# CSBO SYTADEL : SYNCHROMODAL PROTOTYPE FOR DATA SHARING AND PLANNING

***Task 2.3 Data space scale-up roadmap***

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# CONTENT

# 1 Introduction

This chapter presents the scale-up roadmap for the logistics data space, consolidating the key lessons learned throughout the SYTADEL project. As identified during the project, there is a clear need for public and private stakeholders to understand how a logistics data space can be expanded and sustainably implemented in Flanders and across the EU. The chapter highlights key considerations, drawing from stakeholders' interaction and real-world applications in the Living Labs. It also outlines a structured roadmap for scaling up, providing a clear trajectory for short-term, medium-term, and long-term implementation. By bundling stakeholder feedback and project findings, this roadmap serves as a reference for institutions, industry players, and technology providers to support the continued development of a sustainable and interoperable logistics data space.

# 2 Project Key Insights - Lessons Learned

## 2.1 Lessons learned from the implementation

In the early stages of implementing the synchromodal data space, existing baseline contracts and commercial relationships are crucial. These are expected to evolve as trust in data usage policies, along with smart contracts and blockchain technologies, expand. Such contractual agreements between shippers, LSPs, barge operators, terminals, and other stakeholders are key in aligning interests during the initial deployment stages of the data space. Moreover, in response to increased trust needs, some usage policies and overarching agreements have been revised to fulfill data criticality demands. While not all participants initially used the data space connector directly, establishing robust and clear standard data usage policies—compliant with fundamental regulations such as the GDPR—was advantageous. For example, these policies encouraged initial trust among data owners and users, reinforced through diligent monitoring of policy implementation. In other words, trust is critical in this context; without it, maintaining high-quality standards of the data space is a significant challenge.

Based on existing data usage policies (e.g., permissions, prohibitions, and obligations), additional use-for-purpose policies with different obligations can be employed upon identifying a valid new route, mode, or alternative. In this respect, control policy patterns proposed in Dataspace Connector (2021), such as "Connector-restricted Data Usage," permit data usage for a specific connector, meaning specific data is only shared with particular stakeholders. Similarly, a "Use Data and Delete it After" policy can allow data usage within a specified time interval with the restriction to delete it at a specified timestamp. Consequently, data will be retained only as long as necessary for the intended purposes and will be securely deleted afterward.

Secondly, the issue of data quality is essential. Inconsistencies in AIS coverage areas exemplify this concern, with certain European waterways lacking full coverage, often due to geographical challenges like mountainous terrain or lack of terrestrial receivers, thus resulting in gaps in historical route data for vessels or real-time signals. Furthermore, the availability and uptime of cargo data is critical. It is essential for AIS sources to offer real-time visibility of the entire fleet and for relevant stakeholders to provide cargo details and terminal and logistical planning information to ensure timely access to the most current, relevant data regarding cargo and planning. Although AIS and transport mode location gaps can be complemented with other satellite sources, it is essential to study and identify the main hinterland areas with signal gaps and proactively anticipate lost signals.

A third note is related to interoperability. While data sharing for AIS data (or similar position tracking systems for other transport modes) is standardized and widely recognized, the sharing of information regarding vessel nominations, logistics planning, terminal schedules, and other pertinent details often presents greater challenges. This is evident even within the scope of this Sytadel. For instance, inconsistencies arise due to varying naming conventions for specific locations and different cargo descriptions. Additionally, from an integration standpoint, it has become clear that the existing IT infrastructure supporting logistics operations is not optimally configured for interoperable data exchange. For instance, this infrastructure frequently depends on ad-hoc exports in flat files or similar methods to disseminate data among various stakeholders. From this perspective, services in the data space to overcome such challenges could include strong metadata management to ensure data is updated in real-time and accessible to all relevant parties and services free of inconsistencies. The living labs developed here are only examples that explore the potential of various available data sources that can be integrated to develop diverse applications and services within the data space.

## 2.2 Opportunities from the implementation.

The data space has the potential to fulfill several visibility characteristics identified by Caridi et al. (2014), which are crucial for successful synchromodal operations. These characteristics include:

(i) ensuring access to critical information both within and outside the organization, vital for overseeing and adjusting operations;

(ii) allowing stakeholders to access or exchange relevant information, benefiting all parties involved;

(iii) enabling stakeholders to receive notifications about deviations in supply chain operations and respond accordingly; and

(iv) providing visibility as a tool for gathering and analyzing supply chain data, supporting decision-making and reducing transport-related risks.

Additionally, the data space approach also advances the literature on mechanisms that enable technologies to support synchromodality proposed by Giusti et al. (2019). These mechanisms include *traceability* of transport modes and routes using geolocation (e.g., AIS data and terminal geofencing), *optimization/rerouting* capabilities that incorporate data from owners via *app providers*, and an integration platform were entities, such as *orchestrators* (Ceulemans et al., 2024) can mediate synchromodal operations while maintaining information exchange balance.

The impact of the synchromodal data space extends beyond visibility, contributing to other key characteristics of synchromodality. One notable contribution is the integration of multiple stakeholders in a decentralized, collaborative effort that spans various sectors or industries. This integration requires coordinating and managing a system composed of interconnected supply chains or networks (Giusti et al., 2021; Kourounioti et al., 2018; Tavasszy et al., 2010), rather than focusing solely on the isolated platforms and supply chains of individual stakeholders. This approach promotes community-building within supply chains by enabling decentralized data connections among trusted stakeholders. The collective commitment of stakeholders to integrate the data space connector, make their data discoverable, and utilize it according to agreed-upon usage policies represents an integration that goes beyond traditional transport contracts, potentially evolving into dynamic partnerships. However, the extent to which this transformation will occur in larger setups remains uncertain and is worth further exploration.

The current data space applications in different domains in the International Data Spaces Association (2023) and Gaia-X (2023) initiatives can be used as an example of how a wide range of organizations and entities with diverse core businesses and objectives can be integrated. This is particularly significant in synchromodality, as it extends beyond the typical transport and logistics players such as shippers, carriers, LSPs, authorities, or terminals. Additionally, it encompasses the integration of entities that might be considered peripheral to the core of logistics, including *data space service providers*, *metadata brokers* and *app providers*, along with their various potential services (e.g., optimization models, data cleansing, simulations, digital twins, or interfaces to physical internet developments). As a result, synchromodality should incorporate such data space actors, who frequently align more closely with technology companies than traditional logistics players and exert influence in the tangible implementation of the concept.

Finally, with significant implications for expanding the synchromodal data space, the European Data Act was enacted in 2024, establishing new rules for a fair and innovative data economy (European Commission, 2024). At the European level, the approach to the synchromodal data space is aligned with the mobility strategy outlined in Flagship 6: Making Connected and Automated Multimodal Mobility a Reality, which is part of the European Green Deal (PrepDSpace4Mobility, 2023). Moreover, this contributes to developing the European Common Mobility Data framework. Further alignment is evident in the work on data spaces for mobility by PrepDSpace4Mobility (2023), which emphasizes decentralized data sharing and data spaces as key priorities for the European Commission. These priorities are reinforced by initiatives such as the European Data Strategy, incorporating essential components like the Data Act and the Data Governance Act. The European Commission's commitment extends to supporting the development of reference architectures, as well as the implementation and rationalization of data spaces, in alignment with its policy and regulatory frameworks. The

EU's Data Strategy ambitiously envisions a future of federated data sharing within common European data spaces.

# 3 Roadmap for Scale-Up

## 3.1 Overall reference for the data space development

To systematically approach the implementation of the Data Space, we propose a generalized reference framework based on foundational elements of the data space concept. Designed to be flexible and adaptable to synchromodal transport use cases, the framework serves as an overarching guide, with its implementation varying depending on the specific requirements and context of each case. It incorporates essential technical building blocks that align with the structure and needs of synchromodal transport, forming the foundation for secure, interoperable, and scalable data exchange across stakeholders and domains (Nagel & Lycklama, 2021).

As suggested by Data Spaces Support Centre (2023), the first building block, data interoperability (Figure 1a), encompasses the standards and tools required for efficient data exchange, including semantic models, data formats, APIs, and mechanisms for provenance and traceability. For example, semantic data models should act as conceptual frameworks that define entities, relationships, and attributes while capturing the semantics or underlying meaning of data elements such as asset locations or the geographic scope of transport operations.

The second building block, data sovereignty and trust (Figure 1b), refers to the identification of participants and assets, the establishment of trust, and the enforcement of access and usage control policies. The goal of this building block is to ensure the reliability and authenticity of participants and allow stakeholders to retain sovereignty over the data they choose to share. Achieving this requires the definition of clear data usage policies, the development of robust trust services, and the implementation of onboarding processes for stakeholders, particularly shippers, carriers, and logistics service providers, potentially leveraging existing agreements and ongoing commercial relationships.

Finally, the third building block, data value creation (Figure 1c), includes capabilities that support value generation within a data space, such as the registration and discovery of data offerings or services, as well as the provision of value-added functionalities. In the context of synchromodality, value creation is achieved through the seamless integration of both internal and external services and applications into the data space. This enables dynamic modal shift decisions by leveraging real-time data through various application services and enhances operational insights by enriching existing datasets with additional sources, such as combining vehicle positional data with cargo information and infrastructure availability. For a comprehensive overview of the building blocks' detailed components and interactions in the data space, see Data Spaces Support Centre (2025).

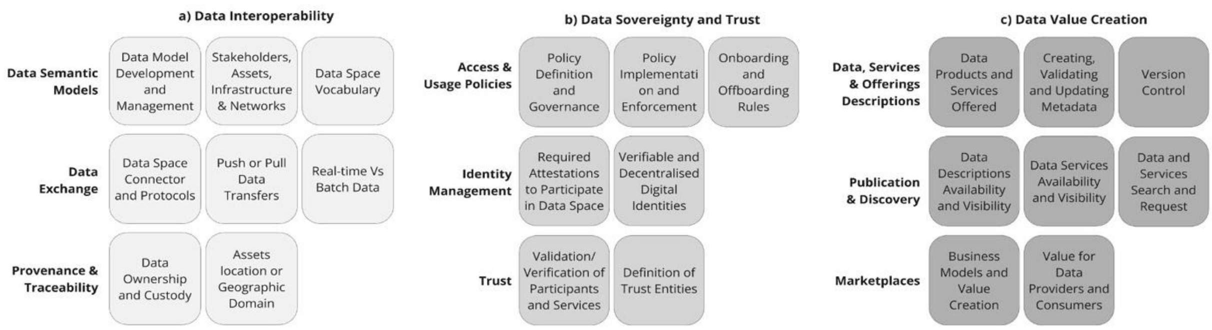


*Figure 1. Data Space Building Blocks: (a) data interoperability building block. (b) Data sovereignty and trust building blocks. (c) Data value creation building blocks. Extracted from* Data Spaces Support Centre (2023)

## 3.2 Potential applications for other transport modes

The living labs from the project primarily focused on the inland waterway transport and deep-sea transport ecosystems, addressing the specific stakeholders and their needs for data products and services derived from deploying a data space. However, it is important to highlight that the proposed framework is not limited to these two transport segments; it can be further developed and adapted to suit or integrate various transport domains depending on the stakeholders, the objectives of the data space, and the available assets and resources.

Interoperability refers to the capacity of different systems to operate together seamlessly, enabling devices, applications, or products to connect and exchange information in a coordinated manner without requiring additional effort from end users (Data Spaces Support Centre, 2023). In the context of road transport, positional data from vehicles follows a structure similar to that of AIS used in IWT, which enables comparable integration into the data space architecture.

As described by Adam et al. (2021), in 2016, Belgium introduced a kilometer-based taxation system for heavy-duty trucks over 3.5 t, equipping each vehicle with a Global Navigation Satellite System (GNSS) device that records its location every 30 s. While originally intended for tax billing, this positional data can also be repurposed to address broader operational challenges in transport systems. In this respect, a truck fleet operator can define a geographical data usage policy triggered by potential delays (e.g., a late-arriving barge), allowing truck positions and ID to be shared with relevant stakeholders in the data space. This enables real-time coordination with terminals and carriers, facilitating operational decisions like truck rerouting, reallocation of cargo handling activities, and partial transshipments when urgent cargo must be prioritized. Additionally, reference data such as terminal locations and nomenclature can be standardized using the EuRIS nomenclature as used in the Living Lab 1.

A clear example of how truck and barge operators can benefit from a data space is the Real-Time Schedule Co-Planning approach proposed by Larsen et al. (2020). In this model, barge operators propose departure schedules based on historical performance data and uncertainty metrics. Truck operators then assess these proposals by simulating associated costs and providing aggregated feedback, which enables mutual schedule adjustments. This approach aligns well with the data space vision, as it supports secure, efficient, and collaborative optimization between barge and truck operators while preserving data sovereignty. Table 1 outlines the data characteristics of this integration, which, when combined with other datasets like cargo details and intermediate/final destinations (e.g., Deliverable 2.1 Stakeholders Map), can significantly enhance multimodal synchronization.

*Table 1. Key Data for truck-barge integration.*

| Data | Description | Source | Type |
|---|---|---|---|
| **GNSS Data for Trucks** | | | |
| ID | Unique truck identifier | Onboard GNSS | Integer |
| Truck Position | Latitude and Longitude (WGS84) | Onboard GNSS | Float |
| Timestamp | Date/time of position report | Onboard GNSS | DateTime |
| Velocity | Current ground speed of the truck | Onboard GNSS | Float |
| Direction | Heading of the truck | Onboard GNSS | String |
| Country Code | Country code of truck registry | Onboard GNSS | String |
| Euro Value | Emission standard class (e.g., Euro 5) | Onboard GNSS | String |
| MTM | Maximum permissible mass data | Onboard GNSS | Float |
| **Real-time co-planning Data** | | | |
| Barge Location | Current terminal where the barge is docked | AIS systems | Binary |
| Barge Schedule | Planned departure times from terminals | Fleet operator | DateTime |
| Container Demand | Volume of containers needing transport (by destination) | Booking systems | Float |
| Truck Availability | Number of available trucks at terminals or surroundings | GNSS/Fleet operator | Float |
| Cargo Inventory | Containers waiting at terminals | Terminal systems | Float |
| Travel Times | Road and waterway transit durations between nodes | AIS/GNSS | Integer |
| Barge Capacity | Maximum number of containers per barge trip | Barge operator | Integer |
| Operational Costs | Costs for delays, routes, and barge/truck departures | Private Contracts | Float |

Finally, we can learn from Table 1 how standardized and real-time data integration between transport modes can support coordinated decision-making and enable data-driven services. These insights underscore the potential to develop data spaces tailored to various transport modes and operational contexts, not limited to inland waterway transport, but applicable across the broader multimodal logistics landscape.

### 3.3 Research-based services for synchromodal data spaces.

Adapting to shifting demands and disruptions in synchromodal transport relies on the availability of flexible services that align with real-time demand and shipper preferences, thereby minimizing idle capacity and improving vehicle utilization (Zhang et al., 2025). To illustrate how recent research can support the development of such services within a synchromodal data space, Table 2 presents some potential services derived from academic contributions. These services address key operational challenges, including routing optimization, capacity management, real-time orchestration, and strategic planning under uncertainty, and demonstrate how the integration of research-based solutions can enhance the overall functionality of the data space.

*Table 2. Research-based services for synchromodal data spaces*

| Source | Service | Description |
|---|---|---|
| Practice-based from the living labs | Transshipment Infeasibility Prediction | Monitors the operational status of transshipment points and predicts potential infeasibility caused by delays. Leverages real-time data to trigger shipment rerouting decisions. |
| Yee et al. (2021) | Dynamic Routing and Scheduling Optimization | A service using heuristic algorithms to flexibly optimize transport routes and resource allocation in real-time, reducing operational costs while adapting to transport disruptions. |
| Guo et al. (2022) | AI-Based Shipment Matching | A decision-support service using a Reinforcement Learning Algorithm (RLA) to optimize shipment-to-service matching under dynamic and stochastic travel times considering travel time uncertainty. The RLA pre-learns value functions through simulation, allowing immediate adaptation of shipment routing decisions when real-time travel data is revealed. |
| Yee et al. (2021) | Real-time Adaptive Orchestration | Integrates real-time data feeds (e.g., traffic, infrastructure usage, disruptions) to dynamically adjust transport schedules and mode choices for improved system-wide responsiveness. |
| Giusti et al. (2020) | Facility Location Optimization | Optimizing the location of transshipment facilities and allocating freight flows under uncertainty and allocating freight flows across facilities while ensuring operational synchronization. |
| General | Uncertainty-based Scenario Analysis | Generates and evaluates multiple planning scenarios to assess the impact of uncertainties in capacity, infrastructure, and handling performance. Utilizes data such as historical disruptions, weather, and demand shifts to support resilient and informed logistics decisions. |

# 4 Conclusions

Looking to the future, it is crucial to incorporate a broader range of technology stakeholders from the data space into the synchromodal concept. Their roles are vital in meeting the needs of systems like synchromodality. For example, we emphasize the importance of incorporating actors like **data space service providers**, **metadata brokers**, and **app providers**, and advocate for the integration of academic developments (e. g., quantitative models for service allocation, (re)routing problems, horizon control) with these actors in practical applications.

Moreover, this aligns with the EU's strategic direction for data handling and sharing, underscoring the potential for enhanced collaboration among private entities and between academic, governmental, and private sectors. We encourage supply chain stakeholders to explore the vast possibilities that a synchromodal data space offers for the future of logistics and transport.

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