CSBO SYTADEL : SYNCHROMODAL PROTOTYPE FOR DATA SHARING AND PLANNING

Task 2.2 Logistics Data space and synchromodal planning requirements co-creation

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CONTENT

LIST OF FIGURES

1 Introduction

This section outlines the approach taken to define the technical and functional requirements of the data space. It does so from the lesson learned from the two Living Labs 1 and 2. Additionally, it discusses the current challenges related to data sharing in synchromodality and synchromodal logistics in Flanders, as well as the technical requirements necessary to support seamless data integration. These requirements will be formulated based on the scope of each Living Lab, ensuring alignment with participants' operational needs.

The insights gathered were systematically discussed with stakeholders, allowing for collaborative refinement and validation. This iterative process ensured that the foundation of a sustainable data space was shaped together with key participants.

2 Data sharing in synchromodality

2.1 The necessity of data sharing (UA)

The literature on synchromodality is extensive, covering different perspectives. Early research focused on fostering cooperation among stakeholders (Pleszko, 2012) and integrating the latest logistics information into transport operations (Li et al., 2013). In the last decade, there was increasing recognition of the potential offered by real-time adaptation (Pfoser et al., 2016; Reis, 2015; Tavasszy et al., 2015), along with enabling the benefits of dynamic intermediate transfers in inland container transport (van Riessen et al., 2015). These conclusions point out the importance of data sharing.

In essence, synchromodal transport relies thus on the availability of real-time information in integrated systems that coordinate planning (Tavasszy et al., 2010). Equally important is timely access to this information, which is crucial for enabling adaptation to unexpected events or route improvements through real-time re-planning (Giusti et al., 2021). In other words, a synchromodal framework is determined by the accuracy, trustworthiness, and timeliness of the exchanged information (data), often facilitated by ICT/ITS platforms. However, it necessitates data infrastructures capable of managing (sensible) real-time data, among other technological challenges (Ambra et al., 2019; Giusti, Manerba, et al., 2019; Kourounioti et al., 2018).

Several studies leverage centralized historical data repositories to develop synchromodal applications and optimization models, while others propose digital platforms for stakeholder collaboration. For instance, Ferjani et al. (2024) created a decision support system using a simulation-optimization platform to assess itineraries based on shipper preferences, storing stakeholder data in Excel files within a centralized database. Similarly, Giusti, Iorfida, et al. (2019) introduced a maritime cloud system where data is stored on centralized servers with restricted access via authentication. However, both approaches highlight concerns about data centralization, trust, and scalability.

While these developments demonstrate that real-time data sharing is fundamental and valuable for finding optimal solutions in synchromodality, the overall data exchange process remains unclear, particularly regarding the circumstances under which it occurs and how trust and control over data usage are ensured. These platforms also face the challenge of data centralization, leading to siloed data that is isolated from external participants and confined to platforms requiring tailor-made IT developments and, in some cases, costly licenses, which hinder scalability.

Few studies have addressed the data exchange dimension of synchromodality or linked decentralized, open, and scalable systems to their research. For example, Singh & Van Sinderen (2015) incorporates contextual data (e.g., weather, location, traffic) into a common XML format for 4PL and LSP, yet does not delve into trustful data sharing mechanisms. Meanwhile, Hofman et al. (2016) and Hofman (2019) introduce data space concepts, such as semantic technology and federated architectures, to enable more flexible data sharing but offer limited real-world demonstrations involving logistics companies and shippers.

In conclusion, synchromodality requires continuous, real-time data exchange and high levels of trust, in contrast to the more fragmented information flows seen in conventional hinterland transport. This points to the urgent need for a solution that addresses trust, control, and interoperability concerns in a dynamic environment. Developing a data space for synchromodality emerges as a promising alternative, leveraging decentralized and federated principles to ensure flexible, secure, and efficient information exchange among diverse stakeholders.

2.2 Data sharing challenges – stakeholders view (UA)

The following analysis presents the results of the stakeholder workshop held by the University of Antwerp, where participants discussed challenges and opportunities related to data sharing in synchromodal logistics. The workshop aimed to gather insights from stakeholders from the logistics sector on data governance, confidentiality concerns, and the potential benefits of a federated logistics data space. Through a structured questionnaire, respondents shared their perspectives on the desirability of operational data sharing, barriers to implementation, and key functionalities required to facilitate effective data integration. The findings reveal a general agreement on the necessity of data governance, though concerns persist regarding confidentiality and secondary data usage. Participants also highlighted optimization, cost savings, and environmental benefits as key advantages of data sharing, while emphasizing the need for trust, transparency, and clear security measures to encourage adoption. The following are the summary of the findings where the dataset consists of 25 responses across 9 questions related to data sharing in synchromodal logistics, Questions assess attitudes toward data governance, desirability of data sharing, concerns about confidentiality, and the best ways to promote data sharing.

Attitudes Toward Data Governance and Sharing
Most respondents recognize the necessity of data governance between organizations for effective synchronized logistics planning as presented in Figure 1. In addition, as shown in

Figure 2, opinions on operational data sharing are divided, with perspectives ranging from undesirable to neutral to desirable.

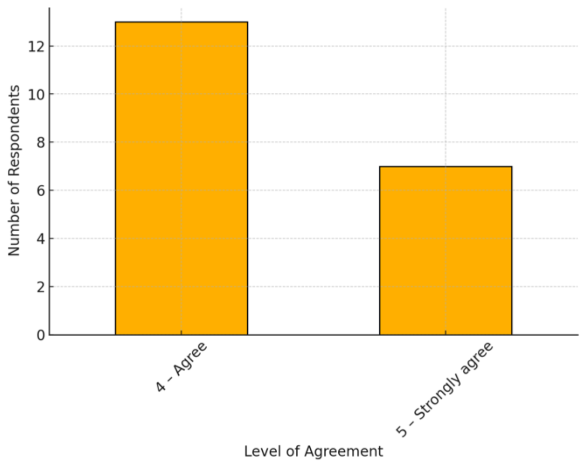

Figure 1. Agreement that data governance is essential for synchromodal logistics

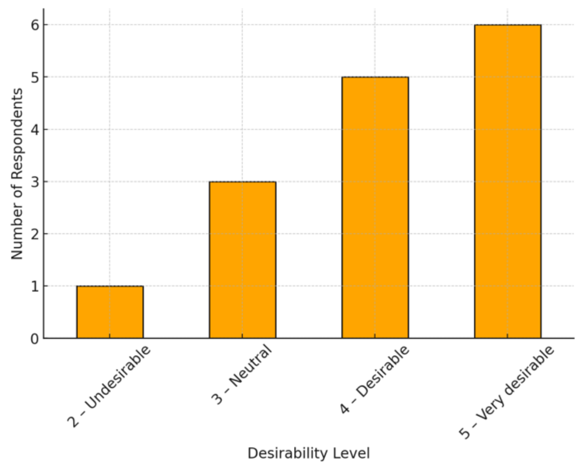

Figure 2. Desirability of operational data Sharing

A key concern among stakeholders is the secondary use of data for unintended purposes, with some expressing fears about potential risks as shown in Figure 4. Additionally, barriers to data sharing persist, largely due to limited data-sharing practices, stakeholder resistance, and confidentiality concerns. Finally, many organizations do not regularly share data, and hesitation often stems from protecting client/customer interests and -sensitive information, further complicating collaboration efforts.

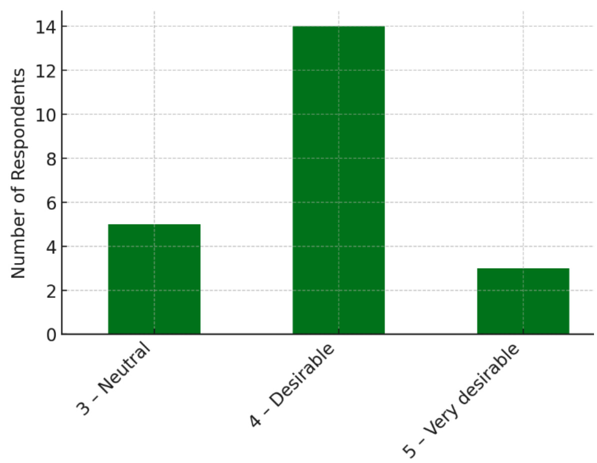

Figure 3. Likelihood of Sharing Data If Confidentiality Is Met

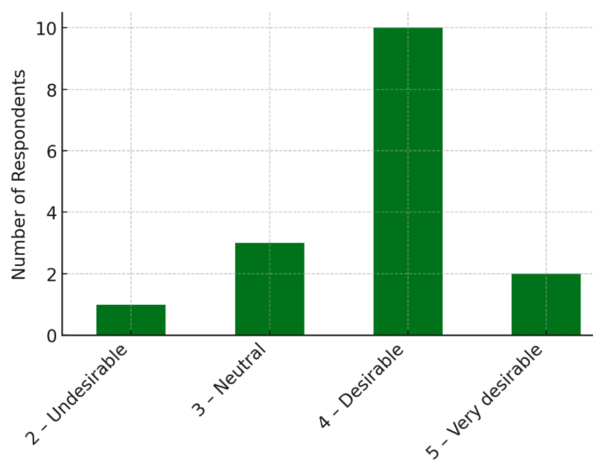

Figure 4. Fears of secondary use of shared data

The findings from the workshop highlight the potential for data sharing in enhancing synchromodal logistics. Participants identified key benefits from a logistics data space development, including asset and capacity optimization, cost and service improvements, and ecological and revenue benefits. Improved coordination and asset synchronization across logistics networks were also emphasized as crucial outcomes of effective data sharing.

However, fostering a data-sharing culture requires strategic efforts. Clarity on benefits, a proven track record of trustworthiness, and transparency in data processing and security were highlighted as essential factors in encouraging participation. Addressing these concerns can help overcome reluctance and create a more collaborative data ecosystem. By addressing these insights, logistics stakeholders can build a more efficient, secure, and collaborative data-sharing environment such as the data space for synchromodality.

In line with this outcome the following section presents the necessary technical and functional requirements.

3 Technical and functional requirements (imec)

3.1 Trust Requirements

Ensuring secure, controlled data sharing while maintaining participant sovereignty

- **Data sovereignty framework**
    - Enable participants to retain full control over their data assets
    - Allow conditional sharing with selected stakeholders through policy-based access

- **Granular access control**
    - Vessel-based ownership verification (proof of vessel ownership/fleet membership)
    - Time-bound access (valid only during transport assignments)
    - Geographical restrictions (zone-based visibility limitations)

- **Identity assurance**
    - Issue and hold decentralized identities (DID) in participant wallets
    - Enforce DID verification for all data transactions
    - Standardized onboarding with automated credential issuance

- **Policy enforcement**
    - Machine-readable ODRL usage policies
    - Prevention of unauthorized secondary data use
    - Immutable audit logs of all transactions and policy changes

3.2 Interoperability Requirements

Enabling seamless data exchange across heterogeneous systems

- **Data standardization**
    - Adopt semantic standards for unified data representation
    - Transform heterogeneous formats from ports, barges and shippers into uniform formats

- **Performance optimization**
    - Facilitate low latency data transfers for high velocity data streams
    - Allow for bulk transfers for historical data

- **Federated discovery**
    - Implement decentralized catalog for dataset discovery across the system
    - Prevent metadata centralization while enabling search

3.3 Data Value Requirements

Maximizing utility and operational impact of shared data

- **Service integration**
    - Provide interfaces for third-party services:
        - ETA prediction engines
        - Route optimization algorithms
        - Delay alert systems
        - Waterway messages

- **Operational visibility**
    - Include real-time monitoring tools:
        - Vessel tracking dashboards
        - Performance metrics visualization
        - System health monitoring

- **Ecosystem features**
    - Enable service composition
    - Support value-added data products
    - Modular architecture for future extensions
    - Easy deployment of components for improved user adoption

4 Data space architecture (imec)

This part of the project had as objective to define a reference architecture for implementing a logistics data space, and as a success criterion, to validate it through the demonstrator in Living Lab 1, Living Lab 2 and present during intermediary Advisory Board Meetings to the broader group of stakeholders.

4.1 Technical Research & Design

The project began by analyzing international initiatives like the International Data Space Association (IDSA), GAIA-X, Eclipse Foundation, and Fraunhofer Institute, which provide frameworks for data space components, standards, and governance. However, transitioning these theoretical models into a practical, domain-specific implementation for synchromodal logistics in Flanders required tailored technical design and specific choices. Despite active industry involvement in these organizations, Flanders lacked tangible proof of concept (PoC) for logistics data spaces—prompting our initiative to develop a prototype.

By synthesizing architectural whitepapers, code repositories, and design patterns from IDSA, GAIA-X, and FIWARE, we iteratively tested and combined components into a scalable blueprint. The resulting reference architecture (Figure 1) balances decentralized data sharing with interoperability, addressing both immediate Living Lab needs and future integrations (e.g., with the PILL project's route-planning algorithms). The architecture's design reflects deep alignment with **IDSA and GAIA-X** principles, embedding governance and interoperability at every layer.

4.2 4.2 Core Technical Implementation

At the core of the data space architecture lies the concept of a connector, for wich the implementation in the Living Labs, leaned on the open-source libraries of the **Eclipse Dataspace Connector (EDC)**, chosen for its adaptability and alignment with federated data-sharing principles. While this piece of software provided foundational capabilities, its **control plane**—responsible for policy enforcement and access approvals—and **data plane**, which handles the actual transfer of information, required tailored extensions to meet the specific needs of synchromodal logistics and the LL's. These customizations ensured seamless integration with existing systems and chosen data-standards while maintaining compliance with data sovereignty requirements. Some of these specific adjustments are references below (e.g. NGSI-LD data plane, custom policies, AIS-data source, …).

To enable efficient dataset discovery across decentralized participants, the architecture incorporates a **Federeated Catalog**. This component automatically synchronizes with individual connectors, creating a unified yet distributed registry of available data assets. By standardizing metadata schemas, the catalog allows stakeholders to quickly identify relevant datasets—from real-time vessel positions to terminal schedules—without compromising data locality or ownership.

For scalable & performant data management, the system uses a **FIWARE Context Broker (Orion)**, which orchestrates both real-time updates (e.g. positional changes of a ship) and orchestrates historical data access (e.g. travelled path of a ship over the previous hours or days). This component, and the scraper & transformation scripts feeding data into it, also acts as a semantic layer, translating heterogeneous data formats of various data providers into a unified model using **NGSI-LD** standards. Complemented by machine-readable annotations, the broker enables federated queries across disparate sources, allowing users to retrieve precise subsets of information (e.g., "all barges within 50 km of Antwerp port") while preserving the decentralized nature of the data space.

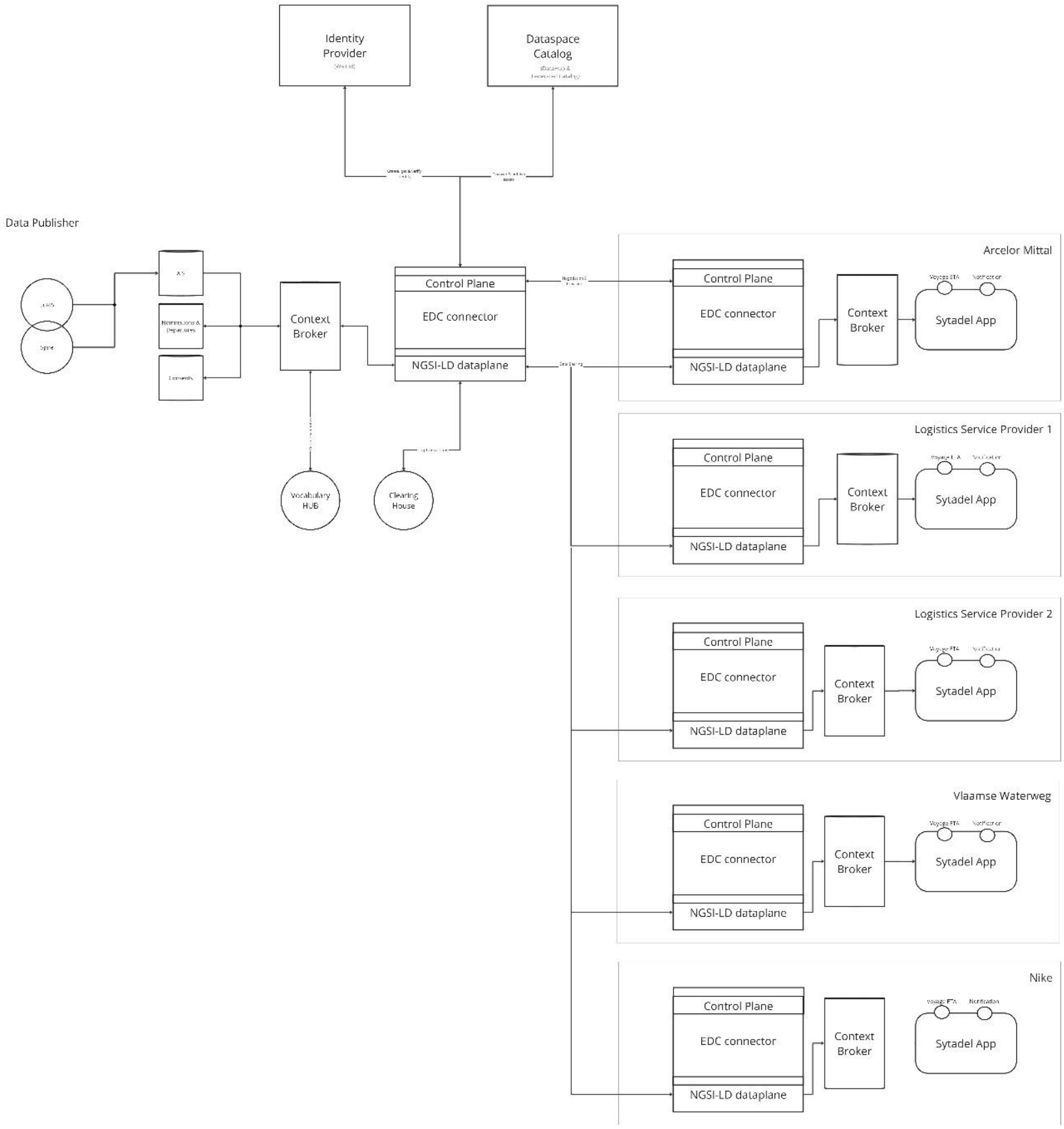

Figure 5Overview of Technical Setup

In the setup, authentication & authorization is enforced through **decentralized identities (DIDs)**, with credentials issued via the **walt.id** framework for the LLs. This approach eliminates centralized authority over authentication, instead empowering participants to cryptographically verify their roles (e.g., barge operator, terminal manager). Access permissions to determine which data you're allowed to receive, are dynamically evaluated against **three granular policies,** which can be expressed in **ODRL (Open Digital Rights Language)** to codify usage rules in a machine-readable way

- The **Vessel Policy** restricts AIS data access to verified owners or operators of specific barges (e.g. Skippers & Barge Operators)
- The **Nomination Policy** grants time-bound access during active transport assignments, ensuring data is only shared when relevant to a cargo's journey. (e.g. Shippers such as ArcelorMittal or Nike)
- The **Geographical Policy** limits visibility to authorized entities within predefined jurisdictional boundaries, such as waterway authorities monitoring regional traffic. (e.g. Vlaamse Waterweg)

This was further operationalized via **Keycloak** for identity management and linking it up to e.g. the implementation of the fronted client (see 4.3).

To accommodate diverse use cases, the architecture supports two transfer modes: **one-time bulk transfers** for static datasets and **continuous synchronization** for dynamic streams like AIS telemetry. Both are facilitated by extensions to the EDC's data plane, which optimize throughput for high-velocity updates while adhering to policy constraints. The former via a normal query between the two provisioned Context Brokers of both the data consumer and the data producer, the latter option via an opened subscription between the two Context Brokers to push new data as it arrives.

The system ingests **high-frequency AIS data**—providing real-time vessel locations—alongside terminal schedules and barge itineraries. These inputs are transformed into **FIWARE-**compliant shemas according to the **open data models for Maritime Traffic**, ensuring interoperability across the ecosystem. For example, positional coordinates are enriched with semantic tags (e.g., vessel ID, cargo type), enabling cross-dataset queries like correlating late arrivals with specific weather events.

4.3 Additional Added-Value Services.

To demonstrate the practical feasibility of the architecture, the proof-of-concept implementations for the LL's incorporated several key components designed to showcase real-world applicability. A **visualization frontend** was developed to provide stakeholders with an intuitive interface for monitoring real-time vessel movements, transforming raw AIS data into actionable insights for track & trace use cases. This frontend not only served as a user-friendly gateway but also validated the architecture's ability to deliver low-latency updates in a decentralized environment with usage policies applied.

Further enhancing operational utility, the implementation integrated **EURIS services**, leveraging the platform's ability to generate dynamic **estimated time of arrival (ETA) predictions**. By correlating live AIS feeds with EURIS's waterway analytics, the system could proactively issue delay alerts, enabling logistics operators to mitigate disruptions before they cascaded through the supply chain. Complementing these features, a dedicated **performance monitoring dashboard** was implemented to track critical metrics such as throughput, latency, and system scalability, providing transparency into the data space's operational health. This was later expanded to include **Dockflow-services** as well, to support LL2’s requirements to also track maritime legs of their full logistics chain with accurate ETA predictions. This specifically was provided by integrating the Dockflow predictions into the data space as well.