

Gaia-X as an Enabler to Shape Interconnected Logistics in Europe

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Abstract: While the interest in the research field of the Physical Internet (PI) has been growing over the last decades and simulations have been able to show significant efficiency potentials resulting in environmental and cost advantages, real-world applications are still in their early stages. This might be driven by the fact that establishing a PI system unlocks its full potential particularly when run at scale across company borders with many participants. Establishing such a system comes with its own set of challenges, not only on a technical level but also in regards of business and policy-related challenges. However, Gaia-X is a European initiative to create an open data infrastructure with strong emphasis on interoperability, trust and sovereignty. It promises to enable trusted decentralized digital ecosystems that allow participants to collaborate under a mutual set of policies and rules. With the Gaia-X specification released, we aim to investigate if and how Gaia-X fits as an enabler to interconnected logistics in Europe. The contribution of this paper is threefold. Firstly, we describe requirements for an open, cross-company PI based on use case diagrams. Secondly, we examine how the Gaia-X principles and components could be used to meet these requirements. Finally, we explore implications to potential business models.

Keywords: Physical Internet, Gaia-X 4 Future Mobility, Open Standard, PI Use Cases in Europe, Green Logistics

Physical Internet (PI) Roadmap Fitness: Select the most relevant area(s) for your paper according to the PI roadmaps adopted in Europe and Japan: ☐ PI Nodes (Customer Interfaces, Logistic Hubs, Deployment Centers, Factories), ☐ Transportation Equipment, ☐ PI Networks, ☐ System of Logistics Networks, ☐ Vertical Supply Consolidation, ☐ Horizontal Supply Chain Alignment, ☒ Logistics/Commercial Data Platform, ☐ Access and Adoption, ☐ Governance.

Targeted Delivery Mode-s: ☒ Paper, ☐ Poster, ☐ Flash Video, ☒ In-Person presentation

1 Introduction

The Physical Internet (PI) provides a promising approach to significantly increase the efficiency and resilience of freight transportation. The increase in efficiency also reduces traffic while transport requirements remain the same. Hence, the PI concept makes a valuable contribution to protecting our environment, i.e. achieving the Paris Climate Agreement (ITF, 2018, 2021). In Europe, 77 % of freight transport takes place on the road (Eurostat, 2023), which means that vehicles on the road will play a key role. Despite expected potentials of approximately 30 % reduction in congestion, emissions and energy consumption from the transport sector (alice-tp, 2020), the implementation of this concept is still in its infancy. The European cloud initiative Gaia-X might be an enabler for the Physical Internet applications. In this paper, Gaia-X is considered to be both, a potential enabler for the implementation of PI use cases in Europe and a basis for further business models.

The remainder of the paper is structured as follows: In the second chapter we give an overview of the latest developments in regards of road-based PI (RBPI) concepts as well as a summary of Gaia-X and its adoption in the PI. In the third chapter we describe requirements of a cross-company PI with focus on private individual motor vehicles based on use case diagrams. We investigate if and how these requirements can be met by the Gaia-X principles in the fourth chapter. We summarize our findings and give an outlook into implications of potential business models in federated ecosystems in the fifth chapter.

2 Background & Related Work

The aim of the PI is to significantly improve the robustness and efficiency of freight transportation. Almost 77 % of transportation takes place on roads (Eurostat, 2023), of which 37 % are empty runs (KBA, 2023) and furthermore a large proportion are underutilized runs. In analogy to the Data Internet, the concept of the PI recommends a decentral approach for the routing of freight or freight components. For the road-based Physical Internet (RBPI) PI transporters are seen in the routing role (Kaup et al., 2020). The negotiation process for the transfer of goods is to be carried out either via distributed representatives of the PI transporters in kind of agents in a cloud system, which was designed in a reference model by Kaup et al. (2021) or a reinforcement learning approach based on vehicle-to-vehicle (V2V) routing (Lu et al., 2022).

A prototype implementation of the RBPI is aimed by the publicly funded project *Requirements and Application of Gaia-X in the Edge-Device Automobile* (Gaia-X 4 AGEDA¹). This project focuses the design of an agreed and standardized interface for vehicles as edge devices to connect to a cloud infrastructure, in particular Gaia-X. Two major use cases have emerged in this project: firstly, *Collective Vision*, including the storage and consolidation of camera and sensor data from participating vehicles within Gaia-X and, as a second use case, *Green Logistics / Physical Internet*, using the RBPI approach based on Gaia-X. The motivation of Academia in the PI research field is primary to foster the intermodality and synchromodality of PI-Transporters, i.e. switching between different modes of transport such as road, rail, water or air (Lemmens et al., 2019). As an integral part of the PI-Roadmap, the aim of the AGEDA project is to design realistic solutions within the most important mode of transport, road, together with a practitioner community consisting of OEMs, suppliers and service providers in the transport sector. Outcome artifacts such as use case descriptions will be discussed both within and outside the project with experts and transportation scientists. One of these evaluation steps is the discussion of results at international conferences. As a next step, MVP's and prototypes will be developed, which will be tested together with support of the Gaia-X infrastructure.

Originally introduced in October 2019 (BMWⁱ, 2019) by members of the government of France and Germany, Gaia-X is an approach that aims to 'create the next generation of data infrastructure for Europe' (BMW^K, 2024). While Gaia-X has since been transformed into a non-profit organization based in Belgium (the Gaia-X European Association for Data and Cloud AISBL²), community-driven hubs and cross-sectoral research projects work to transfer the concept into real-world applications. Gaia-X focuses not only on the underlying technical infrastructure but also takes transparency, legal compliance and interoperability of services into account (Federal Foreign Office, 2020). Although actual implementations are only starting to

¹ <https://www.gaiax4ageda.de/>

² <https://gaia-x.eu/who-we-are/association/>

become readily available³, Gaia-X specifications are updated regularly⁴. In contrast to other standardization approaches, Gaia-X mostly refrains from dictating concrete technologies, making it both independent from specific implementations but also harder to grasp as there are multiple concurrent implementation approaches that are not fully compatible with each other. Although Gaia-X has been explored in greater detail over the last years in various aspects, its potential for the PI has not been analyzed widely.

Grefen et al. (2018) mention the Industrial Data Space (IDS; arguably a precursor of Gaia-X) as a potential basis for logistic processes that might enable federated platforms. Their work focuses on an outlook for future logistics and does not get into more detail on how such a system would meet PI specific requirements.

Dalmolen et al. (2018) describe the IDS and blockchain technology as enabler for trust in a multi-tenant logistic system. They spotlight the architecture of the IDS and roles of the individual components but keep their focus on the trust aspect and do not provide closer insights on how these technologies would benefit other PI requirements.

Hofman and Dalmolen (2019) continue their work by discussing the IDS with its communication protocol as potential enablers for interoperable platform services that would allow the implementation of the PI. While highlighting the need for such standardized platform services and pointing out how these services might be established, the benefits of the IDS for the PI are mostly out of scope of their research.

Klukas et al. (2021) mention Gaia-X in their report on the research project I²PANEMA but keep their focus on an Internet of Things solution for ports without getting into specifics on how Gaia-X mechanisms enable the use cases they present.

Hofman (2023) proposes a protocol stack to build a mobility data space that addresses technological as well as governance and legal aspects. While the paper gives valuable insights into high-level requirements for establishing a dataspace for the PI, use case specific requirements are out of scope.

In conclusion, previous research has mainly portrayed the IDS as an enabler for the PI but kept its focus on the trust aspect without exploring other potential benefits in greater detail. Gaia-X has briefly been mentioned before but a more detailed analysis is required to assess the suitability of Gaia-X for the PI. Therefore, we aim to investigate if and how Gaia-X might be used to establish a PI with a cross-company horizon in the following chapters.

3 Requirements of a Cross-Company Physical Internet

In this chapter, requirements for the underlying technology are established that enable a cross-company PI. The requirements are identified by means of use case modelling. The use case diagrams presented originate from the research project AGEDA. While the use case diagrams are mainly specified for an automotive application due to the nature of the project, a more generic approach with multimodal transport could be achieved with minor adjustments. Therefore, we see the use case diagrams suitable for extracting requirements.

We imagine the PI to be an open system in which multiple parties can provide their own implementations or instances of services, resulting in a cross-company PI. As such, **Trust** among the actors in the system is required (as discussed in Dalmolen et al. (2018)) and can be gained by secure **Identification & Authentication**. To ensure no one actor can take control

³ <https://dih.telekom.com/en/gaia-x-summit-shaping-trustful-digital-ecosystems->

⁴ <https://gaia-x.eu/media/publications/>

over the system, **Federation of Decentralized Services** can safeguard from abuse, further strengthening the trust aspect. Finally, **Openness** to new actors is required under the premise that strictly **Enforced Policies** exist that ensure all actors follow rules decided on.

The use case diagram for the first use case is depicted in Figure 1. In *Parcel Drop-Off*, a sender is first selecting a provider that offers the services required for sending a parcel. As such, a form of **Service Discovery** with a mechanism to select a service provider is required. After selecting a provider, the parcel is registered at a *Registration GUI*. The parcel description might contain properties specifying the mode of transport that can be matched to the capabilities of transport vehicles, e. g. if cooled transport is mandatory. After registration, a trace entry for the parcel is logged. Therefore, **Immutable Logging** is required to achieve trustful tracing of parcel movements. Using the *Cloud Parcel Service*, the sender is then choosing a drop-off location, in this case a motor vehicle. This might be a parked vehicle without the driver at site. To be able to drop-off the parcel, the sender needs to unlock and open the vehicle. This permission is given by the *Cloud Parcel Service*. Since the permission should only be valid for this specific drop-off, this indicates the requirement for **Conditional Authorization**, preferable based on the trust mechanisms already established. The *Vehicle Parcel Service* running in the vehicle identifies and traces the parcel, thus concluding the *Parcel Drop-Off* use case.

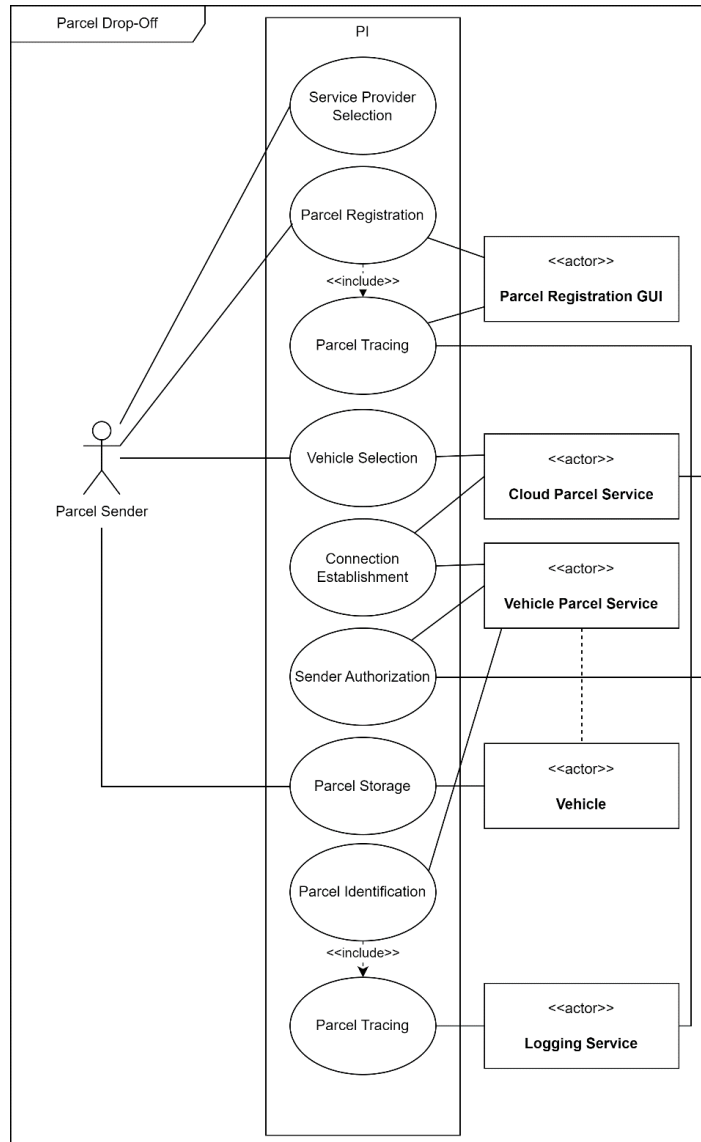


Figure 1: Use Case Diagram 'Parcel Drop-Off'

The use case diagram for the use case *Rendezvous* is depicted in Figure 2. In this diagram, the handover of a parcel from one vehicle to another is visualized. As a prerequisite, vehicles – represented by a *Vehicle Agent* – are periodically sharing their planned routes and vehicle characteristics with the *Infrastructure Hub* and receive potential transfer points in return. If the handover of a parcel becomes necessary, e. g. because of diverging routes of the vehicle and parcel, the *Vehicle Agent* searches for a potential rendezvous vehicle and initiates a negotiation with the corresponding *Vehicle Agent* to determine a possible location and time for the parcel handover. If both *Vehicle Agents* come to an agreement, this is also traced at the *Logging Service*. The negotiation process implies the requirement of a **Contracting Mechanism**. After agreeing on the terms, both vehicles meet, transfer the parcel and ensure the handover is traced accordingly, concluding the use case.

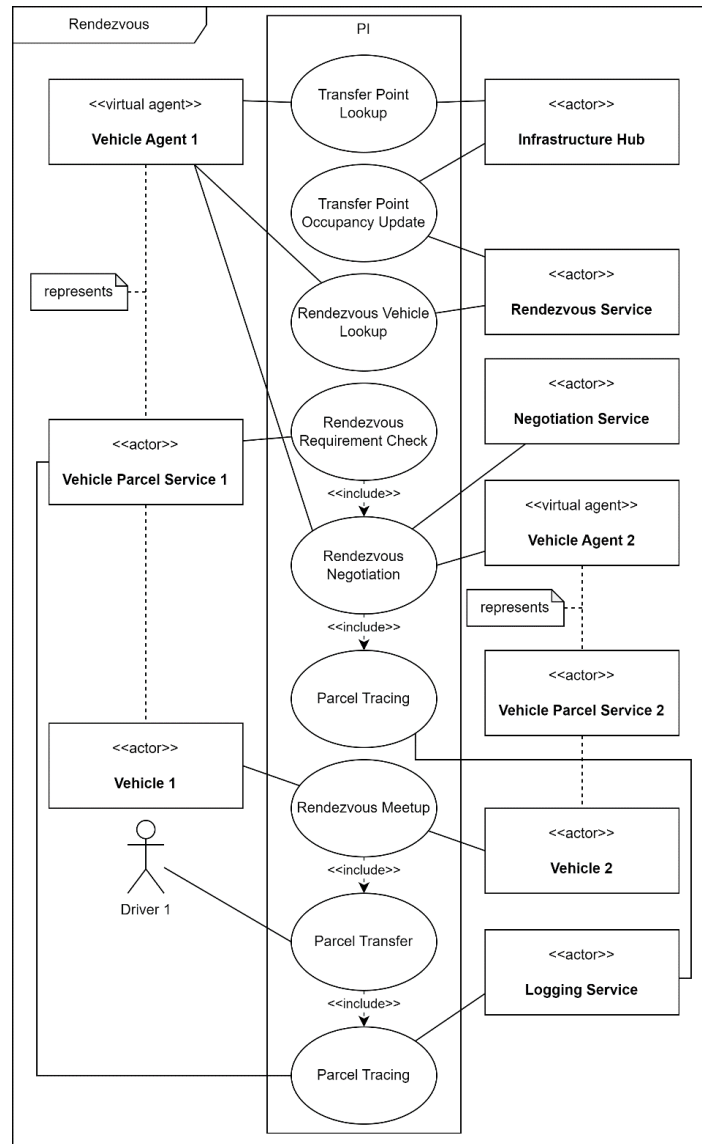


Figure 2: Use Case Diagram 'Rendezvous'

Based on the use case diagrams, we have identified the following nine requirements for the underlying technology that enables a cross-company PI: I. Trust, II. Identification & Authentication, III. Federation of Decentralized Services, IV. Openness, V. Enforced Policies, VI. Service Discovery, VII. Immutable Logging, VIII. Conditional Authorization and IX. Contracting Mechanism.

4 PI Requirements alignment to Gaia-X Principles

After having identified requirements for the implementation of the cross-company PI in the previous chapter, we assess if Gaia-X can fulfill the requirements in this chapter.

The Gaia-X documentation is publicly available in multiple documents.⁵ The *Trust Framework* describes how an actor (called *participant*) can be part of the system by defining a set of rules each participant has to follow. Participants must provide a *self-description* (also called *Gaia-X Credential*) following the *W3C Verifiable Credentials Data Model*.⁶ The *Trust Framework* specifies minimum requirements for **Identification** of participants, for example using extended validity certificates. The information is verified and signed and can be verified by participants using the *Notarization service*.

Data spaces are built on top (see Figure 3) of the *Trust Framework* and serve as a ‘federated, open infrastructure for sovereign data sharing based on common policies, rules, and standards’ (Reiberg et al., 2022). In the data spaces *participants* use their *Gaia-X Credentials* to provide and consume data from services. These services are published in a *Gaia-X Federated Catalogue* using *self-descriptions*. Since the *Federated Catalogue* can be queried, it provides capabilities for **Service Discovery**. Using *self-descriptions* serves the additional benefit of allowing consumers to verify that services follow policies by analyzing the attributes of the *self-descriptions*. For example, a policy might dictate that only services provided by participants who follow information security standards might be used. Participants could include their ISO 27001 certification as a claim in their *self-description* and have that claim signed. The consumer would then be able to check if the provider conforms to the policy by analyzing the *self-description*. Therefore, using *self-descriptions* fulfills the requirement of **Enforced Policies**. Since the attributes of *self-descriptions* required for compliance may be extended following domain specific rules, **Trust** can be achieved by defining, signing and verifying them.

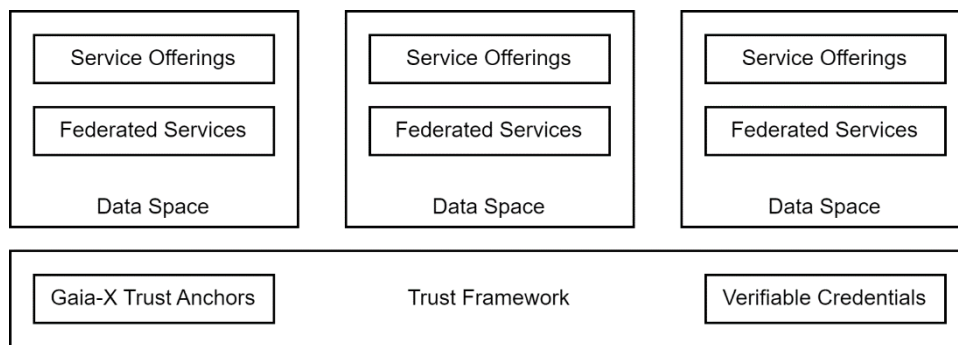


Figure 3: Gaia-X Trust Framework and Data Spaces

Since data spaces are federated by definition and meant to be interoperable, the requirement of a **Federation of Decentralized Services** is fulfilled. To achieve interoperability between service providers, attributes that define interface compatibility may be used. Reiberg et al. (2022) also mention **Openness** as a common concept of data spaces. While an open system allows new participants to join a data space, participants still maintain their choice of which other participants they want to interact with. Using policies based on the *Gaia-X credentials* as described ensures that **Trust** can be preserved even in open ecosystems.

Besides the catalog and trust components, Gaia-X also defines *Data Exchange Services* that allow negotiation and contracting between participants. While this fulfills the requirement for

⁵ <https://docs.gaia-x.eu/>

⁶ <https://www.w3.org/TR/vc-data-model/>

Contracting, it is important to note that these services are to be realized by each participant while the ecosystem may play a supporting role. Therefore, negotiating a contract is mainly to be implemented on the application level. Since agreeing on policies is part of the negotiation process, **Conditional Authorization** might be arranged. Mapped to the use case, this would provide the means to restrict the authorization for unlocking a vehicle to a short time frame.

As described in the Data Exchange Service Specifications, part of a contract might be the notarization and logging of the agreement in a federated *Data Product Usage Contract Store*, which realizes the requirement for **Immutable Logging**. While the Gaia-X specifications do not provide further details on how the contract store is to be implemented in order to guarantee immutable logging, this might be realized using blockchain technology as described in Dalmolen et al. (2018).

An overview of the participants and components that are part of a data exchange in a Gaia-X data space is given in Figure 4.

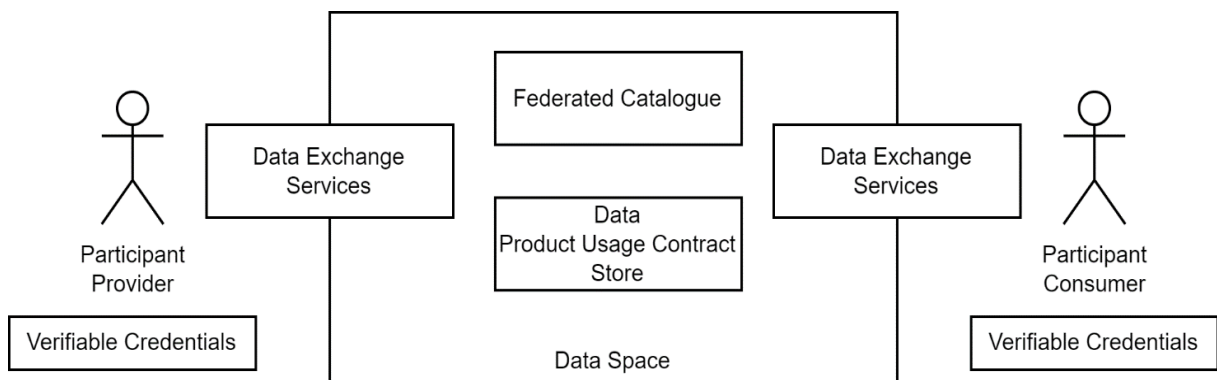


Figure 4: Participants in a Data Space

In conclusion, we found that Gaia-X addresses each of the identified requirements for the implementation of a cross-company PI. While the level of detail of the Gaia-X specifications leaves room for interpretation and the use cases presented are not all-encompassing and therefore additional requirements for underlying systems might exist, Gaia-X seems suitable for the implementation of the PI applications. While Gaia-X provides principles meeting the requirements as described, most of the logic for the use cases would still need to be developed in PI-specific components on the application level.

5 Conclusion & Outlook

The PI has the potential to greatly reduce inefficiencies in current freight transport when building a system in which many actors can participate. As we have shown, these actors have requirements for such a system, particularly in regards of trust. Gaia-X is a European use case independent initiative that specifies the building blocks for setting up open, distributed data spaces that provide mechanisms for gaining trust in automated fashion. The research project AGEDA aims to bring Gaia-X to the edge device automobile. Applying the Gaia-X principles then available in vehicles provides the opportunity to implement a system that meets the requirements of PI actors we identified based on use case diagrams. An interim alignment with concepts of other projects, i.e. of reconfiguration mechanism, has already taken place (Stötzner et al., 2024).

While we have explored the fit of Gaia-X to the PI from a technical viewpoint, participation in open data spaces has implications for intermodal mobility concepts as well. Understanding and addressing the complexity of these concepts is crucial for shaping interconnected logistics in Europe, particularly from an innovation management perspective. These concepts require

careful consideration of the interests of various stakeholder and shareholder groups. Traditional business model modeling techniques often focus on direct 1:1 relationships between a solution provider and a specific target group, neglecting the diversity and interdependence of actors within the ecosystem and leading to a limited perspective on potential business models.

In a systems context, the modeling of use cases refers to a structured procedure that the system undertakes to generate a tangible and beneficial effect for involved entities. Standard practices for representing use cases typically involve visual diagrams, such as those prescribed by the ISO/IEC 19505 Unified Modeling Language (UML). Usländer and Batz (2018) note while these visual depictions serve as helpful tools for outlining system processes, their utility is limited without accompanying descriptive text that clarifies the diagrams' intent. The absence of a standardized method for integrating textual explanations can render the interpretation of these processes arduous and imprecise. At this point, more advanced methods such as the modeling of sub-use cases are suitable to explicitly capture the semantic layer of service descriptions.

Moving beyond those sub-use case models, which typically only map the conceptual requirements of a specific business case into technical requirements through requirements engineering, is essential. This approach risks overlooking unknown or unconsidered target groups, potentially resulting in a service offering that, based on specific data formats and ontologies, only partially meets the requirements of other domains.

To overcome this challenge, the particular interests of other domains must be integrated into the business analysis early on. This integration allows for the derivation of technical requirements that extend beyond purely technical aspects and support ambidextrous business models while including various target groups. Additionally, the interests of potential application groups in the further processing or refinement of data must be considered to achieve a critical mass in the usage of service offerings.

Furthermore, regulatory frameworks such as the Data Act must also be factored into the business modeling equation, ensuring compliance and capitalizing on the data governance structures they establish. The Data Act plays a crucial role by clarifying the usage rights of data holders as well as operators or users of devices. The potential for device operators to develop their own business models based on the data obtained must be considered early in the business modeling process (EU Regulation 2017/2394 and Directive 2020/1828). It is essential to resolve how participants in the presented Physical Internet use case, such as Parcel Senders, can be incentivized to share and process data. Additionally, under the provisions of the Data Act, manufacturers of vehicles are not granted the right to use and process data generated by the vehicle operator. To enable corresponding business models, the individual barriers to consent must be considered and overcome. This consideration promotes a mutually beneficial relationship, encourages the provision of data for further processing and refinement, and enables innovative Customer2Business business models.

In the realm of decentralized data economies, the potential for advanced business model techniques arises from their capacity to address the challenges of traditional approaches. Legacy models, limited by their focus on direct interactions and insufficiently detailed diagrams, fail to capture the complex interdependencies of modern, interconnected systems. The necessity for techniques that can interpret the semantic nuances of service descriptions and consider the broader spectrum of stakeholders is evident. By incorporating these advanced methodologies, business modeling can better accommodate the diverse needs of decentralized data economies, leading to more adaptable and encompassing service offerings.

In this context, Gaia-X can act as a catalyst to enable the shaping of interconnected logistics in Europe. By creating a secure and trustworthy data space, Gaia-X provides the foundation for the development and implementation of business models that consider the complexity and interdependence of the modern logistics landscape.

While this paper assessed the capabilities of Gaia-X as the underlying technology in the PI, future work needs to prototypically implement the system to demonstrate its capabilities while considering the current state of Gaia-X and elaborating on the border between Gaia-X and application-level components. Regarding the use case diagrams presented, more work needs to be done in further detailing interactions and expanding system capabilities. For example, the PI system should be capable of working in situations with limited network connectivity, i.e. using V2V communication. Using V2V-communication. With respect to Gaia-X itself, we see additional work in further detailing the specifications as current implementations only provide limited interoperability. This might be a cornerstone for further establishing Gaia-X across the borders of Europe.

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