# IoT for Rail Transportation: The Case of Railigent

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***Abstract*— Internet of Things (IoT) platforms are often designed horizontally to serve requirements of various vertical industries, but some are custom-built and implemented only by the market participants in a specific industry vertical. This paper takes a case study approach to investigate the IoT platform Railigent, which facilitates IoT solutions exclusively for the rail transportation ecosystem. Offered by Siemens Mobility GmbH, the platform's architecture, business model and platform ecosystem management are analyzed based on an archival analysis of publicly available material. The case findings emphasize the usefulness of IoT platforms in practice to enable data-driven maintenance optimization, potentially supported by a platform verticalization strategy.**

***Keywords*— *ecosystem, internet of things, platform, railway transportation, verticalization***

## I. Introduction

The adoption of platforms across the industrial value chain has gained enormous interest by both the private sector and policymakers alike. Given that the market capitalization of platform companies exceeds traditional supply chain-oriented firms by an order of magnitude, digital platforms are thought to potentially become an important pillar of the fourth industrial revolution [1]. A key characteristic of this quantum leap in technological innovation is the application of digital technologies to enable the Internet of Things (IoT) for the industrial value chain: within factories and connecting industrial machinery as “industry 4.0”, or in general for the connectivity of industrial assets in non-production environments [2, p. 239]. The commercial promise of a successful IoT platform, often utilizing other future-oriented technologies like Artificial Intelligence (AI), is significant, and “platform strategies, combined with the need to be more customer-centric and to enhance products with data, are shifting many industries from a focus on selling products to delivering services” [3, p. 58].

In recent years, industry has seen the emergence of IoT platforms in various manifestations. Many large IoT platform owners aim to serve different vertical industries with the same platform, which might however be customizable with applications and solutions to individual industry needs. Whereas others develop market-specific IoT platform solutions, often then tailored to the requirement of dedicated verticals. This phenomenon was first described by Fink and Markovich [4] as verticalization in the context of enterprise software systems, which was adopted as similar perspective in digital platform research [5], [6].

A helpful method to understand the characteristics and mechanisms of these different types of digital platforms is by means of case study research, and platform specific manifestations like IoT platforms and mobility platforms have frequently been analyzed by scholars [7] – [10]. In the industrial domain, Siemens AG has attracted scholarly interest as the platform owner of the IoT platform MindSphere. This might be owed to its prominent position in the market, as MindSphere was evaluated as one of the four leading Industrial Internet of Things (IIoT) platforms [11, p. 9]. It is also one of the largest, as MindSphere offers platform solutions that serve more than 15 vertical industries [12]. In the academic literature, Pauli et al. [13] applied the Platform Ecosystems Modelling Language (PEML) to describe the MindSphere ecosystem from a structural point of view. And in a series of three consecutive papers, Petrik and Herzwurm [14], [15], [16] have used MindSphere as single case study to research its platform ecosystem, platform boundary resources, partner relations and complementors.

In view of this in-depth research, it has been somewhat neglected that Siemens also offers the IoT platform Railigent (or in the company’s wording, “application suite”) that is positioned to serve the industry vertical of rail transportation. Notable exceptions are Lorenzo [17] and Visnjic, Birkinshaw, and Linz [18], who highlight aspects of the platform’s value co-creation processes and partner relations as remarkable characteristics. The present paper extends their work with an in-depth case study of Railigent’s platform architecture, its business model, and the platform ecosystem management to enhance the understanding of a market-specific IoT platform solution for rail transportation. The case study approach is based on an archival analysis of publicly available documents such as company reports and presentations, press releases and news articles.

## II. Commercial Background

Siemens AG is one of Germany’s leading technology firms offering industrial automation and digitization software and hardware, smart infrastructure solutions for buildings as well as mobility products and related intelligent software. These fields are covered in three core industrial businesses – Digital Industries, Smart Infrastructure and Mobility.

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In addition, the firm owns the consulting branch Siemens Advanta and other operating units bundled in the Portfolio Companies [19, p. 10]. Siemens AG works together in an ecosystem with the publicly listed subsidiary Siemens Healthineers AG, in which Siemens AG holds a majority stake, and Siemens Energy AG, an associate in which Siemens holds a minority stake [19, p. 9], [20].

Siemens Mobility GmbH is a wholly-owned subsidiary of Siemens AG in the legal form of a German limited liability company, which has been classified as a strategic company until the spin-off of Siemens Energy AG and is responsible for the mobility business [21]. One of the most successful offerings of Siemens Mobility GmbH is the “application suite” Railigent, which can be described as a stand-alone platform solution that is dedicated to offering IoT services to the rail industry. However, elements of the technology stack are connected to the much more comprehensive MindSphere platform that aims to enable the IIoT across many vertical industries [22]. Whilst MindSphere is offered and implemented by Siemens AG, Railigent was developed and commercialized by Siemens Mobility GmbH before the introduction of MindSphere. Nowadays, Railigent is offered exclusively by Siemens Mobility GmbH and available in more than 30 countries, where the platform supports more than 60 rail transport operators and 1.500 vehicles worldwide, both “private or state transport companies or train and infrastructure owners or manufacturers” [23, p. 6], [24].

It targets digital services for the rail industry as a data analytics platform for Availability-as-a-Service (AaaS) in the form of a MindSphere-based application suite [25, p. 6]. A version 2.0 was released in July 2018, and a third version in December the same year [26]. Railigent is therefore one keystone in Siemens Mobility GmbH’s approach to capitalize on what the firm calls “data opportunity” in the mobility sector, representing use cases that could add nearly US$100 billion per year to the global economy [27, p. 9].

## III. Platform Architecture

### A. *Interaction with Siemens MindSphere*

The platform architecture is comparable to MindSphere itself, although it differs in many aspects. Railigent is based only in parts on MindSphere, which forms the technological foundation in core functions like the data connectivity, data handling and system security [23, p. 11]. On top, Railigent uses its own cloud-based platform layer, which is open for customers and partners [26]. This layer builds the basis for rail-specific applications with specific data models, format translators that are adjusted for usage in the rail industry, and tailored data analytics models; applications and components can be supplied and developed by customers and partners [23, p. 11], [26].

### B. *Data Connectivity*

Similar to MindConnect that is used by Siemens for MindSphere, Railigent has introduced Railigent Connect for data gathering as a “modular and flexible software and hardware solution” [28]. This connectivity toolbox is based on the data capture unit MindConnect Rail and creates a secure transmission via MQTT for streaming data, or otherwise batch data upload, to the data lake analogous to MindSphere where it is securely stored [23, p. 11], [28]. After the decryption of the data and categorization, it is marked with identifiers, and a generic JSON file remains in the data lake [23, p. 11].

### C. *Cloud Layer*

Originally, Siemens Mobility GmbH had offered an on-premises solution with functionalities comparable to Railigent, which however showed disadvantages due to siloed data, manual data analytics and low response time [29]. Moreover, modern locomotives produce a massive amount of about 700-800 million data points annually, which is difficult to process without a cloud’s automation features and computing power [30, p. 3]. Therefore, it was decided to use a cloud-based data lake hosted by Amazon Web Services, with a technology stack of third-party technologies that comprises Teradata Aster, Spotfire, Spark, Hortonworks and Talend [31, p. 12]. This cloud architecture is more favorable:

> “In our AWS data lake, we can store large unstructured datasets in Amazon S3 and use the Amazon Athena schema-on-read capability to create virtual tables for specific new use cases as needed. (…) Cloud services like Amazon EMR, Amazon S3, and Amazon Athena give us much more flexibility in dealing with data than would be possible on premises or even with other public cloud providers.” [29]

The architecture enables Railigent to make use of reusable application components that are provided to its complementors alongside toolboxes, higher data processing and transformation capabilities, and serverless orchestration, integrating the four AWS accounts for sandbox, development, test and production [32, p. 3]. If the data model is still being developed, analytics is conducted sandboxed, otherwise in full; most of it with supervised machine learning or deep learning [23, p. 12].

### D. *Application Layer*

The algorithms are generalized and use case independent, but adjusted to rolling stock and infrastructure, and various analytics libraries as well as mathematical approaches developed by Siemens are used [23, p. 12]. Languages are mainly Python, pySpark and R, depending on the use case [23, p. 12]. Data is analyzed and cleaned with the TIBCO Spotfire software at the edge while a train is rolling [33, p. 1]. Applications are composed based on micro services that are bundled in an UI framework [26]. Moreover, Railigent uses the RDS Microsoft SQL Server Web Edition [32, p. 4]. In the meantime, Railigent offers “hundreds of applications” to solve rail-related problems for its customers, which enable around 250 employees to perform data analytics that add value for the customers [29].

In the beginning, Railigent was limited to mainly analyze Siemens-own systems; opening it up for third-party applications and development partners has made it more attractive for customer companies that are involved in the development process [34]. The customers thus profit from a reliable and secure platform with differentiating adjustments for the rail industry branches, to generate relevant insights without the need for Siemens Mobility GmbH to always develop entirely new solutions [23, p. 11]. Designed as a modular platform, Railigent offers “customized solution packages” with reports tailored to the customer [31, p. 14]. It is scalable in a sense that it offers upgradeable solutions in a spectrum from basic to advanced and provides an openness based on an interoperability in different environments with standardized interfaces. For example, Railigent can integrate information provided by an Enterprise-Resource-Planning (ERP) system via an API interface [35]. The user interface offers analyses for three target user groups: rail management, dispatchers and maintenance engineers [36, p. 10].

Railigent is accessible in a control and operations center with either screens for the control center staff or a direct push alarm to the tools available at the customer's control center. In the first case, both a visual alarm on the screens or a SMS to a control staff's mobile phone could be sent, but the final configuration depends on the customer's technology landscape [30, p. 3].

### E. Platform Security

The cloud infrastructure emphasizes security aspects with an integration of CloudCheckr that supports its monitoring and allows for infrastructure security after adjustments of Railigent's security protocols based on a Continuous Integration and Continuous Deployment (CICD) pipeline with Jenkins and Self-Healing Automation [26], [32, p. 2]. VPN tunnels protect the "train-to-ground"-data transmission, and further measures prevent "man-in-the-middle attacks", ensure a secure access and inhibit faulty code to enter the train's network from the outside [23, p. 19]. Like MindSphere, Railigent is certified under IEC 62443 [23, p. 19]. A prioritization of security problems also helps to reduce related cloud costs by up to 20% [32, pp. 3-4]. The platform is updated frequently [30, p. 7]. Siemens Mobility GmbH has its own "Computer Emergency Response Team" that monitors customers' systems to identify vulnerabilities, and conducts hacking tests within Railigent [23, p. 19].

Data sharing is restricted with non-disclosure agreements between Siemens Mobility GmbH and the customer, which does not allow for a sharing of raw data to other parties, but sharing of algorithms remains possible [23, p. 20]. Especially machine learning algorithms are frequently shared with partners to enable them the creation of applications [37, p. 16].

## IV. Platform Business Model

### A. Business Objective: Establishing the Internet of Trains

Railigent is a platform for the transmission, visualization and analysis of data including the application of algorithms for predictive error identification [38]. Its main purpose is that of a classical IoT platform connecting data points collected by sensors. It saves them, and enables the usage of data analytics methods for an improvement of asset availability for customers; especially rail operators, which are aiming to follow an accurate schedule by avoiding unanticipated maintenance [38]. Rail assets could be rolling stock like vehicles with telematic systems, infrastructure like tracks, or signalling systems [26].

Issues to avoid are for instance "rail defects" in trains, tracks, and signals, which could be caused by fractures and stress of tracks and warps, that should be detected early on to enable an instant repair [29]. A holistic view of the railway system therefore combines rail asset data of rolling stock, signalling and infrastructure [39, p. 10], focusing on the track-wheel interface by synchronizing vehicle and track data [40, p. 488]. Weather and traffic data offered by third parties is integrated [41, p. 2]. This has been coined as "Internet of Trains" by Siemens [39].

### B. Customer Data as Key Resource

Within Railigent, all data is bundled centrally and not only spatially dispersed available for analysis [28]. However, data analysis is performed also decentrally, comprising sensor systems, control, and automation systems, as well as operations and enterprise management data [39, p. 7]. This type of edge computing, where data is processed in proximity to the IoT devices, is expected to increase in relevance due to the growing volume of data and might necessitate the expanded usage of distributed processing capabilities [42]. Three types of data can be collected, analyzed, or created with Railigent [23, pp. 9-11]:

*1) Process data:* This type of data is collected during the operation of the rolling stock or infrastructure sensors and is continuously produced over time in massive amounts.

*2) Diagnostic messages:* They indicate a failure that has been identified and alerts that a system is running outside of its parameter space.

*3) Log messages:* These are created with every change in the state of a component. This results in a large variety of types and legacy formats, and could also include work orders, the movement of spare parts and images.

The data is either live data for a prediction horizon of 10 to 12 hours; or historical data if the data transmission depends on USB or hard discs for a prediction horizon as long as three to four weeks, which usually comes in the form of batch data and is less expensive than real-time connectivity [30, p. 6]. In the case of rolling stock, the sensors build a network of intelligent nodes that are positioned across a train and comprise the sensor itself, a power source, microcontroller, and a data transmitter for connecting the sensor with the TCP/IP protocol [23, p. 10]. The data of the on-bard train diagnostics system, for example based on a running gear diagnosis, can be combined with characteristic features of the train and infrastructure, which is then provided as information to the operator [40, p. 495].

This process and diagnostic data alongside maintenance and configuration data can then be used to make an analysis of the present state, as well as a prognosis of future states and trends; when being coupled in Railigent and becoming a "Digital Twin", this allows for a holistic configuration management (CMMS) and combination of the physical and virtual worlds, which very much characterizes the ultimate digitization objective of Siemens [40, p. 495]. The data can then be analyzed by Siemens Mobility GmbH or the train operator and is used to generate a comprehensive insight into the current state of the train system and potential problems that could reduce the availability of the train service. Railigent is thus a platform solution for the "entire value chain from data transmission to analytics and provision of action proposals" [43, p. 22].

### C. Main Value Propositions

The application suite aims to improve three maintenance strategies for rail operators [23, pp. 7-8]. When using condition-based maintenance, a train or infrastructure device is repaired once a condition has been identified. By using data analytic capabilities, Railigent can then recognize and resolve the problem faster and more accurately. Second, using the platform helps to schedule maintenance activities planned in intervals more efficiently due to a life-cycle transparency. It also allows for a preventive maintenance scheme, in which parts can be repaired and changed before they develop a fault and potentially harm the system. With this predictive maintenance approach, a repair is only carried out once a component wears, which helps to reduce unnecessary routine checks. Some of the relevant benefits claimed by Siemens Mobility GmbH are listed in Table I, derived from [29], [35], [40, pp. 492-493], [45, p. 18].

TABLE I. PROMISED BENEFITS OF RAILIGENT FOR RAIL CUSTOMERS

| **Value Dimension** | **Description** |
|---|---|
| Availability | Increases availability to more than 99%; reduces costs for maintenance and energy consumption by 10-15% utilizing predictive maintenance methods. |
| Efficiency | Optimizes planning capabilities and accuracy for less delays (20%) and fewer downtime (30-50%); trend analysis; linkage of railway system components; lower capital expenditure due to reduced excess capacity. |
| Transparency | Allows for real-time monitoring of assets based on GPS position and sensors, less transfer to maintenance (>30%); quicker report generation time (50%). |
| Root Cause Analysis | Fast diagnostics for fault identification and resolution; constant surveillance of critical components. |
| Sustainability | Fewer part replacements over life-time necessary, requires less resources due to predictions about the remaining useful lifetime and lower life-cycle costs. |

All these measures help to increase the availability, which promises large savings for the rail operators. McKinsey [44, p. 7] have estimated that the market's savings potential when using condition-based and predictive maintenance are up to €4 billion for rail operators and €2 billion for rolling stock Original Equipment Manufacturers (OEM) in reduced maintenance costs. Most importantly, Railigent allows for data-based diagnostics and for a shift from time-interval maintenance to condition-based and predictive maintenance as servicing strategies [40, p. 493].

For realization of its "Internet of Trains", generally four layers of value propositions that build upon each other and serve customer needs are aimed for by Siemens Mobility GmbH as the platform owner and service provider [39, p. 6]:

- Target of the platform owner is a guaranteed availability of rolling stock and infrastructure at all times based on the optimization of maintenance intervals.
- The platform offering should be commercialized at competitive cost, which can be achieved by promising a high energy efficiency and the optimization of maintenance cost.
- In addition to constantly available assets, the platform should allow for operations management in real-time to enable rail operators a guaranteed service offering with these assets.
- Ultimately, scheduling of the rail services should follow end-customer demand based on data-driven demand modelling, facilitating "Mobility-as-a-Service" (MaaS).

### D. *Role of the Platform Owner*

The business processes backing the IoT platform for rail transportation are more centralized than observed for most industry-agnostic IoT platforms, as it requires in many cases the direct involvement of the IoT platform owner as service provider; in the case of Railigent, Siemens Mobility GmbH fulfills these two roles [23, p. 14]. The service provider receives operational data and access from the rail operator, who in return performs the analytics and identifies possibilities for optimizations that is fed back to the rail operator.

This means that the Railigent team performs the service on behalf of the train operator, after it has identified areas for maintenance based on the analytics conducted in Railigent with the train operators' data; the service could be offered in a spectrum from a full-service by Siemens Mobility GmbH to a smaller analysis share depending on the rail operator's expertise [23, p. 15].

Potential services and improvements could be done by visualizing the train's condition and locating it, by monitoring single components and sub-systems for failure modes, and by predicting potential machine problems and their impact on the network [23, p. 15].

> "In the case of [German national train operator] Deutsche Bahn, we have been monitoring the bearings, the gearboxes, motors and other elements since October and we have not overlooked a single component failure – I am very glad that we managed to pick them all up." [46]

The most important customer segment are thus rail operating companies, which provide a steady revenue stream based on service fees out of a service contract [23, p. 13].

## V. PLATFORM ECOSYSTEM MANAGEMENT

### A. *Ecosystem Actors and Stakeholders*

Railigent is embedded in and dependent on a platform ecosystem that is centric to the rail industry, after Siemens Mobility GmbH conducted more than 130 projects with over 80 customers in 35 countries based on Railigent services [47, p. 3]. The platform ecosystem is described as "open ecosystem for best-in-class rail applications – powered by MindSphere" [48]. In general, the ecosystem of an IoT platform for rail transportation involves several different groups of actors. The most important of these stakeholders are summarized in Table II based on the analysis by [23, p. 7], exemplary for the sub-industry category of cargo rail in Germany.

The best position in the ecosystem have operators and manufacturers, as they own a large proportion of the generated data in the rail system. Siemens Mobility GmbH's current complementor partners in the ecosystem comprise 23 firms [48]. A mix of small and medium-sized enterprises (SME) and corporations, they provide software and hardware solutions, or support with security and implementation consulting. Most of them offer specialized products or services tailored the rail industry. Although many firms are based in Germany like Siemens Mobility GmbH, some are located in neighboring countries of Mainland Europe or the United Kingdom.

The open ecosystem allows for an integration of third-party applications just like MindSphere, but mainly from leading rail companies, and it is also open to some competitors of the platform owner [29], [33, p. 3]. The ecosystem is integrated in a sense that it comprises partner firms for the whole value chain from sensor to report generation [24]. Railigent therefore profits from a combination of Siemens Mobility GmbH's domain knowledge and the rail expertise in its ecosystem [32, p. 2].

TABLE II. RAILIGENT ECOSYSTEM ACTORS FOR GERMAN CARGO RAIL

| **Stakeholder** | **Description** | **Example** |
|---|---|---|
| Original Equipment Manufacturer (OEM) of rolling stock / Manufacturer of infrastructure | OEM manufactures trains and locomotives, potential integration with sensors for collecting data; manufacturer of infrastructure develops and manufactures tracks or signaling devices, also with a potential to collect data. | Siemens Mobility GmbH |
| Owner of rolling stock / infrastructure | Owners of rolling stock and/or infrastructure, as well as data that is potentially collected by these assets; could also operate assets. | Deutsche Bahn AG |
| Operator of rolling stock / infrastructure | Provides the transport service to end-customers, relies on the monitoring of collected data for maintenance management. | DB Cargo AG |
| IoT service provider / IoT platform owner | Offers data analytics platform allowing operators to generate insights on train status and availability for more efficient maintenance planning. | Siemens Mobility GmbH |
| Maintenance service provider | A third party that provides maintenance for the rail operators' trains if they decide to outsource it. Requires data access. Could be the IoT service provider, as well. | Siemens Mobility GmbH |
| Software / Hardware Complementors | Develop applications for Railigent, e.g. as component suppliers, provide analytics or sensor technology for the technology stack. Could also be the IoT platform owner. | Knorr-Bremse AG |
| End-customer | Could be public passengers or logistics companies using the train to transport goods, expect high reliability and punctuality. | Kühne + Nagel International AG |
| Rail regulators | The operation terms of the rail industry and potentially the data transmission and storage are highly regulated as critical infrastructure by governmental bodies. | Federal Network Agency |

## B. *Management of Partner Relations*

A major target in Railigent's third release was to provide features for a better partner integration and simplified access to analytics elements and real-time data handling [26]. Siemens Mobility GmbH has recognized the need to view their asset management as an "Outcome-as-a-Service" (OaaS) paradigm that adds customer value by utilizing outcome-based partnerships, rather than technical support agreements [39, p. 16]. Especially for the creation of the full IoT technology stack, technology partnering was required for data transfer, data integration as well as data management and storage [31, p. 11].

Relationships with customers are preferably long-term oriented, which is why Siemens Mobility GmbH focuses on a problem-based service approach providing the suitable solution for a given problem; this might not necessarily involve data analytics, but rather "identifying the question and then trying to solve it with the means [at disposal]" [30, p. 2].

Railigent customers comprise rail operators and asset owners. Examples are the British rail operator Thameslink, in the USA the Metropolitan Atlanta Rapid Transit Authority and Charlotte Area Transit System, the Hispanic rail operator Renfe, the Russian national railway RZD, and DB Cargo in Germany as described in detail [49], [50]. The Railigent ecosystem is embedded in the extensive industry-specific "Alliance for Availability", in which the unit Siemens Mobility Customer Service bundles different processes, technologies and expert knowledge in cooperation with partners from the rail industry, suppliers and universities [51]. Increasing competition outside of Europe, for instance in China, might incentivize rail industry stakeholders to seek further opportunities for collaboration on the Railigent platform [23, p. 16].

> "I believe that partnerships around sharing risks and gains will become the norm. Siemens can provide expertise and partners, but customers need to learn to think in value networks to be able to get most out of such offerings." [52]

To enhance the attractiveness of Railigent for both partners and customers in the market, the platform is actively marketed and branded as "powered by MindSphere" which has a prominent position as a considerably larger and leading IoT platform for industrial purposes. Railigent is nevertheless advertised as its own registered trademark that is actively used for marketing and sales purposes both by Siemens AG and Siemens Mobility GmbH [53, p. 4].

## C. *Value Co-Creation Processes*

It is an increasing phenomenon that the manufacturer of the rolling stock also services the trains on behalf of the train operator [23, p. 16]. For this purpose, Siemens AG has established 14 MindSphere Application Centers (MAC) across the world, in which data analytics teams co-create applications with customers and perform data analytics tasks for maintenance purposes based on MindSphere, but also Railigent insights when rail-related solutions are developed [47, p. 3]. These agile teams use existing and reusable analytics solutions and adjust them to the specific rail customer's use case [26]. Several of these MACs directly extend Siemens Mobility GmbH's own Data Services Centers (DSC) focusing on the rail industry; they are locally dispersed to allow for catering to the needs of a country's legislation and regulation [26]. Embedded in a global network, they are thus adapted to local specificities but utilize a pre-defined number of tools and processes shared by all MACs, with a central function responsible for product development [26].

A two-fold strategy steers the development of offerings like Railigent: main elements are developed in the Siemens Mobility GmbH headquarters, but at the same time the platform allows for decentralized co-creation of solutions in a DSC with agile teams and at the location of the customer [54]. The process facilitates the repair to being scheduled based on insights generated at a DSC, enables the maintenance to function like a "pit stop", and includes efficient documentation:

> "In the example of Siemens' Thameslink operations in the United Kingdom, 40 per cent of all corrective maintenance tickets are created automatically by the Railigent system, while the other 60 per cent come from data fed from the system to the maintenance desk, where it is assessed so appropriate work orders can be created while the train is still on the tracks." [35]

The largest DSC is located in Munich-Allach, where Siemens Mobility GmbH also manufactures locomotives [44, p. 17]. In the meantime, more than 500 trains are monitored there [49]. Other DSCs have been established in the United States, United Kingdom, Russia, China and Australia [31, p. 17]. This proximity to the physical assets, maintained in the DSC and connected to the MAC, has advantages for the data analytics team [55]. They need to a degree access to domain knowledge for developing and applying the data models on a data structure that is industry-specific; the implementation is conducted by the customer or Siemens Mobility GmbH [31, p. 16], [39, p. 15], [41, p. 2].

> "From my experience, the best way to implement digital technologies in a rail operator business is to bring together domain experts from maintenance and operations, software developers and data analysts in small data labs. These labs should focus on specific problems in operations or maintenance and deliver a first end-to-end implementation." [52]

It has turned out over the course of Railigent's usage that proximity to the customers and speed in the development process is favorable. Siemens Mobility GmbH has therefore formed an "agile accelerator team", that develops customer insights often in collocation within a week and provides first web-based functionalities to the customer [26].

## VI. Conclusion

The case study of Railigent highlighted the characteristics of an IoT platform for rail transportation from an architectural, business model and platform ecosystem perspective. Whilst the platform architecture is comparable to more generic IoT or IIoT platforms in the industrial market, it has become evident that the platform business model and surrounding platform ecosystem are tailored to the rail industry.

More than observable in other industries, the platform owner also fulfils a role as service provider, given that Siemens Mobility GmbH applies their own platform solution to offer maintenance services for rail operators. Although this contradicts the idea of platformization and weakens potential network effects that might usually be desirable – as evidenced by the relatively small platform ecosystem – this very much takes the limitations of the market structure with few OEMs and large-scale service providers into account. It might have contributed to overcome the chicken-and-egg problem of attracting platform users and ecosystem participants. The prominent position of Siemens Mobility GmbH as reputable rail manufacturer and servicing firm has likely also accelerated an adoption of the platform in the market.

Furthermore, the platform ecosystem resembles around firms that specialize in the rail industry and it offers few incentives for more generalized businesses to partake. This might be attributable to the characteristic of the rail industry as highly regulated industry and to the concentrated market structure. Siemens Mobility GmbH can also profit from its strong market position that existed prior to the introduction of Railigent as servicing platform, as such a reputation generally simplifies the forging of partnerships with complementors and management of a platform ecosystem. The IoT platform solution then constitutes an additional environment for collaborations that contributes to further innovative projects.

All in all, the case indicates that at least for some industries their characteristics might play a role when a platform owner attempts to develop and deploy a commercially successful IoT platform. This would provide some empirical substantiation for the utilization of verticalization as IoT platform strategy.

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