MAGPIE

SMART GREEN PORTS

Definition of Modular Architecture for Port Digital Twin

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D4.2

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Abbreviations

Below is a list of abbreviations used throughout this document. The table contains the abbreviations and description.

Abbreviation	Description
CA	Certification Authority
DSSC	Data Spaces Support Centre
DAPS	Dynamic Attribute Provisioning System
DT	Digital Twin
EIF	European Interoperability Framework
GHG	Green House Gas
GUI	Graphical User Interface
JSON	JavaScript Object Notation
IAA	identification, authentication, and authorization
IDS	International Data Spaces
IDS RAM	International Data Spaces Reference Architecture Model
ParIS	Participant Information System
RDF	Resource Description Framework
STH	Semantic Treehouse

1. Index

Executive Summary

This deliverable reports on the work carried out within task 4.2 of WP4. The objective of T4.2 is to develop a target architecture for a data sharing infrastructure that supports the port digital twin concept.

The development of the target architecture follows the approach of use case development, abstraction of the functional requirements which leads to the target architecture for the port digital twin.

The use case, called Proto Port, is built around container transport coming overseas that needs to be forwarded into the hinterland. The forwarding process in Proto Port uses new energy matching and planning functions to optimize the logistic efficiency and the use of green energy to reduce the Green House Gas (GHG) emissions.

Proto Port uses the concept of digital twins (port digital twin). A digital twin is a virtual representation of a physical object or location that has the capability to simulate its behaviour and influence reality by feeding back the digital simulation results into the real world. With the digital representation of the reality within simulation and optimization tools, it is possible to provide decision makers along the entire value chain with powerful tools for strategic decisions and operational support.

To achieve the functionality of a digital twin, a few essential components are required. Firstly, tools or systems that enable simulation and influence reality. Secondly, a language specification that indicates how the various tools and systems can share their data. Finally, an architecture that facilitates the sharing of data, connecting the various tools/systems following the specified language recommendation. This deliverable focusses on the last component, data sharing architecture. The first and second will be covered by the deliverables, D4.3, D4.4 and D4.5.

The data sharing architecture is the infrastructure that enables data sharing between the various tools and systems over different domains or sectors, e.g., maritime, energy, environment. It should facilitate the connection for data users to draw data from the data holders and should facilitate data holders to make their data available in the shared language specification. This study and document propose to use the data space concept for the implementation of the data sharing infrastructure. This data space concept satisfies the requirements identified from the Proto Port use case.

There are various initiatives in different stages of maturity that develop (standards for) data spaces. The results in this report build and extend upon the work of several related data space projects that share the ambition of working towards a federation of interoperable data spaces as outlined in the EU Data Strategy [1][2] and adhering to the design guidelines provided through the EU Open DEI initiative [3][4]. This applies to data space and data sharing initiatives across sectors.

The EU Open DEI initiative is working towards a reference architecture for data spaces. It has defined a data space as *“a decentralised infrastructure for trustworthy data sharing and exchange in data ecosystems based on commonly agreed principles.”* From a technical perspective, a data space can be seen as a data integration concept which does not require common database schemas and physical data integration but is rather based on distributed data stores and integration on an “as needed” basis on a semantic level. The users of such data spaces are enabled to access data in a secure, transparent, trusted, easy and unified

fashion. These access and usage right can only be granted by those persons or organisations who are entitled to dispose of the data.

Based on maturity level, the demonstrated use in practice and own experience[1], there is chosen to use IDS (International Data Spaces) as the current data space in the target architecture. The so-called IDS Connector will facilitate the connections between the data providers and consumers in the Proto Port, enabling them to share information about the data they have and need, under what conditions they want to share, and what semantic data model they use. In other words: setting-up a data space.

The IDS based target architecture proposed in this document will be implemented in various proof of concepts supporting the different tools and demos build in the various work packages of MAGPIE.

[1] Various implementations of IDS are already used in production, such as the Smart Connected Supplier Network, supported by the TNO Security Gateway, for the supply chain industry.

1. Introduction

This document is the deliverable of task T4.2 in work package WP4. This task will develop an architecture for continuous controlled data collection with secure, safe, and private data exchange mechanisms. The objective of the architecture is to support the various use cases, demos and tools developed in MAGPIE with a data sharing infrastructure.

The development of the target architecture and the writing of this deliverable are done following the planned timelines of the MAGPIE project. The consequence of the MAGPIE/WP4 planning is that the target architecture needs to be delivered while the development of the digital tools and demo's in the different work packages are still in an early developmental phase. Due to this planning, many of the information required for developing a thorough description of the functional architecture is not available yet, such as insight in the involved stakeholders, tools and systems, their role and/or functional description, their data requirements and interface specification.

To partially circumvent this limitation, a detailed example use case with storyline is defined which we refer to as "Proto Port". The Proto Port use case is based on best assumptions as well as interviews and feedback from the demo and tool developers. From this use case, the needed insight is gained to determine the functional requirements which lead to the target architecture for the port digital twin.

Note that this approach results in a target architecture that is generic and based on the assumptions made which are likely to change during the development of the tools and demo's to be supported. The tools and demos can be developed to follow or adapt to the preliminary target architecture, or the target architecture can be made more specific once the tools and demos are ready.

The document is structured as follows:

- Chapter 2 describes the functional requirements extracted from the Proto Port use case and need to be supported by the target architecture. The interested reader can find the Proto Port use case/storyline description in Annex 1.
- Chapter 3 describes the concept of the digital twin and what is required to achieve its functionality.
- Chapter 4 describes the concept of data spaces which will be the core of the target architecture.
- Chapter 5 describes the functional components of the architecture and ends with a practical example integrating tools and demos of the Proto Port use case into an IDS data space.
- Chapter 6 describes the conclusions and next steps.

2. Functional requirements

As mentioned in the introduction, to derive the functional requirements for the digital infrastructure, a realistic use case is required that provides insight into the involved stakeholders/systems, their role(s) and/or function(s) and the dynamics and relations between the stakeholders and systems. In particular, information about the data requirements, who is sharing data with who and what is the exact data needed, should be learned from the use case. Based on the functional requirements the target architecture for the required data sharing infrastructure can be developed.

The current chapter briefly describes some of the main characteristics of the Proto Port use case and then continues to identify the functional requirements for the data sharing infrastructure that should support the Proto Port. A detailed description of the Proto Port use case is provided in annex 1.

2.1 Proto Port use case

The Proto Port use case is built around container transport coming overseas that needs to be forwarded into the hinterland. The forwarding process in Proto Port uses new energy matching and planning functions to optimize the logistic efficiency and the use of green energy to reduce the Green House Gas (GHG) emissions. These new functions and systems are in focus within the following MAGPIE demos and tools development (see annex 1 and D4.1 chapter 4 [D4.1] for more details):

- Demo 6: Autonomous e-barge
- Demo 9: Green connected trucking
- Tool 4.5.1: GHG-tooling
- Tool 4.5.2: Energy matching
- Tool 4.5.3: Port's smart and green logistics

Besides these demos and tools, an energy grid, terminals, infrastructure, port authority, freight forwarder etc. were added as stakeholder in the storyline to put everything in a realistic port context.

The Proto Port use case is all about information sharing between the stakeholders, systems, and tools in the logistic chain of container transport. By sharing the required information on time and complete, these stakeholders, systems and tools in the logistic chain can perform their duties which will result in a smarter, greener port and container transport. Figure 1 shows schematically all the stakeholders, tools and systems and the function of the data sharing infrastructure: connecting all these stakeholders.

Annex 1 provides additional details on the Proto Port use case, such as a detailed story line of the container transport and an overview of all the mentioned stakeholders, tools and systems as well their roles and data requirements.

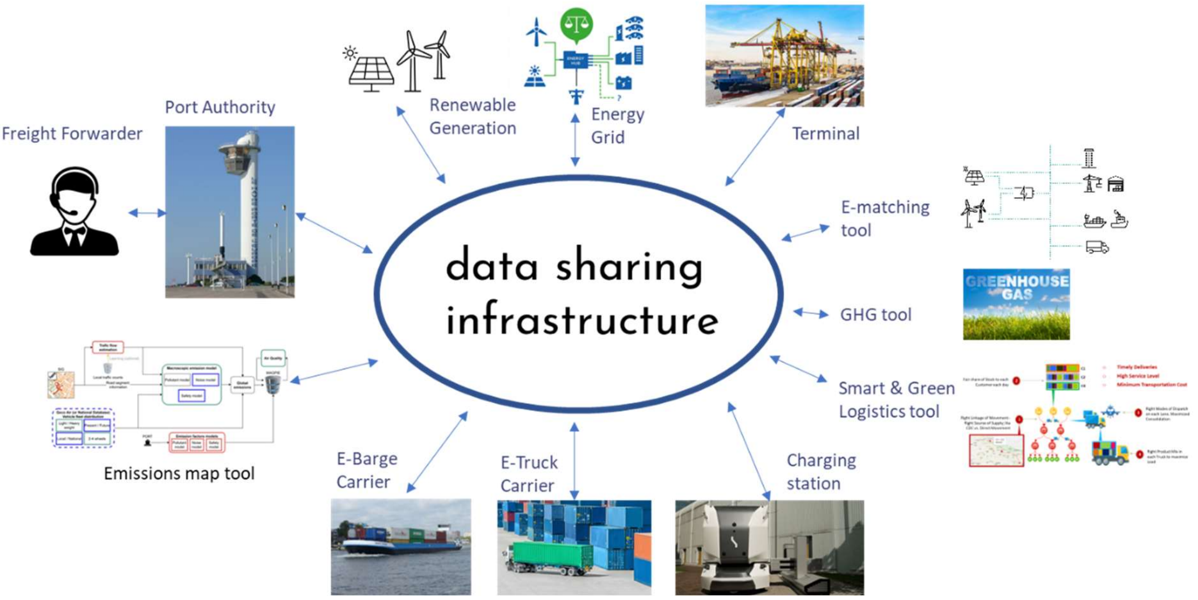

Figure 1: Proto Port data sharing infrastructure.

So, the overall requirement is a data sharing infrastructure that facilitates the information sharing as mentioned in the use case and summarized in table 1 of annex 1.

2.2 Functional requirements

What are the features/functionalities that should be supported by the data sharing infrastructure to facilitate the needed communication? The following functional requirements can be thought of:

1. All stakeholders should be able to understand each other. This means that every message should be understandable throughout the infrastructure. A single common language is not explicitly required, but rather that specifications and translations for all languages in use are commonly available. This requirement is called *semantic interoperability*.
2. All stakeholders should easily connect with those who they like to share data with. The data sharing infrastructure is accessible to all stakeholders which implies that installed base of platforms and investments done by stakeholders are safeguarded. This requirement is called *technical interoperability*.
3. There are different types of data sharing that can be assumed which should be supported by the digital architecture, namely: sharing of persistent[2] data, sharing of (real-time) streaming data, sharing of sensitive data and sharing of conditioned data (smart contracting). This requirement is called *types of data sharing*.
4. It is anticipated that participants will share data between more than one sector, data group or port, therefore the architecture should enable interoperability between data sharing infrastructures. This requirement is called *inter data space interoperability*.
5. Each stakeholder should have full control over their own data, what and with who do they share their data. This is important because companies are becoming more

[2] information that is infrequently accessed and not likely to be modified

and more convinced that data represents a valuable asset. This requirement is called *sovereignty*.
6. All stakeholders must be able to trust the digital infrastructure they connect with. It is safe to share data, the other stakeholders are identified, authenticated, and authorized. This requirement is called *trust*.
7. All stakeholders can rely on a reliable, secure, and reliable way of communication. One can always prove that a message/information/data is sent and/or received. By log and audit trail. This requirement is called *integrity*.

The first functional requirement "semantic interoperability" leads us to semantic technology: semantic models, ontology and digital twin. The next chapter will start with unpacking the concept of Digital Twin: what is it? What are the requirements for this digital twin? Are these consistent with the requirements as identified above from the Proto Port use case?

The second (technical interoperability), third (type of data sharing) and fourth (inter data space interoperability) functional requirement lead us to the concept of data spaces. Chapter 4 will get into the concept of data spaces and investigates whether it can support the digital twin approach with the MAGPIE demos and tools as described in the Proto Port use case. Are data spaces the appropriate technology to base the target architecture on? And does it support the remaining requirements: sovereignty, trust and integrity?

3. The concept of Digital Twin

In this section, we want to operationalise the definition of a digital twin. A multitude of definitions are used and have been proposed of what constitutes a Digital Twin. The MAGPIE project proposal has adopted the definition that a digital twin is "the virtual and computerized counterpart of a physical system that can be used to simulate the system behaviour considering different circumstances and environments, exploring the real-time synchronization of the sensed data and is able to decide between a set of hypotheses which represent a better option". (MAGPIE proposal, page 11)

Additionally, the Digital Twin is the "central framework which will connect" the various infrastructures and vehicles in the port. It is the platform where the logistic modalities (road, railways, sea, etc) should be connected to each other, as well as potentially to other port digital twins.

This digital representation of reality within simulation and optimization tools can provide decision makers along the entire value chain with powerful tools for logistics and process optimization and configuration, both for strategic decisions and for operational support. However, we cannot foresee exactly the various kinds of tooling that the Digital Twin eventually needs to facilitate. The tools and systems identified in this document are therefore intended as a proof of concept rather than a final implementation of the Port DT.

The capability of the DT to facilitate previously unconsidered use cases conforms to the MAGPIE proposal where the digital twin is described as an "ever-evolving system" to which we can add "functions and infrastructures" along the way. Additionally, the digital twin delivered at the end of the project will have "primary functionality, ready for further evolvement".

3.1 Support of the port digital twin

We identify three essential types of components that are required to achieve the functionality of the Port DT as envisioned in MAGPIE. Firstly, tools or systems that enable simulation and optimization of the port logistical operations. These tools may support strategic and policy decisions as well as operational decisions that are at real-time enforced on the logistic process. Secondly, a language specification that indicates how the various tools and systems can share their data. Finally, an architecture that facilitates the sharing of data, connecting the various tools/systems following the specified language recommendation. The current deliverable describes the data sharing infrastructure, deliverable 4.3 covers the language specification, and the various tools and demo's will be described in the deliverables indicated in section 2.

Existing types of infrastructural components can implement these Digital Twin components as follows.

1. The **data sharing architecture** is the infrastructure that arranges the communication between the various tools and systems. It should facilitate the connection for data users to draw data from the data holders and should facilitate data holders to make their data available in the shared language specification. Additionally, the data sharing architecture should arrange for security and governance aspects of the data.

2. The **language specification** indicates the format for the various tools and systems to share their data to each other. The language specification should introduce an agreement on the meaning (i.e,. the semantics) of all terms used throughout the systems involved. Therefore, we call the language specification a semantic model.

   The goal of the shared specification is to greatly reduce the cost of aligning the data of one member to the data of a partner. Instead of aligning each data holder to each data user, we align the application only once to a shared model. The language specification should additionally follow the principles of open data, be flexible enough to adapt to future use cases, and support data sovereignty.

3. The **tools and systems** category represents all data producers and data consumers, ranging from relational databases of which the data needs to be shared across the DT, to applications that draw their data from the DT, to potentially Internet of Things devices that stream their data to the other DT components.

   The quality of the DT is best indicated by the ease with which additional tools and systems can be reliably and securely integrated with the DT. In principle, any GUI that is established using a full integration with the DT can also be build using a regular relational database as the backend. By enhancing interoperability between systems, however, a well-functioning DT increases the ease with which such tools and systems are integrated in the data sharing infrastructure.

In the next subsections we cover the three components of the DT in additional detail. After having described these components, chapter 4 and 5 describe the principles behind European data spaces in general and how the IDS architecture components correspond to the MAGPIE functional requirements.

3.2 Data sharing architecture

In the Port many different sectors and domains are involved, like logistics and energy. Data sharing and exchange within specific domains and sectors is already happening in existing initiatives. However, each of these initiatives follow their own approach and are therefore not interoperable.

Data sharing is a crucial factor that necessitates organizations to recognize the value of their data assets. Various organizations across different sectors and domains operate their own (IT) systems and are responsible for collecting and consuming data. Although sharing data can prove to be beneficial for these organizations, they seek means of sharing data while retaining control over it.

The European Commission is also placing emphasis on the significance of data and data sharing. The Commission's Data Strategy aims to establish 'a Common European Data Space' or 'a federation of interoperable data spaces'. MAGPIE builds upon this vision for the Port by creating a digital data sharing environment (i.e. a data space) that enables the discovery and controlled sharing of potentially sensitive and valuable data.

Digital data sharing infrastructure for the Port aligns with the European Commission's vision, as stated in the European Strategy for Data, that *business and the public sector in the EU can be empowered using data to make better decisions, boosting growth, and creating value, while minimising the human carbon and environmental footprint.*

3.3 Language specification

As mentioned in chapter 2, one of the functional requirements is that all participants should be able to understand each other. This can be ensured by various means ranging from on the one hand a single shared language that provides the meaning of all data to on the other hand a common translator that performs the job of translation between the various languages used. We propose several functional requirements of this language specification. In D4.3 we will describe the language specification in terms of contents and technology.

- The language specification should be globally available and follow the FAIR[3] principles. This means that all stakeholders should have access to the language specification. It is important to note that this implies that the data *model* is open. The actual data about the port and the logistic companies should remain secured at the source and be only accessible to whom has been granted access.

- The language specification should be globally unique. This means that any specification of a data entity has some unique identifier, ensuring semantic agreement among the users. This prevents semantic confusion as is the case when identical identifiers are applied to different specifications.

- The language specification should be reusable and extensible. The objective of MAGPIE is to develop techniques and digital tools that are not just applicable in any single port, but instead should allow for reuse by stakeholders in other ports. Further, an unknown number of future stakeholders may need to be integrated into the digital architecture for data sharing, making it highly beneficial if the semantics for data sharing can be easily adopted by these parties. The reusability of the data model by new partners and the extensibility for additional use cases therefore provides an important feature to achieve the MAGPIE objective.

- The language specification should be descriptive rather than prescriptive. This means that participation in the digital infrastructure should not *require* participants to use any specific data model or language specification. This would be an unrealistic requirement as not all parties may always agree upon a single data model. A consortium of parties collaborating in the digital infrastructure, such as the participants in a given data space, may, however, *recommend* a specific language specification or data model. Such agreements can often be beneficial for data sharing purposes.

3.4 Tools/systems

The tools, systems, and applications using the digital twin infrastructure are ultimately where the proof is. However, that proof should be sought at the backend of the tools instead of in the GUI. Already before implementation of the DT has started, we have seen a nice demo of the tool functionalities. However, those tools each use their own database as the backend instead of being connected to the shared DT infrastructure. The various tools proof the ease of integrating yet another tool into the DT environment.

These applications consist of both data consumers and data producers, which usually correspond to applications for the former and databases for the latter. Some applications

[3] The FAIR Data Principles – FORCE11

may fulfil both roles: a planning tool may consume times of arrival of various transport means and produce a reservation at a charging station. Another dual role may be the green connected truck demo, which may consume the attributes of the truck and produce a planned itinerary, which is immediately shared to the destinations.

The integration with the data space will happen through a connector. This component will be configured with a semantic data file mapping the application to one of the language specifications. Data consumers need to specify the data they are interested in in terms of a query. Data producers need to specify a translation of their internal data format to the semantic model. Applications that fulfil both roles naturally need to implement both.

The tools and systems are aided by the semantic model in facilitating the data sharing on a functional level. The recommended adoption of the semantic model reduces the time spent on configuring the data mapping. Instead of creating a connection from each data holder to each data user, we can create a single connection from each data holder or data user to the shared model.

4. Data Spaces

Participants in MAGPIE will join many different data spaces to share data with partners in different domains. Each of these data spaces will have standardized the way of sharing data within their data space. This chapter elaborates on the concept of data spaces and federative data sharing between MAGPIE tools and demos.

4.1 Data Sharing in the Port

Many different participants in and around the Port exchange information. Vessels communicating with the Port authority, freight forwarders with terminal operators, terminal operators with transporters, etc. Sharing different types of data amongst participants, like semi-static data or (near) real-time streaming data, in different data formats using various communication protocols. Data sharing happens at different granularity levels. For example, data sharing happens inside the terminal of a Port between different IT systems (see Figure 2).

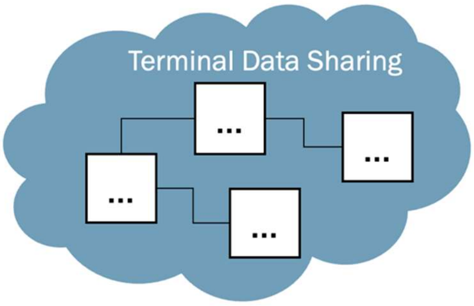

Figure 2: IT systems inside a terminal sharing data

IT systems sharing data in the context of a terminal might be connected to systems outside of the terminal like a freight forward or the Port Authority's IT systems. Therefore, participating in data sharing initiatives at different granularity levels, as shown in Figure 3.

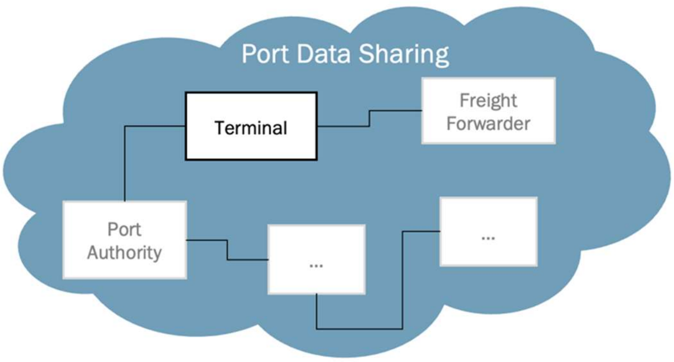

Figure 3: Data sharing in the Port, at a different granularity level

With many different participants involved in a data sharing ecosystem, interoperability becomes increasingly important. Each additional system introduces another language specification. In this context, the interoperability of the digital ecosystem is the extent in which the technology can overcome the language barrier to have the different systems communicate with each other. This problem becomes even more prevalent when we zoom out further. The port can be seen as potentially being part of an even larger data sharing ecosystem covering domains beyond the port and even logistics (Figure 4).

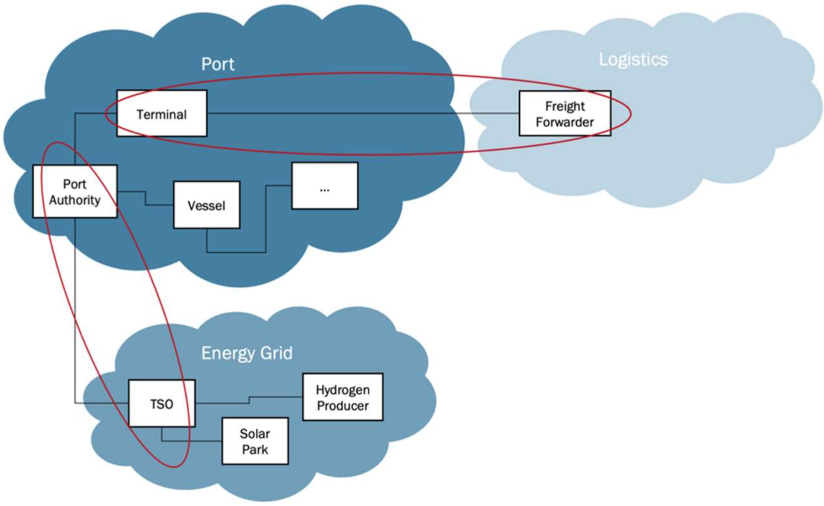

Figure 4: Port being part of a network of data sharing ecosystems

The participants in the Port can take part in multiple data sharing initiatives. A Freight Forwarder might be exchanging data with organizations inside the Port but might also share data with other parties that are not relevant within the context of the Port. Similarly, the Energy Grid might share information regarding availability of energy with the Port, but other organizations inside the Energy Grid might be sharing data about the Energy Grid which is not relevant for the Port but is relevant for participants inside the Energy Grid.

4.2 From Data Sharing to Data Spaces

For organizations interested in exchanging data it is a challenge to figure out which parties within an ecosystem are exchanging what data, under what conditions/policies, and the data exchange format that was agreed upon. Centralized data sharing solutions, like data hubs, provide a way of sharing data where there is one single place where all participants store and share their data. With a centralized approach organizations lose data sovereignty and will therefore be hesitant to participate. Alternatively, Data Spaces promote a federated data sharing ecosystem within a certain application domain based on shared policies and rules in a secure, transparent, trusted, easy and unified fashion.

Various industries and fields recognize the necessity of a federated network consisting of platforms and IT systems that can provide secure and high-quality data sharing capabilities in a decentralized, open, and neutral manner. This approach is also known as "federative data sharing." Various (European and national) initiatives are exploring the potential, architectures, and implementations for federative data sharing.

According to the Netherlands AI Coalition (NL AIC)[15], the concept of federative data sharing has garnered significant attention from the European Commission, as evidenced by the release of the European Data Strategy [5], the Data Governance Act [14], and the solicitation of further input on data spaces via the Open DEI initiative [3][4]. This demonstrates the European Union's recognition of the vital role that data sharing plays in both society and the economy.

The overarching objective of federative data sharing, as articulated in the EU Data Strategy, can be encapsulated as follows:

'Towards a federation of interoperable data spaces'.

Three concepts in the EU's ambition for a federation of interoperable data spaces need clarification:

- *Data space*

  The EU's Open DEI initiative [3] strives to design the reference architecture for data spaces. It defines a data space [4] as a "decentralized infrastructure for trustworthy data sharing and exchange in data ecosystems based on commonly agreed principles". Open DEI's position paper Design Principles for Data Spaces[6] includes three types of building blocks: (1) data platforms, (2) data marketplaces, and (3) building blocks that ensure data sovereignty.

- *Federation*

  According to the NL AIC[15], a wide array of European data spaces will be created, such as those for specific sectors, application areas, or geographical regions. The seamless sharing of data across and among these data spaces can offers considerable benefits, as it broadens the range of accessible data and enables the development of new business models and solutions across different sectors and regions.

- *Interoperability*

  To enable a smooth connection between data spaces within a federation, an interoperability framework is required for managing and coordinating secure and controlled data sharing among participants in multiple data space instances. The European Interoperability Framework, developed by the European Commission [15], offers a systematic approach to address these challenges. It demonstrates that data space interoperability goes beyond merely the technical components' compatibility. The framework distinguishes four levels of interoperability (technical, semantic, organizational, and legal) and emphasizes an overarching integrated governance approach. Each of these interoperability levels needs to be addressed.

4.3 MAGPIE builds and extends upon related data space projects

There are various initiatives in different stages of maturity that develop (standards for) data spaces. The results in this report build and extend upon the work of several related data space projects that share the ambition of working towards a federation of interoperable data spaces as outlined in the EU Data Strategy [1][2] and adhering to the design guidelines provided through the EU Open DEI initiative [3][4]. This applies to data space and data sharing initiatives across sectors.

Through re-use of the approach and results over these projects, several benefits have been achieved, i.e., alignment, support and adoption for a common architectural approach and efficiency in developing the architecture deliverables over the various projects.

4.4 Data space interoperability levels and aspects

The scope of data space interoperability goes beyond just technical component interoperability. The European Commission has developed the European Interoperability Framework (EIF) as a systematic method for categorizing interoperability aspects. The framework outlines four levels of interoperability (technical, semantic, organizational, and legal) and emphasizes an integrated governance approach to ensure comprehensive interoperability.

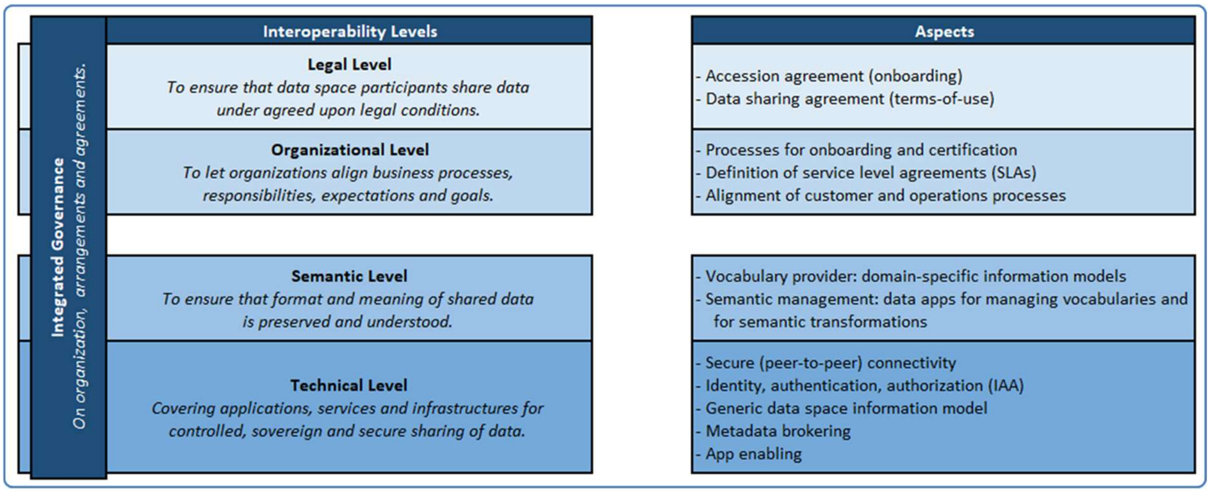

Figure 5: Interoperability model as build upon the New European Interoperability Framework [15]

Each of the four EIF interoperability levels needs to be addressed in developing the interoperability architecture for data spaces, both for intra and inter data space interoperability. Moreover, various interoperability aspects are further distinguished within each of the four levels of the EIF, as described in the right column in the figure.

In order to support the integration of the MAGPIE demos and tools, the semantic and technical interoperability aspects are partly covered by this document. This allows the demo and tool builders to integrate their IT systems into a data sharing infrastructure. This does not exclude other interoperability aspects, which will have to be addressed in a more comprehensive data space architecture.

4.5 Inter and intra data space interoperability

In Towards a Federation of AI Data Spaces[15], the Netherlands AI Coalition (NL AIC) describes how adequate architectures and governance are essential for both interoperability within single data spaces and between multiple data spaces. These are known as intra and inter data space interoperability, respectively.

Intra data space interoperability entails a significant level of autonomy in creating and implementing internal agreements and structures. It focuses on harmonizing the diverse capabilities, or building blocks, within a single data space.

Inter data space interoperability concerns the connection between multiple data spaces. To guarantee seamless interaction between them, inter data space interoperability necessitates the establishment of guidelines and alignment of individual data spaces.

As mentioned before, participants in the Port will not be exclusively involved in one single Data Space, but more likely participate in multiple data space initiatives. Therefore, inter and intra data space interoperability aspects which will have to be addressed in a more comprehensive data space architecture.

5. Data sharing architecture

This chapter introduces high-level building blocks a data sharing infrastructure for the Port. These building blocks are based on the building blocks for data spaces as provided by Open DEI[3][4]. Open DEI works on alignment on reference architectures for data spaces.

There are various initiatives in different stages of maturity that develop a data space. Based on maturity level, the demonstrated use in practice and own experience[4], there is chosen to use IDS (International Data Spaces) initiative as the current data space in the target architecture.

5.1 Integrating MAGPIE tools and demos into a Port data space

IDS Reference Architecture Model (RAM) describes roles and tasks for participants in a data space [17]. Next to this a high-level architecture model providing an overview of the individual components of the International Data Spaces (Connector, Metadata Broker, App Store, etc.).

For each of the demos and tools in MAGPIE that want integrate with the Port data space its role and tasks in the data space need to be clearly defined. Participants might have one or many roles in the data space. IDS RAM defines interactions between these roles, this is show in the figure below.

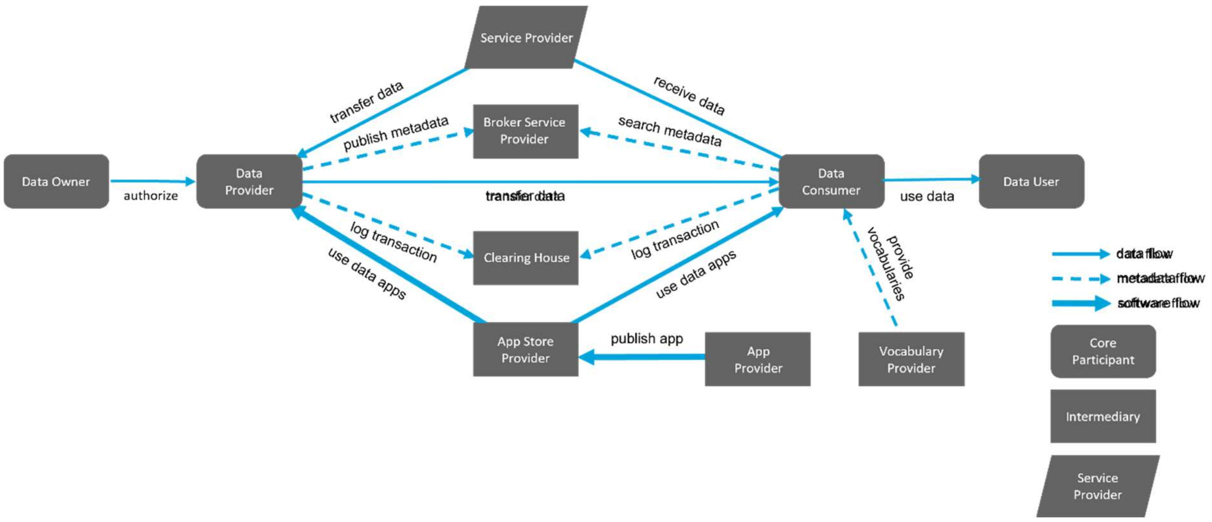

Figure 6: Interactions between roles defined in IDS RAM [17]

Two types of roles are defined by IDS RAM, basic roles, and business roles. Basic roles are the basic tasks that need to be performed and business roles comprise one or more basic roles. This chapter focussed on a few of these basic and business roles that are relevant for the semantic and technical interoperability in a Port data space. It's important to note that the identity provider role is not mentioned. This role is linked to all the individual roles. It's

[4] Various implementations of IDS are already used in production, such as the Smart Connected Supplier Network, supported by the TNO Security Gateway, for the supply chain industry.

a fundamental role for establishing trusted data sharing and data exchange. Its role is described in more detail in the IDS RAM section about digital identities [19].

The Connector has a basic role and is a technical core component required for a participant to join a data space. It is one of the core components that facilitates data sharing and data exchange, enabling participants to share (meta)information about data assets, specifying under what conditions data is shared and what (semantic) data model to be used.

Each of the tools and demos in the Port data space will have to implement a Connector. This requires implementing at least a subset of the Connector and its protocols. Existing implementations of IDS Connectors have already been developed and made available for (re)use. It is recommended before implementing a connector to assess already available Connector implementations.

5.2 IDS Components

In the Port data space tools and demos integrate into an IDS data space, this requires integration with individual components of the International Data Spaces like Connector, Metadata Broker, App Store and Vocabulary hub. This chapter briefly introduces these components and their relevance to the Port Data Space.

- Identity Provider: provides secure and trusted identity management for the participants in the Port data space. [16]
- The IDS Connector initiates data exchange between participants in the Port data space. Acting as a bridge, it initiates the network exchange and provides metadata to the Metadata Broker. [21]
- IDS Metadata Broker: is an IDS Connector which is responsible for maintaining information such as technical interface descriptions, supported authentication mechanisms, and policies for data use. With this information, Port data space participants can easily discover what data is available. [20]
- IDS Apps: can be used by Port data space Connectors for data processing or data transformation tasks. Apps can perform tasks ranging from simple data transformation to more complicated tasks such as connecting existing IT systems. An App Provider typically creates IDS Apps and published them to an IDS App Store. [22]
- Vocabulary Hub provides the Port data space vocabulary to the network of participants when sharing data within the network. [23]

The identity provider is linked to all these components. It's a fundamental role for establishing trusted data sharing and data exchange. Its role is described in more detail in the IDS RAM section about digital identities [19].

The interaction between the technical components as described in the IDS RAM is shown in the figure below. The remaining sections in this chapter will briefly show the relevance of these technical components by providing an example of two participants in the Port data space and the role of the Connector, Metadata Broker, Apps and Vocabulary Hub,

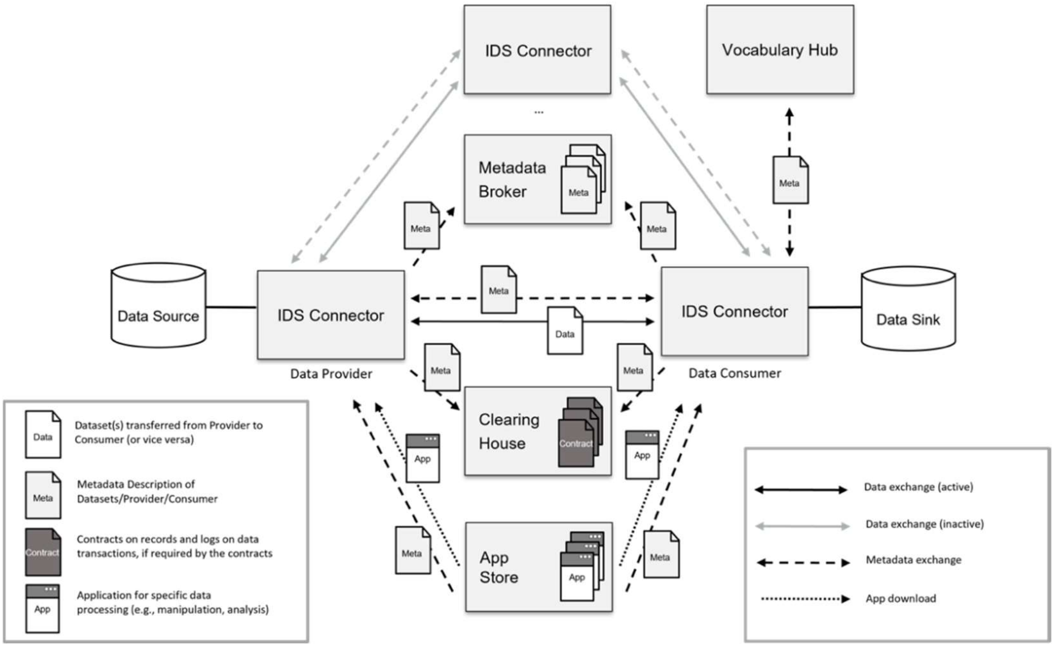

Figure 7: Interaction of technical components [8].

5.3 IDS components in the Port

The IDS Connector's primary responsibility is to commence the transfer of data between an organization's data and that of other organizations on the network. Within an IDS data space, the Port tools and demos will be linked together via IDS Connectors as shown in the figure below.

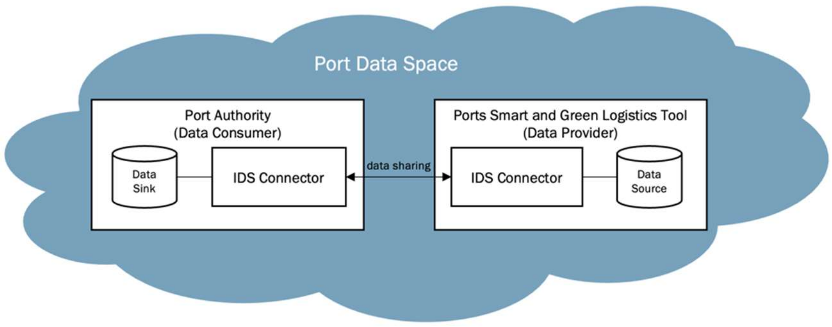

Figure 8: Data Consumer and Provider using an IDS connector.

In this example the Ports Smart and Green Logistics Tool is sharing data with the Port Authority (Data Consumer) using an IDS Connector. The Connector shares data coming from a (existing) Data Source at the Data Provider side, with the Data Consumer which passed the data to a Data Sink. A Data Source/Sink could be any (existing) IT System.

Developing a Connector for integrating any MAGPIE tools or demos require (architectural) design work. The IDS connector architecture describes in more detail what needs to be considered when designing such a connector.

IDS Connectors expose metadata about the data assets they provide via the IDS Connector component. Optionally they can publish information about the data assets to a Metadata Broker. In the Port, even though it's an optional component, it would be beneficial to store this metadata about (all) the data assets provided by the participants in the Port data space in a Metadata Broker. By querying the Metadata Broker, Data Consumers can discovery relevant data assets made available by the Port's data space participants. Interactions with the Metadata Broker by a Data Provider and Data Consumer are shown in the figure below.

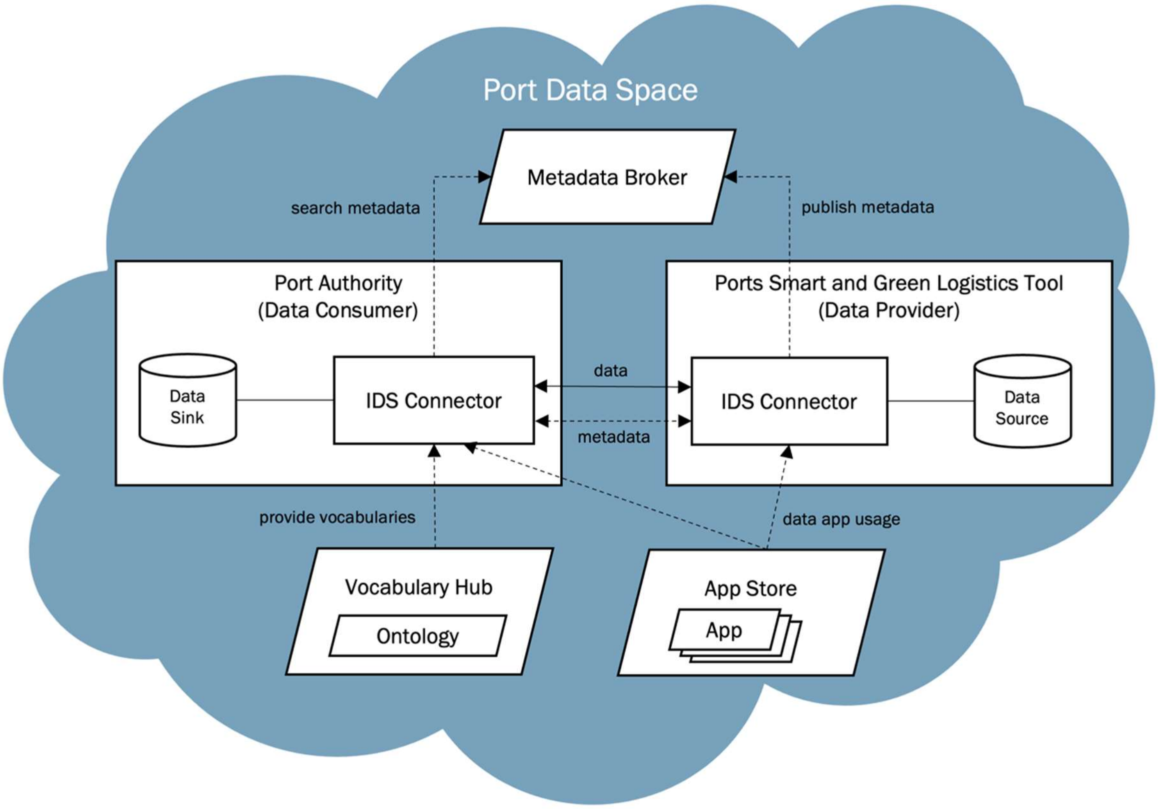

Figure 9: Port Data Space with a Metadata Broker, Vocabulary Hub, and App Store.

Apps [11] provide specific functionality to Connectors and can be re-used by data space participants. The App Store facilitates sharing of Apps across participants in a data space. For MAGPIE specific Apps will have to be created to facilitate for data processing or transformation tasks. IDS Apps also play a role connecting backend systems. Example App apps, like an App that allows for connecting to existing APIs, have been implemented by the TNO Security Gateway (TSG) [9] which is an open-source IDS connector implementation, initially developed at TNO.

5.4 Semantic interoperability within and among Digital Twins

Semantic Interoperability between participants is achieved by making use of shared data space semantic models. The adoption of a shared semantic model significantly facilitates the data exchange between parties. These ontologies relevant to a specific data space are shared using a Vocabulary hub. IDS Vocabulary Hubs give the developer of domain-specific vocabularies the tools and functions to create, improve, and publish their terms.

While it is expected that these vocabularies are serialized using RDF, other standards, such as JSON-Linked Data, can be equally valid. The usage of semantic technologies may require additional IDS connector functionalities, such as integration with existing platforms that already exhibit a tighter integration with RDF. An example could be the Interconnect Platform [12].

The users can leverage the Vocabulary Hub to collaboratively work to document or visualize their data definitions, and at some point, to publish them to a data space. The Vocabulary Hub enforces that the users follow the constraints and facilitates the user to leverage the concepts of the chose data model. The user may also include existing, third-party vocabularies into the Vocabulary Hub. The data definition that is ultimately constructed will used to configure the IDS connector to correctly map between a data source and the semantic model.

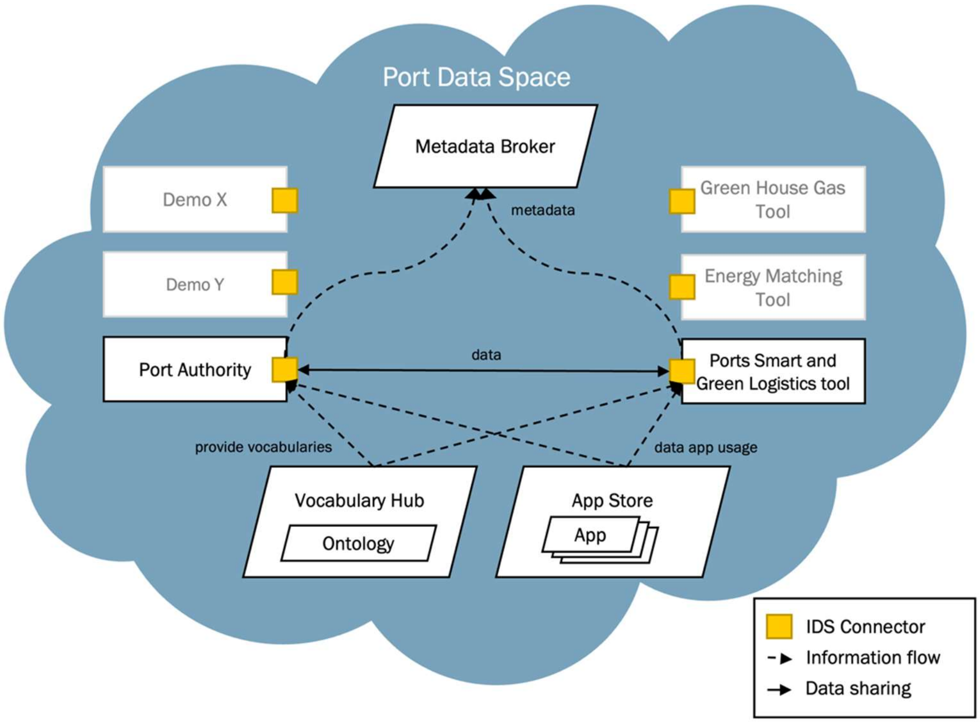

Figure 10: Vocabulary Hub, App Store, and the IDS Connector.

Using a semantic model for data sharing between participants in the Port data space ensures semantic interoperability. Data holders and data providers would have to convert this semantic data to their internal data structures and vice versa. IDS Connectors can use the IDS Data App functionality for this purpose.

6. Conclusions and next steps

In this deliverable we have shown how the data sharing architecture should function in relation to the MAGPIE Digital Twin of the port. For this effort we operationalized the DT definitions employed by MAGPIE and identified three types of components required:

1) The **data sharing architecture** that facilitates the continuous information exchange according to the principles specified in the MAGPIE proposal: safety, security, and privacy.
2) A **language specification** that recommends and instructs users how to easily exchange data about common information objects throughout the network. Following the MAGPIE proposal, the language specification should be reusable and extensible for previously unidentified use-cases. In D4.3 we will elaborate on the contents and technology to implement a language specification for the port.
3) A collection of **tools and systems** that provide simulation or optimization capabilities for the port logistical operations. These tools may give insight into the sustainability of port operations for strategic purposes, as well as operational decisions that are enforced at real-time on the logistic process. These tools are developed in T4.5 and the WPs 3, 5, 6, and 7.

Centralized data sharing solutions like data hubs lead to loss of data sovereignty. Data spaces provide a solution by promoting federated data sharing, based on policies on the three components above, as well as organizational, and legal policies.

We conclude that at the moment the IDS's architecture is the best fit among initiatives that follow the European Data Strategy [5] to create data spaces. The Identity Provider and its subcomponents can provide the trust, integrity and sovereignty identified in the functional requirements.

The technical and semantic interoperability can be achieved via IDS Connectors. Several implementations of the IDS Connector reference model already exist [9]; however, for each tool or use case it is crucial to evaluate which implementation best aligns with their requirements when starting the implementation stage. Some use cases may conclude that none of the currently available IDS Connectors sufficiently fit their needs regarding specifics such as the integration with a specific IT system. A highly specific IT-component, such as an IoT system, element may require the adaption of an existing IDS Connector [12].

The IDS reference architecture also identifies a Vocabulary Hub that should facilitate the semantic interoperability between the various systems and tools. The Vocabulary Hub provides easy access to the available shared data models for the various IDS Connectors. The Semantic Treehouse platform [10] can function as a Vocabulary Hub, however, it should be checked against the technical requirements before the implementation phase.

The actual implementation of a digital infrastructure and digital twin to support the demos and tools will start from M35[5]. As a result, there is a gap of approximately 17 months between the publication of this document, which outlines the target architecture, and the commencement of its implementation. In this period many aspects and specifics about the demo's, tools, and use cases will become clear. Also, new ideas and developments will see the light. We therefore recommend to closely monitor the developments in different data spaces initiatives.

[5] M35: in line with the WP4 milestones where initial versions of the software components are planned to be are ready

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Annex 1: Proto Port Use Case

Objective

This annex describes the Proto Port use case and storyline. The use case should contain a realistic storyline that picturizes clearly the port digital twin concept, the involved stakeholders/systems, their role(s) and/or function(s) and the dynamics and relations between the stakeholders and systems.

Based on this use case the functional requirements for the data sharing infrastructure can be extracted from which a generic target architecture will be developed.

Focus

The use case is built around container transport coming overseas that needs to be forwarded into the hinterland. The forwarding process in Proto Port uses new energy matching and planning functions to optimize the logistic efficiency and the use of green energy to reduce the Green House Gas (GHG) emissions. These new functions and systems are in focus within the following MAGPIE demos and tools development (see annex 1 and D4.1 chapter 4 [D4.1] for more details):

- Demo 6: Autonomous e-barge
- Demo 9: Green connected trucking
- Tool 4.5.1: GHG-tooling
- Tool 4.5.2: Energy matching
- Tool 4.5.3: Port's smart and green logistics

Besides these demos and tools, an energy grid, terminals, infrastructure, port authority, freight forwarder etc. were added as stakeholder in the storyline to put everything in a realistic port context.

In the Proto Port use case, we made the following assumptions about the 2 demo use cases and the 3 digital tools mentioned above.

Demo 6: Autonomous e-barge

This demo provides the modal option of container transport by e-barge. In the Proto Port use cases the e-barges can be deployed for container shipment into the hinterland. For this, an infrastructure is required for e-barges to re-charge their batteries in Proto port and enroute to the inland ports. Furthermore, it is required that the e-barge fleet owners/shipping lines can support/provide digital interfaces to the needed logistic and system data of the e-barge.

In the Proto Port use case, the autonomous features of the e-barge are left out of scope.

Demo 9: Green connected trucking

This demo provides the modal option of container transport by e-truck. In the Proto Port use case electric heavy trucks available for container shipment into the hinterland. This requires an infrastructure in Proto Port with charging stations, digital interfaces to logistic and system data. Furthermore, the use case requires that there are fleet owners delivering this modal option. The option of Automated docking for recharging of these electric heavy trucks is in focus.

Chapter 5 of [D4.1] can be consulted for an extensive description of the intended functionalities of the different digital tools developed in T4.5. Below, we briefly describe the assumed functionalities of these tools for the Proto Port use case.

GHG-tooling

The Green House Gas (GHG) emissions tool will be used to select the greenest transport chain and initiate a modal shift. At the operational level, the GHG emissions tool will combine transport costs, operational data and GHG emissions (and their implied monetary value) to create an overall score that aids decision-making. A typical choice set at the operational level is the modality choice for hinterland connections, the choice between different service providers and carriers, operational routing of the containers through hinterland terminals. Shippers and truck/train/barge/ship owners and operators are expected to use the GHG emissions tool at an operation level to select the greenest transport chain and initiate a shift to more sustainable modalities.

Energy Matching

The main objective of the Energy Matching tool is to match the supply and demand sides that co-exist in a port ecosystem. In other words, the tool will ensure power system balance while considering all the system constraints.

The Energy Matching tool intends to work on two different timeframes: 1) Day-ahead; 2) Near real-time.

The fulfilment of 1) is dependent on forecasts while 2) depends on the availability of real-time measurements from the different demand/supply sources.

Concerning data flow requirements, a bidirectional flow between the Energy Matching tool and the majority of stakeholders will probably be needed. There is no doubt that all the stakeholders involved with the grid, demand, supply, and will need to provide inputs to the Energy Matching tool.

Ports smart and green logistics

The Ports smart and green logistics tool will be a Decisions Support System (DSS) that will provide recommendations to the end-user of the tool on the choice of transport modality (i.e., a choice between rail, trucks, barge, or their combinations) as well as carrier(s) along with an estimate of charging requirements per modality.

The objective of delivering such recommendations as the tool's output is to balance the cost and emissions generated over the entire 'container' transport chain from the Port to the destination in the hinterland. The tool will consider various factors, such as the transport modality, distance travelled, and the type of container used.

The tool developed uses (as input) the output of the GHG tool i.e., the allocation of emissions to the different transport modes. This information provided by the GHG tool helps drive the decisions of selecting the greenest and cheapest transport chain from the port to the final container delivery destination.

The output of the tool is fed back into the GHG tool for a detailed emission calculation. In a similar way, the tool uses inputs from the E-matching Tool regarding the availability of energy, while the results are used back by the E-matching Tool to perform the energy matching in detail.

Use Case Storyline

In this use case we deal with a semi-finished product ordered directly from a factory in the US. The cargo is ordered by a factory in the Netherlands, and it needs to be transported in a 40ft container. The process described here starts with a client/customer ordering a product. The storyline will follow the container shipping process as depicted below.

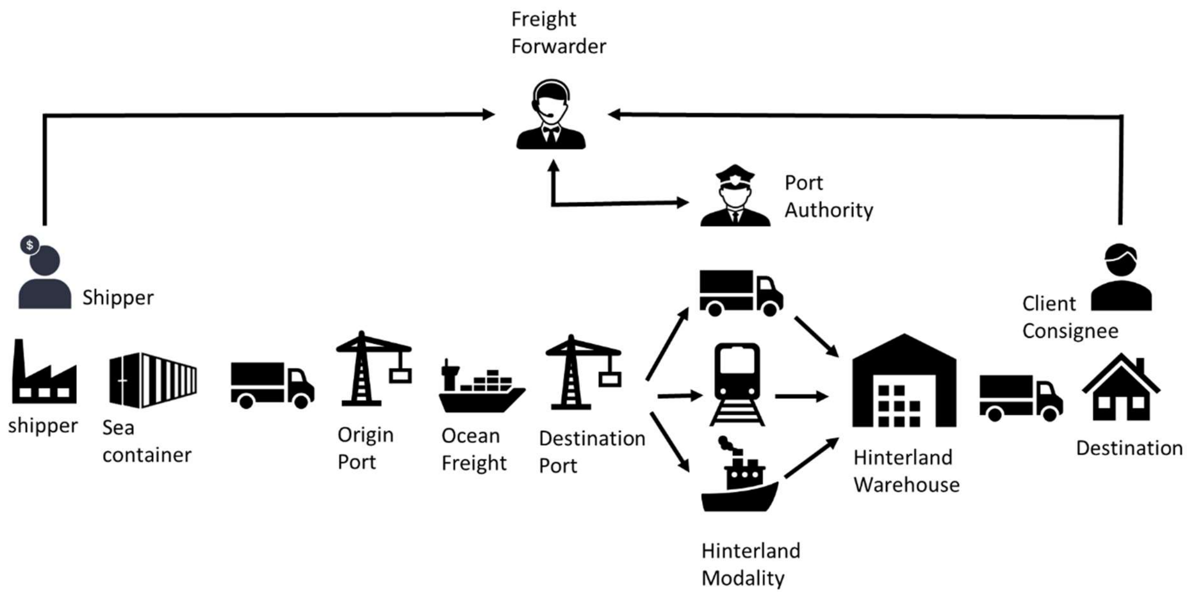

Figure 11: container shipping process.

The manufacturer/shipper is located near Springfield in Massachusetts. The receiving factory client/consignee is located near Arnhem, 150km in land from the port of Rotterdam.

The shipper takes the responsibility for the shipment and will involve a freight forwarder to arrange for transport from the manufacturer's location (origin) to the location of the consignee (destination).

The job of a freight forwarder is to organize and execute the transport of goods on behalf of the shipper or the consignee. That means that a freight forwarder needs to handle the pick-up of goods from the supplier, customs clearance at the proper authorities, handling at the warehouses involved, and secure a spot on the ship, plane, train, or truck delivering the goods.

The 40ft container and its destination makes its ocean freight with Boston as the port of origin and Rotterdam as the destination port.

The freight forwarder contacts a shipping company to plan the ocean freight part of the shipping. The moment the freight forwarder knows the details of the vessel, such as its ETA, the Port Authority Rotterdam can be contacted to announce the container and its cargo.

The Rotterdam Port Authority replies with the notice that the vessel will dock in a new part of the port: the so-called Proto Port. This Proto Port is part of an innovative project that plays a major role in boosting the use of cleaner technologies, green energy carriers and logistics concepts in maritime transport (sea), port operations (transhipment and storage) and hinterland transport (road, rail, barge, and pipeline) to reduce GHG emissions.

In this context, the freight forwarder is pointed to the special digital portal of Proto Port. This digital portal helps announcing the container and its ETA. Furthermore, it helps sharing the required documents and planning the hinterland transport to the final destination.

> *Proto Port Digital Portal is owned and controlled by the port authority and interacts with a set of digital tools, some relevant stakeholders, and systems of the port. Via the Proto Port Digital Portal, the freight forwarder can access the Ports smart and green logistic tool to plan the transport to the final destination in the hinterland.*

The Ports smart and green logistic tool is part of a set of co-operating digital tools including the energy-matching and GHG-tool. Which considers the ETA at the port, planned ETA at the final destination, and container details such as size and weight, along with inputs from energy-matching and GHG-tools, can provide a comprehensive recommendation for the most environmentally friendly transportation mode and optimal planning.

The Ports smart and green logistic tool contains knowledge of logistic chains, best routes, etc. The energy-matching tool checks renewable energy and demand forecast for ETA, including any additional energy needs for the container (e.g., refers) based on the container destination, weight, size, cargo, and schedule. The GHG-tool is checked for the GHG footprint for the combinations of transportation modalities.

Note: Proto Port has strict objectives on energy transition, air quality and GHG emissions, as the port is responsible[6] for its land, water, and air. Therefore, the tool's recommendations on the most efficient planning and greenest transport modalities are not always optional.

The port authority of Proto Port will be able to monitor the GHG and pollutant emissions of the activities taking place within its borders. This will allow Proto Port to know its contribution to the air quality at any given time in comparison with its surrounding environment (i.e., road transport in neighbouring cities). Based om this knowledge the port can anticipate by "pushing" more on the recommendations of the Ports smart and green logistic tool.

> For example: the port will promote the greenest options by lower dues and cheap green energy supply. This is all funded by the "penalties" for less green transportation from and towards the harbour.

Based on the input of the freight forwarder (ETA, size, weight, cargo details, final destination, timing, priority), the Ports smart and green logistic tool recommends the transportation modality for the hinterland transport including its full-time schedule. As shown in the figure of the shipping process, the transport modality options are:

1. Road: by heavy freight e-trucks
2. Waterway: e-barge
3. Rail: freight train

[6] The port of Rotterdam is a so-called landlord port. This means that the port is responsible for the infrastructure and safety in the public areas, e.g., roads, waterways, air, and traffic planning.

For the options road and waterway, the recommendation includes the time schedule for the battery charging of the e-truck/e-barge. The energy demand is estimated, the charging stations in the port area are checked for availability and timeslots.

The Ports smart and green logistic tool recommended the use of e-truck for transportation in this particular case.

Because the tooling now knows the shipping and container details, it will track both by following the updates pushed by the shipping company. Relevant updates on e.g., the ETA will be used to check for possible impact on the recommended modality and time schedule.

Based on this recommendation, the freight forwarder can check and select an e-truck carrier/fleet owner. In case this carrier is connected to the Proto Port information service/infrastructure, the carrier will get updates about the pick-up time of the container and the battery charging details.

In this use case we assume that there are no delays and/or changes in the ocean freight part of the container transport. So, the ship/container arrives at Proto Port on ATA = ETA.

As soon as the container ship is cleared (by port authorities/customs) to enter the port, it is allowed to dock at a berth next to large cranes (the terminal) that will unload the cargo containers. The Harbour Master assists with timing and the route to the berth/terminal.

Upon arrival at the berth, the ship will berth and commence unloading and loading immediately.

The terminal publishes the exact moment and location where the container can be picked-up. This notification is published via the Proto Port Digital Portal and received by the freight forwarder, the Ports smart and green logistic tool, and the e-truck carrier. In case the final terminal pick-up has consequences on the battery charging timing schedule, an update will be processed and forwarded to the freight forwarded and e-truck carrier.

The e-truck is equipped with yard-automation functionality. This means that the truck can find its own way on the controlled yard of the Proto Port. The truck driver drives the truck to a parking lot, parks it on reserved spot and can take some time to rest or eat. The truck receives the exact coordinates of the charging station (charging point) and terminal (gate) and the time schedule. The truck navigates itself to charge the batteries and pick-up the container. After both activities are successfully executed, the truck drives back to the parking lot and parks on its reserved place. The waiting truck driver can step in and drive away leaving the Proto Port heading to the consignee or the hinterland warehouse.

Stakeholder and roles

The Proto Port use case storyline as described above contains a number of actors, tools, and systems. These stakeholders are interacting by sharing and/or enriching data/information. Table 1 identifies these stakeholders (actors, tools, and systems) from the storyline and combines them with its role, the data/information it possesses (output data) and data needed (input data). The possible source for the required input data is given in the last column.

Table 1: Stakeholders of the Proto Port use case storyline.

Stakeholder	Role	Output data	Input data	Data source
Consignee/ client	places order	□ Product requirements □ Sending requirements □ Expected/required receiving time	ETA	Shipper
Shipper/ Manufacturer	□ produces the cargo/order □ Sends the cargo □ Selects Freight Forwarder	□ Container details □ Expected/required receiving time □ Freight Forwarder	□ ETA □ Itinerary plan	□ Freight Forwarder □ Shipping company
Freight forwarder	organises the logistic plan/mission	□ ETA □ Itinerary plan □ Modalities □ Shipping company □ Carrier hinterland	□ Expectations consignee and shipper □ ETA shipping company □ Modality hinterland transport	□ Consignee □ Shipper □ Port Authority □ Smart/Green logistic tool
Shipping company	executes the shipment between the sea ports	□ ETA □ Container location on ship □ Terminal at destination port	□ Cargo details □ Expected/required receiving time □ Terminal details □ Harbour traffic	□ Freight Forwarder □ Port Authority □ Terminal
Port Authority	□ facilitates the physical and digital harbour □ facilitates the Proto Port digital portal and digital tools	□ road/waterway traffic information □ berth availability/ location	□ ETA □ Shipping company □ Carrier hinterland	□ Freight Forwarder □ Shipping company
Smart/green logistics tool	Provide preferred hinterland modality including the logistic planning	□ Recommended hinterland modality □ Preferred Itinerary plan □ Time schedule for pick-up. □ Location of pick-up □ Charging station, location, time schedule	□ ETA at port □ ETA at (final/next) destination □ (final/next) destination □ Cargo details □ Energy availability □ GHG emission per modality option	□ Freight Forwarder □ Energy-matching tool □ GHG-tool □ Terminal □ Charging station □ E-truck □ E-barge □ Train
Energy-matching tool	Provides green energy availability best matched with energy demand	Energy availability vs. Energy demand	Total energy sources Total energy demand	□ Energy grid, Battery system □ Terminals □ Smart/green logistics tool
GHG-Tool	Provides GHG emissions for each specific logistic case	GHG emissions	□ Cargo details □ Modality □ Itinerary plan	Smart/green logistics tool
Terminal	unloads the container	□ Exact time for container pick-up □ Location for container pick-up □ Energy demand	□ ETA □ Shipping company □ Ship details □ Cargo details	□ Shipping company □ Freight forwarder
e-truck	performs the transport into hinterland	□ battery status □ position □ energy-demand	□ Cargo details □ ETA □ Pick-up time	□ Smart/green logistics tool

		battery charging spec ETA	Pick-up location Destination	Freight forwarder Terminal
e-barge	performs the transport into hinterland	battery status position energy-demand battery charging spec ETA	Cargo details ETA Pick-up time Pick-up location Destination	Smart/green logistics tool Freight forwarder Terminal
train	performs the transport into hinterland	position energy-demand ETA	Cargo details ETA Pick-up time Pick-up location Destination	Smart/green logistics tool Freight forwarder Terminal
Charging station	Charges the batteries of the e-truck and e-barge	Location # charging point Schedule availability	ETA Energy demand	Smart/green logistic tool Energy-grid e-truck e-barge
Energy Grid	Supply of renewable energy	availability of energy source of energy		

Note that the table above just gives a high-level impression of the data needed and shared by each stakeholder. It is limited to the context of the storyline. This means that the roles, functions, and data need of the stakeholders can be much broader than mentioned in the table (and storyline). In D4.3, some of the stakeholders will be modelled in detail, e.g., all the input and out data is identified, described, and related.