Towards the implementation of smart technologies for movable bridges in the Netherlands

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Abstract

Smart technologies for movable bridges could potentially yield major benefits for Dutch movable bridge owners who face structurally deficient movable bridges, and constrained budgets and labour resources. Smart technologies could enable predicted maintenance and autonomous operation based on traffic demand, which could lead to reduced costs and positive societal effects (e.g. reduced vehicle loss hours and negative environmental effects, and improved safety and reliability). Despite the potential benefits, very few smart technologies have been implemented yet. Hence, this study identified the factors influencing the implementation of smart technologies for movable bridges. In this way, the conditions were determined under which smart technology for movable bridges in the Netherlands might be implemented. Based on factors identified in existing studies a conceptual theoretical model was developed. The model was used to better understand decision-making regarding the implementation of smart technologies for movable bridges in the Netherlands. In a practical sense, it helped to identify relevant interview questions and a label-structure for analysing the results. A stakeholder analysis was used to identify most important stakeholders, as a result of which 14 interviews were conducted. The results showed that smart technologies for movable bridges indeed seem to offer great potential, but there are important conditions to be fulfilled for the implementation. From a technical perspective, non-functional requirements (i.e. reliability of safety sensors and detection systems, cyber secure unlocking and sharing of data, and privacy) should be fulfilled. From an economic perspective, a business model is required that provides insight into the long-term benefits. From a social perspective, a different way of working within and between organisations is needed. Within organisations a more positive attitude towards change and innovation is required, and more knowledge on and experience with smart technologies should be gained. Between organisations appropriate maintenance contracts are found crucial. In addition, more insight into the effects of smart technology on the safety of bridge operation is required. From a political perspective, there should be appropriate laws and regulations. Finally, the results showed that collaboration between stakeholders, the inclusion of movable bridge users and trust are important conditions for the implementation as well. Hereby, this study contributes to the factors identified in literature and the practical implementation. Although this study provides a representative overview of the conditions expressed by Dutch movable bridge stakeholders, it is questioned whether the findings are generalizable to other contexts (e.g. other countries and infrastructure objects). Therefore, it is recommended for future research to study the conditions also in other contexts and compare the results. In addition, a comparative study on successful implementations of smart technologies within other sectors and quantitative research into the societal effects of smart technologies are recommended.

Keywords: Smart technology; Predictive maintenance; Autonomous bridge operation; Movable bridges; Innovation adoption.

1. Introduction

Increased traffic load and the fact that most movable bridges in the Netherlands were built between 50s and 70s, has resulted into infrastructure that is nowadays structurally deficient (Lourens, Van der Male, Hartmann, & Stipanovic, n.d.; Nederlands Instituut voor de Bouw, 2019). Most of the current bridges in the Netherlands are due for replacement. In addition, high user expectations with respect to infrastructure performance in terms of reliability, availability and safety put pressure on existing movable bridges (Annaswamy, Malekpour, & Baros, 2016; Parlikad, & Jafari, 2016; Arts, Dicke, & Hancher, 2008). Together with limited budgets and labour shortage, this resulted in a major challenge for movable bridge owners in the Netherland. To counteract degradation of infrastructure, larger budget is required. Taking this into account, increased technological possibilities have led to more focus on smart technologies for movable bridges (Ogie, Perez, & Dignum, 2017: Mao, Koide, Brem, & Akenji, 2020; SWOV Institute for Road Safety Research, 2016). Smart technologies could enable predicted maintenance and autonomous operation based on traffic demand, which allow movable bridge owners to take more targeted investment decisions and make most out of existing infrastructure (Cambridge Centre for Smart Infrastructure & Construction [CSIS], 2016a). Despite that investments in movable bridges still have to be made, smart technologies could lead to reduced maintenance costs, damage and disruption costs (due to less vehicle loss hours and unexpected technical failures), more efficient use of labour resources and improved quality of life (i.e. less road accidents or better response to disasters and less negative environmental externalities) (Ogie et al., 2017; Barth & Boriboonsomsin, 2008; CSIS, 2016a).

Despite these potential benefits, currently very few smart technologies have been implemented for movable bridges (CSIS, 2016a; Gkoumas et al., 2019). Although existing literature provides an overview of challenges faced by institutional governments in the implementation of smart mobility and smart infrastructure in general, these studies emphasize that further research into the conditions for implementing smart technology within specific contexts is needed (CSIS, 2016b; United Nations Economic and Social Council, 2016; Spaans, 2018).

Smart technologies could yield great benefits particularly for movable bridges compared to other infrastructure assets, including fixed bridges, because movable bridges are more sensitive to maintenance and the opening/closing of the bridges often results in vehicle loss hours (Todinov, 2006; Lammers, 2017). Smart technologies for movable bridges could be specifically valuable in the Netherlands, because it is the number one country in Europe with the highest inland waterway goods transport and the fourth country in Europe in terms of recreational boat fleet in use (Central Commission for the Navigation of the Rhine, 2019; European Competitiveness and Sustainable Industrial Policy Consortium, 2015). In addition, in the Netherlands movable bridges are essential for good accessibility, because there are relatively many movable bridges due to the high population density (Rijkswaterstaat, 2015; World Class Maintenance, 2015). However, the conditions under which smart technologies for movable bridges in the Netherlands might be implemented are not described in existing literature yet. Therefore, the main objective of this study is: '*to determine the conditions for implementing smart technologies for movable bridges in the Netherlands in order to provide insight in the further development of these potentially beneficial technologies and support movable bridge stakeholders with the implementation.*' This has led to following research question:

'Under which conditions might smart technologies for movable bridges be implemented in the Netherlands?'

To be able to answer the research question, a literature study was done to identify the research gaps, and gain a better understanding on what exactly could be considered as 'smart' technology for movable bridges, how movable bridges in the Netherlands are currently managed, maintained and operated, and the factors influencing innovation adoption. Based on these insights, a definition was formulated on what might be considered as smart for movable bridges, the level of 'smart' of the currently used management, maintenance and operation approaches and technologies was assessed, and a conceptual model with factors potentially influencing the implementation of smart technology for movable bridges was developed. The conceptual model was mainly based on the factors described in the Political Economy of Transport Innovation framework (Feitelson & Salomon, 2004). The results of the literature study were used as the theoretical foundation for formulating effective questions for semi-structured expert interviews. In addition, the conceptual model was used as a label structure for coding and analysing the interview results. For the interviews, experts were selected mainly based on a stakeholder analysis. In addition, a criterion-based selection technique was used. Based on the results of the interviews, the conditions under which smart technologies for movable bridges in the Netherlands might be implemented were explored.

By answering this research question, the study aims to not only provide practical contributions for movable bridge stakeholders when implementing smart technologies, but also to contribute to science and society. From a scientific perspective, this study aims to close the knowledge gaps in literature by providing insight into what exactly could be considered as 'smart' technology for movable bridges, the level of smart technology that is currently implemented in the Netherlands and the conditions required for the implementation of smart technologies for movable bridges in the Netherland. From societal perspective, this study aims to contribute to the further development and implementation of smart technologies for movable bridges in the Netherlands, which could potentially yield great societal benefits, such as reduction of vehicle loss hours and a higher quality of life (i.e. improved reliability, safety and environmental effects).

In the next section, the methods used in this study are further elaborated. Hereafter, Section 3 discusses the literature that was studied. Section 4 presents the results of this study, which are discussed in the subsequent section. The research is concluded in Section 6. Finally, recommendations for further research and practitioners are made in Section 7.

2. Methods

As discussed, to answer the research question a literature study was done and interviews with experts were conducted. In the next subsection both methods will be further elaborated.

2.1. Literature study

In this research literature study was used as a method to map the state-of-the-art, theoretical approaches and knowledge gaps. This was especially helpful for scoping the research and defining the right research questions that contribute to existing literature. The insights retrieved from the literature study were used to formulate effective interview questions. In addition, a conceptual model with factors that potentially influence the implementation of smart technology for movable bridges in the Netherlands was developed as a tool (i.e. labelling structure) for the analysing the interviews. More about the interview analysis will be discussed in the next subsection.

To retrieve useful information different sources were used (i.e. Scopus, ScienceDirect and Google Scholar), different keywords and Booleans were used (i.e. “SMART” AND “TECHNOLOGY”, “TECHNOLOGY” AND “ADOPTION”, etc.), and different search techniques were used (i.e. forward and backward snowballing). To make a selection from the found articles the usefulness of the found articles was determined based on the summary of the article and the year of publication. Although smart technologies are a relatively recent topic, transport infrastructure in general has been studied for a long time. Therefore, the literature study was focussed on papers after the year 1990.

2.2. Interviews

Interviews are a qualitative research method suitable to explore the interests, attitudes and normative behaviour of different stakeholders (Hammarberg, Kirkman, & de Lacey, 2016). In this research interviews were used to collect the required information to answer the research question and contribute to existing literature. In addition, the interviews were used to critically reflect on the findings of the literature study.

The interviews were conducted in a semi-structured way. With semi-structured interviews some degree of structure is followed, but it also allows flexibility for the interviewee in the way issues are addressed (Dunn, 2005). Based on the gaps identified in the literature study interview questions were formulated. During the interviews a predetermined sequence of questions was maintained as much as possible to ensure that the required information was retrieved and measurement errors were minimised. However, some flexibility for the interviewee was allowed in the way and order the questions were addressed.

2.2.1. Interviewee sampling

In interview-based qualitative research participants are often selected because of their personal experience or knowledge on the topic under study (Clearly, Horsfall, & Hayter, 2014). In this study interviewees were purposefully selected based on various techniques. First, a stakeholder analysis was done to identify relevant actors involved in the implementation of smart technology for movable bridges. Stakeholder analysis is ‘a method to systematically gather and analyse qualitative information to determine whose interests should be taken into account when developing and implementing a policy or program’ (Schmeer, 1999, p. 3). With the use of a power-interest grid and a formal chart, important stakeholders and their interrelationships were identified. Second, a criterion-based technique was used to select experts on their ability to provide rich and focused information on the research question. Experts were selected based on their level of experience and knowledge in the management, operation and maintenance of movable bridges, and particularly their expertise on smart technologies related to movable bridges.

This was determined based on work experience in the field and any publications.
Finally, the selection was partly based on the available contacts within Witteveen+Bos and a snowball effect (i.e. via selected experts other experts could be reached). Table 1 shows the interviewee sample that resulted from these techniques.

2.2.2. Interview analysis

There are several methods to analyse qualitative data, such as narrative, grounded theory, content, and discourse analysis (Merriam, 1998; Bernard, 2000). The most foundational one is thematic content analysis (Anderson, 2007). The analysis process involves three types of coding: open, axial and selective coding (Strauss & Corbin, 1990). In this study for each of type of coding the conceptual model, which is discussed in Section 3, was used as the theoretical basis. Before coding the interviews were transcribed in a literal (i.e. letter-by-letter) way. In the first step of the analysis process, codes or labels were assigned to units of data. Hereafter, axial coding was used to categorize the labels assigned to the data during open coding. These categories were based on the factors identified in the conceptual model. In the final step, selective coding, categories were related to other categories in order to move towards a theme. The themes were based on the requisites for innovation adoption identified in the conceptual model. If categories or themes were not covered by the factors and requisites defined in the conceptual model, a new category or theme was created. In this way the effectiveness of the conceptual model as a tool for analysing the implementation of smart technology for movable bridges in the Netherlands was determined. To determine the relative importance of the different labels, categories and themes, frequencies were used. Frequencies or "counts" are the most common way to introduce numbers into a qualitative research (Niglas, 2004). Frequencies indicate the number of times a label, category or theme is assigned to the interview data (Baarda, De Goede, & Teunissen, 2001). Although frequencies are not suitable for statistical analyses, they can give a rough estimate of the relative importance of that label, category or theme (Onwuegbuzie & Teddlie, 2003; Assessment of Teaching and Learning Washington State University, 2015). Counts indicate whether or not something has been repeatedly mentioned or only been mentioned once or twice in passing. This helps against researcher bias, as humans tend to notice unusual or dramatic occurrences more and assign higher importance to these occurrences (Fife, 2020). In addition, to determine in what sense labels, categories and themes are

Table 1: Interviewee sample

Type	Level	Organisation and function
Bridge owners, managers & operators	National	Rijkswaterstaat national program 'Vitale Assets' *Program manager/ senior consultant network monitoring*
		Rijkswaterstaat North-Netherlands *Senior consultant industrial automation (asset management)*
	Regional	Province of Overijssel *Expert electrical engineering and drive systems movable civil engineering structures (asset management)*
		Province of Overijssel *Technical engineer movable civil engineering structures*
		Province of Groningen *Electro-technical engineer*
		Province of Friesland *Electro-technical engineer*
	Local	Municipality of Zaanstad *Asset manager civil engineering structures & responsible for bridge operation centre*
		Municipality of Haarlem (Port Authority) *Technical coordinator management and maintenance*
Market parties		SPIE Smart City *Junior maintenance engineer*
		SPIE Industry Services *Junior maintenance engineer*
		'Kroneman Industriële Automatisering BV' *Owner/ lead engineer*
Branch associations		World Class Maintenance *Project manager Fieldlab CAMINO*

important, the charge (i.e. positive or negative) in which they are mentioned can be used (Baarda et al., 2001). This charge or context is often illustrated by means of quotes or short text fragments. In this study it was taken into account whether labels, categories and themes were mentioned in a positive, negatively or neutral sense. The results were illustrated by means of quotes and short fragments of text from the interview data.

2.2.3. Interview reflection

Although it is argued that the terms validity and reliability are only applicable for quantitative research, these terms are also considered as important quality checks for qualitative research (Patton, 2002). In qualitative research validity and reliability are determined based on the trustworthiness and consistency of research design and results (Golafshani, 2003). To establish valid and reliable results in this study interviewees were selected based on various sampling techniques (i.e. stakeholder analysis and criterion-based sampling), a relative large sample size was used and expert consensus from others was used. The aim was to validate the results by others in a workshop setting, because this is considered as an efficient way to validate interview results (O'Neill, Palanque, & Johnson, 2003). However, due to the COVID-19 outbreak, an alternative validation setting was chosen. The results were sent via email to experts from Witteveen+Bos, who were selected based on their knowledge with smart technologies for movable bridges and their experience with different movable bridge owners. In Section 5 is reflected on the sample size by discussing the data saturation.

3. Literature

The objective of the literature study was threefold. First, literature on definitions of smart infrastructure was studied to develop a theoretical understanding of what exactly is considered as 'smart' technology for to transport infrastructure. Second, literature on the management, operation and maintenance of movable bridges was studied to gain a better understanding of the current practice and technologies that are used. Third, literature on innovation adoption was studied to better understand of decision-making regarding the implementation of new technologies and develop a conceptual model with factors that potentially influence the implementation of smart technology for movable bridges in the Netherlands. In the following subsections the different literature findings will be discussed.

3.1. 'Smart' transport infrastructure

For the first goal mainly two frameworks were used, the Levels Values Principles (LVP) and the Digital Layers for Smart Infrastructure frameworks, which were found useful for defining smart technology for transport infrastructure and movable bridges in particular.

3.1.1. Levels Values Principles (LVP) framework

The LVP framework provides a typology to classify, compare and benchmark different smart infrastructure initiatives (Ogie et al., 2017). It can be used as a reference point for the stakeholder's expectations and how they can change over time as the technology is constantly changing (Buckman, Mayfield, &

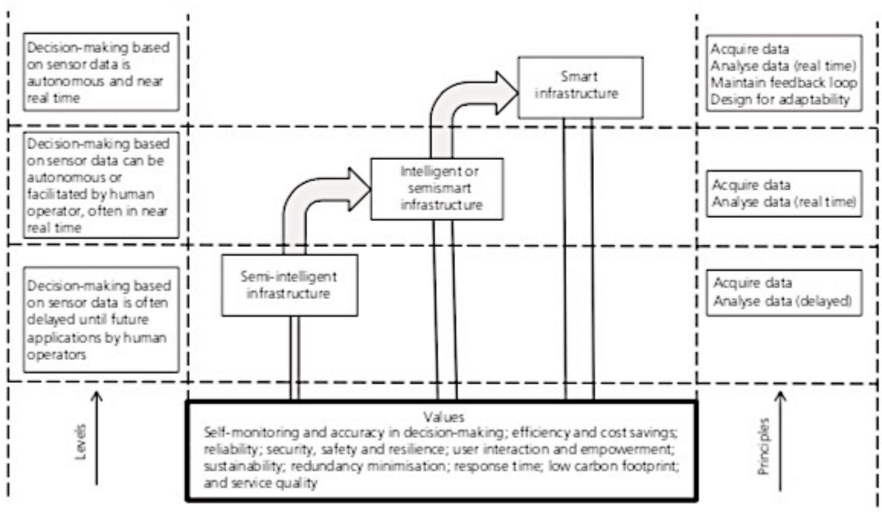

Figure 1: LVP framework (Ogie et al., 2017)

Beck, 2014). Figure 1 illustrates the framework. The framework distinguishes three levels of smart infrastructure depending on the degree of human involvement in the decision-making process and the speed of the adaptability (The Royal Academy of Engineering, 2012). The first level is semi-intelligent infrastructure, which is infrastructure that collects data about its own performance, but is not able to make decisions based on this data. The data is rather used to improve efficiency in the future (The Royal Academy of Engineering, 2012). The second level, intelligent or semi-smart infrastructure, is infrastructure that processes the collected data into real-time actionable information, which the system or a human operator uses to take more efficient decisions. For example, this could be a movable bridge that is able to detect congestion and informs users about when and how long a bridge will be opened, who then can take more efficient routing decisions. Lastly, the third level is smart infrastructure, which is infrastructure that performs the data collection, data processing and decision-making autonomously and adaptive to real-time or near real-time situations (Ogie et al., 2017). For example, this could be a movable bridge that is autonomously operated (i.e. without intervention of a human operator) based on real-time traffic demand.

The values in de framework define the drivers of making infrastructure more intelligent or smart, which are self-monitoring and accuracy in decision-making (e.g. predictive or condition-based maintenance), efficiency and cost savings, reliability (i.e. reducing down-times and disruptions), security, safety and resilience, user interaction and empowerment, sustainability, redundancy minimisation, response time (i.e. early detection of failures), low carbon footprint, and lastly service quality.

On the right side of the figure the principles for the design and construction of smart infrastructure are shown, which are data collection, data analysis, maintaining feedback loop, and designing for adaptability. The principles should ease the implementation of smart infrastructure. First, it is important to acquire the data needed to improve the decision-making process. Second, is analysing the data by processing the data into actionable information. Furthermore, there should be a feedback loop, which allows that the collected data is continuously used to optimize operations. Lastly, adaptability must be taken into account. This allows real-time adjustments to varying environmental conditions (The Royal Academy of Engineering, 2012).

Although the framework provides a clear distinction between different levels, values and principles, it does not provide insight in the ways of collecting the data, analysing the data and using it for decision-making. Therefore, in the next sub-section another framework is discussed that further elaborates these parts.

3.1.2. Digital Layers for Smart Infra framework

Although smart infrastructure systems vary for each sector (transport, electricity, waste, etc.), each has a similar anatomy of three

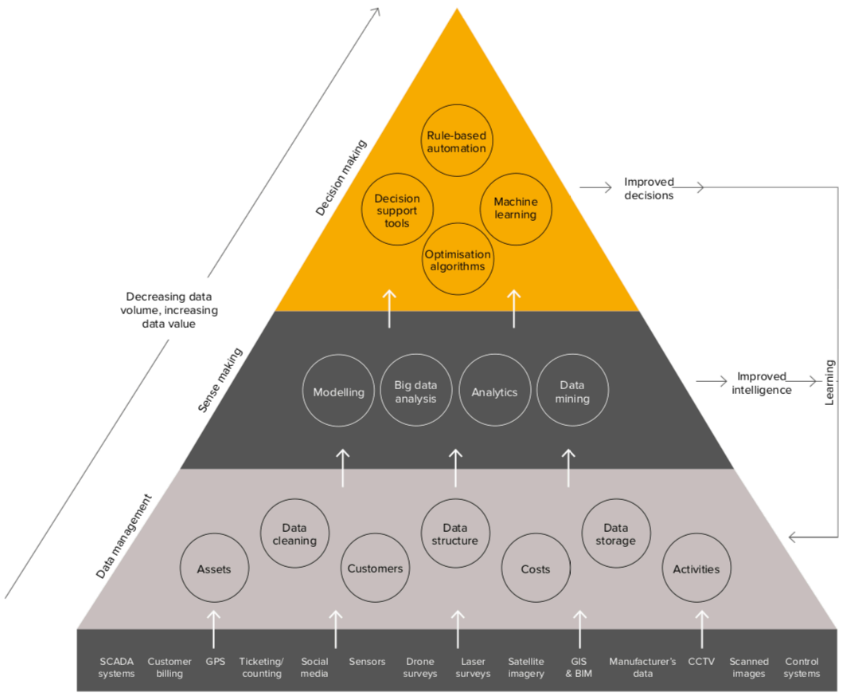

Figure 2: Digital layers for smart infrastructure framework (CSIS, 2016a)

layers connected by communications. Overlaying these layers onto a physical infrastructure is what it makes smart (CSIS, 2016a). Figure 2 illustrates the framework. The layers in the framework are structured as a pyramid in which a higher layer is characterised by a decreased data volume and increased data value. The first layer of the framework represents data management, which involves unlocking, structuring, cleaning and storing of data from different sources (e.g. supervisory control and data acquisition (SCADA), building information modelling (BIM), global positioning system (GPS), sensors, etc.). Internet of Things and special networks, such as long rang (LoRa) networks, are often used to transmit the data from assets to the data systems (Van Oerle, 2017). The second layer represents 'sense making' in which the information of the lower level is processed and analysed. Different modelling techniques and big data analytics are used to improve the intelligence of the infrastructure (CSIS, 2016a). Finally, the third layer represents how high value data is used to improve the decision-making process resulting in better decisions, which are made faster and more cost-efficient. In this layer, for example machine learning based on artificial intelligence (AI) is used. Based on the framework the following definition of smart infrastructure was formulated:

'Smart infrastructure is infrastructure that responds intelligently to changes in its environment, with the ability to influence and direct its own service delivery, use, maintenance and support (CSIS, 2016a).'

This definition was used as to define what could be considered as smart for movable bridges. The applicability of this definition to movable bridges and if this is actually considered as 'smart' was evaluated during the interviews and will be discussed in the next section.

3.2. Movable bridge management, maintenance and operation

For the second goal, a distinction was made between bridge functions related to management and maintenance of movable bridges and to operation of movable bridges.

3.2.1. Movable bridge management and maintenance

Movable bridge management is about balancing costs, risks and performance of movable bridges (Van de Kerkhof, Lamper, & Fang, 2018). This involves necessary technical maintenance, but also ensuring that the asset continues to meet the requirements of the users. These changes put pressure on movable bridges and sometimes require structural adjustments. Therefore, infrastructure monitoring is an important part of movable bridge management (Rekenkamer Amsterdam, 2015). Currently, the condition of movable bridges is mainly determined by means of visual inspections. Due to lack of insight into the technical condition of movable bridges, maintenance is mainly done with a preventive (periodic) or corrective approach (Van de Kerkhof et al., 2018). Technologies for better monitoring of infrastructure (e.g. sensor technology) are becoming less expensive, which has led to a growing interest for condition-based and predictive maintenance (Van de Kerkhof et al., 2018). Existing monitoring technologies include sensors for measuring temperature (of structure and outside air), wind speed and direction, water levels, vibrations, displacement, energy use and quality, corrosion, etc. Such sensors often are easy to install and relatively low cost, and could result in large economical benefits (Lourens et al., n.d.). Sensors can detect wear that is invisible to the eye. In this way action can be taken in time and major maintenance can be prevented. This not only saves costs, but also improves the reliability and availability of a movable bridge (Van de Kerkhof et al., 2018). For predictive maintenance data of the sensors needs to be analysed to predict future failures. For this often artificial intelligence based on machine learning is used (Croonwolter&dros, 2020). Most of the technology used for condition monitoring and predictive maintenance is already technically proven in other sectors. However, it is not yet proven in the context of movable bridges. Therefore, currently several pilots are being done (Van de Kerkhof et al., 2018). The maturity of technology can be defined based on Technology Readiness Levels. The TRLs are developed by NASA and are based on a scale form 1 to 9, with level 9 as the highest level of maturity in which a technology is "flight proven" (NASA, 2012). Pilot production is considered as TRL 5 to TRL 7. This means that the technology is already validated in a lab environment. TRL 5 indicates that technology is validated in a relevant environment, TRL 6 that technology is demonstrated in a relevant environment and TRL 7 that a system prototype is demonstrated in an operational environment. After this, systems are implemented. This means that in TRL 8 systems are complete and qualified and in TRL 9 the actual system is proven in operational environment (NASA, 2012).

3.2.2. Movable bridge operation

Most movable bridges in the Netherlands are locally operated by a human operator and increasingly operated from an operation centre (Dutch Safety Board, 2019). Other bridges have a self-service operation and very few are autonomously operated without any human intervention (Rijkswaterstaat, 2017). Centralisation of operation allows better coordination of bridge openings and could result in a reduction of vehicle/vessel loss hours (Rijkswaterstaat, 2014; Ministry of Infrastructure and Environment, n.d.). However, there is also discussion on remote operation, because accidents have occurred with remotely operated bridges (Dutch Safety Board, 2016). Therefore, the camera and detection systems are questioned in terms of safety. Detection systems involve sensors detecting arriving vessels, free space detection and microwave scanning. These systems are required for autonomous operation, but are currently mostly used as support for the operators (Cobouw, 1994). They support the operator in making a safety assessment whether it is safe to open the bridge or not. In addition, technologies support the operator in making a traffic assessment to determine the optimal moment for opening the bridge. The increase in traffic intensity made this more challenging (Dutch Safety Board, 2016). Therefore, more supportive technologies, such as the bridge management system, are used. This system combines different types of traffic data and operation hours of nearby movable bridges, to provide bridge operators with information about the optimal moment to open the bridge from a traffic management perspective (Lammers, 2017).

Technology is also used to improve the information provision for road and waterway users. Real-time data and predictions on when and how long bridges are opened are shared with users via navigation systems and applications, which can suggest alternative routes to minimise travel loss hours (Ministry of Infrastructure and Environment, n.d.). For example, currently the National Data Warehouse for Traffic Information collects

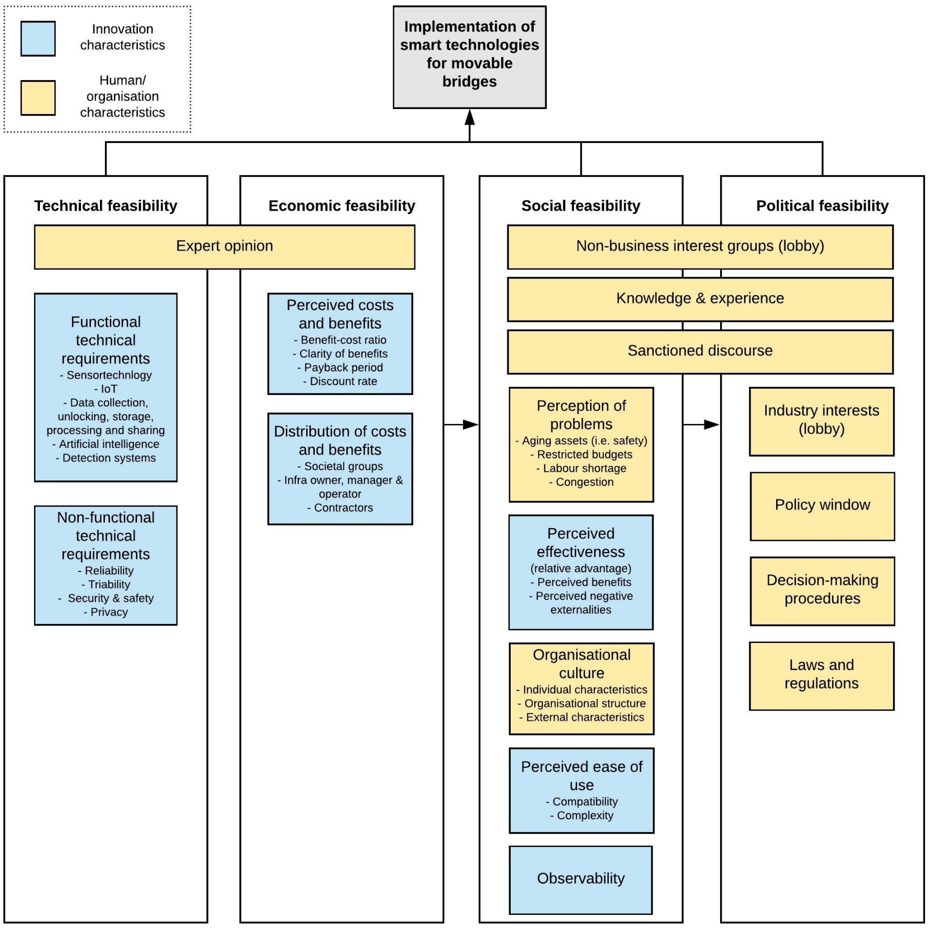

Figure 3: Conceptual model for analysing the implementation of smart technologies for movable bridges in the Netherlands

real-time data on bridge openings of 300 bridges in the Netherlands, which is used by the road information applications, Flitsmeister and Waze (Transport Online, 2019).

3.3. Technology implementation

Previous studies on implementing smart infrastructure in general have identified the lack of finance, localisation of smart infrastructure, skills gap, application of a suitable governance model and inclusivity of all population groups as main challenges (United Nations Economic and Social Council, 2016). In addition, the lack of a common language for information sharing, standardization of asset information, and security protocols and standards are identified as main priorities for the implementation of smart transport infrastructure (CSIS, 2016a). Moreover, data management is often considered as cornerstone of smart solutions and must be perfectly developed before implementing smart solutions, which are sensitive for data security and safety (Spaans, 2018). Therefore, privacy is identified as a challenge (The Royal Academy of Engineering, 2012). Furthermore, it needs to be taken into account that people are reluctant to change and focus more on the reasons not to do something than on the reason to do something (Pieterse, Caniëls, & Homan, 2012). To determine the factors influencing the implementation of smart technology for movable bridges specifically, a conceptual model was made with factors influencing the adoption of innovations. The conceptual model was based on the Political Economy of Transport Innovation framework (Feitelson & Salomon, 2004). This framework was most suitable for the context of movable bridges, because it focuses on transport innovations and includes the important role of public authorities in the adoption of these innovations. The framework distinguishes four requisites for innovation adoption, which are technical, economical, social, and political feasibility of an innovation. For each of the requisites the framework describes different factors. In addition to these factors, other factors identified in other studies were included in the model. Figure 3 illustrates the conceptual model with all the identified factors that potentially influence the implementation of smart technology for movable bridges in the Netherlands. Table 2 shows factors added to the framework and from which studies they were derived.

Table 2: Additional factors derived from literature

Additional factor	Described in
Perceived ease of use (Compatibility & complexity)	TAM (Davis, 1989)
	MLP (Geels, 2004)
	Resistance (Kleijnen, Lee & Wetzels, 2009)
	DOI (Rogers, 1983)
Organisational culture	TPB (Ajzen, 1991)
	I-TPB (Unsworth, Brabant, Murray & Sawang, 2005)
	DOI (Rogers, 1983)
	MLP (Geels, 2002)
Policy window	MLP (Geels, 2002)
Laws and regulations	MLP (Geels, 2002)
Observability	DOI (Rogers, 1983)
	Resistance (Kleijnen et al., 2009)

4. Results

The goal of the interviews was threefold. First, to gain a better understanding of stakeholder' views on what is 'smart' technology for movable bridges. Second, to gain insight into current use of smart technologies by stakeholders. Third, to identify the factors influencing the implementation of smart technology for movable bridges viewed by the stakeholders. In the following subsections the different interview results will be discussed.

4.1. What is 'smart'?

During the interviews the definition of smart movable bridges, defined in Section 3.1.2, was validated. All experts agreed that smart movable bridges could be defined as:

'A movable bridge is smart if it is able to respond intelligently to changes in its environment, with the ability to influence and direct its own operation, maintenance and support' (based on CSIS, 2016a).

However, most experts were not convinced that this is already feasible. In particular, autonomous decision-making by technology is questioned. At this point, experts are not convinced that technology is able to make good trade-offs between traffic demand management and asset management, will be reliable (i.e. no failures) and fits into current guidelines. Because of these reasons, expert argue if these technologies are at this point smart in terms of safety, reliability and availability. Therefore, experts prefer movable bridges to have technologies implemented as supportive tools, rather than as autonomous systems directing their own operation and maintenance.

4.2. The level of smart of the current situation

The results show that the level of smart of the current way of managing, operating and maintaining movable differs per stakeholder. However, in general experts agree that 'smart' technology as defined by the definition discussed in the previous section is not yet used. Several experts mentioned that pilots are performed to test the technical possibilities of smart systems. According to LVP framework, discussed in Section 3.1.1, existing practice mentioned by the experts could not be considered as smart yet. With 'smart' data is analysed in or near real-time and autonomously (i.e. without the intervention of a human). The technologies that currently are used still largely depend on human action in the data analysis and application of the data in the maintenance and operation practices. However, in pilots some technologies related to predictive maintenance are tested that could be considered as intelligent or semi-smart.

Table 3: Frequencies of themes, categories and labels

Theme	Category	Label	Frequency
Technical feasibility	Functional requirements	Related to sensors technology	14
		Related to data collection & unlocking	23
		Related to data system	10
		Related to data analysis	9
		Related to data sharing	3
		Related to artificial Intelligence	14
		Related to detection systems	7
	Non-functional requirements	Reliability	45
		Triability	17
		Cyber security	22
		Safety	18
		Privacy	4
	Expert opinion		-
Economic feasibility	Perceived costs and benefits	Benefit-cost ratio	23
		Payback period	14
		Discount rate	-
	Distribution of costs and benefits		3
Social feasibility	Perception of problems	Aging assets	11
		Restricted budgets	6
		Shortage of labour	10
		Congestion	3
	Perceived effectiveness	Safety	18
		Congestion	16
		Labour efficiency	10
		Availability & Reliability	18
		Sustainability	2
	Perceived ease of use	Compatibility	24
		Complexity	5
	Organisational culture	Individual characteristics	20
		Organisational structure	24
		External characteristics	34
	Observability		24
Political feasibility	Non-business interest groups		4
	Industry interests		-
	Knowledge & experience		16
	Sanctioned discourse		5
	Policy window		1
	Decision-making procedures		2
	Laws and regulation		20

With 'intelligent or semi-smart' technology autonomously collects, analyses and uses this information near real-time, but with an operator facilitating the process. Technologies, such as the bridge management system, could be considered as in between semi-intelligent and intelligent/semi-smart. With semi-intelligent technology the analysis and use of data largely depends on a human operator and is not near real-time. The bridge management system collects, analyses and uses real-time data to provide human operators supportive information for more efficient bridge operation. This system does depend on a human operator, but the data is real-time analysed and used. Therefore, it could be considered in between both categories. Moreover, some experts mentioned technologies that could be considered as semi-intelligent. For example, some experts experiment with condition or network monitoring, but the data is analysed by a human, with large delay and often not actually put into use. Finally, several experts do not use technologies as described by the three categories. They mentioned that they do have data, but just do not use it yet.

Furthermore, during the interviews experts were asked to rate the readiness for smart technology of the existing movable bridges on a scale from 1 to 10, where 10 indicates that no adjustments are required in the assets and where 1 indicates that the movable bridges are not future proof and a lot of adjustments need to be made to realise smart technology. Based on ranking of 11 experts an average of 6.2 was mentioned.

4.3. Factors influencing implementation of smart technology for movable bridges in the Netherlands

The interview results show that almost all factors identified in the conceptual model were mentioned. Table 3 shows the factors of the conceptual model and the number of times that they were mentioned. The factors 'expert opinion', 'discount rate' and 'industry interests' were not mentioned. In addition, three new factors were mentioned that were

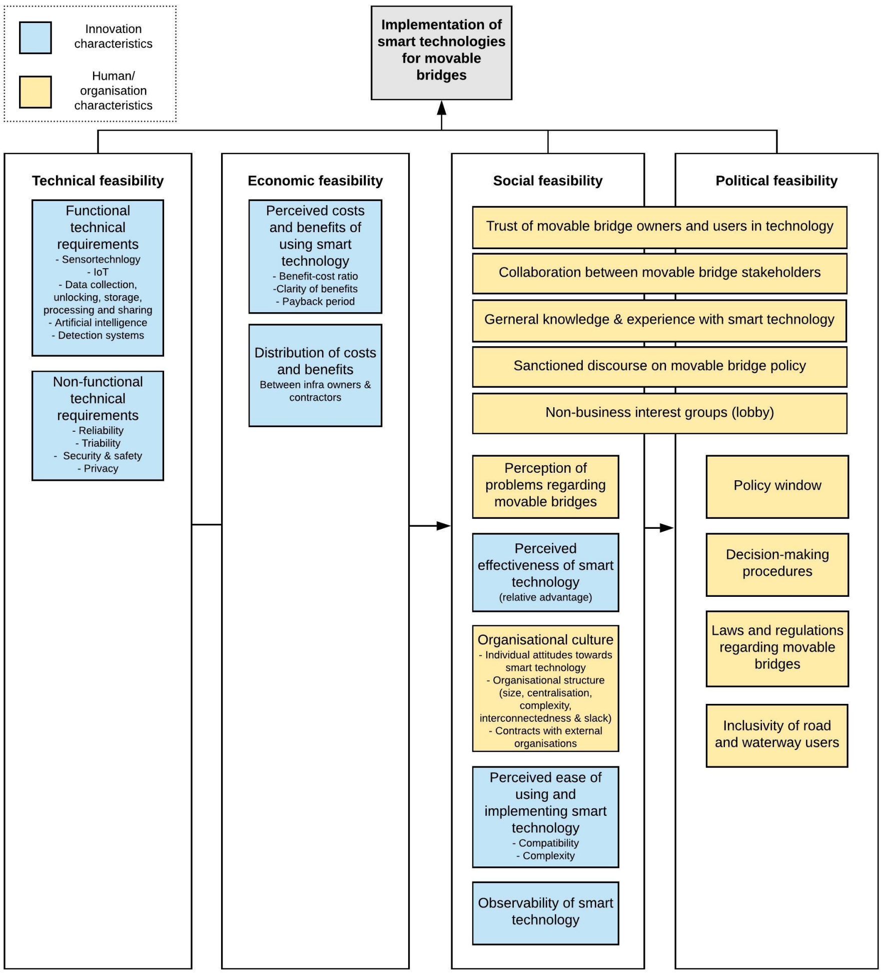

Figure 4: Final model for analysing the implementation of smart technologies for movable bridges in the Netherlands

not in the conceptual model, which are 'trust', 'collaboration' and 'user inclusivity'. The frequencies of these factors are six, 18 and nine respectively. Figure 4 illustrates the final model for analysing the implementation of smart technologies for movable bridges in the Netherlands. Furthermore, differences in results between stakeholders were analysed.

5. Discussion

This section reflects on the results and discusses the limitations of this study.

5.1. Reflection on results

The results showed that in terms of technical feasibility reliability of technologies and cyber security are important factors. Previous studies identified cyber security also as a challenge or priority when implementing smart infrastructure (Spaans, 2018). However, the reliability of technologies was not identified as challenge yet in literature.

In terms of economical feasibility, the results showed that lack of insight in long-term benefits is an important factor. This was also identified in literature as the lack of finance and the need for alternative business models (United Nations Economic and Social Council, 2016).

In terms of social feasibility, the perceived ease of use (i.e. compatibility), the safety of technology and organisational culture were found to be important factors. Within the organisational culture, results showed that external characteristics (i.e. contracts between stakeholders), organisational structure (i.e. complexity and organisational slack) and individual characteristics (i.e. conservative attitude) are important factors. The compatibility and safety of technologies, and the contractual agreements between stakeholders were not discussed in literature yet. That importance of organisational culture and structure is consistent with the challenges identified in previous studies. Conservative attitudes within organisations and organisational slack were identified as a lack of resources and a skills gap (United Nations Economic and Social Council, 2016).

In terms of political feasibility, the results showed that the knowledge and experience, and laws and regulations are two important factors. The importance of knowledge and experience is consistent with previous research as skills gaps were identified as a challenge (United Nations Economic and Social Council, 2016). Laws and regulations were not specifically identified in literature. However, a lack of a suitable governance model was identified as challenge (United Nations Economic and Social Council, 2016). Laws and regulations could be considered as part of a governance model.

Finally, the results showed that trust, collaboration and user inclusivity are important factors, which were not included in the conceptual model.

The results provide a representative overview of the factors influencing the implementation of smart technology for movable bridges expressed by movable bridge stakeholders. Important determinants for generalizability to larger populations are the selection of interviewees and the number of interviewees (Steckler & McLeroy, 2008). In this study experts are carefully selected based on different sampling techniques (e.g. stakeholder analysis and criterion-based sampling). In addition, in total 13 different experts were interviewed. Figure 5 illustrates the saturation of labels that were mentioned during the interviews. After six interviews most labels were already discussed. The other interviews were conducted to further validate the results. Therefore, it can be concluded that the results do provide a representative overview of the stakeholders' current views on the implementation of smart technology for movable bridges.

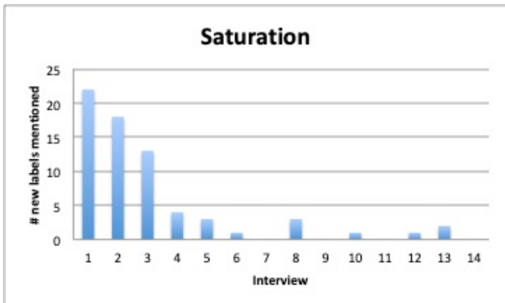

Figure 4: Saturation of interview labels

However, it is questioned whether the results are generalizable to other contexts (i.e. other countries, infrastructure objects or moments in time). The results of the interviews provide insight into the current use of smart technology and the barriers that are being faced. In this sense it provides only a 'snapshot' in time. It could be possible that in a year from now more technologies are tested, technically proven and used, and that other barriers are being faced. Furthermore, in other countries for example the condition of existing movable bridges, the traffic intensities, organisational culture and laws and regulations could be different. Moreover, for other infrastructure objects, such as fixed bridges or tunnels, the effects of smart technology could be very different. For example, the failure patterns of fixed assets are more predictable compared to movable assets. Therefore, benefits of smart technology could differ. In addition, organisations could have different budgets for fixed transport infrastructure. Because of these reasons, a similar research that is performed on another context would probably result in different findings.

5.2. Research limitations

As the main research method semi-structured interviews were conducted. A limitation of this method is that it is sensitive to measurement error and bias, which can affect the following stages of the interviewing process: asking the questions (i.e. deviation from the interview structure and interrogation error), recording the answers (i.e. recording error), and interpreting and coding the answers (i.e. interpretation error) (Mathers, Fox, & Hunn, 1998). The different possible errors were taking into account when performing the different steps of the interviewing process to minimise the level of bias and achieve a high level of internal validity. First, a conceptual model was developed based on literature that was used to structure and formulate interview questions. During the interviews the structure was maintained as much as possible and questions were asked as neutrally as possible to prevent interrogation error.

Second, during the interviews a recording device was used and recordings were transcribed in a literal (i.e. letter-by-letter) way in order to minimise recording errors.

Furthermore, a conceptual model based theory was used as a standard labelling structure for analysing the results of the interviews. Hereby, interpretation errors during the coding process were minimised. However, an intercoder reliability check could have been used to further validate interview analysis (Mouter & Vonk Noordegraaf, 2012). Unfortunately, due to a limited time available, this check has not been performed.

In addition, in Chapter 4 the results were further elaborated by presenting quotes of what the experts mentioned during the interviews. Because the selection of quotes by the researcher is very sensitive to bias, it was taken into account that the quotes provide a good balanced representation of the content of the interviews. In addition, frequencies were used to indicate relative importance of factors. It should be noted that frequencies in the results only provide a rough indication of the relative importance and are not statistically reliable.

As a final check for subjective or perceptual bias, results were validated by means of ‘expert consensus from others’. In total three experts from Witteveen+Bos with knowledge and experience related to smart technologies for movable bridges validated the results and indicated that the results correspond to their practical experiences.

6. Conclusion

This section concludes the research by answering the main research question and discussing the practical and scientific contributions of the study.

6.1. Answering the research question

The main objective of this study was to determine the factors influencing the implementation of movable bridges in the Netherlands. Based on the scientific gap and objective of this study, the following research question was proposed:

‘Under which conditions might smart technologies for movable bridges be implemented in the Netherlands?’

Based on the results of the literature study and semi-structured interviews the following definition was formulated for what is exactly ‘smart’ technology for movable bridges:
‘*A movable bridge is smart if it is able to respond intelligently to changes in its environment, with the ability to influence and direct its own operation, maintenance and support* (based on CSIS, 2016 a)’.

From the literature study and the interviews followed that this type of smart technology for movable bridges is not yet implemented in the Netherlands. To determine the conditions under which these technologies might be implemented in the Netherlands, a conceptual model was developed based on literature. The model was improved based on the results of the conducted interviews. The factors of the final model determine the conditions under which smart technologies for movable bridges in the Netherlands might be implemented.

The results indicate that the non-functional properties of smart technologies need to be improved. In particular, sensors and detection systems required for autonomous operation do not meet the current reliability requirements. Therefore, in terms of operation the safety of smart technology is crucial. This requires inclusion of user behaviour and attitudes. In addition, cyber secure ways to unlock and share data need to be further developed. Here, the privacy of users also needs to be considered.

Furthermore, a suitable business model needs to be developed. Insight in the short-term and long-term benefits is necessary to increase investment in smart technology for movable bridge. Because smart technology for movable bridges is at the beginning of development, gaining knowledge and experience, for example by starting pilots, is crucial. In this stage of development, wide dissemination of acquired knowledge and achieved (economic) results between organisations is important. There will have to be more realisation that gaining knowledge and experience largely depends on collaboration and sharing data, obtained insights and benefits. This is crucial because many organisations have limited labour resources and well educated people. Therefore, the implementation of smart technology for movable bridges is a joint task. This requires clear agreements and contracts between organisations. Existing contracts between movable bridge owners/managers and contractors do not have the right financial incentives for the use of data and smart technology. In addition, clear agreements on the ownership and use of the data is necessary.

Within organisations dissemination of acquired knowledge and involvement of individuals in an early stage of development is important for increasing support. Within organisations people are not sufficiently aware of the technological possibilities and the potential benefits. In addition, organisations are characterised by a fairly conservative attitude. Therefore, in organisations is possibly a change in mind-set needed. Sharing experiences and results will help people to gain trust in the technology. This is crucial, because the implementation of smart technology largely depends on people and organisations, rather than on the technology itself. Smart technologies require infrastructural adjustments, but more importantly a different, more data driven way of working. This requires flexibility, but also education and training of people.

Lastly, laws and regulations should be adjusted to support implementation of smart technology. Guidelines and standards are required for the use of detection and sensor technologies. In addition, clear rules should be established about who is accountable when smart technology autonomously makes decisions.

6.2. Contributions of the study

The practical and scientific contributions of this study are discussed successively.

6.2.1. Scientific contributions

This study contributes to science in three ways. First, it contributes to the understanding of smart transport infrastructure by providing a definition specifically for movable bridges. The definition, as presented in Section 4.1, corresponds to the views of the experts that were interviewed. Second, this study contributes to the understanding of the level of smart technologies that is currently implemented in the Netherlands. Third, this study provides insight into the conditions required for the implementation of smart technology for movable bridges in the Netherlands. As discussed in Section 5.1, many of the conditions that were found support findings of previous studies. In addition, the Political Economy for Transport Innovations framework has been extended and contextualised for movable bridges in the Netherlands. The factors ‘perceived ease of use’, ‘organisational culture’, ‘policy window’, ‘observability’, ‘laws and regulations’, ‘collaboration’, ‘trust’, and ‘user inclusivity’ have been added to the framework. These factors might be useful for future research into the implementation or adoption of new technologies.

6.2.2. Practical contributions

From a practical perspective, the findings of this study can support organisations with the realisation of smart movable bridges. First, the definition defined in this study could contribute to the current discussion on what is ‘smart’ and provides stakeholders something to focus on.

Second, the gained insight into the current level of smart technologies that is used provides stakeholders an indication of the current stage of development towards smart movable bridges that they are in and the steps that still need to be taken. This is important for developing long-term planning, objectives and budgeting.

Third, the factors influencing the implementation of smart movable bridges that were identified in this study support organisations to take targeted measures to meet the conditions under which smart technology for movable bridges might be implemented. This also helps to prevent unexpected setbacks or difficult situations in which a lot of time and money is lost.

7. Recommendations

This section successively presents recommendations for future research and practice.

7.1. Future research

For future research it is recommended to perform a quantitative study on the effects of smart technologies for example on the availability, reliability and safety of movable bridges. If movable bridge stakeholders have more insight into the quantitative effects of these technologies, it is more likely that they implement them. In addition, these insights could substantiate the societal importance of smart technologies for movable bridges.

Furthermore, a comparative study between successful implementation of similar smart technologies in other sectors and application domains (e.g. predictive maintenance in industry) is advised. This could provide useful insights for the implementation of these technologies in the context of movable bridges. For example, these insights could support movable bridge stakeholders in developing effective pathways or roadmaps.

Moreover, in order to be able to generalise the results of this study to other countries or objects, research into the factors influencing implementation of smart technologies within other contexts is recommended. Hereafter, a comparison study could be done. In addition, experts of ProRail could be interviewed to determine the representativeness of the results regarding movable railway bridges.

7.2. Practice

For movable bridge stakeholders it is recommended to focus on reliability of the smart technologies, because of the large societal impact of movable bridges. Smart technologies should be reliable to prevent failures and safety risks for users and the environment. To ensure reliability, extensively testing technologies in for example pilots is advised.

Besides, it is recommended for movable bridge owners to focus on defining appropriate contractual agreements with contractors that include financial incentives for contractors to start using data and that clearly define ownership and user rights of data to prevent that data and information is lost when is switched to another contractor.

In addition, it is recommended for stakeholders to make better use of the data that is already available from systems, such as SCADA, before other sensors are implemented. This prevents that even larger amounts of data need to be stored, shared and analysed without having a clear objective and approach.

Furthermore, it is recommended to collaborate between stakeholders, and share available data, knowledge gained from the data and experiences. Insight gained by one organisation could help others to determine which type of data is required and how this data could be used to prevent failures or improve operation. In addition, sharing positive experiences could stimulate others to start implementing smart technologies.

Moreover, for stakeholders to start implementing smart technologies and break through the status quo, it is recommended to make innovation more a priority, involve everyone in the process and share all experiences and knowledge gained in order to create more awareness and positive attitudes towards change and the use of smart technologies. This is important, because smart technologies often require another way of working of people.

Lastly, for policy-makers it is recommended to implement laws and regulations (i.e. standards, requirements and guidelines) for the use of smart technologies. Appropriate standards and guidelines could accelerate the implementation process and reduce uncertainties about accountability when using smart technologies for movable bridges.

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