Adapting a Generic Smart Service Platform Architecture to the Road-Based Physical Internet

Jonah Windolph[1][a], Steffen Kaup[2][b], Robert Wehlitz[1][c], Bogdan Franczyk[3,4][d]
and André Ludwig[5][e]

[1]*Institute for Applied Informatics (InfAI), Leipzig, Germany*
[2]*Mercedes-Benz AG, Group Research, Böblingen, Germany*
[3]*Leipzig University, Germany*
[4]*Wrocław University of Economics, Poland*
[5]*Kühne Logistics University, Hamburg, Germany*

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Abstract: Global trade will lead to more than a doubling of transport demand by 2050 in comparison to 2020. At the same time, the impact of pollutant emissions on the global climate is leading to increasingly stringent legislation regarding the environmental friendliness of transportation. Against this background, the transport and logistics industry has to undergo a major transformation in the coming years. Hence, transport efficiency will become more and more important. This will inevitably lead to a rethink in the industry about completely new transport and logistics concepts, such as the Physical Internet (PI). Here, transport efficiency and thus more environmental sustainability are supposed to be achieved by organizing the freight traffic like the data traffic on the digital Internet, with the highest expected potential through a road-based Physical Internet (RBPI). However, the realization of the RBPI depends on the existence of intelligent RBPI services enabled by suitable smart service platforms. In this paper, we propose to adapt a generic architecture for smart service platforms to the RBPI as a cornerstone for its technical implementation. This food for thought may serve as a starting point for further discussions and detailed development in the future.

1 INTRODUCTION

The Green Deal of the European Union (EU) to reach net-zero emissions of greenhouse gasses by 2050 triggered a paradigm shift in the transportation industry, forcing companies to rethink their logistics and supply chain operations (Laurent, 2020). As climate change has been recognized and accepted as a major societal challenge of the 21st century, it is becoming increasingly apparent that emissions in the transport sector need to be drastically reduced to meet the EU's ambitious targets. 77 % of freight traffic in Europe is caused by transport vehicles on the road (Eurostat, 2022). In 2020, around one-fifth of the total road freight transport in the EU was carried out by empty vehicles (Eurostat, 2021). Transport demand is expected to greatly increase by 2050 (ITF, 2021).

The Physical Internet (PI) is a vision of how physical objects could be transported from a point of origin to a desired destination in a manner similar to the routing of data packets on the digital Internet (Montreuil, 2012). Here, freight loads are divided into subcomponents that can take different paths through an agile intermodal transportation network. This approach enables a higher utilization of transport vehicles as well as a higher degree of resilience due to redundant connections of transshipment points, and the resulting scalability of the entire transport system.

Since the majority of freight transportation takes place on the road, the potential for implementing a road-based Physical Internet (RBPI) appears to be the largest in this transport sector.

Research on the PI in the form of a cross-transport carrier system has been going on for more than 10 years (Ballot et al., 2021; Montreuil, 2012). The focus of research was directed to the RBPI with in-

[a] https://orcid.org/0000-0001-5371-0952
[b] https://orcid.org/0000-0002-6679-3387
[c] https://orcid.org/0009-0002-6288-7797
[d] https://orcid.org/0000-0002-5740-2946
[e] https://orcid.org/0000-0002-0358-3470

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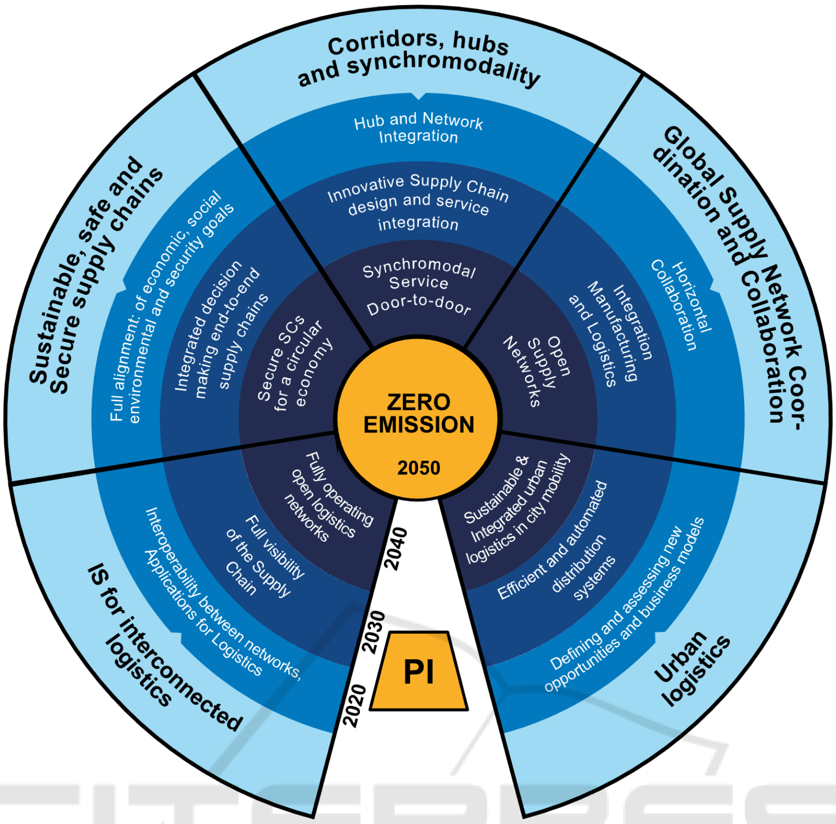

Figure 1: ALICE Roadmap to Zero-Emission Logistics by 2050 (Liesa et al., 2020).

creased engagement of the automotive industry (Kaup and Singer, 2016). In a next step, the gap to the last mile was closed by the integration of crowd-delivery into the RBPI (Kaup and Demircioglu, 2017). This research has resulted in a concrete framework for the RBPI (Kaup et al., 2021) that provides a basis for this paper.

The goal of the RBPI is to reduce road freight traffic while maintaining the same transport volume with fewer number of vehicles and at the same time improved efficiency. Hence, this will lead to a higher degree of scalability even in the event of an increase in transport demand. In contrast to today's processes in transport logistics, where the routing of goods is determined by proprietary forwarders, in the RBPI, freight loads and freight components are forwarded decentrally from network node to network node and thus routed to the destination.

Digital logistics services related to the vision of the RBPI ”bring numerous advantages in the optimization of integrated logistics ecosystems” (Osmólski et al., 2019). However, their technical implementation requires suitable smart service platforms. Such platforms leverage Internet of Things (IoT) technologies as well as advanced data processing and analytics capabilities to automatically acquire, integrate, analyze and use transport-relevant data beneficially. In this paper, we propose to adapt a generic smart service platform architecture, that already has proven itself in other fields of application, to the RBPI in order to enable intelligent RBPI services, such as dynamic routing of freight transports.

The remainder of this paper is structured as follows: Section 2 gives the background and current state of the art in terms of smart service platform architectures in the PI. In Section 3, the architectural proposal adapted to the RBPI is presented. Finally, conclusions were drawn in Section 4 with an outlook to further work.

2 BACKGROUND

The main milestones of the PI are visualized in the form of a roadmap in Figure 1 (Liesa et al., 2020). This roadmap was created by European researchers who are mostly part of the ‘Alliance for Logistics Innovation for Collaboration in Europe’ (Ballot et al., 2021). It describes the path of implementation towards a sustainable logistics vision of zero emissions for freight transport within Europe by 2050 (Liesa et al., 2020). Important and yet unachieved implementation goals lie specifically in the area of Information Systems (IS) for interconnected logistics. Here, smart service platforms that enable full transparency of supply chains and open logistics networks are needed.

The current state of the art for smart service platforms in the context of the PI is still in early stages of development and implementation. Already existing approaches aim to improve the efficiency and effectiveness of logistics and supply chain management by utilizing advanced technologies, such as IoT, artificial intelligence, and blockchain.

Hasan et. al (2021) describe potential applications and benefits of integrating blockchain technology with the PI. The authors also compare two different blockchain architectures they found most promising to meet PI service requirements. The work mainly addresses decentralized and secure data exchange within PI networks but does not cover data integration and data analytics aspects that are crucial for intelligent RBPI services.

Fahim et. al (2021) propose an information architecture for track-and-trace in the PI with the focus on maritime ports. The architecture is based on the Reference Architecture Model for Industry 4.0 (RAMI 4.0) and concentrates on four layers. At the business layer, logistics processes are defined on an operational level. The functional layer comprises components that process track-and-trace data and make them available through a PI open interface system. The information layer is responsible for data exchange, storage and quality assurance. The asset layer enables the data acquisition for track-and-trace functionality. The proposed architecture lacks technical details and also does not consider data integration, processing and analytics.

A service-oriented architecture (SOA) for creating IoT logistics services for the PI is described by Tran-Dang and Kim (2018) and Tran-Dang et. al (2020). The authors define IoT technologies as an important enabler in regard to the PI and view SOA as a means to meet PI requirements best. Their proposal extends across a physical layer, a network layer, a service layer and an interface layer. The physical layer comprises identification, sensing and processing technologies to acquire transport-relevant data. The network layer connects heterogeneous IoT devices and allows for data exchange between them. In order to integrate multiple heterogeneous resources the service layer provides a middleware as well as logistics and SOA infrastructure services. The interface layer exposes services, e.g. through web services, so that they can be accessed by the end users. Despite the proposal addressing data integration, it is missing a data analytics perspective that is needed to develop sophisticated PI services. Furthermore, the publication only provides a high-level overview of the architecture.

Mededjel et. al (2021) propose a cloud-fog architecture to optimize the freight routing in the PI and to increase visibility and traceability throughout supply chains. It consists of an edge, fog and cloud layer. At the edge layer, sensing data is collected as well as preprocessed and transmitted through an IoT gateway. The fog layer is responsible for the acquisition, aggregation and processing of the data transmitted from the edge layer. Data analytics and permanent data storage are realized at the cloud layer. Overall, the authors also describe a high-level architecture that is following basic fog computing principles. Specific system components to support the development and operations of intelligent PI services are not further considered.

Since the approaches mentioned above focus on the PI in general and have their limitations and shortcomings, our goal is to investigate how a generic smart service platform architecture, that has been evaluated in other application domains, can be successfully adapted to the RBPI. As a starting point, we use preliminary work that was initially published in 2017 and originally addressed the smart energy domain (Wehlitz et al., 2017). The described architecture comprises four core system areas, that are interfaces, data, services, and processes. The initial concept and its system areas have been continuously enriched and developed over time. As an example, a generic metadata model was introduced to abstract implementation details on IoT devices and to enable a unified access on them (Wehlitz et al., 2020). In addition, much emphasis has been placed on data processing and data analytics capabilities in order to be able to develop powerful smart services for different use cases, e. g. smart home, weather and environmental monitoring, as well as predictive maintenance in industrial applications (Zschörnig et al., 2022). In the following, we present a new and adapted version of the mentioned smart service platform architecture that addresses the technical implementation of the so far conceptual RBPI and shall serve as a basis for further discussions.

3 PLATFORM ARCHITECTURE

The proposed architecture is depicted in Figure 2 and has five different functional layers: *edge layer*, *inte-*

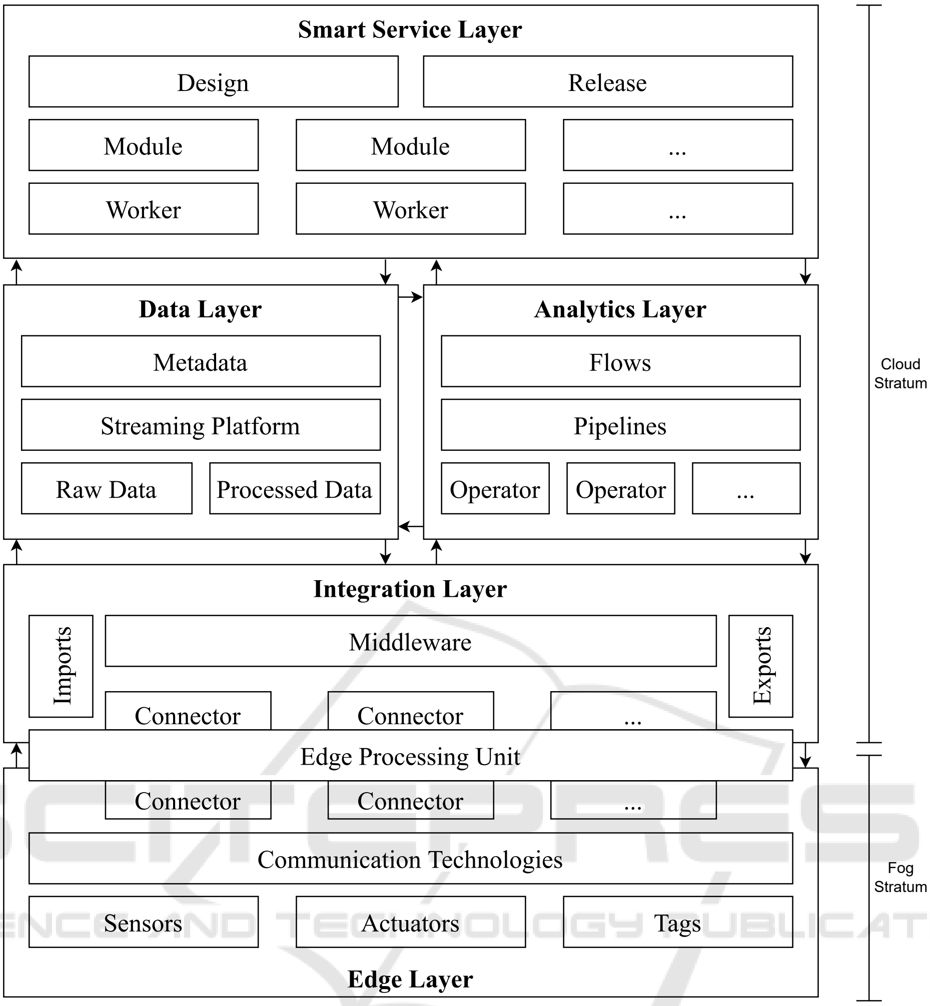

Figure 2: Platform Architecture.

gration layer, *data layer*, *analytics layer* and *smart service layer*. They serve the purpose of acquiring and integrating data as well as processing and analyzing it in order to derive meaningful insights that are the basis for intelligent RBPI services. Dividing the architecture into fog and cloud stratum follows the the fog computing paradigm, in which computation may be performed closer to the edge of the network in order to improve latency, energy efficiency and bandwidth usage (Mouradian et al., 2018; Abdali et al., 2021). In the following, each of the layers, their interactions and their relation to the RBPI will be described in a bottom-up fashion.

3.1 Edge Layer

In the context of the RBPI, the edge layer's main purpose is to acquire, transmit and process transport-relevant data inside vehicles. In addition to basic vehicle data, such as its location and speed, this also includes metadata about planned transport routes, loaded freight items and the measurement of remaining free capacity in the freight compartment. Free capacity can basically have two different dimensions: volume and weight. When transporting fast moving consumer goods, which is what the RBPI is almost always about, the volume limit is usually exhausted before the weight limit. Therefore, a volume-optimized utilization of vehicles is desirable.

The edge layer is placed in the fog stratum and comprises different edge components, that are sensors, actuators, and tags that may support a variety of different communication technologies, such as Wi-Fi, ZigBee or Bluetooth Low Energy.

The seamless recording of transported goods can be achieved by using camera-based sensors. The data collected from these sensors can also be used to assess whether a product or group of products, such as those positioned on a pallet, can be stacked and thus whether the space above them can be used for other goods. Alternatively, ultrasonic or 'light detection and ranging' (LiDAR) sensor systems can be used. Ultrasonic sensors are easy to integrate into the cargo space of transport vehicles, but can only detect the outline of the cargo space. LiDAR, on the other hand, has a good range of environment detection and good 3-D characteristics, but is comparatively expensive and complex. The identification of freight objects can be achieved by means of AUTO-ID methods that use tags with different underlying technologies such as QR codes, RFID or NFC tags or bluetooth beacons.

Another important category of edge components includes actuators. For example, an actuator might be used to enable remote access to a vehicle in order to allow for unattended transport goods exchange. Furthermore, they are used to secure loads, i.e. to protect cargo against slipping and damage. This can be realized by variably adjusting a matrix of piezoresistive expansion actuators that create a 3-D contour in the cargo space that conforms to the shape of the loaded cargo, and thereby securing it (Kaup et al., 2021).

The mentioned edge components are connected to an edge processing unit through hard- and software connectors that enable different communication technologies and protocols. The edge processing unit not only serves as a connection point between the fog stratum and other layers in the cloud stratum for data forwarding, but also provides the option for data analytics at the edge level based on specific edge device processing capabilities.

Gradually, vehicles are being equipped with more and more computing power in the form of vehicle processing units, not least because of the requirements arising from autonomous driving. These computing resources might serve as a suitable base for an edge processing unit. In respect to the RBPI, possible analytics tasks are the aggregation and filtering of sensor data to reduce the required bandwidth during the transmission to cloud backends, the encryption, anonymization and pseudonymization of data for privacy and security reasons as well traffic-related algorithms such as route planning or arrival time estimations.

3.2 Integration Layer

The integration layer addresses the registration, connection and management of heterogeneous edge components of different vendors as well as the communication between the fog and the cloud stratum of the architecture. It also enables the integration of data from third-party systems using imports, e.g. for integrating data of supply chain management and fleet management systems or open data providers, such as traffic data services. Imports must first be implemented as an import type that addresses the specific format and protocol used by the data source. The import type must then be registered with the platform. After these preliminary steps, imports can be configured and instantiated (Windolph et al., 2021).

On the other hand, the integration layer allows data access for external systems using exports. An export collects raw or processed data from the data layer and makes it available to external systems. Analogous to imports, exports may use a variety of different target formats and protocols in order to support a wide range of external systems. The middleware translates incoming messages (e. g. sensor data) into a unified platform-internal message format using metadata and connectors, and stores the data at the data layer. The middleware also retranslates outgoing messages (e.g. control commands to actuators) into device-specific requests that are handled by the edge layer.

In terms of the RBPI, the integration layer refers to the integration of all the systems and technologies that are part of the RBPI. These include, for example, available transshipment points and additional rendezvous points identified by vehicles, but also information about the vehicles themselves, their currently loaded transport goods, available routes, the conditions of the roads and the toll sections along them. This data is so far stored in a variety of different isolated systems. The integration layer now enables the combined processing of all these different sorts of data.

3.3 Data Layer

The data layer stores all raw and processed data in a streaming platform that provides access to the data for other layers. In the scalable streaming platform raw sensor data and processed analytics data is stored in topics that multiple platform components can use at the same time by publish and subscribe mechanisms. Playback of historical data in the original order as well as the consumption of real-time data is possible. In contrast to typical database access, data is processed one message at a time.

The metadata required for the integration of heterogeneous sensors and actuators is stored in this layer as well. In contrast to the raw sensor data, this metadata is stored outside of the streaming platform to enable access to them without having to implement a streaming client. Metadata is described by a purpose-built model that eases the integration of sensor data and actuator control through semantic integration (Wehlitz et al., 2020).

Concerning the RBPI, the data layer refers to the data that is collected by the various systems and technologies of the physical internet. This data includes the location of vehicles, the speed of vehicles, the traffic conditions, and the utilization of cargo spaces. It also refers to the metadata of vehicles, transport goods and the road infrastructure.

3.4 Analytics Layer

The analytics layer refers to the software and hardware infrastructure that enables the analysis of all data collected by the integration layer and stored at the data layer. In the analytics layer, pipelines are used to analyze the data collected by vehicles and other components of the road infrastructure. Analytics pipelines are designed as analytics flows and constituted of one or more analytics operators. An analytics operator consumes data from the streaming platform, performs a specific analytics task and writes the results back to the streaming platform (Zschörnig et al., 2020; Zschörnig et al., 2022). From there, they can be used in other layers, but also reused in other analytics pipelines to avoid redundant processing. Chaining multiple analytics operators enables the creation of complex analytics pipelines, while the segmentation of complex tasks into multiple analytics operators allows horizontal scaling of analytics pipelines and the reuse of analytics operators in different analytics flows. Analytics pipelines can be deployed in cloud, hybrid or fog fashion to address use case-specific processing requirements and edge processing unit capabilities.

In regards to the RPBI, the analytics layer could be used to implement algorithms that predict traffic congestion and systems that forecast traffic accidents, but also algorithms that provide data aggregation and anonymization to ensure data protection. Combining these analytics results into a complex analytics pipeline could enable a system that determines the optimal route for a vehicle.

3.5 Smart Service Layer

The smart service layer simplifies the implementation of complex use cases by combining all other layer functionalities in order to allow for the orchestration of data integration, data analytics and actuator control. When creating a smart service, the first step is to model it as a design. A design consists of multiple tasks that need to be run in order to prepare all resources that are required for a specific use case. Once a design has been created, it can be prepared for use by creating a release. Releases are versioned designs, which enables update mechanics. After a release has been made, users can deploy it as a smart service instance. If a smart service uses additional configurations, such as the selection of a specific sensor, this configuration has to be provided during this step.

If a smart service requires the instantiation of other platform resources, such as an analytics pipeline, this task is handled by resource-specific smart service workers that instantiate the resource and save a reference to it in a smart service module. Using this approach allows for other workers to further use instantiated resources (e.g. an export could make results of an analytics pipeline accessible for external systems). Referencing all resources in modules also enables deleting them once the smart service instance is discarded.

The smart service layer would serve as the interface between the smart service platform and its users. In this layer, intelligent RBPI services, such as route planning, traffic monitoring and incident management could be developed, evaluated and provided to the user. Using this layer of the architecture has the potential to conceal complex implementation details of the RBPI to users by reducing the required contact points, resulting in an improved usability of the overall platform.

4 CONCLUSION AND OUTLOOK

The RBPI vision is expected to have great potential to revolutionize road-based transportation in terms of increased efficiency, robustness, scalability, and sustainability. By providing a reliable, high-speed sensing and communication infrastructure in combination with a suitable smart service platform, intelligent RBPI services enable vehicles to share data and cooperate with each other in order to optimize traffic flow, reduce congestion, and improve safety.

However, research in the field of RBPI is still in its beginning stage and almost always theoretical in nature. In this paper, we propose an adapted version of a generic smart service platform architecture that aims to bring the RBPI a step closer to its technical realization.

As future work, the individual layers of the proposed architecture need to be detailed and investigated deeper. Furthermore, each of them as well as their interaction as a whole have to be evaluated against the specific requirements of the RBPI. Thinking ahead, a possible extension could be direct communication between multiple edge processing units in local ad-hoc networks to enable additional use cases such as handling freight exchange among each other in the near distance or to compensate for the outage of a cloud connection.

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