Impact of Platform Openness on Ecosystems and Value Streams in Platform-Based PSS Exemplified Using RAMI 4.0

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Abstract. With the digital revolution, the IoT (Internet of Things) platform approach emerges as a supportive way for the implementation of IoT platform-based Product-Service System (PSS) offerings. To exploit the full potential of the platform economy and considering the complexity of the multitude of different actors in all the lifecycle stages, value creation architectures for digital and service platforms are one of the critical points to develop. In this work, the concept of Platform-based PSS is presented, and for representation purposes, an extension of the RAMI 4.0 reference model has been proposed. Specifically, the ecosystem perspective has been added to RAMI 4.0, to approach Platform-based PSS with a multi-actor lens. Moreover, the different contributions and benefits of the main participants in Platform-based PSS are illustrated. Therefore, three different scenarios have been exemplified with the proposed RAMI 4.0 extension relating the actors` possibilities to contribute to Platform-based PSS to the level of openness of a platform.

Keywords: Platform-based PSS, Platform openness, RAMI 4.0, Ecosystem

1. Introduction

Digital solutions and communication technologies transform the daily life of people and companies “as fundamental as that caused by the industrial revolution”[1]. However, with the rise of digital platforms and platform economies like e.g. Siemens MindSphere, or the Amazon Market Place, a wide spectrum of challenges regarding the infrastructures and the society have to be addressed reaching from wireless network and computing capabilities, to data ownership and security. While meeting these challenges, the European Commission Data Strategy strives to utilize industrial and commercial data in a common infrastructure to cope with the massive data growth as well as to utilize the business potential [2]. One of the key themes for research and development is the value creation for Industry 4.0 and digital servitization that represent two of the most impacted field from platform approach. This includes the understanding of networks with dynamic value creation along the lifecycle as well as value creation models and data valuation. Furthermore, value creation architectures for digital and service platforms [3] are a main development need. Companies show confidence and invest resources to support their servitization approaches with platform-centered architectures with a trend into modularization [4]. Thus, companies use a multitude of technologies and layers (structural tiers of the architecture) to complement their specific infrastructure and business needs [5]. Platform openness is among the decisions that goes to impact the ecosystem configuration and enable different value creation mechanisms, both to the end-users, the platform and to the application developers [6]. Additionally, the design of the architecture for each individual ecosystems have to be determined. Both aspects, the opennens and the architecture of the ecosystems are not fully understood in industry and research, and thus, represent the research gap for the paper. Moreover, openness is the only viable approach to achieve the European strategy. Therefore, the main objective of this paper is to analyze the different layers of platforms in correlation with interdependent value creation, providing an exemplification on how an open reference architecture model for Industry 4.0 supports this scope. The paper is structured as follow: Section 2 presents Platform-based PSS and platform openness. Industry 4.0 reference models are also presented, since they represent the starting point adopted to describe the Platform-based PSS. Section 3 explains the extension of RAMI 4.0 to address the Platform-based PSS representation while Section 4 exemplifies the ecosystem perspective of the architecture with three different scenarios. Section 5 concludes the work.

2. Background

2.1. Platform-based PSS and platfrom openess

This paper defines a Platform-based PSS as a Product Service System (PSS) that relies on an IoT Platform Technology stack for their operations. This stack can be represented by three essential elements (Fig. *1*): (i) Constrained Devices, (ii) Gateways and (iii) IoT cloud Platform [7]. *Constrained Devices* are the physical end-products of a PSS generating data via sensors or interacting with the environment via actuators. Often these products are limited in their IoT capability, due to, for example, constraints in power supply, computing capacity, etc. The *Gateway* helps overcoming the limitations of constrained devices, e.g. by bridging network latencies or compensate for incompatibilities between different end-devices. Many gateways are able to execute software code and manage an IoT Ecosystem even when a connection to the IoT Cloud platform is lost (edge computing). Finally, the *IoT Cloud platform* is the backend, typically implemented via a cloud infrastructure due to cost and scalability reasons. It executes various digital services, e.g. device and data management, thus enabling smart services. In addition, platform-based PSS differ in the type of data and information that is evaluated in the context of providing offers. Depending on the use case, different types of data are the main asset of individual digital services, such as business data for business forecasts, operational data for predictive maintenance, user data for customization, etc. [8]. Depending on the data, different analysis goals are also pursued and different algorithms are required to achieve these goals. Until now, data management in platform-based PSS and according industrial applications, especially in light of the digital twin, is not yet common practice for many companies [9]. In addition to the value-added by digital services, additional value can be created on platforms through network effects. These synergies arise when several end devices or stakeholders are networked on a platform and create added value, e.g. because more data is exchanged, more services are provided or more devices are networked [10]. In accordance, platform-based PSS derive competitive edge from an intelligent formation of their ecosystem.Therefore, the design of an ecosystem is essential to optimize the value co-creation of different stakeholders in platform-based PSS [11].

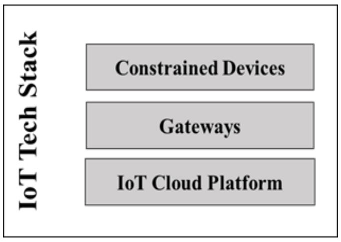

Fig. 1: Representation of IoT Technology Stack

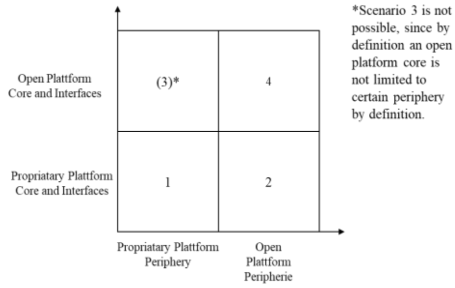

Fig. 2: Scenarios of Openness of Platform Core and Periphery (own representation)

The openness of a platform plays an essential role here, as it determines who can participate in a platform and thus what design options an ecosystem has. According to [12], platforms consist of a *platform core*, *interfaces*, and *periphery* that connects to the platform core through interfaces. While the platform core provides the basic functionality for the ecosystem to operate and is relatively stable over time, the periphery can change and is flexible. The openness of the platform core indicates the extent to which a company has proprietary access to the platform core and thus control over the entire platform and its design[13]. Fig. *2* presents scenarios depending on the level of openness of a platform core and it`s periphery. Today, many companies are striving to develop a proprietary, that should either extend the benefits of their own products exclusively (*Scenario 1)* or, in addition, integrate products and services from third parties (*Scenario 2*). From an economic point of view, platforms according to Scenario 2 gain considerable market power through hyper-scaling and winner-takes-all situation [14]. However, this situation allows a single company to control large markets, distort competition and possibly exclude third parties from these markets [15]. Open platforms with an open platform core do not focus on capturing profits, but enable broad participation (*Scenario 4*) and are therefore often politically driven.

2.2. Industry 4.0 reference models

To enable cross-domain interaction, facilitate system interoperability and compatibility and boosting the growth of IoT, different attempts have been made in the definition of a reference model and architecture for IoT systems [16]. Different working groups have proposed reference architectures and the two more discussed are the IIRA and the RAMI 4.0. IIRA model was developed in 2015 by the IIC and it is continually under refinement. It is composed of four viewpoints: business, usage, functional and implementation. It is based on the ISO/IEC/IEEE 42010:2011 standard. In this view, each layer represents a perspective of the stakeholder and decisions from a higher-level viewpoint guide, influence and impose requirements on the viewpoints below. The RAMI 4.0 architecture was developed in Germany in 2015 by BITCOM, VDMA and

ZWEI. It takes its roots in the Smart Grid Architecture Model and results as a three-dimensional structure that describes all critical component of Industry 4.0. The three axes are: The Hierarchy Levels, Life Cycle & Value Stream and Layers. The hierarchy level represents the production system, following IEC 62264 and IEC 61512 standards, adding the product and the connected world levels. They represent, respectively, the fact that Industry 4.0. needs smarter and connectable products and the resulting network of enterprises. The lifecycle and Value stream differentiates between the concept of a component and its creation. The vertical axis is composed of six layers, which represent the IT structure of an Industry 4.0 components.

3. RAMI 4.0 for the representation of platform-based PSS

The reference models mentioned before are domain-specific for different industries; nevertheless, as presented in some previous research and considering some limitations, the architectures are also suited to represent Platform-based PSS [18;19]. Indeed, it deploys Industry 4.0 scenarios outside the typical industrial environment [17].

In order to decide which model is the most appropriate for the scope, existing comparisons of reference models have been considered [20; 21] evaluating their views and viewpoints, as summarized in Table 1. Overall, it is possible to state that the RAMI model better fits the Platform-based PSS since it includes specific views, like the Asset and Lifecycle, that are crucial for the description of a general PSS. Additionally, some other works have made successful attempts to describe Platform-based PSS using RAMI 4.0. For example, [17] stated that the underlying design of the ICT platform of such services presents many interesting similarities with RAMI 4.0 and was able to describe a real case within the architecture. Bousdekis et al.,.designed a predictive maintenance architecture according to RAMI 4.0 and developed a unified predictive maintenance platform that can be exactly seen as one Platform-based PSS [18].

Table 1_ IIRA (1) and RAMI 4.0 (2) Viewpoint comparison (adapted from [19] [20])

	Business	Usage	Functional	Information	Communication System	System	Asset	Lifecycle/ Value Chain	Hierarchy
(1)	x	x	x			x			
(2)	x		x	x	x	x	x	x	x

In this work, an evolution of the RAMI4.0 is proposed, considering two changes to include important aspects of Platform-based PSS. The first one is an extension of the “Life Cycle & Value stream” dimension, adding the “Usage” phase. This extension is opportune because the actual service provision and data flow only start from the beginning of the Mid of Life phase. The second change is made on the Hierarchy levels, between “Enterprise” and “Connected world”. “Enterprise” level refers to factories where IT systems, like ERP, CRM, SCM, PLM are deployed and monitored on a usual basis. This level directly comes from the IEC 62264 standard, referring to the highest level of the smart factory. The “connected world” level is the representation of the possible integration of information between all different manufactures and IT systems. Authors included the “Ecosystem” between the two hierarchy levels, in order to describe the actors that participate in the value creation process and contribute to the Platform-based PSS. The ecosystem perspective has been recognized as a fundamental of Platform-based PSS, that should be approached with a holistic, multi-actor lens considering the collaboration of interfirm and intrafirm actors [21].

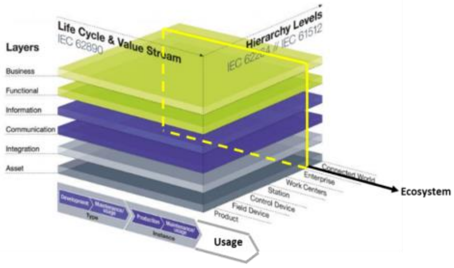

Fig. 3 Platform-based PSS RAMI 4.0 architecture (adapted from [22])

4. Exemplification of Ecosystem in platform-based PSS

Intending to represent the contribution of different actors in Platform-based PSS, we selected three examples, based on [23], that matched the scenarios described in Section 2.2 and exemplified them with the introduced “RAMI 4.0” architecture. Three main actors have been selected, that are: the product/service provider, the IoT platform provider, and the end-customer. The focus of the exemplification in this paper lies on the usage phase (*Life Cycle & Value Stream*) and *Layers*, so other *Hierarchy Levels* than the Ecosystem level and other life cycle phases other than the proposed Usage phase are excluded for simplification purposes. *Fig. 4, 5, 6* show the contribution and the benefits of the three actors in the three scenarios on the RAMI 4.0 layers, with grey and white boxes respectively. The three scenarios are the following:

- *Scenario 1*: ThyssenKrupp Max [24]. ThyssenKrupp is a manufacturing company of inter alia elevators. They developed a proprietary platform to deploy predictive maintenance services. The platform core provides data analytics services for failure predictions. Only ThyssenKrupp elevators can connect to the platform core, i.e. it is not open to third parties.
- *Scenario 2:* Siemens MindSphere [25]. The platform core enables data handling and usage of industrial apps that are operated through a scalable MindSphere backend architecture. The platform core is based on open source technology but is modified and controlled by Siemens due to proprietary interfaces. The platform allows connecting any third-party device.
- *Scenario 4*: Gaia-X [26]. Gaia-X is a German initiative designed to provide a safe and sovereign European data infrastructure. The idea of an open platform core is that it is not proprietary. Third parties cannot be excluded from using open platform cores. Consequently, any periphery can also use the platform.

From the representation, it is possible to see how different contributions to value streams are directly impacted by different levels of platform “openness”. In Scenario 1, the main value stream is related to the customer data flow that comes from products enabling the provision of more efficient maintenance services and greater elevator uptime for the customer. Those data linked to the provision of analytic capabilities enable also ThyssenKrupp to enhance its asset and reshape business models. Indeed, operational data feed predictive maintenance algorithms and enable service field operators to better schedule required activities and perform them proactively. Other data may also feed the system, e.g users may directly provide feedbacks during the elevators utilization. This creates a direct link between end-users and the manufacturer and enables the latter to enhance customers' final experience.

Ecosystem level – Usage phase

	P/S - Thyssenkrupp	IoT (Microsoft)	End Customer
Business	New business models may be deployed Revenues from products, service, platform subscription	Indirect revenue from product sales or PSS contracts	Reduction in down time and improvement in efficiency Risk- sharing
Functional	Customer data used to enhance functionality and provide proactive services Product and customer visibility	Platform uptime Computing power Back-end functionality	Access new functionality and services
Information	Different internal unit can access data (service tec., R&D, Marketing) Know-how help to transform data into information	Algorithms	Access information on one asset typology
Communic.	Proprietary gateway (Controller Box)	Elevators are connected to the Azure IoT Hub via MQTT	
Integration	Creation of a large data base to run analytics	Tens of thousands of Thyssenkrupp`s elevators are integrated	
Asset	Customer data used to enhance product and service Elevators	Server infrastructure	Elevator operational data; service data; user feedbacks

Fig. 4. Scenario 1. Ecosystem level on RAMI4.0 for Platform-based PSS (own elaboration)

Ecosystem level – Usage phase

	P/S providers	IoT (MindShpere)	End Customer
Business	New business models may be deployed Revenues from products, service, platform subscription Use 3rd party services to enlarge portfolio	Royalties from third party P/S providers Network effect	Improvements where services are provided Risk- sharing Network effect
Functional	Customer data used to enhance functionality and provide proactive services Product and customer visibility	Selected actors are available to develop functionalities; documentation and developer forums, marketplace Back-end functionality	Access various functionality and services
Information	Multiple function can access insight generated by algorithms Know-how help to transform data into information	Several ML and IA analytics tools Platform governance	Access information and insight at system levels
Communic.		Flexibility due to different protocols Mindconnect, proprietary solution uses open communication protocols such as HTTPS, MQTT or PC UA	
Integration	Multiple devices can be managed through a single IoT platform; multiple information and system may be integrated	SDKs and APIs for third-party developers	System level vision may be reached
Asset	Customer data used to enhance product(s) and service(s) Products	MindSphere can be run on different infrastructure (e.g. AWS, Azure)	Product data

Fig. 5. Scenario 2. Ecosystem level on RAMI4.0 for Platform-based PSS (own elaboration)

In Scenario 2, the functionality of the platform core is handling data and making MindSphere apps available for various applications. The openness to third-party providers also allows for synergy effects as external developers provide apps and other manufacturers connect their devices to the MindSphere platform core, enabling the creation of multiple application at the functional layer both to the end customer and to the P/S provider(s) and network effects at the business layer. MindSphere enables multiple data flows to be integrated together, not only from devices but also for different customer databases and enterprise systems such as ERP, MES and SCADA enabling the possibility to create system-level visions and whole context analysis. In Scenario 3, additional value creation mechanisms are made possible since data are available for all users and a common standard for data and communication interoperability is defined enhancing trust. All users may contribute to the creation of a single database that can be accessed by all participants as well as to the development of new applications and functionalities that contribute to the creation of networks effect, even at the information layer. Even the technical details are still under development, information is accessible to every stakeholder although ownership remains with the data creator. Since the platform core is not proprietary, no profit can be captured so that no data-driven business model for the IoT platform provider is possible.

Ecosystem level – Usage phase

	P/S providers	IoT (Gaia X)	End Customer
Business	New business models may be deployed Revenues from products, service, platform subscription Use 3rd party services to enlarge portfolio Network effect	Network effect	Improvements where services are provided Risk- sharing; Network effect
Functional	Customer data used to enhance functionality and provide proactive services Product and customer visibility	Everyone may deploy new platform functionality Back-end functionality	Access various functionality and services Possibility to develop its own application
Information	Access insight generated by algorithms Different cloud services may access data Synergies of competences – Network effect Know-how help to transform data into information	Network effect Platform governance	Access information and insight Network effect
Communic.	Different cloud services easily interact	Single and shared standard for sharing data	
Integration	Multiple devices can be managed through a single IoT platform	Open data infrastructure Structure for data interoperability	End to end visibility may be reached
Asset	Customer data used to enhance product(s) and service(s) Products, data	Server infrastructure	Product data

Fig. 6. Scenario 3. Ecosystem level on RAMI4.0 for Platform-based PSS (own elaboration)

5. Limitations and Outlook

The presented work is a first approach to exemplifying platform-based PSS with an enhanced RAMI 4.0 reference model. The adoption of a three-dimensional model reflected difficulties in the representation of all axis at the same time and even using only a partial model to exemplify the three scenarios, connecting the layers and describing all relations between them was difficult. Further studies may consider the integration of all the other axis into one single representation, the diversification of different value creations paradigm and formalization of relations between value creation processes of different stakeholders. Furthermore, value creation is closely linked to the development of business models, which are addressed by the layer "Business". However, there is no defined notation for representation of a sophisticated business model logic as, e.g. monetary flows, risk distribution and legal aspects should also be presentable. This limitation should be addressed in the future to take full advantage of RAMI 4.0 for business model development. Finally, in our example, a deeper analysis into the overall structure, starting from the data typology, to the duration of storing, aggregation and analytics to be applied to deploy applications.

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