Role of Industrial Internet Platforms in the Management of Product Lifecycle Related Information and Knowledge

Karan Menon(✉), Hannu Kärkkäinen, and Jayesh Prakash Gupta

Tampere University of Technology, Tampere, Finland
{karan.menon, hannu.karkkainen, jayesh.gupta}@tut.fi

Abstract. This paper addresses the data, information and knowledge management challenges in product lifecycle management (PLM) using novel industrial internet/industry 4.0/cyber-physical system platforms. PLM is quite seminally related to data, information and knowledge, and about getting these properly to serve a company's business and product development as well as to create value for the customer. We analyze Industry platforms, that are enabled by industrial internet based technologies as well as certain collaboration and social media platforms that help solving certain PLM challenges. This analysis will allow companies to make informed decisions while selecting platforms to solve their PLM challenges.

Keywords: Industrial internet · Industry4.0 · Platform · PLM
PLM challenges

1 Introduction

Product lifecycle management (PLM) can be defined as a systematic and controlled concept for managing product related information and products throughout the whole product lifecycle [1]. PLM is quite seminally about data, information and knowledge, and about getting these properly to serve a company's business and product development (e.g. [2–4]), as well as to create value for the customer [2].

However, there are various challenges related to accessing and managing all relevant data, information and knowledge related to products' lifecycle, which is often due to the fact that such relevant information may be dispersed among a number of various actors, who also have their personal conception of the product and its performance [5]. Relatively recently, it has been understood that various technologies and approaches related to Internet of Things and Industrial Internet, such as sensors, machine-to-machine communication and various types of platforms can, however, offer quite important and novel solutions to the management of product lifecycle information, such as providing access and real-time insights to the data of many PLM-related actors.

For instance, the flow of real time data from the various sensors across the value chain will enable for the first time the chance to observe the entire value chain instantly. This will enable the optimization of the entire value chain rather than some part of

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it [6]. Hence, industrial internet will go way beyond the traditional factory automation and will reduce the transaction costs for every transaction in the value chain. Yet, partly due to the recent maturation of many industrial internet related technologies and concepts, there is relatively little research that study the possibilities of industrial internet to PLM field. One of such topic is the role of various types of industrial internet- related platforms to enhancing the management of relevant data, information and knowledge related to products' lifecycle and different lifecycle phases.

The significance of platforms has grown increasingly (e.g. [7]). Importantly, platforms and platform-like digital services can provide new ways to access and accelerate the capturing of data and converting it into insightful information and knowledge. The role of various platforms, industrial internet–related platforms in particular, in the context of PLM and in facilitating the management of product lifecycle information has not been studied previously, according to our survey of current PLM and industrial internet literature [2, 6, 8, 9].

Thus, we have come up with the following research questions which will be addressed in this study:

- Which kinds of PLM related data, information and knowledge management challenges are addressed by novel platforms in industrial internet?
- How do the industrial internet platforms address the information and knowledge management issues in product lifecycle management?

To address the above research questions, this study will try to discover and analyse novel types of platforms from academic literature as well as other relevant sources. Selection of different types of platforms for further analyses, and evaluation of their capabilities to address the various challenges related to the management of data, information and knowledge in PLM context will be done.

2 PLM and Product Lifecycle Management Challenges

Product lifecycle management (PLM) can be defined as a systematic and controlled concept for managing product related information and products throughout the whole product lifecycle [10]. However, the focus of our study lies essentially in the management of data, information and knowledge related to products and product lifecycle, not e.g. product management as such. PLM aims to provide a shared platform for effectively capturing, representing, organizing, retrieving and reusing product-related lifecycle information across companies, and to support the integration of the existing software systems. PLM is often seen essentially as PLM software (either essentially a single PLM solution, or a large group of different types of solutions, such as PDM, CRM, ERP, excel sheets, various collaboration tools etc.). Commonly, however, PLM can be seen as a larger PLM concept which involves e.g. people, processes and technological solutions (e.g. [2, 11]). In our study, we focus on the latter, more extensive concept of PLM.

There are a number of different types of challenges related to the management of product lifecycle information. We will review some of the major challenges here, and analyse in later sections how such challenges can be dealt with through the novel

possibilities of Industrial internet and specifically the identified various Industrial internet platforms. Here, we focus on the important overall challenges of PLM that can most probably be addressed through means of Industrial internet and Industrial internet platforms, not e.g. topics related to standards.

There are various PLM-related literature reviews and outlook or survey-type of articles (e.g. [1, 5, 8, 12, 13]) and other found relevant generic articles on the broad topic of data, information and knowledge management in PLM context. The many challenges in the management of data, information and knowledge in PLM context are rooted in the long lifecycles of products (e.g. [14]); the transfer of information between product lifecycle phases (beginning, middle and end of life) and so-called "closed-loop" PLM (e.g. [1]); problems related to the extended enterprise and the collaboration and communication of companies, customers and other relevant actors with relevant expertise and knowledge during the lifecycle (e.g. [15]); the real-time accessing, transfer, management, aggregation and analytics of all different types of data, information and knowledge needed in PLM, including structured, not structured and even tacit knowledge of employees (e.g. [15]) as well as making sense of the data and connecting it to the decision making of various PLM-related processes. The goals and challenges of PLM might be very different in different types of companies, e.g. project-based or one-of-the-kind organizations vs. mass-customized or many-of-the-kind organizations (e.g. [4, 5]). The interoperability of Information Systems throughout the product's life cycle is primordial for a successful Product Lifecycle Management approach. The ability of two (or more) systems to communicate, cooperate and exchange services and data, thus despite the differences in languages, implementations, executive environments and abstraction models [12].

3 Industrial Internet Platforms

3.1 Types of Platforms

Platforms on a very broad level can be divided into "internal" or firm level platforms and "external" or ecosystem level (industry wide) platforms. This broad classification allows us to place external or industry platforms as key enablers for enhancement in the management of data, information and knowledge during the lifecycle of a product.

We take the definition of Industry Platform by [7]. According to them, *"industry platforms are defined as products, services, or technologies developed by one or more firms, and which serve as foundations upon which a larger number of firms can build further complementary innovations and potentially generate network effects."* External or Industry platforms are probably most relevant forms of platforms in the context of PLM, because they can enhance the management of data, information and knowledge not only internally, but also amongst the various organizational actors throughout the lifecycle phases (BOL, MOL, EOL).

In case of Industry or external platforms, there are differences in the degree of platforms' *openness meaning* how 'open' the platform is in order to let third party developers and companies to make applications over the platform using the data and information from the platform [7, 16]. In an external platform the degree of openness

can vary on a number of factors or dimensions [7]: the access to information in the platform to build applications can vary, the rules that allow the usage of platform can differ, and even the fee to get the access (license fee) can change. The more open the platform is in these three dimensions, the more easily it is for the different parties to access and share the relevant data through the platform.

3.2 Industrial Internet Platform Functionalities

Industrial internet, Industry 4.0 and CPS can be collectively defined as industrial systems that integrate computational and physical capabilities of machines in order to provide advanced analytics and interact with humans [9, 17–20]. In this study, we define industrial internet platforms as platforms which adhere to the general definition of industry platform (as in Sect. 3.1) and the industrial internet definition mentioned above.

In the context of product lifecycle management (PLM), there has been a marked shift in its vision, which would ideally mean the ability to access, manage and control product related information across various phases of lifecycle [5]. In case of PLM, industrial internet platforms can provide the real time management of data and information flows and help in the data-information-knowledge (D-I-K) transformations along all the phases of product lifecycle.

The industrial internet platforms can access data from different sensors, actuators, enterprise systems, social media and other novel data sources [21, 22]. The industrial internet platform is able to aggregate data into a single database which can be stored, either in dedicated in-house servers or with other third party cloud storage providers [19, 23]. This organised data can be used, for example, by technicians to remotely monitor the condition of machine without physically being present [24], the data can also be run through machine learning algorithms to predict the health condition of a machine and notify the concerned technician to make an informed decision about the need to have the machine maintenance [25]. The data, via the platform, can provide different analytics like descriptive, predictive and prescriptive to create proper infographics which facilitate experienced knowledge workers [18]. Consider the example of a new industrial internet platform based risk assessment solution in Oil & Gas sector, which allows real time visual representation of risks to oil pipeline, based on internal and external environment factors. These infographics provide the experienced pipeline operators a new way to check pipeline integrity. [26] In many cases the industrial internet platforms enable development of applications (“apps”) on top of the platform. These applications help in sharing the relevant information between the different actors and can also help in sense-making [27].

Today, there is a plethora of platforms available. We selected a subset of platforms that enable efficient and real time management of data, information and knowledge over various lifecycle phases. These platforms were searched from mainly academic articles (example [17, 28–31]) and other relevant sources which reviewed characteristics of platforms, functionalities of platforms and data and information management perspective of platforms. Some platforms, such as Exosite and IndustryHack, were added into this pool because they were discovered to be interesting in some of their

characteristics. From this subset a large pool was selected based on the following inclusion criteria:

1. Platforms that are relevant to industrial internet and cater to manufacturing and industrial companies.
2. Platforms that are international. This allows various actors involved in the lifecycle of the product to use them from different geographical locations.
3. Platforms that satisfy the definition of External/industry platforms [7] that allow the inter-organizational collaboration to manage data, information and knowledge.

Table 1 above shows the examples of various platforms in the domain of Industrial internet/Industry4.0/CPS [9, 17], Internet of Things (IoT). [28, 31], social media platforms in manufacturing industrial companies [32], crowdsourcing and collaboration platforms [33]. These examples are not an exclusive list of platforms but they are representatives of the domains.

Table 1. Large pool of industry platforms by their domain

Division by domain	Platform examples
Industrial internet/Industry 4.0/cyber physical system (CPS) platforms	General Electric's Predix, Microsoft Azure, Cyberlighting's Cyberville, Schneider Electric's Wonderware, SAP Hana Cloud Platform (Connected Manufacturing & Predictive Maintenance and services), Bosch Production & Logistics, LifeCycle Care (Your KoneCranes + TrueConnect), John Deere Forest Insight
Internet of things platforms	PTC-Thingworx, IBM BlueMix, Exosite, Google Brillo, Sap IoT Platform, Intel IoT, Salesforce IoT Cloud
Social media platforms in manufacturing industrial companies	Yammer, LinkedIn, Twitter
Crowdsourcing & collaboration platforms	IndustryHack, GrabCad, Innocentive

4 Analysis of Industrial Internet Platforms from PLM Perspective

In order to do an in depth analysis of industrial internet platforms from the perspective of PLM, we further selected 10 platforms (see Table 2), that represent different platform domains and have unique features as platforms, considering especially their capabilities to address various challenges (drawn from Sect. 2, and represented as the major evaluation criteria in Table 2). We further selected 5 platforms (see Table 3), that provide analysis to highlight the effects on management of data, information and knowledge across various PLM phases using industrial internet as a technology enabler.

Table 2. Platform analysis based on industrial internet based on data, information and knowledge

Industrial internet based Information and knowledge functionalities	GE-Predix	MyJohnDeere	Bosch IoT Suite	Sap-Hana Cloud	Microsoft Azure	PTC-ThingWorx	Cyberlighting-CyberVille	Industry Hack	Yammer
Data Access & Collection	++	++	++	+	+	--	--	++	--
Data Aggregation & Sharing	++	+	+	++	++	++	+	--	--
Data Storing	+	+	+	+	+	--	--	--	--
Analytics & Visualizations	+	+	+	+	+	++	++	+	--
Information Sharing	+	+	+	+	+	+	+	+	+
Sense making	--	+	--	--	--	--	--	++	++

-- Not present

+ Present

++ Unique Feature

In Table 2, IndustryHack is a unique actor as it uses the concept of hackathon [34] in industrial setting to bring together outside experts who can help in rapid prototyping [35] and present a proof of concept for the given industrial problem. In terms of data access, Predix, MyJohnDeere and Bosch IoT Suite have the unique advantage of providing their own sensors which can work in different environments [9, 21, 26]. These platforms have capability to directly access a new source of data which is not possible for platforms which don't provide their own hardware (example sensors, actuators). On the other hand, IndustryHack collects data in terms of a pool of experts which can collaborate with industries in the hackathons. Hana, Azure, Predix, Thingworx also allow the real time data integration with data from novel data sources like social media [28–30]. This kind of combination of data can lead to creation of new information. Platform like Cyberville provides feature like multilayered 3D view of complex network in real time. Thingworx lowers technological complexities for users through codeless mashup capabilities. This enables easy creation of variety of visual infographics. [29, 31] in business context, sense making needs experts who can help in making quality decisions after an informed sense making process (Namvar et al. [27]). While sense making is enabled by most of the platforms in the above list. Platforms like Yammer (microblog) and IndustryHack directly support sense-making by bringing together relevant experts to make sense of provided information.

Table 3 provides detailed analysis of 5 platforms that address the challenges of PLM in the context of data information and knowledge management. Platforms have different degrees of openness [7]: Access to data and information, Rules governing the platform and cost of access to data and information. Cyberville is open from the viewpoint of DIK in a way that it follows the open source standards of the internet technology. Access to data information and knowledge across the life cycle phases and

Table 3. Detailed analysis of industrial internet platforms in the context of PLM

Platforms to be analyzed →		GE Predix	Microsoft Azure	PTC ThingWorx	MyJohnDeere	CyberVille-CyberLighting
Criteria for analysis ↓	Detailed criteria for analysis ↓					
Openness of the platform	Access to information	High	High	High	Low	Medium
Level of openness – low, medium & high	Cost of access	High	High	Medium	Low	Low
	Control in terms of rules to use the platform	High	Low (users can decide about data access)	Low (users can decide about data access)	High	Low
Used in product lifecycle phases	BOL	Across and within all phases	Across and within all phases	No	Across and within all phases	No
	MOL			Across and within MOL and EOL		Extensively in MOL
	EOL					Less in EOL
Interoperability between different information systems	Yes/no	Yes	Yes	Yes	Yes	Yes
Real time monitoring/analytics	Basic	Advanced	Advanced	Advanced	Advanced	Basic
	Advanced					
On-demand tailored solutions	Demand-side user (end user)	Yes	Yes	Yes	Yes	Yes
	Supply-side (application developer)	No	Yes	Yes	No	Yes

within the different phases (in case of Closed Loop PLM) is the key to the value creation from product related lifecycle data, information and knowledge [8]. MyJohnDeere is a kind of a platform that enables the product manufacturer to tap into all the data and information throughout the lifecycle phases and also access within different lifecycle phases. Interoperability [12] which is one of the key issues in all industry softwares (for example PLM, PDM, CRM, ERP) is solved by the use of industrial internet platforms by the use of plugins. In order to create value of data and information it is important to get this data and information in real time and provide analytics based on this data in real time as well. GE Predix and Microsoft Azure kinds of industrial internet platform have incorporated Big Data technologies in the platform architecture to enable real time monitoring as well as analytics [9, 26, 28]. One of the key differentiator between traditional industry softwares and platforms like PTC Thingworx, Cyberville, GE Predix is the availability of On-demand tailored solutions [29, 31] or "apps" which result into a marketplace. These "apps" or applications create value of data, information and knowledge for the platform users. The popularity and acceptance of this marketplace generates network effects for the platform [7].

5 Discussion and Conclusion

The challenges with the management of data, information and knowledge in case of PLM is a very important area of research. Problems such as real-time data access, transfer, management and analytics are some of the challenges that need to be solved efficiently. Industrial internet platforms address to the challenges of data information and knowledge during and within the PLM phases. Most of the platforms are efficient and similar in the storing the data and sharing information. Platforms like IndustryHack that allow tapping into outside experts while Yammer is centered on supporting collaboration between experts enable the sense-making of the data and information. Advanced analytics like the multi-layered real-time 3D visualization and mashup kind of applications (for analytics) is enabled by industrial internet platforms. The On-demand tailored solutions help visualize and manage data and information using portable devices (mobile phones, smart watches) which the large PLM and PDM systems do in a restricted manner.

Our purpose was to analyse and understand the potential role of II platforms in the management of product lifecycle related information and knowledge. From our analyses, first, we can conclude that there exist quite different types of external industry platforms with different emphases in their capability of addressing various types of PLM challenges. In addition to IoT platforms, industry 4.0 platforms and CPS platforms, these include also crowdsourcing and social media platforms that can address some of the relevant PLM challenges that others are not well-positioned to do, such as tapping into external knowledge resources and helping to make sense of various existing data. The analysis, in overall, demonstrates that many of the platforms seem to cater for the PLM challenges in rather different and unique manner compared to traditional PLM software, even if various PLM software have recently adopted platforms features and even developed their own app store solutions. This uniqueness is related to for instance enhanced interoperability and the ability to make use of novel data sources in a flexible and real-time manner. Second, we claim that industrial internet platforms can and should, in many cases, be adopted to allow more extensive and useful management of all relevant data from the lifecycle, and combined to existing PLM software through the platforms' capabilities to connect to external software and hardware. We believe that such platforms, when selected in an informed manner, can have even a significant role in enhancing the management of product lifecycle related information and knowledge. Simultaneously, companies should be careful when selecting platforms (as well as any other software solutions), because switching to other software can be difficult later on due to the path-dependency of the decisions.

A small or medium sized company might want to select a platform based on open source standards and open interfaces, such as CyberVille- Cyberlighting, while a large established company might prefer a more mature and developed platform like Predix or ThingWorx. Companies should also take care to make a decision which suits the core objectives of PLM in the longer term, defining these objectives carefully before the decision.

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