animal studies, or sensitive data. All information used in the paper is publicly available or based on secondary data sources.

AI declaration: No AI tools were used in the development of this paper. The manuscript solely reflects the authors' intellectual contributions, interpretations, and domain expertise.

References

Alavi, M. and Leidner, D.E. (2001) "Review: Knowledge management and knowledge management systems: Conceptual foundations and research issues", *MIS Quarterly*, Vol. 25, No. 1, pp. 107–136.

Dalkir, K. (2017). Knowledge Management in Theory and Practice (3rd ed.). MIT Press.

European Commission (2024a) 'DTLF II SG2 Interim Report', *European Commission*, Brussels, Available at: https://transport.ec.europa.eu/document/download/34d0e597-1a9a-41cd-97e6-13e3221016e3_en.

European Commission (2024b) *EU Transport Policy Framework*, European Commission, Brussels. Available at: https://transport.ec.europa.eu/document/download/ecd6598f-a748-4331-9c85-4e3a6ece36c2_en.

European Commission (2024c) 'Eurostat Statistics Explained', *European Commission.* Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?oldid=658740.

European Commission (2025d) *Cyber Resilience Act, European Commission*. Available at: https://digital-strategy.ec.europa.eu/en/policies/cyber-resilience-act .

European Commission (2025e) 'Digital Transport and Logistics Forum (DTLF)', *European Commission*. Available at: https://transport.ec.europa.eu/transport-themes/digital-transport-and-logistics-forum-dtlf_en .

European Commission (2005f), RESPER: Réseau permis de conduire. European Sources Online. Available at: https://www.europeansources.info/record/website-resper-reseau-permis-de-conduire/

European Commission (2024g). European Register of Road Transport Undertakings (ERRU). Available at: https://transport.ec.europa.eu/transport-modes/road/rules-governing-access-profession/european-register-road-transport-undertakings-erru_en

European Commission (2024h). TACHONET. Available at: https://transport.ec.europa.eu/transport-modes/road/tachograph/tachonet_en

European Commission (2025i) 'Transforming European mobility data sharing through DeployEMDS project', *European Commission*. Available at: https://transition-pathways.europa.eu/projects/transforming-european-mobility-data-sharing-through-deployemds-project .

European Union (2025j) '*Regulation (EU) 2020/1056 on electronic freight transport information*, 9 January. Available at: https://eur-lex.europa.eu/eli/reg/2020/1056/2025-01-09 .

Grancharova, V. (2021) "Challenges to the multimodal transport networks based on sustainable growth in the volume of containerized cargoes", Pedagogika-Pedagogy, 93, pp. 53–64.

Golińska, P. (2013) "Information management supporting multimodal transport utilization in virtual clusters", Management and Production Engineering Review.

neKaram, A., Jensen, A.J.K. and Hussein, M. (2023) "Analysis of the barriers to multimodal freight transport and their mitigation strategies", *European Transport Research Review*, 15, Article 43.

KEYSTONE EU Project (2024) *Requirements Analysis*. Available at: https://static1.squarespace.com/static/648c2485bcc39e6c2950f8b4/t/668503e047c6e4716f992807/1719993317944/KEYSTONE_WP1_D1.2+-+RequirementsAnalysis.pdf.

Keystone EU Project (2025) *KEYSTONE D2.1 Public Deliverable, API Reference Model*. Available at: https://www.keystone-project.com/deliverables.

Kumar, K., Jain, A.K., Tiwari, R.G., Jain, N., Gautam, V. and Trivedi, N.K., 2023. Analysis of API Architecture: A Detailed Report. In: 2023 IEEE 12th International Conference on Communication Systems and Network Technologies (CSNT), Bhopal, India, 2023. pp. 880-884.

Nakash, M. and Bolisani, E. (2025) 'Making knowledge management transparent: a new perspective on KM processes integration in the organizational framework', Business Process Management Journal, 31(8), pp. 49-66

Neumann, A., Laranjeiro, N. and Bernardino, J., 2021. An analysis of public REST Web service APIs. IEEE Transactions on Services Computing, 14(4), pp.957–970.

Paddeu, D., Calvert, T., Clark, B. and Parkhurst, G. (2019) New Technology and Automation in Freight Transport and Handling Systems, University of the West of England, Bristol. Available at: https://assets.publishing.service.gov.uk/media/5c73fc7340f0b603d87fe977/automation_in_freight.pdf

Sarraj, R. et al. (2013) 'Interconnected logistic networks and protocols: Simulation-based efficiency assessment', *International Journal of Production Research*, 52, pp. 1–24.

Tomicová, J., Poliak, M. and Zhuravleva, N.A. (2021) 'Impact of using e-CMR on neutralization of consignment note', *Transportation Research Procedia*, 55, pp. 110–117.

Wittenberg, D. et al., 2024. Information requirements and legal framework for multimodal transport system coordination. *Logistics*, 8(4), p.123.

WSJ (2024) 'TSA wants to expand cyber rules for pipelines and railroads', *Wall Street Journal*. Available at: https://www.wsj.com/articles/tsa-wants-to-expand-cyber-rules-for-pipelines-and-railroads-011b9d96