Internet of Things in Asset Management: Insights from Industrial Professionals and Academia

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Abstract

Based upon the needs of industry, academia is producing a growing number of decision-making models and tools for maintenance and asset management. At the same time the amount of data available for companies is overwhelming and unorganized, as our previous research and experience have shown. The acquisition of relevant input data for these models can be time consuming, prone to error and often difficult with the current technologies and systems. The emerging Internet of Things (IoT) technologies could rationalize data processes from acquisition to decision making if future research is focused on the exact needs of industry. This paper contributes to this field by examining and categorizing the applications available through IoT technologies in the management of industrial asset groups. Previous literature and a number of industrial professionals and academic experts are used to identify the feasibility of IoT technologies in asset management. This paper describes a preliminary study, which highlights the research potential of specific IoT technologies, for further research related to smart factories of the future. Based on the results of literature review and empirical panels IoT technologies have significant potential to be applied widely in the management of different asset groups. For example, RFID (Radio Frequency Identification) technologies are recognized to be potential in the management of inventories, sensor technologies in the management of machinery, equipment and buildings, and the naming technologies are potential in the management of spare parts.

Keywords: Internet of Things, IoT, Technologies and applications, Data acquisition, Asset management, Smart factory

1. Introduction

As a result of the rapid and world-wide globalization in the industry today, companies and other organizations are networking, whether intentionally or unintentionally, at an increasing pace. Complex interdependencies in the organizational interface set entirely new requirements for data acquisition and data transmission as well as for generating usable decision-making information from the data. Based upon the above-mentioned need to manage and control inter-organizational environments, academia is producing a growing number of decision-making models and tools designed for industrial asset management. The authors of this paper have previously developed a number of models to support asset management decision making, including "Life-Cycle Model for Maintenance Service Management", created for inter-organizational operation and maintenance planning and decision making of a production asset (Kivimäki et al. 2013; Sinkkonen et al. 2014), and the "Flexible Asset Management Model" or "FAM-model", targeted for optimizing a network's asset quantities and balance sheet -positioning in a strategic level (Marttonen et al. 2013).

The amount of data in companies and the numerous information systems are constantly growing, which has created a number of problems in separating relevant data from irrelevant data. Therefore, it has proven very difficult to generate accurate, adequate and timely data for industrial asset management models and tools, such as the "Life-Cycle Model" or the "FAM-model". One viable solution to improved data acquisition and transmission are the Internet of Things (IoT) technologies that will automate asset-related data processes in smart factories of the future through embedded communication within the existing internet infrastructure (Vermesan & Friess 2013). IoT does not however intrinsically solve any difficulties in data utilization, i.e. turning data to business information, where suitable data penetration and analytics software or techniques, so-called middleware is highlighted instead (Wang et al. 2008). There is a trend to generate more value from an array of ubiquitous sensors utilizing the IoT which will have the ability to monitor and measure the assets, the operators, the business and the environment in which they work (Baglee and Knowles 2010). As IoT technologies are altogether a novel approach, the field remains somewhat unclear, which creates a need to carry out research especially from an industrial asset management perspective. Therefore research is needed to clarify industrial applications in order to improve data exploitation and data-based decision making in an industrial environment. The objective of this paper is to collect, correlate and study the Internet of Things technologies which are relevant for asset management systems by connecting an industrial asset group to an IoT technology both in theoretical and at a practical level. The remaining sections of this paper are structured to support the following research questions:

1. What are the essential IoT technologies to be employed in the data acquisition and data transmission of various physical industrial assets in smart factories of the future?

2. How do the industrial professionals and industrial engineering and management academic experts foresee the industrial asset management potential of IoT technologies?

2. Methodology

This research is qualitative research by nature. Qualitative research aims to understand and interpret the phenomena and highlight the viewpoints of research participants (Bryman & Bell 2011). Our research employs two methods. Firstly, current knowledge on existing IoT technologies and their potential applications are studied by conducting a comprehensive literature review in order to achieve a theoretical overall view and to determine the research gap. Theoretical framework is formed based on previous literature to create a basis for empirical research. Secondly, the empirical evidence is mapped via an industrial professional panel and an academic expert panel. Qualitative data is gathered through these panels to complement the perception based on the literature review and to get valuable insights and rich description about the potential of IoT technologies in industrial environment. An industrial professional panel is comprised of industrial asset management and industrial maintenance professionals representing internationally distinguished companies in Finland and Sweden. An academic expert panel consists of industrial engineering and management researchers in the fields of cost, performance, and asset management. The empirical evidence is gathered through these panels separately and they are compared and analyzed in order to get the perception in which ways the views of industrial professionals and academic experts encounter.

3. Theoretical Framework

In this section the foundations for theoretical framework are explored. The terminology and definitions related to IoT technologies and asset management are presented. Section 3.1 discusses the IoT technologies and section 3.2 presents the definitions for asset management and asset groups. Section 3.3 combines the IoT and asset management perspectives into matrix framework. The literature matrix sums up the current state of literature concerning the essential IoT technologies to be employed in asset management. The purpose is to present the theoretical framework which acts as a basis for the empirical research.

3.1 IoT Technologies

IoT comprises of a network of smart objects that are connected to the Internet. In the context of industry, the term of Industrial Internet and Industry 4.0 are often used alongside IoT. Applications utilizing IoT technologies are increasing as enabling technologies are developing and becoming less expensive. IoT is transforming businesses and it has been stated to be an industry revolution taking place right now (Porter & Heppelmann 2014). Companies are developing new applications and innovative uses for IoT technologies. IoT technologies have been applied to numerous environments, such as logistics, manufacturing, security, and healthcare. Hence, the applications vary from inventory control to e-Health applications. The possibilities of IoT enabling technologies and applications have received attention in the literature (Atzori et al. 2010; Miorandi et al. 2012; Gubbi et al. 2013; Li et al. 2014). The categorization of IoT technologies is not uniform and different technologies are often applied together. Commonly discussed technologies are: RFID (Radio Frequency Identification), WSN (Wireless Sensor Networks), WSAN (Wireless Sensor and Actuator Networks), WPAN (Wireless Personal Area Networks), NFC (Near Field Communication), as well as naming and localization technologies which are mainly used for identification, sensing and communication purposes.

RFID technology uses radio waves to identify and is primarily used for identification purposes but it enables also storing limited data in RFID tags (Jantunen et al. 2010). RFID technology consists of electronic tags (RFID tags) and RFID readers. RFID tag stores the unique code of the attached object and RFID reader can act as a gateway to the Internet by transmitting the object identity, read-time and the object location which therefore enables real-time tracking (Kopetz 2011). RFID technology enables automating the process of object identification and eliminating the human link. Researchers, for example, Zhu et al. (2012a) have reviewed applications based on RFID technology in different industries. RFID technology enables preventing stock outs and excess stocks, improving data accuracy, and increasing information visibility in the supply chain. RFID technology is applied, for example, to inventory control, product tracking, building access control and real-time location system in complex manufacturing processes (Zhu et al. 2012a).

WSN technology refers to a group of sensors that can monitor and record the physical conditions of the environment. WSN technology utilizes sensors to collect data about the targeted phenomenon and transmits the data to base stations that can be connected to the Internet (Kopetz 2011). There are many different types of sensors and they are able to monitor a wide variety of physical conditions, including temperature, humidity, vehicular movement, pressure, noise levels and mechanical stress levels on attached objects (Akyildiz et al. 2002). WSN technology can be applied to great variety of different applications, for instance, to machinery condition monitoring, traffic estimation, and power consumption monitoring (Jacquemod et al. 2014; Jantunen et al. 2010; Tubaishat et al. 2009).

WSAN technology combines sensing technologies with actuating possibilities. Sensors gather information about the physical world, while actuators take decisions and then perform appropriate actions upon the environment. This allows remote and automated interaction with environment. (Akyildiz & Kasimoglu 2004) WSAN technology provides innovative application possibilities and it is applied to a variety of building automation applications, for example to temperature control, to air conditioning system which reacts to the presence of people, and to other applications that can provide energy savings in buildings (Jung et al. 2012; De Paola et al. 2012; Fortino et al. 2012).

WPAN enables the energy efficient wireless access and data transfer to smart objects over a short distance (1 m–100 m). Examples of WPANs are Bluetooth and ZigBee. Bluetooth defines a complete WPAN architecture, including a security layer. However, the main disadvantage of the Bluetooth is its relatively high energy consumption. Therefore, Bluetooth is not usually used by sensors that are powered by a battery. ZigBee is developed to be corresponding technology but simpler and less expensive than Bluetooth. Additionally, ZigBee has low power consumption and is more energy efficient. (Wang et al. 2014b; Kopetz 2011)

NFC refers to short-range high frequency wireless communication technology which enables the exchange of data between devices over a distance of less than 20 cm. NFC technology is compatible with existing smartcards and readers but also with other NFC devices and it is suitable for use in mobile phones (Kopetz 2011). NFC technology can be utilized in public transportation, proximity payment and access keys for offices and houses, for example. NFC utilized in mobile phones enables peer-to-peer communication between two NFC devices and, for instance, business cards and other information can be exchanged (Conskun et al. 2013; Kopetz 2011).

In order to be able to communicate via the Internet, smart objects need appropriate naming technologies. Smart objects need to be identified and the access path to the object needs to be established. Examples of naming schemes are barcodes, 2D (two-dimensional) barcodes, EPC (Electronic Product Code) and IP (Internet Protocol) address. Naming technologies make it possible to identify items with appropriate accuracy. Then, sometimes it is adequate to identify items at item group level and sometimes an item specific identification is needed. Item specific identification is needed especially when particular object or device needs to be accessed, for example when tracking vehicle (Rajkumar et al. 2013) or controlling particular appliance in building automation (Jung et al. 2012). Then EPC or IP address would be more appropriate choice.

Localization technologies can be categorized into three groups based on the infrastructure of the technology: satellite based, mobile networks based and local area networks based technologies. Satellite positioning technology utilizes distance measurement to satellites to determine three-dimensional location. An example of satellite positioning systems is GPS (Global Positioning System). A satellite positioning system is intended to be used outdoors and it is not suitable for indoors. Network based positioning technology is based on mobile networks that maintain the location data, whereas local area networks can utilize technologies, such as RF (Radio Frequency) signals or local positioning properties of Bluetooth (Motamedi et al. 2013).

By applying and combining these IoT technologies, there is a potential to develop enormous amount of new IoT based applications in different environments. When considering supporting technologies, such as mobiles and memory capabilities of cloud computing, the IoT based application possibilities increase. These IoT applications produce increasing amount of data which is known as big data. Big data is often semi-structured or unstructured by nature and collected data is useful only if it is analyzed (Chen et al. 2014a). The challenge is how to effectively exploit the collected data in applications and therefore turn data into business information. For companies to actually start gathering, analyzing and using the data, the decision making value and potential end use of data must be transparent for them.

3.2 Definitions of Assets and Asset Management

An asset is generally defined by the ISO 55000 standard as “an item, thing or entity that has potential or actual value to an organization”. The value will vary between different organizations and their stakeholders, and can be tangible or intangible, financial or non-financial. Tangible or physical assets usually refer to equipment, inventory and properties owned by the organization. Physical assets are the opposite of intangible assets, which are non-physical assets such as leases, brands, digital assets, use rights, licenses, intellectual property rights, reputation or agreements. (ISO 55000 2014, p.13)

In the context of this research the assets are considered as physical items in a factory environment. Physical industrial assets include various assets with different management decisions and data needs. To include the special features of these various assets we have divided physical assets into the following five categories: machinery and equipment, buildings, vehicles, inventories, and spare parts. As the research is limited to explore physical industrial assets in factory environment, the category of vehicles includes all mobile vehicles at the factory area, such as motor vehicles and trucks. Vehicles can be considered assets as long as they are transporting the property of the company to other destination, although the vehicle leaves the factory area. Therefore, e.g. the company's own railway wagons and trucks can be counted among assets in this research.

The asset group of inventories comprises four types of inventories: 1) finished goods, 2) work-in-process, 3) raw materials, and 4) maintenance and operating items, such as spare parts. Spare parts have been separated from inventories to a category of their own. Spare parts are replacement items that are required to keep assets operating in a plant and they prevent excessive down-time in case of a breakdown (Gulati 2009). The category of buildings at factory area includes factory buildings and other buildings, such as warehouses and office buildings. Machinery and equipment are the physical assets that are required in factory-specific processes. In addition to process-related machinery, this category includes also other equipment such as tools and computers.

Asset management is defined to be broader perception than the term of maintenance gives to understand. Asset management is considered as a set of activities associated with 1) identifying what assets are needed, 2) identifying funding requirements, 3) acquiring assets, 4) providing logistic and maintenance support systems for assets, and 5) disposing or renewing assets. Therefore, asset management aims to manage assets optimally and sustainably over the whole life cycle of assets. (Hastings 2010)

3.3 Matrix Framework

In the context of this research, a matrix framework (Table 1) combines the aspects of IoT technologies and asset management has been generated. A detailed literature review has been conducted to identify IoT based technologies and if they have been applied to the different asset groups and asset management. These findings have been included into the matrix framework (Table 1). Academic articles, in which IoT technologies have been researched or applied to a specific asset group, are referred to in the matrix.

According to the literature matrix, it can be stated that IoT technologies have been applied to a range of asset groups. RFID and WSN technologies have been researched widely and several applications have been identified. WSAN applications have not been studied widely but recently this technology has got more attention in literature. WSAN technology has not been applied to inventories or this just does not appear in literature. This might be because of the possibilities to benefit from sensing and actuating features in the management of for example equipment (turn off and on are practical possibilities) whereas with stock there are not such possibilities or they are not seen equally tempting. WPAN communication technologies have been applied in different contexts and especially the potential of ZigBee has been acknowledged in literature. Also NFC technology has been studied in literature and there are several applications. Barcodes have been in use for many years but 2D barcodes and their ability to store data and the potential of IP address to identify a certain object have become useful in the management of different asset groups. Localization technologies have also been applied to different asset groups and particularly in smart factory context the indoor localization applications stand out in literature. When examining asset groups, it can be noticed that machinery and equipment, buildings and inventories have most applications while vehicles and earlier mentioned spare parts do not have as many applications or they just do not appear in academic publications.

Table 1. Literature matrix: IoT technologies applied to the management of asset groups.

		ASSETS				
		Machinery and equipment	**Buildings**	**Vehicles**	**Inventories**	**Spare parts**
IOT TECHNOLOGIES	**RFID**	Remote condition monitoring, failure follow-up notifications, embedded health history with the asset (Haider & Koronios 2010), device management, equipment monitoring (Wang et al. 2014a), maintenance information sharing platform (Lin et al. 2014), collecting real-time production information (Liu et al. 2015)	Access control system (Qiu et al. 2012; Zhu et al. 2012b)	Electric vehicle batteries (Wang et al. 2013)	Storage levels of parts, real-time information about products on assembly line (Chen et al. 2014b), inventory control (Chang et al. 2012; Liu & Chen 2009), resource management system (Liu et al. 2006)	Spare part tracking in assembly lines (Giannoccaro et al. 2014), spare parts supply chain management (Cheng and Prabhu 2012; Chen et al. 2013)
	WSN	Condition-based maintenance (Jantunen et al. 2010; Tiwari et al. 2004), fault diagnostics (Lu & Gungor 2009), collecting running parameters (Hsu 2010)	Energy monitoring, behavioral monitoring, space monitoring (Fortino et al. 2012), energy management, power consumption monitoring (Jacquemod et al. 2014)	Traffic estimation, traffic control (Tubaishat et al. 2009)	Online inventory management system (Vellingiri et al. 2013), inventory management (Mason et al. 2010)	Condition monitoring data from equipment to support the spare part ordering decisions (Godoy et al. 2013)
	WSAN	Gas detection and immediate isolation of gas leak source (Somov et al. 2014), process control applications (Lu et al. 2016)	Energy saving, maximization of the comfort in the building (Fortino et al. 2012), temperature control in a work environment (De Paola et al. 2012), power management (Survadevara et al. 2014), building automation (Jung et al. 2012)	Unmanned ground vehicle (Li & Selmic 2015)		
	WPAN (Bluetooth, Zigbee)	Collecting running parameters (Hsu 2010)	Bluetooth, Zigbee, Wifi: communication of smart living space (Bai & Huang 2012)	Bluetooth-enabled headset and voice-activated features (Mahmud & Shanker 2006)	Inventory tracking with Zigbee (Yang & Yang 2009)	
	NFC	Context-aware mobile support system (Papathanasiou et al. 2014), recurring maintenance processes: central process control and documentation (Karpischek et al. 2009b)	Classroom access control (Palma et al. 2014), access keys for offices and houses (Conskun et al. 2013)		Availability and stock information of products (Karpischek et al. 2009a), inventory control (Iqbal et al. 2014)	
	Naming technologies, (barcodes, EPC, IP address)	Maintenance information sharing platform (Lin et al. 2014)	IP address: building automation (Jung et al. 2012)	IP address: tracking of individual vehicles (Rajkumar et al. 2013)	2D barcodes: product information, mobile product verification (Gao et al. 2007)	Barcodes in spare parts management (Gan et al. 2013)
	Location based technologies (satellite, mobile networks, local area networks)	Tool tracking and localization with RF signals (Goodrum et al. 2006)	NFC smartphone indoor interactive navigation system (Choo et al. 2014)	Asset localization (Motamedi et al. 2013), GPS: location of vehicles (Rajkumar et al. 2013)	Indoor locating with RF signals (Chang et al. 2012)	

Based on the matrix framework, it can be concluded that 1) RFID technology has been widely researched and applied, 2) WSN technology appears to be easily varied in different contexts, 3) WSAN has interesting applications and there might be untapped potential as automation can be employed more widely in the management of different asset groups e.g. in machinery and equipment, where automation can be used to prevent failures, or in vehicles, 4) NFC technology might have potential to be applied more widely in different contexts, such as in simplifying documentation during maintenance tasks and access control in various contexts, and 5) there are various applications for communication, naming, and localization technologies.

4. Empirical Results

This section discusses the empirical results of industrial professional and academic expert panels. Firstly, the results of each panel are presented separately and then the results of both panels are compared. The section 4.3 compares and discusses differences and similarities between the insights of industrial professional and academic expert panels.

4.1 Industrial Professional Panel

Empirical data have been gathered via an industrial professional panel that is comprised of industrial asset management and industrial maintenance specialists from five companies, representing original equipment manufacturers and their customer companies from mining and energy industries. Mining and energy industries are traditionally asset and capital intensive industries where IoT technologies and automation create significant potential. In total, six professionals from these companies participated in the panel.

Industrial professionals were asked to evaluate the potential of IoT technologies in the management of different asset groups. The scale was 0–5, where 0 is “cannot say”, 1 “no potential”, 2 “some potential”, 3 “potential”, 4 “quite high potential”, and 5 “high potential”. The first matrix (Table 2) sums up the views of professionals, as an average number given by the six professionals. In addition to numbers, the potential is also illustrated by the shades of grey, darker grey representing higher potential and lighter grey representing less potential. White areas mean that potential is unclear or a large proportion of respondents, i.e. over half of the respondents could not say if there is potential, and therefore the average value could be distorted. In addition, the average value of each asset group and the average value of each technology category have been calculated.

Table 2. Potential of IoT technologies in the management of asset groups evaluated by industrial professionals

	ASSETS						
	IOT TECHNOLOGIES	Machinery and equipment	Buildings	Vehicles	Inventories	Spare parts	Average value
	RFID	3,0	3,7	4,0	3,7	3,0	3,5
	WSN	4,4	4,0	4,7	2,7	2,0	3,5
	WSAN	3,8	4,8	3,3	2,7	1,5	3,2
	WPAN	4,8	4,0	4,0	2,7	2,8	3,6
	NFC	3,5	2,3	3,5	2,5	3,0	3,0
	Naming technologies	3,2	2,5	3,0	3,7	4,5	3,4
	Localization technologies	2,8	2,7	4,2	4,5	2,0	3,2
	Average value	3,6	3,4	3,8	3,2	2,7	**3,3**

By observing Table 2 from the asset management point of view each asset group and the potential of IoT technologies in the management of each group can be reviewed. The asset group of vehicles has highest average value (3.8) and the technologies such as WSN, localization technologies, RFID, and WPAN have highest potential in the data acquisition and transmission from vehicles. The asset group of machinery and equipment has quite high potential (average value 3.6) and especially the technologies such as WPAN, WSN, and WSAN have highest potential in the data acquisition from machinery and equipment. The potential related to the buildings is 3.4 and the highest potential is related to WSAN, WSN, and WPAN technologies. The potential related to the inventories is 3.2 and the highest potential is related to RFID, naming technologies, and localization technologies but the value of localization technologies might be distorted as half of the respondents could not say the potential. The asset group of spare parts has the lowest potential but on the other hand the potential of naming technologies stands out in the data acquisition from spare parts and the naming technologies have high potential in the management of spare parts.

By observing the IoT technology point of view the results of industrial professional panel (Table 2) indicate that 1) RFID technology is seen as a potential technology (average value of 3.5) to be applied to different asset groups, 2) there is potential to utilize WSN in the management of machinery and equipment, buildings, and vehicles, 3) WSAN technology has potential to be applied especially to management of buildings, but to machinery and equipment and vehicles as well, 4) potential of WPAN has also been recognized (average value of 3.6), 5) NFC technology could be potential in the management of machinery and equipment, 5) naming technologies might be useful to important spare parts, inventories, and machinery and equipment, 7) localization technologies have been identified as potential technologies especially when tracking vehicles.

In addition to the summary matrix, professionals have provided comments and usage examples of IoT technologies. For example, related to RFDI technology the professional from the original equipment manufacturer company in mining industry has said that: *"RFID technology could be applied to the control of raw material and spare part inventories"* and *"RFID technology could benefit condition-based maintenance calculation when operating hours can be targeted at each component".*

Regarding NFC technology, the professional representing an energy company has said that: *"NFC can be utilized to access control and signing for working orders", "NFC applications are handy in mobiles and tablets, and therefore other separate devices are not needed",* and *"NFC could work better in some contexts where RFID applications are inflexible to use".*

Regarding naming technologies, the professionals from mining and energy industries have said as follows: *"While doing maintenance work, the equipment could be identified and then the information and conducted operations could be entered into the follow-up system", "The most important spare parts should be named and this allows monitoring the spare part consumption of whole installed base"*, and *"2D barcode could enable the access to the documentation".*

Although the potential of localization technologies in the management of machinery and equipment is not high, the professional from the OEM in mining industry highlighted that: *"Sometimes it would be practical if maintenance worker could localize accurately the equipment that needs to be overhauled".*

In addition, apart from the benefits and potential that were mentioned above, the threats of IoT technologies have also been recognized especially by the professional representing energy company: *"If it is possible to control important assets, such as machinery, via IP address, information security challenges must be acknowledged".*

4.2 Academic Expert Panel

The panel was duplicated with a group of Finnish researchers in the fields of performance, cost and asset management. In total, twelve researchers participated to the researcher panel. The researchers who participated in the panel have knowledge of asset management and they consider the topic from industrial management perspective, specialized in performance and cost management. The matrix (Table 3) sums up the views of researchers in the field of performance, cost and asset management, as an average number given by twelve experts. The same scale (0–5) was utilized and the shades of grey are illustrating the potential. In addition, the average value of each asset group and the average value of each technology category have been calculated.

Table 3. Potential of IoT technologies in the management of asset groups evaluated by academic experts

	ASSETS					
IOT TECHNOLOGIES	Machinery and equipment	Buildings	Vehicles	Inventories	Spare parts	Average value
RFID	3,7	2,3	4,0	4,7	4,6	3,9
WSN	4,5	4,9	4,3	3,0	2,4	3,8
WSAN	4,1	4,9	4,2	3,4	2,4	3,8
WPAN	4,7	3,6	3,7	4,0	3,3	3,9
NFC	4,0	3,4	3,6	3,3	3,3	3,5
Naming technologies	4,0	2,6	3,6	4,2	4,5	3,8
Localization technologies	3,5	2,6	4,9	3,6	3,5	3,6
Average value	4,1	3,5	4,0	3,8	3,4	**3,8**

By observing Table 3 from the asset management point of view each asset group and the potential of IoT technologies evaluated by academic experts can be reviewed. According to the academic experts the asset group of machinery and equipment has highest potential (average value 4.1). In the data acquisition and transmission the technologies such as WPAN and WSN have highest potential but the other technologies have significant potential as well. As regards the asset group of vehicles the average potential is 4.0 and the highest potential is related to localization technologies (4.9) but the other technologies such as WSN, WSAN, and RFID have also significant potential related to the data acquisition from vehicles. The asset group of inventories has the average value of 3.8 and RFID technology stands out with the potential of 4.7. Naming technologies and WPAN have quite high potential as well in the data acquisition and transmission related to the management of inventories. Regarding the buildings WSN and WSAN technologies are highlighted with the average potential of 4.9. The asset group of spare parts has the lowest average potential (3.4) but the usability of RFID and naming technologies stand out with high potential (4.6 and 4.5) whereas sensing technologies (WSN and WSAN) do not seem to have significant potential.

By observing from IoT technology point of view, the results of researcher panel (Table 3) indicate that 1) RFID has high potential in the management of inventories and spare parts, 2) WSN have high potential related to machinery and equipment and buildings, 3) WSAN have high potential in the management of buildings but quite high potential in the management of machinery, equipment and vehicles as well, 4) The potential of WPAN is high in the management of machinery and equipment and also the potential to apply WPAN to the inventories has been recognized, 5) There is potential related to NFC but only the group of machinery and equipment has quite high potential, others have the value below 4, 6) Naming technologies have quite high potential related to the inventories, spare parts and Machinery and equipment, and 7) The vehicles are emphasized when considering localization technologies.

Academic experts also provided some comments and usage examples of IoT technologies. For example, RFID was mentioned to be usable technology for several kind of tracking purposes, e.g. inventory and spare parts inventory. WSN was mentioned to be usable in the management of each asset groups what comes to condition and health monitoring. WSAN in the management of machinery and equipment were mentioned to have *"high potential"*. WSAN in the management of buildings were mentioned to have *"high potential"* as well, especially in factory environment where *"the external circumstances of process environment need to be at certain level"*. Thus, WSAN enable e.g. to maintain the required and favorable temperature level. The role of naming technologies was identified to be important in the management of different asset groups. Remote monitoring and control were mentioned to be possible because of naming technologies. Naming technologies were also named to be "*a key to view the spare part history of certain machine or equipment and help to select right spare parts*".

4.3 Comparison and Analysis

Here the views of industrial professionals and academic experts about the industrial asset management potential of IoT technologies are compared and some highlights are discussed. In general, academic experts have evaluated the potential higher than the industrial professionals, which can be noticed by comparing the average values in Table 2 and Table 3. Based on the views of industrial professionals the overall average potential of IoT technologies in asset management is 3.3 while the overall average potential of IoT technologies by academic experts is 3.8. One reason can be that the academics are very development oriented and they are also interested in applications for a variety of industries whereas companies usually tend to see things mostly from the perspective of their own business. Academics consider the topic broadly but the industrial professionals have deeper knowledge of their own specific business and they can provide the ideas of practical applications for the specific industry.

The fact that the industrial professionals have expressed more practical applications might be because the industrial professionals have more operative perspective to asset management whereas the academics often to focus on strategic rather than operational asset management. This might be a result of not working with a specific industry but the academics usually have a wider perspective and ideas of several industries. An example about this situation is the potential of NFC technology. Academic experts did not highlight the potential of NFC technologies but the industrial professionals emphasized the practical potential of NFC technologies in the management of machinery and equipment while performing e.g. maintenance tasks and entering the tasks with mobile phones and tablets.

Table 2 and Table 3 show that it can be concluded there is the potential to utilize sensor technologies in the management of machinery and equipment, buildings and vehicles, according to both panels. Sensor technologies have been evaluated to have significant potential in sensing the physical conditions of these asset groups. However, the potential of actuating possibilities that WSAN technology is providing did not have as high potential as the WSN technology. There were high potential related to WSAN technologies merely in the management of buildings i.e. the highest potential to exploit automation is related to buildings. However, the academic experts evaluated that the WSAN technology has quite high potential in the management of machinery, equipment and vehicles while the industrial professionals did not value the potential of WSAN equally high.

Both the industrial professionals and the academic experts emphasized the usability of naming technologies in the management of spare parts. Both panels agree that there is significant potential (average value 4.5 in both panels), and they also provided examples of practical applications related to the utilization of naming technologies in the management of spare parts. Monitoring the spare part consumption of at the level of asset fleets, viewing the spare part history of certain machine or equipment and helping to select right spare parts were mentioned as the examples. In literature, Gan et al. (2013) have also mentioned the potential of barcodes in the management of spare parts. However, the literature related to spare parts seems to be quite limited and perhaps not all the potential related to utilization of IoT technologies in the spare part management has been utilized.

5. Discussion and Conclusions

IoT technologies and applications have been studied in detail. However this paper has shown that there is a lack of academic and peer reviewed literature which discusses in detail IoT technologies and applications in asset management. In addition, the results highlighted within this paper have described an understanding of applying IoT technologies in the asset management of the smart factories of the future and the understanding of utilizing the technologies to rationalize data acquisition and transmission in industrial applications. The research acts as a kick for interest to apply IoT technologies more in industry. The research also helps to identify the potential of IoT technologies for data processes and recognizes themes for further research.

The literature matrix and empirical matrixes present the results from the respondents to both research questions. According to the literature review, IoT technologies can be applied widely in the management of different asset groups. Also industrial professionals and academic experts see the potential to exploit technologies in a number of business environments and in the management of different asset groups.

If the literature matrix is compared to the views of industrial professional and academic expert panels the main difference is related to spare parts. While research is limited, the industrial professionals and the academic experts see potential for a number of technologies, especially for naming technologies. A reason for this might be the fact that research has not focused on spare part inventories while asset management practitioners and academic experts in the field of industrial engineering and management are more interested in spare parts in particular. Another difference is that, based upon the literature, there are fewer IoT applications for vehicles than the views of industrial professionals and academic experts indicate. In both panels vehicles have been valued one of the most potential asset groups regarding IoT applications. This could be because the research is only just increasing or IoT innovations related to vehicles might be carefully protected by companies from publicity but on the other hand the possibility to utilize technologies in the management of vehicles is acknowledged. Thus, there could be a lack of academic discussion compared to for example, machine or inventory-related applications. Comparison between the views of industrial professionals and academic experts indicates that the academics evaluate the potential of IoT technologies higher than industrial professionals. This might be because of the wider perspective of academics compared to industrial professionals who are focusing on their own business environment. Another reason could be that the expectations of industrial professionals are not as high as the expectations of academics, related to e.g. WSAN technologies, since there are still lots of work to be done before even the less developed technologies (sensors, naming technologies) are implemented widely in industrial environments.

IoT technologies have a huge potential but more needs to be done before applications can be exploited more widely in real industrial environments. The emerging IoT infrastructure is now being designed to support a range of systems, i.e. assets, people and the environment. Until as recent as 2010 this was deemed unnecessary, technically challenging and cost prohibitive. The recent introduction of intelligent predictive analytics is used to support the use of IoT technologies to intelligently process the large amount of data, often called Big Data. Such tools and techniques are still in their infancy, although the data and internet revolution is moving at a pace often difficult to follow. An important issue is how the collected data can be effectively turned into business information. The IoT will undoubtedly affect different industrial sectors at a rate of change that may be difficult to foresee. It is estimated that 20% of manufacturers within the world are using or planning to introduce Internet of Things technologies. By 2030 this figure could be over 85%.

The main limitation of this research is the small size of the industrial professional and academic expert panels, and therefore more comprehensive empiric research needs to be conducted. Further research could concern more comprehensive empirical research regarding the potential to apply IoT technologies in different business environments. The future research could also focus on examining the limited amount of research in the field of spare parts. Naming technologies in the management of spare parts were highlighted by both panels while the literature concerning IoT applications in spare part management are quite limited. It needs to be researched if there is untapped potential related to e.g. automation possibilities in spare part management. The next step is also to study how all the collected data could be used effectively in applications and decision making.

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