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## Abstract

**Purpose** – Managers are increasingly looking to adopt the Internet of Things (IoT) to include the vast amount of big data generated in their decision-making processes. The use of IoT might yield many benefits for organizations engaged in civil infrastructure management, but these benefits might be difficult to realize as organizations are not equipped to handle and interpret this data. The purpose of this paper is to understand how IoT adoption affects decision-making processes.

**Design/methodology/approach** – In this paper the changes in the business processes for managing civil infrastructure assets brought about by IoT adoption are analyzed by investigating two case studies within the water management domain. Propositions for effective IoT adoption in decision-making processes are derived.

**Findings** – The results show that decision processes in civil infrastructure asset management have been transformed to deal with the real-time nature of the data. The authors found the need to make organizational and business process changes, development of new capabilities, data provenance and governance and the need for standardization. IoT can have a transformative effect on business processes.

**Research limitations/implications** – Because of the chosen research approach, the research results may lack generalizability. Therefore, researchers are encouraged to test the propositions further.

**Practical implications** – The paper shows that data provenance is necessary to be able to understand the value and the quality of the data often generated by various organizations. Managers need to adapt new capabilities to be able to interpret the data.

**Originality/value** – This paper fulfills an identified need to understand how IoT adoption affects decision-making processes in asset management in order to be able to achieve expected benefits and mitigate risk.


**Keywords** Asset management, Internet of Things, IoT, Business process, Adoption

**Paper type** Case study

## 1. Introduction

### *1.1 Motivation*

The Internet of Things (IoT) can be used to collect more and more data which can be used by decision-makers to acquire the necessary insights in a timely fashion. IoT and data analytics will transform complete supply chain processes (Kumar *et al.*, 2016) and has the potential to revolutionize management (Fosso Wamba *et al.*, 2015). But developing and managing this data to an acceptable level whereby the right information can be provided to the right people at the right time is a complex undertaking.

Modern economies are supported by large infrastructures of transport systems, water and waste disposal networks, and energy and telecommunications networks. As such, the proper management and maintenance of the assets making up the infrastructure is vital to prosperity. IoT has the potential to improve the management of these assets by providing insight into the utilization of the infrastructure and the quality of the assets for



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maintenance and replacement strategies. Asset management as a type of business process is highly dependent on large amounts of data from which relevant information can be created and is used for decision-making during the life-cycle of assets. Infrastructure assets are stationary systems (or networks) that serve society where the system as a whole is intended to be maintained indefinitely to a specified level of service by the continuing replacement and refurbishment of its components (Herder *et al.*, 2008). Asset management is generally understood to be the set of activities of a business objective associated with: identifying what assets are needed; identifying funding requirements; acquiring assets; providing logistic and maintenance support systems for assets; and disposing or renewing assets so as to effectively and efficiently meet the desired objective (Hastings, 2010; Woodhouse, 1997).

### *1.2 Research problem, objective and approach*

The term, IoT refers to a network of physical objects that are able to communicate their data over the internet (Hounsell *et al.*, 2009; Ramos *et al.*, 2008). IoT enables asset managers to access remote sensor data and to monitor and control the physical world from a distance, allowing many physical objects to act in unison, through means of ambient intelligence (Ramos *et al.*, 2008). IoT can benefit asset management organizations by providing enough quality data to generate the information required to help asset managers make the right decisions at the right time (Brous and Janssen, 2015b). For example, IoT can be used to collect data to determine the position and length of traffic jams, and to redirect traffic or offer alternative multi-modal forms of transport by using location sensors and analyzing traffic flow. But IoT adoption can also impact the asset management organization in unexpected ways. Automating processes often necessarily leads to changes to organizational structures and cultures as tasks previously performed by people become automated, whilst other tasks and responsibilities which previously did not exist become apparent (Brous and Janssen, 2015a).

Technology and organization influence each other in many ways, and analytical efforts to treat these as distinct conceptual units are increasingly being called into question (Boos *et al.*, 2013). As such, it is important to understand how IoT adoption affects decision-making in asset management business processes in order to be able to achieve expected benefits and mitigate known and unknown risk. This research fills that gap by analyzing the changes in the business processes of maintaining civil infrastructure assets brought about by IoT adoption. The research objective is to understand how IoT adoption affects decision-making processes in asset management. As there is limited knowledge in this field and deep insight into the field is needed, case study research is used. Case study is a qualitative research method particularly suited to researching contemporary phenomena that cannot be separated from the environment they are embedded in (compared to laboratory experiments, for example) and that have not been scientifically studied to a large extent so far (Benbasat *et al.*, 1987). The case studies comprise two organizations that have similar goals to reduce confounding effects in the study. Two case studies of IoT adoption within the asset management domain are presented in this paper. The cases have been made anonymous in the interests of privacy. The first case, a water measurement network, is managed by a central government organization. We refer to this case as case "X" in this paper. The second case study, a pump management decision support system, is managed by a water board. We refer to this case as case "Y" in this paper.

This paper read as follows: Section 2 presents the literature background; Section 3 describes the research methods in detail; and Section 4 describes the case studies background and compares the cases. The case studies are discussed in Section 5 showing how business processes need to be changed driven by IoT. Finally, conclusions are drawn in Section 6.

## 2. Background

According to Kabir *et al.* (2014), decision-makers are increasingly being faced with competing investment demands whilst needing to distribute limited resources so that the infrastructure systems can be maintained in the best possible condition. Kabir *et al.* (2014) show that infrastructure management decisions are often based on multiple and conflicting criteria/data that are subject to different levels and types of uncertainty, and traditionally, these decisions incorporate engineering judgment and expert opinion. However, in a data-driven world, many stakeholders are gaining increased access to information about the asset and are often capable of arguing for opposing courses of action in the face of unsubstantiated decisions. In this research we identify three main decision-making processes of asset management, namely:

(1) decision-making for performance management (Archetti *et al.*, 2015);

(2) decision-making for managing how infrastructure services are perceived (Hentschel *et al.*, 2016); and

(3) decision-making for improving infrastructure services (Koo *et al.*, 2015).

### *2.1 Decision-making for performance management*

Decision-making processes with regards to maintaining current service levels are generally focused on preventing malfunction or asset failure or to quickly assess damage to infrastructure after an event such that maintenance procedures could be directed to the areas that need immediate attention (Aono *et al.*, 2016). As such, performance measurement is required for corrective, preventive and predictive maintenance as well as other supportive activities (Parida *et al.*, 2015). According to Phares *et al.* (2004), routine inspections are the traditional method of gathering information regarding the performance of the infrastructure. Routine inspections are regularly scheduled inspections to determine the physical and functional condition of infrastructure assets. Generally, a series of condition ratings that describe the general condition of the asset are considered for performance measurement. According to Phares *et al.* (2004), these condition ratings, consider both the severity of deterioration and the extent to which it is distributed throughout each of the components. The more often these inspections take place, the higher the granularity. Often, traditional inspections are performed subjectively. In other words, inspectors visually inspect the asset and makes an expert judgment based on what they see and their past experience.

### *2.2 Decision-making for managing how infrastructure services are perceived*

According to Parida *et al.* (2015), maintenance is often integrated into a production process involving human factors. As such, although difficult to measure (Simões *et al.*, 2011), perception management of infrastructure services is an important aspect to the asset management decision-making process as the effectiveness of the different facets of the performance system is often dependent on the competency, training, and motivation of people interacting with the infrastructure and the asset management systems (Ljungberg, 1998). For example, when planning maintenance on a busy section of highway it is important to take into account how the maintenance will affect the public and how the public will perceive the need for the maintenance. Decisions such as when to perform the maintenance (at night or during the day), or how best to inform the public, for example to provide alternative routes, are important aspects of infrastructure decision-making which require large amounts of data. For example, IoT data can provide insight into such aspects as the busiest times of day or night, or popular destinations (for determining alternative routes). Therefore, the relationship between the organization and the customer may be critical due to the influence that service quality has on user satisfaction level and the fact that people are involved in decisions related to maintenance and execution of tasks (Ardalan *et al.*, 1992).

### *2.3 Decision-making for improving infrastructure services*

Traditional thinking about the strategic decision-making process rests on the belief that actors enter a decision-making process with a known set of objectives, gather information about these objectives and select an optimal alternative to achieve these objectives (Eisenhardt and Zbaracki, 1992). However, Eisenhardt and Zbaracki (1992) also suggest that whilst people may be rational, power tends to win battles of choice. For example, according to Smith (2014), competing interests mean that managers increasingly embed poorly managed tensions into their organization's strategy which require ongoing responses rather than one-time resolutions. Despite this, Marquez and Gupta (2006) believe that having a strategic perspective to asset management is a key factor for success. For example, detections of damage or failure of critical public infrastructure may have significant societal and economic impacts (Tien *et al.*, 2016).

### *2.4 Effects of IoT adoption on asset management decision-making processes*

Infrastructure systems consist of many different types of assets that could have long life cycles. For example a bridge lasts for at least 30 years, however, regular maintenance might be needed. Civil infrastructure assets need to be maintained to ensure their optimal value over their entire (long) life cycles (Hassanain *et al.*, 2003). As early as 2001 there were already many software tools for asset management (Hassanain *et al.*, 2003; Vanier, 2001), and since then many data formats, data sources and pools of unstructured data have become available over the years. At a high level, Hassanain *et al.* (2003) suggest that asset management tooling should at minimum provide the following functionality:

- identification of assets;
- identification of performance requirements;
- assessment of asset performance;
- plan maintenance;
- manage maintenance operations;
- life-cycle costing analysis;
- life-cycle analysis and long-term service-life prediction; and
- central repository for asset information.

It is expected that IoT adoption will change performance measurement of infrastructure services, like applying statistical learning (Archetti *et al.*, 2015). Second, IoT adoption is expected to change the perception of infrastructure services, like perceiving sudden changes in temperature by which a fire could be detected (Hentschel *et al.*, 2016), or the deterioration of the quality of assets over time (Brous *et al.*, 2017). Finally, IoT adoption is expected to change business processes, for example through self-organizing resource planning (Zhang *et al.*, 2015). In the next sections, we discuss these effects of IoT on asset management.

### *2.5 IoT adoption expected to change performance management of infrastructure services*

IoT services are knowledge intensive and require collection of appropriate data contents, data analysis and reporting (Backman and Helaakoski, 2016). As such, statistical learning and network science is expected to play a critical role in converting data resources into actionable knowledge (Archetti *et al.*, 2015). Due to increasing pressure on budgets and personnel as well as increased utilization of civil infrastructure, public asset management organizations increasingly need to intelligently manage their infrastructure with fewer resources (Rathore *et al.*, 2016). By managing and analyzing various IoT data, it should be possible to create new services to achieve an efficient and sustainable civil infrastructure (Backman and Helaakoski, 2016; Hashi *et al.*, 2015). IoT may bring an improved understanding of complex processes which is expected to help improve the efficiency of transport management and infrastructure services, and help with effective reporting (Kothari *et al.*, 2015). IoT infrastructure could potentially be used to reduce costs in terms of time and money (Aono *et al.*, 2016), as traditional methods of inspecting infrastructure, such as highway structures and bridges, for damage are often reactive in nature and require significant amounts of time and use of costly equipment. By specifying events (Hashi *et al.*, 2015; Tao *et al.*, 2014), it should be possible to obtain a set of data before and after an event to be used for analysis and evaluations, taking the effect of the event into consideration.



### *2.6 IoT adoption expected to change perception of infrastructure services*

Rathore *et al.* (2016) believe that smart management of traffic systems with the provision of real-time information to the citizen based on the current traffic situation should enhance decision-making. Jonoski *et al.* (2013) believe that an important potential of IoT adoption may lay in developing applications for the broadest user base of individual citizens, not only as recipients of information, but also as suppliers of data. As such, Jonoski *et al.* (2010) suggest that a possible approach toward meeting this challenge may be the development and deployment of information systems that integrate the operations of data collection, data and model integration, and information dissemination such that organizations can work together with the users of their information for mutual benefits. In this way, IoT is expected to be able to provide users with information on costs, time, environmental impact and perceived quality of services (Archetti *et al.*, 2015).

### *2.7 IoT adoption expected to change business processes of infrastructure services*

In order to keep civil infrastructure such as bridges safe and functioning, regular inspections to determine the condition of the asset are a necessity (Ahlborn *et al.*, 2010; Neisse *et al.*, 2016). For example, traditional inspections of bridges are usually visual assessments by trained personnel where all the asset's component conditions are observed once every three to six years, and are summarized into one report (Phares *et al.*, 2004). After the inspection is done, asset managers must decide what maintenance interventions are needed based on these inspection reports. However, inspection reports of bridges can be biased by subjective judgments of the experts or by lack of information (Kallen and van Noortwijk, 2005). IoT data may make it possible to remotely observe the condition of objects and thereby enhance the available information on the current condition of public infrastructure (Ahlborn *et al.*, 2010) and their environments.

### *2.8 Summary of effects of IoT adoption on the asset management decision-making process*

The expectation is that IoT will be used for key decision-making in operational activities. It is expected that IoT will be used in a variety of ways related both to the real-time measurement and analysis of data as to trend analysis of historical data over time (Brous and Janssen, 2015b). Expected benefits of IoT adoption for business processes include:

- self-organizing resource planning (Zhang *et al.*, 2015);
- creation of new services to achieve a sustainable civil infrastructure (Backman and Helaakoski, 2016);

- improving the efficiency of infrastructure services (Kothari *et al.*, 2015) and thus reducing costs in terms of time and money (Aono *et al.*, 2016);
- automation of processes (Hentschel *et al.*, 2016);
- timelier provision of information (Rathore *et al.*, 2016) allowing for more accurate inspections and analysis (Ahlborn *et al.*, 2010);
- greater frequency of inspections (Neisse *et al.*, 2016); and
- reduce or remove the need for physical, on-sight inspections (Ahlborn *et al.*, 2010).

But adopting IoT also has consequences for asset management business processes. Expected consequences for asset management business processes include:

- requires understanding of the conditions and factors for effective and sustainable adoption of new data sources (Brous and Janssen, 2015b);
- requires statistical learning and network science to convert data resources into actionable knowledge (Archetti *et al.*, 2015);
- requires the development and deployment of information systems that integrate the operations of data collection, data and model integration and information dissemination (Jonoski *et al.*, 2010); and
- requires defining events in terms of sensing (e.g. sound, light, etc.) for localized events. For example, when is a loud noise an accident or simply a car back-firing? (Hentschel *et al.*, 2016).

## 3. Research approach

There is a void in literature in improving business processes by using the potential of big data (Fosso Wamba and Mishra, 2017). The objective of this research is to understand how IoT adoption affects decision-making processes in asset management. To this end, a background of relevant literature was developed in order to place the research in context, gain insight into the asset management decision-making process and identify expected changes to the decision-making process that IoT adoption may bring. The case study method was employed to examine how IoT adoption in real life settings have affected asset management decision-making processes. Case study research was chosen as the main research method because it allows the examination of the effects of IoT adoption in a real-world context (Eisenhardt, 1989; Yin, 2003). The case studies were explorative in method and descriptive in nature.

According to Eisenhardt (1989), a broad definition of the research question is important in building theory from case studies. This research assumes that asset management organizations need data to achieve their business goals, but that the traditional approach of providing disparate systems for each information requirement is no longer adequate. IoT has much potential for improving decision-making about assets, however, the impact of IoT adoption on asset management business processes has not yet been investigated systematically and remains largely anecdotal. This leads us to our main research question which asks:

*RQ1.* How IoT adoption affects decision-making processes of asset management?

Following Ketokivi and Choi (2014), induction type reasoning was used in order to look for both similarities and differences across the cases and proceed toward theoretical generalizations. As with other multiple case study research (Otto, 2011; Pagell and Wu, 2009), the data analysis in this research contained both within and across case analysis

(Miles and Huberman, 1994). Within case analysis helps us to examine the impact of IoT on asset management decision-making processes in a single context, while the across case analysis triangulates the constructs of interest between the cases. Within case analysis is a process of data reduction and data management (Miles and Huberman, 1994), and in this research had five main components. First, we tried to make sense of the social fabric of these asset management organizations and how IoT adoption affects the company's business culture. Second, we cross-referenced the organization's asset management activities in relationship to required skills and how these skills may change with adoption of IoT. Third, we identified how organizational structures and policies are affected by IoT adoption. Fourth, we identified how decision-making business processes are affected by IoT adoption. Finally we considered how IoT adoption introduces decision-making changes regarding the technology choices of an asset management organization. With regards to cross-case analysis, data reduction was primarily done through categorization. Table III below is partly a result of this process. The end result of the within case analysis was an inventory of effects of IoT on asset management decision-making processes.

### *3.1 Case selection*

Whilst single cases are recommended where the case represents a critical test of existing theory, or where the case is a unique event, or where the case serves a revelatory purpose, a limited number of case studies is considered to be more successful with regards to theory formulation and testing (Yin, 2003). Using more than one case study provides us with the opportunity to build the theory irrespective of an organization, which improves the argument for generalization. The evidence from multiple cases is often considered more compelling and the research more robust (Herriott and Firestone, 1983). We followed a similar approach to that employed in studies conducted by Pagell and Wu (2009) and Wilhelm *et al.* (2016) and selected two different organizations by applying a number of criteria. Two organizations tasked with maintaining infrastructure were selected. Case X operates at the national level, whilst case Y operates at the regional level. This enables us to compare differences between the levels to determine possibilities for generalization. Any use of multiple-case designs should follow replication logic to guarantee external validity. For this reason, we defined the following criteria which were used to select the different cases:

(1) The case must be a complex functioning unit.

(2) The primary processes supported by the case must be focused on the management of civil infrastructure.

(3) Asset management processes must be supported by the asset management data infrastructure, evidenced by the existence and monitoring of key performance indicators.

(4) People operating within the case must be willing to cooperate in the research and must be willing to provide access to the information required for the research.

(5) The case environment should be "data-rich." This means that the organization should produce, manage and maintain at least 5 large data sets as well as a more than twenty small to medium data sets.

(6) The asset management data infrastructure must include at least one use case of IoT adoption.

The research studies the impact of IoT adoption on business processes in asset management data infrastructures. The cases of IoT adoption to be investigated were selected based on the criticality of their use and their importance to the organization. To avoid confounding effects, the study was limited to the examination of cases of IoT adoption in asset management according to specific criteria as specified above.

*3.2 Data collection*

It is not only generalization that presents challenges when adopting the case study methodology; the reliability aspect should also be taken into consideration (Yin, 2003). Reliability refers to the demonstration that the operation of a study, such as the data collection procedures, can be repeated with the same results (Yin, 2003). Yin (2003) recommends employing a well thought out research protocol to ensure reliability. According to Yin (2003), a case study protocol is a formal document which describes the set of procedures involved in the collection of data for a case study. The protocol used in this research follows the advice from Yin (2003) and included the problem statement, a delineation of the unit of analysis, the steps (including the altering of the steps) to be taken, the procedures for contacting key informants and making field work arrangements, reminders for implementing and enforcing the rules for protecting (the privacy of) human subjects, a detailed line of questions, and a preliminary outline for the final case study report. The protocol used in the case studies includes a variety of data collection instruments including documentation, individual interviews and group discussions as suggested by Choi *et al.* (2016). The use of multiple research instruments is encouraged to ensure construct validity through triangulation, taking different angles toward the studied object (Runeson and Höst, 2008), which provide a stronger substantiation of our propositions (Eisenhardt, 1989). At the start of the research, in June 2015, group discussions were held with staff directly involved in the exploratory use cases or who were tasked with managing and maintain the systems. Between October 2015 and June 2017, individual interviews were held with personnel in the organizations under study. Internal documentation was selected which dealt with issues faced by the adopting projects. All interviews were documented in writing. The documents were then analyzed and transferred into an integrated case document (one for each case). The first versions of this document were then sent to the interview participants for feedback and clarification of open points. Once all the additional information feedback had been incorporated, the final version was reviewed and discussed with the main contacts at the organizations under study. Table I gives an overview of the sources used in the case studies.

## 4. Case studies background

The exploratory cases were chosen as being representative of organizations at the national, and regional levels, respectively, in compliance with the principles outlined in Section 2. The cases are described in the following order, first, case X and then case Y. At the end of the section, a comparison of the cases is provided.

*4.1 Case X*

The first case, the automatic measurement of water data, case X, is managed by a central government organization. Case X is a facility that is responsible for the acquisition, storage and distribution of data for water resources. Case X provides a complete technical infrastructure for the gathering and distribution of water data and delivers the data to various stakeholders within and outside the organization such as, hydro-meteorological centers, municipal port companies, flood early warning services and other private parties.

Case X was created from the merging of three previously existing monitoring networks and also includes data from third parties, including water data from foreign countries and other public organizations such as the shipping and transport industry, logistics, harbor management, meteorology, regional and local water management, and international water management. Case X has approximately 640 data collection points using a nationwide system of sensors. The data are then processed and stored in the data center and is made available to a variety of systems and users. Case X collects data regarding water levels, wind speed, wave heights, water temperature, astronomical tides, water currents, salt content, etc. These data are aggregated and calculated within models to accurately predict water levels and water quality.

| Data sources type | Data sources: Case X | Data sources: Case Y |
|---|---|---|
| Interviews | June 2015: Group discussion<br>Department Head<br>Enterprise Architect<br>Service Delivery Manager<br>Data Manager<br><br>October 2015: Individual Interviews<br>Enterprise Architect<br>Senior Advisor<br>Enterprise Architect<br>Enterprise Architect<br>Data Manager<br>January 2017: Individual interviews<br>Strategic Advisor<br>Solution Architect<br>Process Manager<br>Project Manager<br>Service Delivery Manager | June 2015 – June 2016:<br>Senior Policy Advisor Data Management<br>Project Manager Asset Management<br>Asset Data Manager<br>Manager Asset Management<br>Senior Manager<br>Senior Manager |
| Documents | Websites<br>System audit reports<br>Tender documents<br>Market consultation documents | Asset management plans<br>Data management plans<br>Quality compliancy reports<br>Functional designs<br>Expert presentations |

**Table I.**
Data Sources of the case studies

Based on these models, decisions are made to close storm surge barriers, close swimming areas, send out messages to shipping, etc. As such, we can classify case X services as being collaborative aware services (Gigli and Koo, 2011), as case X services are used to make decisions, and based on those decisions, to perform an action. Case X services have "terminal-to-terminal" communication, as well as "terminal-to-person" communication.

*4.2 Case Y*

Case Y is a decision support system for water management. Traditional water level measurement is performed using a level scale in fresh waterways such as ducts and locks. This is placed during construction of the asset and indicates the depth related to the soil (usually) a plurality of centimeters. Case Y automates this process with IoT measurements. The main pumping stations regulate the water levels in the region. Case Y manages approximately > 3,500 km of polder ditches, > 130 automated polder pumping stations, > 20 automated inlets, > 100 automated weirs, > 100 remote level loggers, > 80 smaller pumping stations, > 200 smaller pumping stations, > 3,000 fixed weirs and > 2,000 fixed inlets. Case Y involves the regulation of the water level in streams, lakes, ditches, moats and canals. This is vital for industrial development, agricultural businesses, environmental management and recreation. The height at which the water level of an area is set depends on the use and function of that area. For example, although water levels in wildlife areas often fluctuates, farmers tend to prefer a relatively low water level to prevent their land from becoming too wet.

In the process screen of case Y, IoT measurements are displayed from telemetry, supplemented by estimations from the system itself. These include inland water levels, meteorological information and volumetric flow rate. The system reads precipitation from rainwater measuring stations every 15 min and water levels on the reservoirs which is measured at the polder mills. In addition, the system receives weather forecasts every 15 min via FTP. These are three files with 1 h, 3 h and 24 h forecasts of precipitation, wind and evaporation. The relevant level manager indicates which target level should be used and whether a precipitation protocol is active. The system in case Y then calculates the desired deployment of each reservoir mill for the next 24 h and makes a "request" for the use of pumping stations for the required time. As such, we can classify the services in case Y as being collaborative aware services (Gigli and Koo, 2011), as the services are used to make decisions, and based on those decisions, to perform an action. The services have "terminal-to-terminal" communication, as well as "terminal-to-person" communication.

### *4.3 Comparison of the case studies*

Both cases are involved in water management in the public sector, and the number of measuring stations is similar. Significant differences are in the levels and how the systems are governed. Case X is a national system, which means that the sensors are spread over a wide geographical region and the asset management processes can affect large numbers of people. Case Y, on the other hand, is regional and has a mix of publicly and privately owned sensors. As such, the risk of poor system maintenance may be higher, but the geographical region is much smaller and there are far fewer people affected, significantly reducing the impact of risks involved. Table II demonstrates how IoT adoption affects asset management business processes and specifically how these effects are manifested in the cases.

As seen in Table II, all effects as expected in the literature were found in both cases. As such, we may infer that IoT adoption impacts the asset management process in a variety of ways, which will be discussed in the next section.

## 5. Discussion: changes to decision-making processes in asset management

The literature background and case studies provided valuable insight into which asset management decision-making processes are affected by IoT adoption, but more research should be conducted into specifically how IoT adoption affects these processes. Business processes for decision-making are executed by people working in organizations having a social culture and supported by technology. In this research we found that all these aspects of business processes needed to be reconfigured to benefit from IoT. Table III groups the aspects of business processes needing to be reconfigured in order to benefit from IoT.

Building theory from cases is a strategy resulting in proposition derived from empirical evidence (Eisenhardt, 1989). In this section these changes are discussed in further detail from organizational through to technical, respectively, in the order described in the list above. For each of the areas a generic and testable proposition is derived which is deeply grounded in empirical evidence. The propositions are consistent with both cases:

*P1.* IoT adoption requires organizational changes to process and make use of the data.

Organizational changes brought by IoT adoption may be identified in the way that ubiquitous sensing enabled by Wireless Sensor Network technologies cuts across many areas of modern day living (Gubbi *et al.*, 2013). Gubbi *et al.* (2013) believe that IoT provides the ability to measure, infer and understand environmental indicators, and the proliferation of these devices in a communicating–actuating network creates the IoT wherein sensors and actuators blend seamlessly with the environment around us, and the information is shared across platforms in order to develop a common operating picture. For example, in case X, sensors installed in buoys in countrywide network of sensors monitor the water levels in rivers and in the sea. The system automatically sends reports to storm surge barriers and to their managers if water levels exceed the defined thresholds. Data analytics are needed to analyze the data generated by IoT devices. New people were hired and a separate department is introduced to deal with the IoT data and make decisions. Early predictions of rising water levels can be made and the storm surge barriers can be automatically closed to prevent major flooding. Utilities and independent power providers can reduce operating

| Expected effects of IoT on asset management business processes | Case | Effects of IoT adoption on the cases |
|---|---|---|
| IoT data expected to change performance measurement of infrastructure service<br>Adoption of IoT has introduced more detailed and accurate predictive analysis for management of water levels and water quality of waterways | Case X | Adoption of IoT has introduced more detailed and accurate predictive analysis for management of water levels and water quality of major waterways. Case X collects, aggregates and models data to accurately predict water levels and water quality. Based on these models, decisions are made to close storm surge barriers, close swimming areas, send out messages to shipping, etc. |
| | Case Y | Adoption of IoT has introduced more detailed and accurate predictive analysis for management of water levels in regional waterways. Case Y calculates the desired deployment of each reservoir mill for the next 24 hours and schedules use of pumping stations for the current time |
| IoT data expected to change perception of infrastructure service<br>Adoption of IoT has allowed greater transparency of conditions of waterways and an increased trust in asset management, risk-based decision-making | Case X | Adoption of IoT has allowed greater transparency of conditions in the waterways and an increased trust in the substantiation of decision-making. The functional requirements of case X are based on the information needs of the primary process. However, the data is also used by other users such as<br>Professional users like other government agencies, engineering agencies, universities and professional services<br>The general public such as sailors, surfers, etc. |
| | Case Y | Adoption of IoT has allowed greater transparency of conditions in the waterways and an increased trust in the substantiation of decision-making. The height at which the water level of an area is set depends on the use and function of that area. For example, although water levels in wildlife areas often fluctuates, farmers tend to prefer a relatively low water level to prevent their land from becoming too wet. Case Y allows the organization to accurately communicate reasons for decisions regarding water levels |
| IoT data expected to change improvement processes of infrastructure service<br>IoT adoption has allowed asset managers faster access to data with higher levels of granularity regarding the state of waterways which has allowed decision-making to become partially automated, and allows for greater certainty as to when and which action needs to be taken | Case X | IoT adoption has allowed asset managers access to greater levels of up-to-data information regarding the state of waterways and has greatly increased efficiency in the collection of this data, making the decision-making less subjective. For example, the information about the state of objects from case X contains real-time information about pump rotation times, lift heights, valve positions, operating time and spray times |
| | Case Y | IoT adoption has allowed asset managers access to greater levels of up-to-data information regarding the state of the regional waterways and has greatly increased efficiency in the collection of this data, making the decision-making less subjective. For example, this means greater insight into which preventive measures should be taken regarding water pollution if severe rainfall is expected |

**Table II.** Comparison of how IoT is used in the cases and the effect of IoT on the asset management process

expenditure and cut costs associated with maintenance and manpower through real-time fault monitoring capabilities provided by IoT solution, improving the day-to-day grid effectiveness and capacity planning with detailed reporting and intelligence:

*P2.* IoT adoption requires people to adopt new skills.

| Types of changes | Aspects of business processes needing to be reconfigured |
|---|---|
| Social changes | Higher levels of trust in the data required as data is provided by new stakeholders<br>Higher levels of trust in the system is required (the decisions do not change unless the people making them change their way of thinking)<br>Changing social dynamics in the organization as data analytics experts gain greater visibility and status<br>New business culture from physical inspection to data-driven |
| People changes | New skills required, e.g. asset managers need to become more aware of the possibilities provided by data analysis, and data analysts need a greater understanding of business processes<br>New ways of thinking required, as asset managers need to describe events in sensing terms in order to be able to link sensor data to events. What are critical variables and how can they be sensed? (the decisions do not change unless the people making them change their way of thinking)<br>Critical view on the limitations of data |
| Organizational changes | Greater levels of automation means that new organizational structures and policies are required with regards to data governance<br>Greater levels of data sharing and varying types of data usage mean that new forms of data governance need to developed in order to ensure accountability for compliancy regulations such as privacy and security |
| Business process changes | Greater levels of automation means that many operational decisions can be automated,<br>Data need to be traced for its origin and quality (data provenance)<br>People made decisions are lifted to more strategic level<br>Data governance processes need to be (re)defined |
| Technical changes | Incorporation of new hardware and software requiring new protocols and routines for making use of them |

**Table III.**
Aspects of business processes needing to be configured

People related changes by IoT adoption may be seen in the way people themselves have to adapt to new technologies. New capabilities, skill sets and new ways of thinking are required to be able to leverage the full benefits of IoT and adopt a data-drive decision-making process. It has become clear that combining information from devices and other systems using expansive analysis, may provide new insights for managers of public infrastructure. For example, it is possible to embed wireless sensors within concrete foundation piles to ensure the quality and integrity of a structure. These sensors can provide load and event monitoring for the projects construction both during and after its completion. This data, combined with data from load monitoring sensors designed to measure weights of freight traffic, may provide managers of physical infrastructure with new insights as to the maintenance requirements of the infrastructure. The managers need to have understanding of what the data means to use them for decision-making. For this they were educated to develop new skills:

*P3.* IoT adoption requires data provenance and governance.

Quality of decision-making processes in asset management are directly linked to the quality of the data and being generated within the business processes. As such, with regards to organizational related changes brought about by IoT adoption, the importance of data provenance and data quality for IoT infrastructures and the persisting requirement for manual intervention suggests the need for instituting strong data governance procedures as data quality issues are often do not arise from existing business rules or the technology itself, but from a lack of sound data governance (Thompson *et al.*, 2015). Data governance is the exercise of authority, control, and shared decision-making over the management of data assets. It provides organizations with the ability to ensure that data and information are managed appropriately, aligns the data infrastructures with business requirements, ensures a common understanding of the data, and ensures compliancy to laws and regulations (Brous *et al.*, 2016). In addition to the resolution of data quality issues, data governance may also assist IoT adoption in other ways as data governance provides both direct and indirect benefits. Direct benefits of data governance for business processes can be linked to efficiency improvements (Hripcsak *et al.*, 2014), reductions in privacy violations (Tallon, 2013), and increased data security (Panian, 2010):

*P4.* IoT adoption requires changes in business processes to collect and use data from multiple sources.

Business process related changes can be found in aligning complex data structures. As such, other changes are often related to changes in the asset management business process. For example, traditional processes are often performed by people. When business processes become automated, people assume new or different roles and people-made decisions are often elevated to more strategical levels. This also often means changes in the organization as people are asked to perform other tasks in changing social and cultural environments and often in changing organizational structures. However, automating business processes is challenging, as aligning semantics or ontology between different IoT eco-systems is a complex task and interoperability and convergence with regards to visibility of processed data at the level of applications remains an issue (Mihailovic, 2016). This barrier has hampered IoT data sharing. According to Cao *et al.* (2016), sharing of IoT data will only reach its full potential if data can be collected by multiple sources such as if people are able to share their data related to different events by leveraging the sensing capabilities of their smartphones (Cao *et al.*, 2016). The business processes should ensure that data from multiple sources will be integrated and can be used in decision-making processes. Some of the data collected may contain sensitive information such as the location data of the owners when using smart phone data. Compliancy to privacy and security regulations is therefore imperative and this need to be embedded in the business processes:

*P5.* IoT adoption requires standardization of technology.

Technical changes brought by IoT adoption may be seen in the introduction of new technologies which creates large amounts of data. The technical changes are therefore not only in the introduction of new hardware, but also with regards to new protocols for data transport and security, new ways to store data and new ways to analyze the data and turn it into useable information. These technologies need to be standardized to avoid fragmentation and lack of interoperability. The confluence of sensor-driven data, cloud computing and mobility is driving a need within asset management in which assets themselves become active participants in the various stages of their own lifecycles. This covers a range of technologies, such as data capture, barcode printing and RFID, but it also involves advanced analytics and machine-learning techniques that bring greater flexibility and dynamism to the multitude of data points that IoT architectures engender. Many asset management organizations are exploring IoT technology as an asset management tool, simply because the complexity and size of their infrastructure forces a new way of gathering data and monitoring systems (Hua *et al.*, 2014; Lee, 2014).

## 6. Conclusions

Following Eisenhardt (1989) theory was built, developing five propositions for effective IoT adoption in decision-making processes. We found the need to make organizational and business process changes, development of new capabilities, data provenance and governance and the need for standardization. This research has shown that in seeking to adapt to changing circumstances, asset managers develop rules that anticipate the consequences of certain responses.

Currently, organizations are experimenting with new data sources and there is a general expectation that IoT will provide significant added value to asset management decision-making. Organizations can effectively and sustainably adopt these new data sources in their decision-making if the data that are measured can monitor the important factors of the asset itself. The propositions have practical implications for organizations and show that IoT adoption can result in far-reaching changes. Adoption of IoT allows for more detailed and accurate predictive analysis, increasing trust in the asset management process and allowing for greater predictability in risk-based decision-making. This has allowed decision-making to become partially automated due to the greater certainty as to when and which action needs to be taken. Business processes for decision-making need to be reconfigured to allow IoT generated data to be included and to ensure data provenance so decision-makers can interpret the limitations and potential of the data and ensuring security and privacy is accounted for. Furthermore, the people in the business processes need to learn new skills to be able to understand and interpret the data. Decision-makers need to become more at home with data and data analytics. The culture needs to be changed to move from physical to data-based inspection of assets. Asset management organizations need to change their cultures to adopt IoT so that is ingrained throughout organization rather than being lost in departmental silos. Adoption of IoT requires an IT infrastructure that can facilitate the new data sources and requires a good understanding of the data collected and its quality aspects. Adoption of IoT needs appropriate management of the data to ensure compliancy to laws and regulations. Sound data governance is required to ensure that IoT can provide trusted data for decision-making. The results show that decision processes have been changed to deal with the real-time nature of the data, and managers need to adapt and develop new skills and capabilities to be able to interpret the data.

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