## The (long) road towards smart management and maintenance: Organising the digital transformation of critical infrastructures

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# The (long) road towards smart management and maintenance: Organising the digital transformation of critical infrastructures

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# The (long) road towards smart management and maintenance

## Organising the digital transformation of critical infrastructures

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# The (long) road towards smart management and maintenance: Organising the digital transformation of critical infrastructures

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door

**Tom Antoon Elizabeth Aben,**

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*Auto, vleegtuug, d’n trein, d’n boet,*
*wat is de werld toch groet.*

Jack Poels (Rowwen Hèze)

# Acknowledgements

Earlier this year, while watching my speedskating heroes battling for Olympic medals during the Olympic Winter Games in Beijing as a much-welcomed break from writing the final version of my dissertation, it struck me. Exactly four years earlier, while watching the 2018 Olympic Winter Games in PyeongChang, I was still enjoying my first weeks as a PhD student at Tilburg University. So, while the Olympians started a new Olympic cycle just after these Games, I started my own four-year academic cycle around the same time. Four years later, while the Olympians were finishing their epic climb towards the top of Mount Olympus, I was finishing my own epic climb to the top of a slightly different mountain: Mount Academicus. In a sense, it brought me closer to my childhood dream of becoming a champion or expert. Similar to an Olympic cycle, a four-year PhD cycle is almost impossible to complete without knowledgeable coaches (i.e. my (co-)supervisors), the occasional training camps in exotic places (i.e. the academic conferences that I have attended in Hungary, Italy, Finland, Argentina and Germany), team mates with which you 'train' together (i.e. my university colleagues) and of course the passionate supporters who stay with you all along the way (i.e. my family and friends). In this acknowledgement, I would like to take the time to reflect on my journey (or the 'long road' to keep close to the title of my dissertation) and to celebrate those people who made it a worthwhile journey.

As I said, completing a PhD is nearly impossible without knowledgeable coaches at your side. Luckily, I had the support of an excellent team of three supervisors with whom the collaboration went as smooth with as I could hope for. Dear Wendy, Saskia and Henk: thank you very much for bringing me aboard the LONGA VIA project and helping me navigate the wonderous world of academia.

Wendy, I am incredibly grateful for all the time and effort you put in the 'daily' supervision of my PhD trajectory. I enjoyed our bi-weekly meetings a lot, which were not only formal meetings on how things were progressing, but during which you also made time to just catch up or talk about personal things that happened outside academia. I am also very thankful for all your critical reviews and extensive comments on all sorts of documents that I have thrown to you over the past years. Lastly, I want to thank you for your role and contributions in the process of writing my first academic journal paper (which was published last year!) and for introducing me to Jens and Kostas who became our co-writers on this very paper.

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Just like an Olympic athlete, a PhD researcher cannot thrive without a great group of teammates that both help you in many ways and challenge you to become better and better. Fortunately, I got to collaborate with a great set of team members (in our department also known as ‘colleagues’) right from the start back in 2018. So, to all my colleagues in the Department of Management: thank you for your warm welcome, your wisdom, for challenging me and helping me wherever I needed it. Although I value all my colleagues, there are some of you I want to mention personally. First, I would like to thank Brenda, my teammate and my ‘legal’ twin in the LONGA VIA project. Ever since the start of LONGA VIA, when we also first met, we had a great collaboration. It was an amazing ride and I genuinely appreciate our many conversations, our numerous trips to the case organisations and NGinfra meetings, your help with organising the consortium meetings and your legal wisdom that helped me to look beyond my organisational silo. Furthermore, I would like to personally thank Feng, Jacob, Joris, Mohammad, Mylène, Roland and Vincent who (as former or current office buddies) lightened up each and every day I went to the office. Many thanks for all the fun conversations, the laughs and your help obviously. I also enjoyed many good conversations and have gotten great help from my more ‘senior’ colleagues Bert, Marianna, Mehmet, Sangho and Sue. Last but not least, I would like to personally thank Joyce and Vesna for letting me be part of their exclusive ‘gossip’ circle and to help them out with maintaining and improving the social foundation of our department.

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Having different groups of friends is mostly a blessing but sometimes a curse. It is a blessing given the many different things I was able to do with the people I like and love that keep me distracted from the hectic life in academia. It was a curse at times given the stress it gave me to plan all the things I wanted to do, while also trying to finish my PhD on time. Nonetheless, to all my friends: thank you so much for making my life outside academic so fun, for keeping me grounded and, above all, keep me sane and (mentally) healthy. I would like to especially thank Robin and Ruud, the only ‘R&R’ that always brings joy to my life. Thank you both for all those lovely beer tasting evenings. Robin also kindly agreed to design the awesome cover of this book: thank you so much for capturing both my research topic and my personality in one design. As you might have noticed already, speedskating has been a huge factor in my life so far and will (hopefully) be in the future. In made some of the best friends while skating on ice and in addition to Ief I would also like to thank Heleen, Jannemiek, JW and Sjoerd: your friendships had a big impact on my life and helped me to develop into the person I am today. Another passion of mine is music. Unfortunately, I am not that good with instruments myself, but I found a way to be a part of it after all through my (volunteering) work at Pop Centre 013 in Tilburg as a ‘stagehand’. Here, I met many cool people that made it quite easy for me to forget about my PhD stress while working hard for the artists that played on our stages. I would like to especially thank Anas, Anne, Jan, Joost, Jordi, Maren, Mikey O and Vincent for all the crazy backstage adventures we had over the years. Last but not least, I would like to thank my ‘old mates’ from high school who are still a big part of my life. Thank you, Bart and Daan for those relaxing and fun nights out in the many cafes and music venues we visited. And thank you Koen and Marcel for being the best travel buddies during the much-needed vacations.

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So here it is… my academic cycle has come to an end, and I can proudly present you this book. I am still incredibly happy with my decision at the end of 2017 to leave my job as SAP consultant and start this PhD trajectory. A PhD is so much more than just doing your research. It teaches you a lot about yourself, your environment and life in general, and I am glad that I got the opportunity to experience it to the fullest. I hope you enjoy reading it. And I hope that the much feared 'black hole' that athletes and many PhD researchers experience after finishing their cycles will not be too bad for me…

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# Chapter 1

## Introduction

### 1.1 Importance of critical infrastructures

Although digital technologies that can help smarten the management and maintenance of critical infrastructure networks are widely available, the managers of these networks, to date, have yet to start adopting these technologies on a large scale (Van de Kerkhof et al., 2018). Moreover, a recent report in the Dutch electricity sector showed that the data coming from digital technologies are not used to its full potential yet (Netbeheer Nederland, 2020). Nevertheless, it is vital that the Dutch infrastructure managers start investing in the digital technologies and the required data processing capabilities to achieve smart maintenance. This urgency is confirmed in the report by Van de Kerkhof et al. (2018) in which they tried to estimate the expected yearly expenditures on infrastructure in the next 10 to 15 years in two scenarios: with or without smart maintenance. The numbers are based on the budgets the Dutch government reserved for maintenance of infrastructures such as railways, waterways and highways, and a broad estimation of the expected costs of replacing all assets that are near the end of their useful lives. This broad estimation of the expected replacement costs of assets ensures that the actual costs are smaller or equal to the estimation, rather than higher. The estimation of the expected costs and savings of introducing smart maintenance, as well as its ability to extend the lifecycles of assets, are based on experiences and conservative numbers from various industry sectors already familiar with smart maintenance. The conservative estimates regarding the costs and the savings here will ensure that the actual costs faced by the infrastructure managers will be lower or equal to the estimation rather than higher, while the actual savings will be equal to or higher than the estimation rather than lower.

As shown in **Figure 1.1**, it is estimated that the Dutch infrastructure managers will face a huge ‘peak’ in expenditures on the replacement of their infrastructure assets, which will easily transcend their yearly budgets, if they do not act now. However, if the infrastructure managers were to start investing in smart maintenance now, which would enable them to increase the life cycles of their current assets and networks, they ‘buy’ themselves more time before it all needs to be replaced. Investing in smart maintenance would provide them with the opportunity to spread out the needed investments in replacements over a longer period, without compromising the safety of the assets. On top of that, it would enable them to plan their maintenance activities more efficiently and spread these activities over a longer time period, without compromising the availability of their respective networks too much. Lastly, smart maintenance is also expected to lower the total maintenance costs for infrastructure managers as it entails the collection of (real-time) data on the condition of infrastructure assets, thereby lowering the need to rely on labour-intensive (and costly) inspections by maintenance specialists.

Focusing our attention specifically on critical infrastructure networks is important as these networks play a key role in the functioning of our modern economies and societies and are thus considered to be crucial for our countries’ citizens and businesses (De Bruijne & Van Eeten, 2007; Pescaroli & Kelman, 2017). Critical infrastructures provide essential products and services that benefit a whole society. Examples include a country’s electricity grids, emergency services (e.g. fire departments, police stations), healthcare, public water systems, transportation systems and telecommunication systems (De Bruijne & Van Eeten, 2007; Egan, 2007; Veeneman et al., 2009). Although the notion of what a country considers a 'critical' infrastructure or not differs per country (due to differences in a country's characteristics, government and society), it is important to note that critical infrastructures typically include a combination of 'hard' technologies and 'softer' elements (Egan, 2007; Pescaroli & Kelman, 2017). The hard technologies include the physical constructions built by engineers (e.g. roads, railways, pipes, wires) that are used to provide citizens and business with services with which they can, for example, transport themselves or products, power their houses or factories, or set up communication channels. The softer elements include the organisational and technical elements (e.g. people, software) that are needed to organise the maintenance and operation of the physical constructions of an infrastructure network.

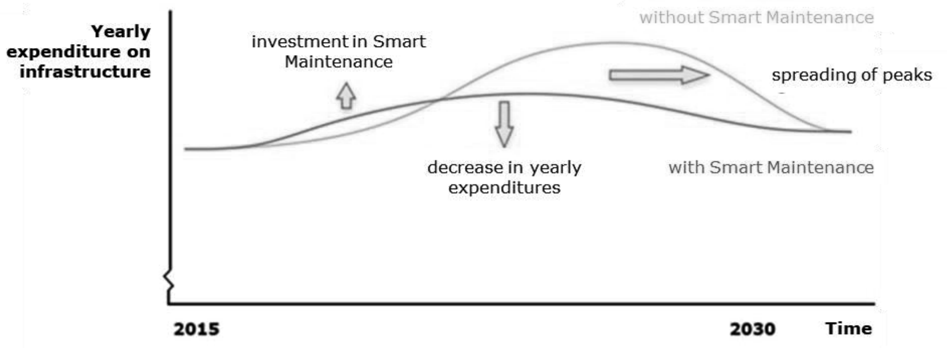


**Figure 1.1** Yearly expenditures on infrastructure assets with and without smart maintenance (adapted from Van de Kerkhof et al. (2018))

Other typical characteristics of critical infrastructures are that these are tightly coupled and complex systems, which provide routine functions to the public and are not easily substitutable (De Bruijne & Van Eeten, 2007; Egan, 2007). An example of this are the underground waterpipes that transport public water to citizens and businesses. Under normal circumstances these pipes routinely transport water to houses all year long without interfering with other infrastructures above ground. However, in 2018, a pipe burst in Amsterdam caused not only a disruption in the city's water supply, but it also created a large sinkhole destroying the roads above ground, which in turn created disruptions in traffic. Moreover, there was no simple substitute for the public water supply in the neighbourhoods that were affected (Pen, 2018). Lastly, critical infrastructures are expected to create significant amounts of harm (to both individuals and society as a whole) in case a sudden dysfunction of the infrastructure occurs and are thus often the subject of public scrutiny and pressures to keep these infrastructures available at all times (De Bruijne & Van Eeten, 2007; Egan, 2007). An example of this is the complex system of dikes and flood barriers on the Dutch coastline needed to protect the Netherlands from floods. In case these would fail, almost half of the Netherlands would flood, leading to massive numbers of casualties and large parts of the country would become uninhabitable. As such, this system is under constant public scrutiny and the responsible (governmental) institutions made sure this system can withstand extreme conditions (e.g. the flood barriers in the province of Zeeland can withstand extreme storms that only happen once in 10,000 years (NOS, 2016b)).

If a critical infrastructure in a country were to fail, there is a high chance that that country's society will 'crumble' (Boin & McConnell, 2007; Veeneman et al., 2009). Hence, it is no surprise that the management and maintenance of these infrastructures is becoming (and should become) increasingly important in policy-making agendas around the world (Boin & Lodge, 2016; Egan, 2007). Moreover, due to their importance, governments often go to great lengths to protect their critical infrastructures, both directly (i.e. ensuring that the operation of a specific infrastructure deemed critical is partially or fully nationalised) and indirectly (i.e. through laws and regulations containing strategies to protect and increase the resilience of infrastructures deemed critical, as well as measures preventing foreign entities taking ownership of these infrastructures). Examples include the European Union (EU) directive 2008/114/EC[1] (requiring member states to identify critical infrastructures and devise plans to improve the protection of these critical infrastructures) and EU directive 2016/1148[2] (requiring "operators of essential services" active in the member states to improve the protection of their digital operating systems and report any serious incidents). But why is it important to focus both on the maintenance and the management of these critical infrastructures?

First, the importance of maintenance. To remain a well-functioning society, a country's critical infrastructures must be well maintained. Only maintaining an asset once it has broken down (i.e. reactive maintenance; Jonsson (2000)) may require extensive repairs leading to a lot of hindrances for end users. Alternatively, managers can employ preventive tactics where maintenance is regularly performed with the idea of preventing a real failure from occurring, or even predictive tactics where maintenance is planned just before the predications indicate that a specific asset breaks down (Jonsson, 2000; Öhman et al., 2021); both options typically lead to less hindrances for end users. Neglecting to maintain infrastructure assets completely can lead to catastrophic failures with widespread economic and social consequences (Frangopol & Liu, 2007). For example, as a precaution, authorities in the Netherlands and Germany were forced to close bridges for the public to avoid catastrophic failures as these bridges were on the brink of breaking down (NOS, 2016a; Van der Marel, 2022). Since these bridges were important linkages between economic centres, their closures forced citizens and businesses to take (lengthy) detours, leading to high economic costs for all. Even more severe was the collapse of the Morandi bridge near Genoa, Italy, which was not only accompanied by serious economic consequences but also by serious societal consequences as 43 people were killed and about 600 people lost their homes (Valkenet, 2018).

Secondly, management is important. Managers of critical infrastructures have been given the task to provide citizens with networks that are managed in a safe, reliable, affordable and sustainable way (De Bruijn & Dicke, 2006). An important management challenge that infrastructure managers will be facing during the next decade are aging assets in their respective networks. Many highways, railways, ports, electricity grids and other critical infrastructure networks around the world are over 60 years old and are nearing the end of their

[1] Council Directive **2008/114/EC** of 8 December 2008 on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection, OJ L 345, p. 75-82.
[2] Directive (EU) **2016/1148** of the European Parliament and of the Council of 6 July 2016 concerning measures for a high common level of security of network and information systems across the Union, OJ L 194, p. 1-30.

lifecycles (Akkermans et al., 2016). Heavy investments are required to replace the 60+ year old assets with new assets to keep the networks, of which these assets are a part of, safe and reliable (Morimoto, 2010). However, due to constraints in resources (e.g. limited budgets, workforce shortages in the construction sector) infrastructure managers will not be able to replace all their aging assets at the same time, requiring more efficient management of these assets (Annaswamy et al., 2016). A recent study in the Netherlands, for example, showed that about 550 bridges and overpasses need to be replaced within the next decade, requiring the Dutch government to spend between €3 billion and €5 billion per year extra on top of the current yearly infrastructure expenditures in case the lifespans of these assets cannot be extended through smarter maintenance (Kompeer & Schellevis, 2020). In the US, the government recently passed a bill that allocated $1 trillion (€897 billion) with which only a part of the aging assets in the US can be restored or replaced (Cochrane, 2021).

## 1.2 New developments and challenges related to critical infrastructures

To manage and maintain their networks more effectively (which can potentially help to flatten the estimated investment peak shown in **Figure 1.1**), infrastructure managers need to shift towards more advanced maintenance regimes such as smart maintenance (Akkermans et al., 2016; Bokrantz et al., 2020a). Recently, smart maintenance was defined by Bokrantz et al. (2020b) as follows: "an organisational design for managing maintenance of manufacturing plants in environments with pervasive digital technologies" (p. 14). Although this definition focuses specifically on manufacturing plants, the concept can also be used for the maintenance of assets in contexts that are outside the specific context of manufacturing plants, such as infrastructure assets, where pervasive technologies can be implemented. These 'pervasive' digital technologies include both technologies to collect data (e.g. sensors) and to analyse the collected data with the aim of transforming it into useful insights (e.g. big data analytics and machine learning) (Bokrantz et al., 2020b).

By combining insights coming from (big) data analytics (based on data on the health of assets as well as on usage data) with other relevant data from external databases (such as weather conditions), infrastructure managers are enabled to 'smarten' the maintenance of their networks by prolonging lifecycles of current assets, as well as better predict when assets fail (enabling more accurate maintenance planning with lower impact on the availability of assets). Moreover, the data produced by digital technologies can also help infrastructure managers with smartening the management of their networks as the insights coming from this data help to optimise networks by increasing productivity, offer significant cost reductions and reduce the size of the workforce needed to operate and maintain the networks (Ferretti & Schiavone, 2016; Morimoto, 2010). Specifically for infrastructure managers in the electricity sector, combining smart meters and smart grids enables 'smart grid management' that not only offers many advantages to the managers themselves, but also to their end users as well as the local environments in which they operate (Parker et al., 2019; Wunderlich et al., 2019). Lastly, digital technologies help infrastructure managers to innovate and potentially improve their services towards their end users (Barrett et al., 2015). For example, real-time data about the usage of a specific highway or railway, collected by infrastructure managers and/or their partners, can be made available to end users who in turn can use this data to determine their exact travel time more accurately and improve their travel plans.

To date, infrastructure managers struggle with leveraging the possibilities provided by digital technologies to implement smart maintenance. Many of these digital technologies recently became widely available for organisations around the world, including infrastructure managers (Yoo et al., 2012). Examples of these technologies include Internet-of-Things (IoT) devices, big data (analytics), (smart) sensors, Radio Frequency Identification (RFID) tags, cloud computing, smart meters and smart grids (Aryal et al., 2018; Ferretti & Schiavone, 2016; Kache & Seuring, 2017; Wunderlich et al., 2019). Since digital technologies typically produce substantial amounts of data, these have the potential to greatly enhance the quantity and quality of the data for decision-making processes (Waller & Fawcett, 2013). For example, infrastructure managers can install (smart) sensors and IoT devices in critical components of their assets to collect, store and send data regarding their behaviour and create large pools of data. With the help of big data analytics, data from these pools can be used to create valuable insights into the health of the components equipped with digital technologies, thereby changing the way, among other things, they make decisions regarding the maintenance of their assets. The implementation of these digital technologies triggers strategic responses from organisations resulting in digital transformations (Vial, 2019) that may occur at an organisational level, but could also transform a whole sector. However, although digital technologies are widely available, the actual digital transformation of the infrastructure organisations and their sectors has not yet occurred as infrastructure managers are still not able to obtain reliable insights into how their assets behave, as well as into the usage of their assets by citizens and businesses. Put differently, not the availability of digital technologies and data is the issue, but the lack of abilities to, and motivation for, gaining insights from these technologies and data hinders infrastructure managers to become smarter in their management and maintenance.

In addition to the new developments in the area of digital technologies, infrastructure managers are also increasingly confronted with changing societal demands because of the movement towards a more sustainable society, requiring significant investments in the renewal or expansion of existing infrastructure networks (Markard et al., 2012). Also here, more efficient management and maintenance is needed to keep up with changing demands and ensuring the infrastructure networks remain ‘future-proof’. In some areas in the world, it might already be too late as illustrated by the breakdown of the electricity grids in California in the summer of 2020 (Penn, 2020). Due to explosive demands for electricity (to power air conditioning units during the extensive 2020 heatwave), the local grids could not produce and transport enough electricity to match demand. The organisations managing these grids were eventually forced to be very selective as to whom they would supply their electricity to, leading to local blackouts and severe disruptions of daily life. As heatwaves are expected to return and intensify in the near future, immediate action at the macro- or institutional level is required, especially in those areas where the current electricity grids are already unable to manage increased demands. It is thus no surprise that, in the U.S., they are experimenting with increasing the maximum load levels on existing grids through smart grid management (Barber, 2021). In the Netherlands, grid managers recently warned that the capacity of the current Dutch grid is almost reached (and in some areas already has been reached (McDonald & Van Rein, 2022)) and that extension of the grid will not be finished before full capacity is reached, thus also requiring smarter options to manage electricity grids (Grol, 2022).

Implementing smart maintenance and dealing with increased societal demands regarding sustainability cannot be done by infrastructure managers alone. In a growing number of countries around the world, the (semi-)public organisations that are responsible for (parts of) their country's critical infrastructure networks are increasingly relying on the capabilities of privately-owned organisations in their infrastructure projects (Zheng et al., 2008), leading to infrastructure managers that embark on public–private collaborations (Van den Hurk, 2016). Especially the maintenance activities for infrastructure assets are being (fully) outsourced by public organisations to private maintenance contractors (Caldwell & Howard, 2014). To become smarter in the management and maintenance of assets, infrastructure managers are thus dependent on their maintenance contractors as these will also need to digitalise their operations. Additionally, digitalisation does not only influence the operations related to the management and maintenance of assets, but it also influences how organisations manage the relationships with suppliers (and other actors in the sector) and the related inter-organisational processes (Holmström et al., 2019; Søgaard et al., 2019). For example, since digital technologies (triggering the digitalisation of operations) produce substantial amounts of data, these have the potential to increase the amount of information available and thereby change the transparency and the level of visibility between the partners (Sternberg et al., 2021). Moreover, suppliers are also faced with the digitalisations of their processes, as they are increasingly embedding digital technologies in their offerings. This provides suppliers with increased computing power and analytical capabilities, generating more detailed information, which can help them improve their (maintenance service) offerings to their buyers (Olsen & Tomlin, 2020).

Infrastructure managers initially started to outsource the maintenance activities to improve the accountability of their spending of public money and due to reductions in resources (e.g. budget cuts) that are imposed by politicians in their country's governments (Hartmann et al., 2014; Selviaridis & Wynstra, 2015). The idea is that (specialised) private maintenance contractors are able to maintain the assets more efficiently than the (semi-)public organisations that are responsible for these. This is because competition among private contractors to obtain the maintenance contracts should force them to become as efficient as possible leading to a situation where the prices of the private contractors are lower than in the situation where the (semi-)public organisations performed the activities themselves. Outsourcing thus helps to deal with budget cuts (maintenance is likely to become cheaper due to private contractors) and it increases the transparency of the infrastructure managers' spending (public tenders need to be organised to select a contractor, requiring involved parties to set prices). Due to the recent digitalisation wave, contractors also became important sources of valuable data, making it more and more interesting to share data and information with them (Huang et al., 2020). This especially holds true for situations where maintenance activities are being (fully) outsourced, as maintenance contractors typically collect a lot of data while performing maintenance activities on infrastructure assets and obtain specific knowledge on how to transform this data into valuable insights.

It is important that outsourcing relationships are supported by effective contracts and a strong relationship (Hartmann et al., 2014; Sumo et al., 2016). However, it is not easy to design effective contracts with efficient KPIs and well-specified (data) clauses in maintenance outsourcing situations that involve public and private organisations. This is because the maintenance activities for assets of public organisations are highly context specific and this cannot be easily compared to situations with only private parties (Baldus & Hatton, 2020). An additional issue for these public–private collaborations is the often-conflicting goals of the public and private organisations involved (Caldwell et al., 2009), as well as the wide variety of different interests that are not aligned (Mahoney et al., 2009). While public organisations are, in general, focused on maximising the social value for all (or at least the majority) of their beneficiaries, private organisations are generally focused on maximising their own economic value. Moreover, public organisations are, on average, more interested in satisfying both the public and political audiences, while private organisations are primarily focused on keeping their shareholders satisfied.

The introduction of digital technologies introduced the additional challenge that infrastructure managers need to ensure that they obtain (and remain having) access to data related to their assets, and that they can leverage the needed expertise from contractors to transform data into information. For this, appropriate inter-organisational governance mechanisms need to be put in place. In this doctoral thesis, the word 'governance' relates specifically to this concept of 'inter-organisational governance' which in turn is defined as: "the formal and informal rules of exchange between partners" (Roehrich et al., 2020, p.453). Without governance mechanisms, infrastructure managers risk losing vital knowledge regarding their assets, making it difficult to smarten the management and maintenance of their assets. These challenges with determining appropriate KPIs, efficiently managing conflicting goals and dealing with the myriad of different interests increase the risk of misunderstandings and irritations between public and private partners and might even lead to a 'bad' image for the public buyers trying to find private maintenance contractors.

As explained in the first section, the management and maintenance of critical infrastructures is of utmost importance for countries around the world. This is challenging since many infrastructure networks are approaching the end of their life cycles, while regular maintenance costs remain and (governmental) budgets are restrained. At the same time, this section showed that infrastructure managers are faced with new developments and challenges in the area of digital technologies and changing societal demands towards a more sustainable future. This requires them to find smarter ways to manage and maintain their respective networks. Luckily, new digital technologies, and the data these produce, can provide infrastructure managers with new and additional insights to become smarter. However, talks with and observations from the case organisations involved in this doctoral thesis show that simply implementing new digital technologies does not mean that the infrastructure managers directly access the right type of data, let alone use the data in an effective way. For this, the infrastructure managers require the input from their direct partners (e.g. contractors) and at times even a combination of different actors that operate in their respective sectors (e.g. governmental institutions, consumers). In this doctoral thesis, it is investigated how infrastructure managers can, in collaboration with other actors in their network, start effectively sharing and leveraging data coming from digital technologies to enable smart management and maintenance of infrastructure assets. Therefore, this dissertation aims to answer the following main question:

> *How do managers of critical infrastructures and their partners organise their (inter-)organisational processes to share data with each other, and leverage it, for the purpose of smart management and maintenance of infrastructure assets?*

## 1.3 Main theoretical foundations and structure of the doctoral thesis

To address the main question of this doctoral thesis, several research questions have been developed that are answered in the three central chapters (i.e. Chapters 2, 3 and 4) of this doctoral thesis. Each chapter, as well as the research question(s) that is/are discussed and the case(s) investigated, are introduced in the text below.

**Chapter 2** – The main question of this thesis revolves around how infrastructure managers should organise their processes to effectively leverage data from digital technologies for the purpose of smart maintenance and management of their assets. Since almost all maintenance activities in the Dutch infrastructure sectors are outsourced to private maintenance contractors, making effective use of digital technologies, and getting access to the data produced by these technologies requires infrastructure managers to collaborate (closely) with their contractors. Hence, the second chapter focuses on how organisations organise their processes around data both internally, as well as in their dyadic relationships with their contractors.

In the second chapter, we first of all draw from the information processing theory (IPT) (Galbraith, 1973). This theory tells us that organisations deploy different information processing activities, including information gathering, information transformation and information communication, to address information asymmetries (Daft & Weick, 1984). These asymmetries are caused by situations of environmental uncertainty, which are situations where an organisation does not possess enough information to perform the required tasks (Galbraith, 1973). Information asymmetry refers to either a lack of information (uncertainty) that can be mitigated through gathering more data or the level of messiness of the information (equivocality) that can be mitigated by deploying cognitive skills to transform the data in a logical way (Zhao et al., 2018). While IPT has mainly been applied in studies focusing on intra-organisational processes (see e.g. Burns & Wholey, 1993; Rosado Feger, 2014; Wiengarten et al., 2017), it only has been limitedly applied in studies focused on inter-organisational situations despite an increasing number of organisations that jointly aim to gather and transform information (Yu et al., 2019).

Organising these information processing activities in dyadic relationships requires effective mechanisms to govern these relationships. Therefore, we also draw from the literature on inter-organisational governance that identified two types of governance (Cao & Lumineau, 2015; Poppo & Zenger, 2002; Roehrich et al., 2020). On the one hand, there is contractual governance which encompasses the formal rules of exchange in the form of written and legally enforceable contracts (Faems et al., 2008; Lumineau, 2017; Luo, 2002). On the other hand, there is relational governance which depends on trust and social norms between contracting parties to foster a common goal (Carey et al., 2011; Poppo et al., 2008). Previous research has shown that organisations typically rely on a mix of these two governance mechanisms to organise their inter-organisational processes. In this paper, we specifically focus on two information processing activities (information gathering and -transformation) and set out to understand how these two processing activities are best governed in inter-organisational relationships between a public and a private organisation. To investigate, an explorative study was conducted with a multiple-case study approach that included cases from two infrastructure organisations (Rijkswaterstaat and ProRail). A total of four cases were selected in which a public organisation that manages and maintains a specific type of infrastructure network needed to collaborate with their privately owned maintenance contractor(s) to gather the necessary data and jointly transform it into information. The central research question in Chapter 2 is:

*How do contractual and relational governance mechanisms address information asymmetry in public–private relationships undergoing digital transformation?*

**Chapter 3** – The findings of the second chapter showed that, ideally, organisations should govern the data gathering processes primarily via contractual governance mechanisms to control the access to the required data and coordinate the sharing of data. It also showed that for governing the transformation processing, organisations should primarily rely on the relational governance mechanisms of social norms and trust to foster a common goal (i.e. joint transformation of data to information). However, the digitalisation of operations and the increased importance of data are new phenomena, making it difficult for contracting parties to exactly determine what to expect as they are faced with uncharted territories (i.e. they are still exploring the processes around data). As contracting organisations are unsure upfront what data is needed and how their data needs change over time, it is difficult to design effective data management clauses at the start of a contract period, requiring a more flexible contract design to begin with and proper mechanisms to govern this flexibility during the execution period. Therefore, the third chapter dives deeper into the design and execution of contracts in public–private collaborations undergoing a digital transformation. More specifically, we set out to investigate how post-formation adjustments to both contractual and relational governance mechanisms are becoming necessary as contracting organisations are jointly learning about the implications of the digitalisation of their operations.

To better understand the impact of digital technologies on the relationships between contracting organisations, we analysed the literature regarding the digitalisation of operations (Holmström et al., 2019), and specifically the impact of digitalisation on buyer–supplier relationships (Søgaard et al., 2019). This review showed that digital technologies, which produce substantial amounts of data and many tools to transform this data (Kache & Seuring, 2017), increase the level of information available in buyer–supplier relationships (Sternberg et al., 2021), but also bring along challenges and risks such as uncertainty (Birkel & Hartmann, 2019). Due to this uncertainty, it is more difficult to *ex ante* design effective contracts that foresee all potential future uses of data and data requirements. As such, there is a higher likelihood that post-formation adjustments need to be made, requiring more flexible contracts and effective relational mechanisms to back the contractual governance up.

To be able to make post-formation adjustments, organisations need to learn from their experiences. Therefore, we also draw from the 'learning-to-contract' literature to understand how contracting organisations learn with respect to designing and executing contracts. Here we focus specifically on the concept of 'intra-contract learning' as it entails translating experiences gained during an ongoing relationship into learnings that lead to immediate (post-formation) adjustments in both the underlying contract and the relational governance mechanisms (Lumineau et al., 2011; Reuer & Ariño, 2002). While previous research already showed how contracting organisations employ intra-contract learnings, and Chapter 2 shows which governance mechanisms are needed for which information processing activities, it is not yet known how contracting organisations adjust the mix of contractual and relational governance mechanisms employed during an ongoing relationship when learning about their digitalising relationship. To investigate this, we performed an exploratory study around a longitudinal case study at the Port of Rotterdam. Over a period of five years, we followed the digitalising relationship between Port of Rotterdam and two of their maintenance contractors to uncover how they learned about the implications of this digitalisation and how these intra-contract learnings led to post-formation adjustments in their contracts (specifically the data clauses) and relational norms. The central research question in Chapter 3 is:

> *How do contracting organisations employ intra-contract learning and make adjustments to contractual and relational governance mechanisms to deal with digitalisation more effectively?*

**Chapter 4** – The fourth chapter builds on the findings of the second and third chapter (that focus on dyadic relationships) and broadens the view towards collaborations between three or more actors within a network or sector. To fully leverage the potential of some digital technologies and the related data these produce, a larger network of actors needs to be involved with collecting, sharing and transforming data into valuable information and subsequently using this information in a smart way to enhance decision-making. Especially transitions that impact a whole society (such as the energy transitions in electricity sectors) call for the involvement of not only organisations that are part of the 'core' of a supply chain, but also the broader set of actors such as governmental institutions and end consumers (Spring et al., 2017). Designing such networks ensures that the input of end consumers is not neglected, especially when dealing with public goods and services (Trischler & Westman Trischler, 2022). To investigate this, an exploratory process study around a single case was conducted around the rollout of smart meters in the Netherlands that occurred between 2012 and 2021.

Since we specifically focus on the electricity sector, we first analysed literature on smart grid management to determine the potential of smart meters and smart grids. This literature showed that smart meters are a digital technology producing data that can, together with a smart grid, be used to trigger an energy transition that aims to lower carbon emissions, as well as support this transition. On the one hand, it can trigger this transition as smart meter data helps end consumers obtain real-time and highly granular insights in their electricity usage and motivate them to lower their usage (Hu et al., 2015). On the other hand, it can support the transition as it enables smarter management of the electricity grids (i.e. smart grid management) by distribution grid operators since due to the switch to more electrically powered machines and products, current electricity grids face significant increases in demand that need to be managed in a smart way (Gouveia et al., 2017; Sovacool et al., 2017). The review of the literature on smart grid management also showed that most papers focus on the technical side of smart grids and which actors are involved (Dehdarian & Tucci, 2021; Rohde & Hielscher, 2021), and that studies on motivating the involved actors to use smart meter data for smart grid management are, while important, still very scarce (Parker et al., 2019).

Effectively implementing smart grid management and triggering a transition requires changing a complete sector which cannot be done by individual actors alone. Rather, the whole network of actors in the electricity sector (i.e. distribution system operators, energy suppliers, independent service providers, governmental institutions, industry associations and end consumers) need to collaborate to facilitate the smart use of data coming from smart meters. Therefore, the second stream of literature we analysed was related to the governance of (extended) networks of actors (Provan & Kenis, 2008). This literature showed that the governance in a (extended) network needs to be orchestrated in such a way that it can effectively incentivise all actors to achieve the common goal of making smarter decisions with smart meter data (Field et al., 2021; Rong et al., 2015). However, studies focusing on how governance mechanisms need to be applied in networks are still scarce (Bastl et al., 2019), even though it is becoming an increasingly important topic for practice. While the government-mandated rollout in the Netherlands went well (almost all households and small- and medium-sized businesses received a smart electricity meter), the rollout as a whole is not yet a success as the data from these smart meters is hardly being used to date. Here, a whole network of actors is needed to activate the leveraging of data from smart meters, and we set out to investigate how the concept of an energy service network can help with this. Therefore, the following two research questions were investigated in Chapter 4:

*How to use smart meter data to support smart grid decisions within the supply network?*

and

*How to orchestrate governance in such a way that network actors are indeed incentivised to make those smarter decisions?*

A summary of the main theoretical constructs used and the research methods that were employed in Chapters 2, 3 and 4 can be found in **Table 1.1**. In Chapter 5, the overall findings and the main implications of this doctoral thesis will be discussed. These overall findings are based on the results from the three studies performed for this thesis and provide an answer to the main research question of this doctoral thesis.

**Table 1.1** Overview of the studies in the three central chapters

| | **Chapter 2** | **Chapter 3** | **Chapter 4** |
|---|---|---|---|
| *Involved partners* | Rijkswaterstaat & ProRail | Port of Rotterdam | Alliander |
| *Other involved organisations* | N/a | Two maintenance contractors (*Grey* & *Green*) | Various actors active the Dutch energy sector |
| *Level of analysis* | Organisational & dyadic relationship | Dyadic relationship | Network |
| *Theoretical constructs* | • Information uncertainty and equivocality<br>• Contractual and relational governance | • Contractual and relational governance<br>• Learning-to-contract | • Smart grid management<br>• Network governance |
| *Type of study* | Cross-sectional | Longitudinal | Longitudinal |
| *Research design* | Multiple case study | Embedded case study | Single case study |
| *Number of cases* | 4 | 2 | 1 |

| | | | |
|---|---|---|---|
| *Data sources* | • 28 interviews<br>• 10 observations<br>• Contract documents (973 pages)<br>• Archival data (557 pages) | • 34 interviews<br>• Contract documents (859 pages)<br>• Archival data (348 pages) | • 13 interviews<br>• Archival data (1,860 pages) |

## 1.4 Research strategy

A defining feature of the research performed in this doctoral thesis, and the larger research project to which it belonged, is the strong ties that were established and maintained throughout the research between the researchers and the practitioners working at the case organisations. This did not only provide excellent opportunities to identify research topics that were interesting to both researchers and practitioners, but it also enabled the production of knowledge together with the partner organisations' employees. Performing academic research in which knowledge is co-produced with participants 'from the field' (e.g. the practitioners active in the case organisation(s) under study) is known as 'engaged scholarship' (Ergene et al., 2020; Van de Ven, 2007). Engaged scholarship challenges the traditional distance between scholars and the phenomena they are studying as this research strategy assumes that scholars cannot be disentangled from the context within which they are performing their investigations (Bansal et al., 2018). Instead, by applying engaged scholarship, researchers are able to leverage their embeddedness in the context to obtain new and deeper insights into relevant phenomena that cannot be obtained through the more traditional research strategies. Moreover, it enables researchers to directly assess the usability of their findings, more easily bridge the gap between academic research and the practitioners' world and provide practitioners with insights from other sectors that typically remain hidden from them (Bansal et al., 2018; Harland et al., 2019), thereby ensuring a high societal impact. Put differently, by consciously opting to be an engaged scholar and leveraging the strong ties with practitioners, the results of this research aim to have both a significant academic and societal impact.

The larger research project to which this thesis belongs is the LONGA VIA –**l**egal and **o**rganisational **n**etwork and **g**overnance **a**spects of data-driven inno**v**ations in **i**nfrastructure m**a**nagement– project. This is a joint project between two schools of Tilburg University: the Tilburg Law School (TLS) and the Tilburg School of Economics and Management (TiSEM). The LONGA VIA project set out to examine the legal and organisational impediments that managers of infrastructures in the Netherlands face when they aim to use digital technologies, and the data these technologies produce, to enable smarter management and maintenance with the ultimate goal to ensure the safe, reliable, affordable and sustainable operations of their infrastructure networks. This project started from the premise that the digital technologies and data to realise smart(er) infrastructures are already available, but that infrastructure managers are not able to use these on a large scale yet. Put differently, although smart management and maintenance is technologically possible, there are legal and organisational challenges to overcome. To investigate this, two separate, yet interconnected, PhD projects were initiated: one within TLS performed by Brenda Espinosa Apráez (focusing on the legal aspects; 'legal PhD project') and one within TiSEM of which the results are described and discussed in this doctoral thesis (focusing on the organisational aspects; 'organisational PhD project').

**Figure 1.2** schematically shows the focus areas of the two separate PhD projects as well as how these two are interconnected. The legal PhD project focused on the macro-level by critically examining the regulatory landscape (including regulatory frameworks and policies) to understand how this landscape is shaping the way data is used and shared among infrastructure managers and their partners. More specifically, Brenda investigated which legal frameworks are applicable to the types of data that are used and shared and the specific types of organisations that are involved. This enabled her to determine the boundaries within which infrastructure managers and their partner organisations are free to take advantage of data-driven innovations and inform the organisational PhD project about the legal implications that managers should consider. The organisational PhD project, on the other hand, focused on the micro-level by investigating the organisational aspects from an operations management (OM) perspective. This OM perspective entails, among other things, investigating the supply network (e.g. how collaborations between two or more actors are organised and governed) and how operations and data can be efficiently managed within, as well as across, organisational boundaries. Through working on the micro-level, this doctoral thesis helped the legal PhD project by providing insights regarding the effectiveness of the policies and regulatory frameworks that were designed to stimulate data usage and sharing.

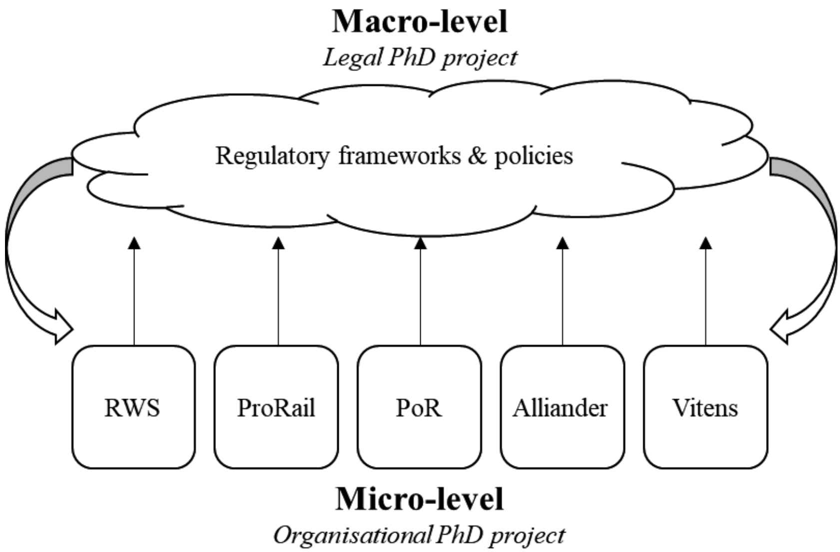


**Figure 1.2** Schematic overview of the two separate PhD projects and their interconnections

The LONGA VIA project in turn is part of the Next Generation Infrastructures' (NGinfra) and the Dutch Research Council's (NWO) "Responsive Innovations" research programme. In total, this programme funded six research projects (including the LONGA VIA project) and included researchers from different universities with a wide variety of backgrounds. The main goal is to develop knowledge regarding future-proof and responsive infrastructure networks and to investigate the possibilities of stimulating and organising multi-disciplinary collaborations between infrastructure organisations and their partners. Moreover, since

NGinfra is the formalised collaboration between six major Dutch infrastructure organisations and NWO is the national financer of scientific research, a third goal is ensuring a close connection between scientific investigations and practical challenges, thereby promoting (engaged) research that has both an academic and societal impact. The LONGA VIA project is backed by five of the six infrastructure organisations that belong to NGinfra: Alliander, Port of Rotterdam, ProRail, Rijkswaterstaat and Vitens. The sixth NGinfra member, Schiphol Group, choose not to back the LONGA VIA project due to different interests and time constraints on their side.

All five organisations involved in the LONGA VIA project are faced with the digital transformation of their organisations, as well as their sectors, making it an interesting research area from a practical point of view. In the last decade, all five organisations started to invest in dedicated departments and/or programmes with the aim to support and promote the introduction of digital technologies and widespread use of data. For example, ProRail set up a 'data lab' in which they pooled all their expertise related to digital technologies, data management and data science to investigate the potential applications of these new technologies and the new insights that can be collected from their growing data pool, and support (organisation-wide) implementations. Another example is the programme initiated by Rijkswaterstaat to support several pilots at their local departments that aimed to use digital technologies and data in the management and maintenance of their assets with the goal of experimenting with it and, when successful, promoting it to the rest of the organisation. Next to in-house initiatives to promote digital technologies and data usage, there are also initiatives that have sector-wide implications. For example, in the electricity sector, the Dutch government mandated a large-scale, national rollout of smart electricity meters providing organisations such as Alliander with substantial amounts of data that could potentially be used to smarten the management and maintenance of their electricity grids.

The digitalisation of operations is also a new and interesting phenomenon from the academic perspective as explained in the first section (see e.g. Holmström et al., 2019). Especially the sharing and joint transformation of data generated by digital technologies among contracting parties, as well as joint efforts to leverage this data, are largely unexplored areas. The research in this thesis thus has an explorative nature for which a qualitative research strategy based on case studies is considered to be the most appropriate (Barratt et al., 2011; Ketokivi & Choi, 2014). The cases in the second and third chapter are used to explore the new phenomenon and build theory (Voss et al., 2002), while the case in the fourth chapter is a theoretically interesting case to exhibit an important new phenomenon and to trigger future research (Hambrick, 2007). All five organisations played a key role during the execution of the research in this thesis, not only as case organisations that provided valuable sources of data for the empirical parts of the three main chapters, but they also acted as a sounding board to check the validity of the results and to discuss the feasibility of the findings. Additionally, the selection of the main research topics for the different studies, as well as the selection of the specific cases that were investigated, were determined in conjunction with the five partner organisations.

Looking at the specific research methods used in each chapter, in Chapter 2 a multiple-case design was employed in which four cases were investigated (two from Rijkswaterstaat and two from ProRail). Each case focused on a regional department and their efforts to get access to the right data, as well as their efforts to transform it into valuable information in collaboration with maintenance contractors. In Chapter 3 a longitudinal case study is performed within the Port of Rotterdam and two of their maintenance contractors in which contract design and execution processes were observed (partly retrospectively, partly in real-time) over a period of five years. Chapter 4 involves a longitudinal case study around a single case that focuses on the introduction of the smart meter in the Dutch energy sector in which changes related to the usage of smart meter data is investigated over a time period of 10 years by collecting both archival data (to look back in time) as well as interviews (to receive data about the current situation). See **Table 1.1** for more detailed information about the research methods and data sources of each study. Although there was a close link between the researcher and the practitioners from the case organisations in all three studies, the engaged scholarship strategy was especially apparent in the third and fourth chapter. This is because engaged scholarship especially benefits from longer term interactions between academics and practitioners (Touboulic et al., 2020; Van de Ven, 2007).

Each of the five partner organisations are responsible for a part, or even the complete network of assets of a specific critical infrastructure within the Netherlands and have a (semi-)public nature. More specifically, **Alliander** is an unlisted public limited company that has three provinces (i.e. Gelderland, Friesland and North-Holland) in which they operate as major shareholders and the municipalities of these provinces as their minority shareholders. As a semi-public organisation, Alliander has been granted the exclusive right and given specific legal tasks by the Dutch government to function as a regional distribution system operator in their service area, thereby making them responsible for managing and maintaining the local electricity grid. **Port of Rotterdam** is an unlisted public limited company that is owned by the municipality of Rotterdam and the Dutch government. As a semi-public organisation they are responsible for the management, exploitation and development of the port area (including all infrastructure assets) in the city of Rotterdam. **ProRail** is an unlisted public limited company that is fully owned by the Dutch government, which placed the shareholding under the Ministry of Infrastructure and Water Management. As a public organisation, ProRail was granted a 10-year 'management concession' in 2015 that runs until 2025, making them responsible for the management and maintenance of all railway tracks in the Netherlands. **Rijkswaterstaat** is an executive agency of the Dutch government's Ministry of Infrastructure and Water Management. As a public organisation, they have the task to manage and maintain all major highways and waterways in the Netherlands, as well as water management systems (e.g. the dikes along the Dutch coast). **Vitens** is an unlisted public limited company that is owned by the five provinces (i.e. Flevoland, Friesland, Gelderland, Utrecht and Overijssel) and several municipalities outside of these five provinces in which they are active as the local drinking water company. As a semi-public organisation, they are responsible for managing and maintaining the local public water system in their service area.

In case one of the infrastructures of the partner organisations would fail, it has the potential of bringing the whole Dutch economy and society to a standstill. Moreover, the Covid-19 pandemic reaffirmed that these networks do not only consist of hardware (e.g. highways, railways, electricity cables), but that also the softer parts, such as the people who operate and maintain the networks, are a vital part of these networks. For example, ProRail cannot operate their railroad network without traffic managers and was recently forced to lower the availability of their network for trains due to personnel shortages as a result of many Covid-19 infections among their employees (NOS, 2022). Finally, all five organisations and their networks are under heavy public scrutiny, as all of these organisations are owned, or even part of, a governmental institution, and laws and regulations are in place requiring the infrastructure organisations to keep their infrastructure networks available as much as possible. Many assets of the five organisations are 60 years or older and either close to reaching the end of their lifecycle or coming to the point that their current capacity is insufficient to cope with explosive increases in demand. Due to their public nature, the management and maintenance of the infrastructures of the five organisations are being funding by public money, allocated by the Dutch government and related institutions. However, in the last decade, many infrastructure organisations in the Netherlands (as many other organisations that receive public funding) were confronted with significant budget cuts. This further increased the number of activities, originally performed by the five (semi-)public organisations themselves, that are being outsourced to private companies. It also further increased the pressures from the (semi-)public organisations (seeking to lower their expenditures) on the private companies to continuously lower their prices, putting additional strains on their relationships.

## 1.5 Declaration of contribution

As the author of this doctoral thesis, I declare that I have performed the majority of the work for each of the chapters and I take full responsibility for the contents of each chapter, as well as any mistakes. At the same time, I also acknowledge the contributions made by my two promotors (Prof. Henk Akkermans and Prof. Saskia Lavrijssen), my co-promotor (Prof. Wendy van der Valk) and my three co-authors (Prof. Jens Roehrich, dr. Kostas Selviaridis and dr. Martijn Jonker) to one or more of the chapters in my thesis. Their specific contributions are discussed below.

**Chapter 1** (Introduction) and **Chapter 5** (General discussion) were written, independently, by me. My two promotors and co-promotor kindly provided feedback to earlier drafts of these two chapters, which I have incorporated in the final versions.

For **Chapter 2**, I independently performed the majority of the work including the initial theoretical framing of earlier versions of the manuscript, the development of the main research question and empirical data collection method, the collection of empirical data, and the writing of the case narratives. Connections with the two case organisations were realised in collaboration with one of my promotors (Prof. Henk Akkermans) and my co-promotor. Coding and analysis of the empirical data was, for the majority, performed by myself with contributions by my co-promotor. The final version of the manuscript was written by me in collaboration with my co-promotor and two co-authors (Prof. Jens Roehrich and dr. Kostas Selviaridis). They were primarily involved in writing the introduction, theoretical background (as it included a major reframing from earlier versions, achieved with help from the two co-authors), discussion and conclusion part of the manuscript.

For **Chapter 3**, I independently performed the majority of the work as well, including the analysis of relevant literature, the collection and analysis of the empirical data, and the writing of the case narratives. I also independently wrote earlier drafts of this manuscript, while my co-promotor provided extensive feedback and helped by editing these earlier versions. Development of the research idea and the main research question was done in collaboration with my one of my promotors (Prof. Henk Akkermans) and my co-promotor. Connection with the case organisation and their two contractors were realised in collaboration with my co-promotor. Finally, while writing later versions of the manuscript, the co-promotor was involved with editing these later versions and (re)-writing specific parts throughout the manuscript.

For **Chapter 4**, I independently performed the majority of the work, including the development of the empirical data collection method, the coding and analysis of the empirical data, and writing earlier versions of the manuscript. The development of the research idea and establishing the connection with the case organisation were done in collaboration with one of my promotors (Prof. Henk Akkermans). Collection of the empirical data was realised in collaboration with my co-author (dr. Martijn Jonker). Developing the theoretical background for this manuscript was initially done with my promotor and later refined with help of the co-author and co-promotor. The final version of the manuscript was written by me in collaboration with my co-author, promotor and co-promotor. They were primarily involved in writing the theoretical background, discussion and conclusion part of the manuscript. Moreover, they all three helped refine the introduction and findings part with extensive feedback.

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# Chapter 2

## Managing information asymmetry in public-private relationships undergoing a digital transformation:

## The role of contractual and relational governance


### Abstract

**Purpose** – Inter-organisational governance is an important enabler for information-processing, particularly in relationships undergoing digital transformation (DT) where partners depend on each other for information in decision-making. Based on information processing theory (IPT), the authors theoretically and empirically investigate how governance mechanisms address information asymmetry (uncertainty and equivocality) arising in capturing, sharing and interpreting information generated by digital technologies.

**Design/methodology/approach** – IPT is applied to four cases of public-private relationships in the Dutch infrastructure sector that aim to enhance the quantity and quality of information-based decision-making by implementing digital technologies. The investigated relationships are characterised by differing degrees and types of information uncertainty and equivocality. The authors build on rich data sets including archival data, observations, contract documents and interviews.

**Findings** – Addressing information uncertainty requires invoking contractual control and coordination. Contract clauses should be precise and incentive schemes functional in terms of information requirements. Information equivocality is best addressed by using relational governance. Identifying information requirements and reducing information uncertainty are a prerequisite for the transformation activities that organisations perform to reduce information equivocality.

**Practical implications** – The study offers insights into the roles of both governance mechanisms in managing information asymmetry in public-private relationships. The study uncovers key activities for gathering, sharing and transforming of information when using digital technologies.

**Originality/value** – This study draws on IPT to study public-private relationships undergoing DT. The study links contractual control and coordination as well as relational governance mechanisms to information-processing activities that organisations deploy to reduce information uncertainty and equivocality.

**Keywords:** *Digital transformation, Information asymmetry, Contractual governance, Relational governance, Public-private relationships, Information processing theory*

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## 2.1 Introduction

The role of information technology in supporting information and process integration within and between organisations is well established (Kache & Seuring, 2017; Venkatraman, 1991). More recently, the concept of digital transformation (DT), driven by new information and communication-based technologies (e.g. data analytics, smart sensors), has attracted scholarly attention (Brinch, 2018; Lanzolla et al., 2018). As these digital technologies may greatly enhance the quantity and quality of data available for decision-making (Waller & Fawcett, 2013), DT is seen as an important enabler for smart maintenance of production assets (Bokrantz et al., 2020).

This study draws on information processing theory (IPT; Galbraith, 1974), which posits that organisations deploy information-processing activities (Daft & Weick, 1984) that best address the amount and type of information asymmetry they are faced with (Bode et al., 2011). More specifically, we build on IPT and distinguish two types of information asymmetry – uncertainty (lack of information) and equivocality (ambiguity of information; Zhao et al., 2018). While gathering more data may help mitigate information uncertainty (Bode et al., 2011), addressing equivocality may require cognitive skills to transform data by ordering and presenting data in a logical way. Both information uncertainty and equivocality are likely to be present in public–private relationships undergoing DT, with the use of digital technologies increasing the amount and quality of available data, while also offering enhanced possibilities for analysis and transformation. Thus, digital technologies can affect information acquisition and transformation processes in these inter-organisational relationships (IORs).

At the same time, collaborative activities of information gathering and transformation may be difficult to organise in public–private relationships due to public and private organisations' divergent goals and incentives as well as their differences in terms of institutional backgrounds, values, practices and decision-making processes (e.g. Caldwell et al., 2017; Roehrich et al., 2014). This raises concerns about how public organisations may govern information-processing activities with their private partners for the purpose of enhanced decision-making (e.g. timing of maintenance activities). Inter-organisational governance – the formal and informal rules of exchange between partners (Cao & Lumineau, 2015; Roehrich et al., 2020) – supported by contractual and relational governance mechanisms (Poppo & Zenger, 2002), may be instrumental in addressing possible information asymmetries resulting from separate yet interdependent data collection and analyses by public and private organisations.

A consideration of the role that governance mechanisms play in leveraging the high volumes of data generated by digital technologies addresses several knowledge gaps in the inter-organisational governance and DT literatures. First, although prior studies on DT have loosely mentioned the possibility of increasing data generation (and so potentially addressing information uncertainty; Sternberg et al., 2021) and digital technology's analytical capabilities (which may address information equivocality; Frank et al., 2019), no detailed and comprehensive study has investigated DT's impact on information asymmetry and processing activities. Developing a more detailed understanding of information acquisition and transformation processes taking place in relation to information asymmetry is crucial in understanding DT and clarifies the relationships between contexts, outcomes and governance mechanisms (Formentini & Taticchi, 2016). Second, prior studies offer very limited insights into how contractual and relational governance mechanisms may support information acquisition and transformation processes (Kache & Seuring, 2017). Lumineau (2017), for example, argues theoretically that contracts influence information processing by specifying rules, operating procedures and incentive schemes, but he does not study in detail how contracts affect information acquisition and transformation nor the role of relational governance mechanisms. Furthermore, the notion that control and coordination dimensions of formal contracts affect their information-processing capacity has so far received limited empirical validation. This is a vital area as the effective governance of IORs is paramount to organisations' survival, requiring governance mechanisms to mitigate information asymmetry.

We address these gaps by studying how organisations in public–private relationships – which increasingly use digital technologies to collect rich data (Baldus & Hatton, 2020) – may deploy contractual and relational governance to support information acquisition and transformation in the context of DT, thereby reducing information uncertainty and equivocality. Public–private relationships represent a suitable research setting as both partners grapple with different information processing needs. For example, public organisations often have strict responsibilities imposed by the national government, meaning that if an infrastructure asset fails, the public organisation is held accountable even when the cause is poor maintenance by a private supplier. As a result, public organisations require more information than a private supplier would usually document. Differences may also emerge with regard to the interpretation of information. While a public organisation often prefers timely replacement of components to avoid breakdowns, private suppliers may use data to perform a risk analysis and consequently decide to stretch the lifetime of that component.

Building on IPT, we investigate four cases to address the following research question: *How do contractual and relational governance mechanisms address information asymmetry in public–private relationships undergoing digital transformation?* The investigated cases concern two Dutch public organisations outsourcing the maintenance of their transportation networks and their relationships with private suppliers. All four public–private relationships are undergoing DT because of increased use of digital technologies (i.e. the implementation of smart sensors to collect data about the health of the infrastructure networks). We draw on a rich data set including archival data, observations, contracts and interviews.

We contribute to extant research in two main ways. First, we advance DT research by showing how DT affects information uncertainty and equivocality as well as information gathering and transformation activities in public–private relationships as a specific type of IORs. We illustrate that digital technologies address information uncertainty by generating more data and equivocality through enhanced transformation activities. Our findings also show that organisations need to develop their data gathering and transformation capabilities, as increased data availability does not imply that these data can readily be accessed or that they make a meaningful contribution to decision-making. Second, our study theoretically and empirically investigates the roles of contractual and relational governance mechanisms in IORs undergoing DT, thus extending prior governance literature. Both governance mechanisms are important, but they each have different roles in supporting information processing. Our findings show that contractual control and coordination are more effective in supporting data-gathering activities, while relational governance underpins information transformation. The use of contractual control clarifies partners' obligations in gathering and sharing data and needs to be complemented by coordination clauses that guide data-gathering activities, with clauses that help accessing the right data type and quality as well as appropriate incentive schemes.

Relational governance supports data transformation as it facilitates openness about what data are gathered and what meaningful information that data could be turned into. The development of relational norms enhances partners' understanding on what data is required for what purposes and fosters pro-active information sharing.

The remainder of the paper is organised as follows. First, we review relevant literature on DT, IPT and inter-organisational governance. Subsequently, we elaborate our research approach after which we present our findings. We then discuss theoretical contributions and practical implications and highlight limitations and future research opportunities, before concluding the paper.

## 2.2 Theoretical background

### *2.2.1 Digital transformation of maintenance service delivery*

DT involves the implementation of data-driven and software-managed processes, which in turn generate large volumes of data that can be used to increase information availability, transparency and visibility in IORs (Sternberg et al., 2021). Following prior studies, our paper treats data as the raw material of information, thus data are unprocessed and an asset awaiting transformation into information (Sivarajah et al., 2017). Data gathered using digital technologies are seen as "the new oil" (Hartmann et al., 2016), highlighting the importance of exploiting and refining data to attain high performance levels for a focal organisation and their supply chain. Various digital base technologies (i.e. the Internet of Things (IoT), cloud services, big data) enable a wide range of front-end technologies (i.e. smart-manufacturing, -products, -supply chains and -working) concerned with operational and market needs along four dimensions (Frank et al., 2019). Smart maintenance (Bokrantz et al., 2020; Huang et al., 2020) comprises elements of both smart manufacturing (e.g. smart sensor data, enabling predictive maintenance) and smart working (e.g. virtual reality, enabling interactive and real-time guidance of maintenance tasks; Scurati et al., 2018). Data-driven decision-making (e.g. prediction and prescription of maintenance actions) and external integration (e.g. sharing and consolidating heterogeneous data sources with external parties) are being noted as key dimensions (Bokrantz et al., 2020). Suppliers are an important source of valuable data, as the digital technologies embedded in their offerings may predict failures and prescribe actions to be taken. As such, the ubiquity of data, computing power and analytical capabilities may help drive performance of maintenance service providers (Olsen & Tomlin, 2020). As suppliers are progressively assuming responsibilities regarding product and process innovation (Blome et al., 2013), information sharing and collaboration with suppliers (Huang et al., 2020) provide ample opportunities for organisations to improve their productivity and to transform processes.

While prior studies offer some insights with regard to how data are being gathered, much less is known about how data are analysed and interpreted (Yu et al., 2019), especially in situations where possibilities and responsibilities for data collection and analysis are distributed across dyadic relationships including public–private ones. A more detailed understanding of how organisations organise these activities to manage information needed for decision-making is crucial for DT.

### *2.2.2 Information processing needs for digital transformation in public–private relationships*

Drawing on IPT, we argue that in the face of environmental uncertainty – that is, "the difference in the amount of information required to perform the task and the information already possessed by the organisation" (Galbraith, 1973, p. 5) – organisations deploy information-processing activities (i.e. gathering, processing and communicating information; Daft & Weick, 1984) that best address information asymmetry (Bode et al., 2011; Galbraith, 1974). Information asymmetry is referred to as either the absence of information (uncertainty) or the messiness/ambiguity of information (equivocality) (Zhao et al., 2018). Whereas gathering more data may help mitigate information uncertainty (Bode et al., 2011), equivocality requires cognitive skills to transform data including ordering and presenting information in a logical way. This is particularly pertinent when the information required is ill-structured, difficult to evaluate and requires more than one individual for interpretation (Daft & Lengel, 1986).

Prior work has addressed organisations' approaches to reducing information-processing requirements (Galbraith, 1973). Here, IPT helps to explain organisational behaviour "in terms of information that must be gathered, interpreted, synthesised, and coordinated in the context of decision-making" (Burns & Wholey, 1993, p. 110). IPT has, for example, been used to assess the impact of internal manufacturing complexity on the organisations' triple bottom line (Wiengarten et al., 2017) and to study the mechanisms managers can use to create internal strategic consensus (Rosado Feger, 2014). Recent work has extended IPT to an inter-organisational level, addressing how organisations develop information-processing capabilities to deal with supply chain disruptions (Bode et al., 2011), sustainability-related uncertainty (Dahlmann & Roehrich, 2019) and cost management challenges in new product development (Ellram et al., 2020). However, relatively little attention is paid to IORs' capacity to gather and process information (Yu et al., 2019), despite the increasing importance of joint efforts between focal organisations and their suppliers to systematically gather and analyse information, especially in light of the possibilities and challenges that DT brings.

Furthermore, the majority of prior (IPT informed) operations and supply chain management (OSCM) studies focus on relationships involving private organisations, despite the fact that information processing is considered essential to "bridge disagreement and diversity" (Daft & Lengel, 1986, p. 556) between two organisations that may have different objectives and values as is often observed in public–private relationships (Caldwell et al., 2009). These public–private relationships are defined as "any long-term collaborative relationships between one or more private actors and public bodies that combine public sector management or oversight with a private partner's resources and competencies for direct provision of a public good or service" (Kivleniece & Quelin, 2012, p. 273). Public–private collaborations are now a global phenomenon, with the United Kingdom leading the deployment of such relationships with approximately 360 public–private partnerships (PPPs; a form of public–private relationships) for a total value of €58bn that have been initiated in the past 10 years (EPEC, 2017). During the same period in the Netherlands, 34 PPPs were initiated that account for a total value of €10bn (EPEC, 2017).

Although prior OSCM studies have highlighted the characteristics of public–private interactions (e.g. Roehrich & Lewis, 2014; Zheng et al., 2008), recent publications call for further empirical research of relationships between public and private organisations (e.g. Mishra & Browning, 2020). While the aim of the private actor is often to appropriate created economic value via private rents, the aim of public organisations is to maximise predominantly appropriable (social) value for various beneficiaries (Klein et al., 2010). Combining the efforts of private, value-maximising firms and more social-interest-driven public organisations (Hart, 2003), public–private collaborations intersect the operating logic of both political and economic markets and may feature a more heterogeneous, interdependent set of interests when compared to private–private relationships (Kivleniece & Quelin, 2012; Mahoney et al., 2009). These relationships may therefore carry potentially vital gains in terms of efficiency, innovation and ability to draw upon unique resources and capabilities residing in the private sector (Cabral, 2017) and outperform either (public and private) sector working alone (Lepak et al., 2007; Roehrich & Kivleniece, 2022).

By the nature of their cross-sector design, however, these collaborations are also exposed to divergent incentives and objectives as well as resource and capability gaps underlying each sector (Hartmann et al., 2014; Quelin et al., 2019). For instance, these relationships may face substantial governance costs tied to the complex nature of underlying contracts and the additional monitoring, control and enforcement needs – not least due to potentially divergent knowledge bases, goals, values, incentives and behaviours, organisational routines and capabilities (Caldwell et al., 2017; Quelin et al., 2017; Rangan et al., 2006). It is vital to avoid coordination failures in these relationships which may stem from, for instance, cognitive limitations (bounded rationality) of those who design and implement coordination mechanisms (e.g. failure to recognise interdependencies, attention constraints which may limit monitoring effectiveness) and from underlying cultural differences (as presented by private and public organisation's goals and values) (Gulati et al., 2012; Kalra et al., 2021). Thus, adopting optimal governance mechanisms is crucial in such relationships to align incentives, allocate decision rights and ensure information flows for maximising underlying partners' commitment (Cabral et al., 2019; Klein et al., 2019) and may address a central tension in terms of how to coordinate across public and private organisations. Hence, public–private relationships offer a fruitful context for studying how the effective deployment of governance mechanisms can support data gathering and transformation activities and help manage information asymmetry in the context of DT.

### *2.2.3 Inter-organisational governance*

IORs are highly dependent on effective coordination and control using reliable information to meet performance targets including, for instance, high-quality maintenance services. This is particularly important in the context of DT, as the adoption of digital technologies provides opportunities for increasing data quantity and quality, while also presenting challenges in terms of how to gather and process data. High interdependence between partnering organisations "increases the need for a common formalised language in order to enable the exchange of information" (Gattiker & Goodhue, 2004, p. 433). Inter-organisational governance mechanisms, i.e. the formal and informal rules of exchange between partners (Cao & Lumineau, 2015; Olsen et al., 2005; Roehrich et al., 2020), may provide such a "common language". In line with IPT, we argue that contractual and relational governance mechanisms may act as frames and filters that influence how organisations collect data generated by using digital technologies and transform data into information that can be used and shared for decision-making in the IOR (Lumineau, 2017; Thompson, 1967).

Contractual governance in the form of written, legally enforceable contracts helps to define roles and responsibilities between exchange partners and support the framing of predetermined promises and obligations for resolving potential disputes and conflicts (Luo, 2002). OSCM research, in particular, has stressed the multiple roles of contracts in managing buyer–supplier relationships, including those in public–private exchange settings (e.g. Kapsali et al., 2019; Roehrich et al., 2021; Zheng et al., 2008). Contracts include a wide range of provisions (depending on contract type such as performance-based contracts; Essig et al., 2016) that can potentially be used to control a counterpart's behaviour and safeguard against possible opportunism (Steinbach et al., 2018), coordinate inter-organisational processes, adapt exchanges in the face of environmental uncertainty and even codify lessons learned regarding efficient inter-firm collaboration and contracting (Howard et al., 2019; Selviaridis, 2016). Contracts can also be used as framing devices aimed at eliciting productive responses by counterparts (Selviaridis & Van der Valk, 2019; Weber & Mayer, 2011).

Contracts influence information processing by specifying explicit rules and operating procedures, planning and incentive systems (Halldórsson & Skjøtt-Larsen, 2006; Hartmann et al., 2014; Lumineau, 2017), which may stimulate suppliers to improve their processing capabilities (Glock et al., 2017). Control and coordination clauses can both facilitate information gathering by explicitly stipulating information exchange (including type, frequency and quality) between contracting parties (Faems et al., 2008; Jayaraman et al., 2013; Mayer & Argyres, 2004). Coordination clauses can influence the way information is interpreted (Daft & Weick, 1984; Fiol, 1994) by facilitating communication and supporting information transfer (Mesquita & Brush, 2008; Zheng et al., 2008) as well as by joint transformation between partners (Puranam et al., 2006). For example, the study by Zheng et al. (2008) showed that contracts can function as a knowledge repository where information is being stored and accessible for contracting partners in addressing information asymmetry. Prior studies (Schepker et al., 2014; Tushman & Nadler, 1978) argued that the more comprehensive contractual control and coordination mechanisms are, the greater the ability to process information and deal with uncertainty.

Compared to contracts, relational governance mechanisms depend on trust and social norms among partners, fostering a joint approach to addressing information asymmetry (Poppo et al., 2008) in buyer–supplier relationships (e.g. Chakkol et al., 2018; Roehrich & Lewis, 2014). Trust has been positioned as minimising the probability of opportunism and conflict as well as increasing collaboration and information exchange (Carey et al., 2011; Inkpen & Tsang, 2005). Relational norms, referring to the shared behavioural expectations of partners involved in a relationship (Cannon et al., 2000; Heide & John, 1992), imply a bilateral expectation that parties will proactively provide useful information to their partner in support of the ongoing relationship. Trust and relational norms based on flexibility, openness and information sharing are instrumental in governing IORs where information processing across organisational boundaries is of essence such as in complex projects (Chakkol et al., 2018) and public–private relationships (Roehrich & Lewis, 2014). Relational governance may influence the processing of information through social processes (Poppo & Zenger, 2002). In the presence of trust, parties are more likely to expend effort into gathering and joint transformation of information. Trust is vital for effective information sharing, operational linkages and cooperative norms among partners (Ghosh & Fedorowicz, 2008). Increasing levels of relational governance and trust between partnering organisations help to jointly transform information to address asymmetry in a dyad when offering more complex services (Kreye et al., 2015). The flow of information in relationships characterised by high levels of trust allows for enhanced synthesis of information; partners actively provide useful information, thereby frequently soliciting and exchanging private information (Carson & John, 2013; Heide & John, 1992).

Overall, in the context of DT, where the provision of maintenance services is increasingly enabled by digital technologies, generating and sharing information in IORs relies on effective coordination and control through governance mechanisms. At the same time, our understanding of the roles of both contractual and relational governance mechanisms in gathering and interpreting information remains limited.

## 2.3 Methods

### *2.3.1 Research setting, design and case selection*

We employed a multiple-case design (Yin, 2009) to investigate the role of governance mechanisms in addressing information asymmetry in four public–private relationships, embedded in two public organisations undergoing DT (see **Table 2.1**). Our design thus yielded multiple observations of contractual and relational governance challenges faced by the two public buying organisations we studied (Golden-Biddle & Locke, 2007). Our research setting was the Dutch infrastructure sector where public organisations have been tasked with managing critical infrastructure networks and have started to adopt digital technologies (Baldus & Hatton, 2020) to enhance infrastructure network management and to stimulate smart maintenance (Bokrantz et al., 2020). At the same time, both public organisations depended on the specialist resources and competencies of their private suppliers for leveraging data produced by these technologies to realise smart maintenance and sharing valuable information related to the networks' condition (RAE, 2012). The infrastructure networks to be maintained were thus fully owned and operated by the public organisations and maintained by private suppliers. The first case organisation (Road) was responsible for all motorways (including bridges and tunnels) and waterways (including sluices and water pumps) in the Netherlands. The second case organisation (Rail) was responsible for the entire railway network in the Netherlands.

The four cases were selected after conducting exploratory research including pilot interviews and the collection and analysis of secondary data (see **Table 2.2**). The investigated cases had a number of unique qualities that made them logical candidates for sampling (Shah & Corley, 2006) and we employed a theoretical sampling logic (Patton, 1990) based on the following key criteria. First, each of the four investigated public–private relationships involved the recent adoption of digital technologies (i.e. mounting smart sensors to critical assets to gather more and better data) that may enable improving infrastructure management and maintenance. Second, we purposefully sampled relationships in which the public organisations rely on their private suppliers for real-time data about the assets (resulting in information uncertainty as private suppliers may not be sufficiently incentivised to provide public organisations with complete data) and in which historical data in databases of the case organisations are incomplete, of insufficient quality and/or messy. As a result, our cases were characterised by different degrees and types of information asymmetry, that is, uncertainty and/or equivocality. Lastly, all four relationships involved public tenders and supplier selection based on best value evaluations and were governed by a contract with durations of at least five

**Table 2.1** Case (organisation) characteristics

| | **Public organisation – Road (The Netherlands)** *Responsible for main road- and waterways and water management in the Netherlands* | | **Public organisation – Rail (The Netherlands)** *Responsible for main railways in the Netherlands* | |
|---|---|---|---|---|
| | **Road A** | **Road B** | **Rail A** | **Rail B** |
| **Private organisation (supplier)** | Consortium of: (1) a large supplier (20,000 employees) specialised in construction; and (2) a medium-sized supplier (175 employees) specialised in hydraulic engineering. | Consortium of: (1) a large supplier (46,500 employees) specialised in electro-technical installations; and (2) a medium-sized supplier (180 employees) specialised in construction. | Medium-sized supplier (275 employees) specialised in construction and maintenance of railroad systems. | Large supplier (6,500 employees) specialised in construction and maintenance of railroad systems. |
| **Public and private organisation's objectives** | *Road (public)*: Safeguard public interests (e.g. availability, security) and maintain aging infrastructure with limited budgets in a sustainable manner, while also dealing with extended responsibility (Road is publicly accountable in case failures occur, even if supplier's actions caused it).<br><br>*Suppliers (private)*: Increase volume of maintenance activities (e.g. remain focussed on preventive rather than predictive maintenance, so that more maintenance activities can be performed), thereby potentially decreasing the availability of infrastructures. | | *Rail (public)*: Safeguard public interests (e.g. availability, security), maintain aging infrastructure with limited budgets, and perform effective traffic management on the railroad network. Rail also needs to deal with extended responsibility (Rail is publicly accountable in case failures occur, even if supplier's actions caused it).<br><br>*Suppliers (private)*: Increase volume of maintenance activities (e.g. remain focused on preventive rather than predictive maintenance, so that more maintenance activities can be performed), thereby potentially hindering effective traffic control. | |
| **Information needs of both public and private organisation** | *Road (public)*: Is reliant on up-to-date information about the health of assets and performed maintenance from their suppliers to more efficiently manage assets and monitor availability/safety of the network due to their extended responsibility. Requires technical knowledge of the suppliers regarding assets to transform data. | | *Rail (public)*: Requires up-to-date information about the health of assets and maintenance activities to re-route or re-schedule trains in case of failures, check suppliers' performance, and monitor availability/safety of the network due to their extended responsibility. | |

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| | *Suppliers (private)*: Requires historical data from Road's systems to calibrate degradation models for assets in order to detect failures and better plan future maintenance activities. | | *Suppliers (private)*: Requires the newest data from inspection trains to complement their own inspection data to monitor the condition of assets. Builds on historical data from Rail's systems to better plan future maintenance activities. | |
| **Prior relationship** | No prior relationship with either supplier. | | No prior relationship with current supplier. | Second consecutive contract. Previous contract period: 5 years. |
| **Contract:**<br>**- Scope** | Maintenance of an important waterway corridor (15,000 ships per year) connecting the eastern part of the Netherlands with Germany. | Maintenance of an important waterway corridor connecting inland waterways to the North Sea. Water pumping station keeps a third of the Netherlands dry. | Maintenance of a major railway connection (10 passenger trains per hour) between two large cities in the middle and southern part of the Netherlands. | Maintenance of the railways directly connected to the area surrounding the most central train station in the Netherlands (100 passenger trains per hour). |
| **- Type** | Locally customised performance-based contract. | Locally customised contract with performance & behavioural aspects. | Centrally led performance-based contract. | |
| **- Duration and start of contract period** | 5 years (option for two 1-year extensions). | | 5 years (with extension option). | |
| | 2014 | 2016 | 2017 | 2019 |
| **Digital strategy (case organisations)** | Recently initiated an organisation-wide programme, focussed on implementing smart maintenance supported by digital technologies. | | An established, central department that acts as a Data Lab that analyses data coming from digital technologies. | |
| **Technologies** | Sensors mounted to critical (moving) parts of sluice doors and to motor units in the water pumps. Started implementation: 2018. | | Sensors mounted to railroad switches (started in 2017) and fourteen passenger trains belonging to one of Rail's customers (started in 2018). | |
| **Data sources** | ▪ Sensors & suppliers' inspection reports<br>▪ Road's operating systems for moving assets (such as sluices)<br>▪ Road and suppliers' asset management systems | | ▪ Dedicated inspection trains equipped with cameras and sensors<br>▪ Sensors and suppliers' inspection reports<br>▪ Rail's asset management system | |

years and concerning substantial revenues for the private suppliers involved. This speaks to the notion of a detailed contract and the importance of contractual governance in these investigated relationships. Following Schilke and Lumineau (2018, p. 2849), who argued that "it seems likely that the contracting process may play a less central role in simpler, shorter, or more exploitation-oriented types of alliances", we purposely selected cases that involved longer, more collaborative types of relationships to ensure that relational governance mechanisms were present and used. We had a rare opportunity to have extensive access to employees and (archival and contractual) documents at both case organisations, which enabled us to explore governance mechanisms fully.

### *2.3.2 Data collection and sources*

Our study combined primary (observations, interviews), contracts and secondary data sources (vision and strategy documents, presentation slides, and government and industry reports). We collected data using a two-stage strategy. During the exploratory research stage (March–September 2018), eight pilot interviews and selected site visits at both case organisations were conducted and archival data were collected. Analysing these data sources helped to establish an interview protocol and to select appropriate cases. The subsequent in-depth case research stage (November 2018–December 2019) involved the lead author conducting 20 interviews to collect data on each of the four investigated cases in real time (during the ongoing public–private relationship undergoing DT). Also, contracts and various other archival data were collected (see **Table 2.2**) to achieve data triangulation (Jick, 1979). Data gathering from multiple sources continued until theoretical saturation was achieved and was key to understanding and unpacking relational and contractual governance and their role in addressing information asymmetry in detail. For example, access to contracts proved instrumental in complementing our interview data with respect to how contracts enabled data collection activities by the case organisations, thereby helping to reduce information uncertainty. The following sections explain in detail the data sources we collected and how they aided our study.

#### *2.3.2.1 Archival data and observations during site visits and meetings*

We collected and analysed 25 documents as well as observational data produced during site visits and meetings (approximately 55h). Overall, the archival data and observations provided a deeper understanding of the case organisations, the sector, key suppliers, the maintenance data that were collected and the mix of contractual and relational governance mechanisms employed by case organisations in relation to the implementation of digital technologies.

#### *2.3.2.2 Contracts*

We analysed 31 contract documents, including core agreements (e.g. specifying supplier responsibilities and scope), specifications of minimum requirements (e.g. asset availability) and general guidelines regarding what data needed to be shared and when (e.g. registering the nature of a failure, actions taken and components that were replaced). Various annexes captured region-specific details (e.g. permits or exemptions). This was vital to unpack how the contract

**Table 2.2** Main data sources and use of data

| Data source | Research stage | Type of data | Use in the analysis |
|---|---|---|---|
| *Archival data and contracts* | Exploratory | 6 public documents in total (64 pages), including<br>• 1 sector wide report on data usage in public entities:<br>"*Best practices: Innovative examples of data usage by the Government*"<br>• 2 sector wide vision documents and 1 presentation on collaborating with private suppliers:<br>"*The market vision*"<br>"*Leading principles for a better collaboration between client and supplier in 2020*"<br>"*Chain cooperation and social innovation management and maintenance of linear infrastructure*"<br>• 2 news items regarding the maintenance of railways:<br>"*Investing in a better collaboration benefits rail maintenance*"<br>"*Supplier wins maintenance contract Rail B*" | Understanding the sector both case organisations operate in and current best practices with respect to data use within the sector.<br>Familiarising ourselves with the general view within the sector on how public-private relationships should be established and maintained. |
| | In-depth | 31 contract documents in total (973 pages), including<br>• 8 contract documents (one describing the tender process [60 pages], one with the core agreement [26 pages], three with specifications [183 pages] and three annexes [211 pages]).<br>• 9 documents describing optional and area specific activities that suppliers can perform to earn additional profits during contract period (153 pages).<br>• 14 documents prescribing area specific activities that the supplier is expected to perform as part of the core agreements (340 pages). | Identifying current contractual agreements between Road and their private maintenance suppliers, including performance objectives that the supplier needs to achieve, provisions regarding data sharing and transformation, and incentive schemes.<br>Triangulation with findings and insights from the exploratory research stage and the semi-structured interviews. |
| | | 19 Internal documents in total (493 pages), including<br>• 6 reports and 2 presentations on Road's innovation program for maintenance:<br>"*Project plan: Vital Assets – Pilot Road A*"<br>"*Project plan: Vital Assets – Pilot Road B*"<br>"*Vision on Vital Assets*" | Understanding on data gathering and transformation activities and on the desired relationship with suppliers.<br>Triangulation with findings and insights from the exploratory research stage, and the semi- |

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| | | “*Expected approach in case of failures and Vital Assets*”<br>“*Proposal investment program ‘maintaining and improving the reliability of aging installations’*”<br>“*LEF future centre: Vital Assets*”<br>“*Pilot Road A: The old sluice – predictive corrosion maintenance*”<br>“*Vital Assets in practice: pilot Road A and other pilots*”<br>• 5 reports on collaboration with private suppliers:<br>“*Get rid of the traditional division of roles in management and maintenance!*”<br>“*Towards a vital infra sector: Project plan for a joint transition process*”<br>“*Vision on Vital Assets in relation to procurement*”<br>“*Handbook of the tender team*”<br>“*Working on change management for IA sourcing: At the intersection of cooperation, market approach and technology*”<br>• 2 presentations (one by Road’s Chief Data Officer and one by a Solution Architect) intended for Road’s employees on how Road gathers & uses asset data:<br>“*Data, the connecting link: Data for a customer-oriented, reliable, transparent and innovative Road organisation*”<br>“*How do you get data? With the Object Data Service!*”<br>• 1 corporate presentation on Rail’s activities intended for external parties:<br>“*Rail: General information*”.<br>• 3 annual reports from Rail:<br>“*Management plan 2018*”.<br>“*Management plan 2019*”.<br>“*Management plan 2020-2021*”. | structured interviews. |
| *Observations (55 hours)* | Exploratory | 10 observations in total, including<br>• 3 tours around Road’s facilities (showcasing critical assets equipped with sensors)<br>• 2 meetings between Road and their suppliers (discussing the progress of fitting sensors and sharing insights from sensor data)<br>• 4 knowledge sharing sessions at Road and 1 at Rail | Obtaining an initial understanding of the various types of assets that are being maintained by Road, and of the roles of both Road and their suppliers in the maintenance process.<br>Experiencing how Road collaborates with their |

| | | | |
|---|---|---|---|
| | | (discussions between internal employees and external experts on using digital technologies for maintenance). | private maintenance suppliers.<br>Further developing our understanding of the various innovations being developed at both Road and Rail. |
| *Pilot interviews (9 hours)* | Exploratory | 8 pilot interviews in total, including<br>• 6 at Road (internal advisors in the area of innovation or contracting)<br>• 2 at Rail (internal advisors in the area of innovation). | Obtaining an initial understanding of the key responsibilities and activities of Road and Rail and current innovations with respect to the maintenance and management of infrastructure assets.<br>Identifying potential cases at Road and Rail.<br>Familiarising ourselves with Road and Rail's current views on how data should be used, the desired relationships with suppliers and market conditions. |
| *Semi-structured interviews (18 hours)* | In-depth | 20 semi-structured interviews in total, including<br>• 5 at Road A (Asset Manager 1, Asset Manager 2, Contract Manager 1, Advisor 1, and Data Scientist 1)<br>• 5 at Road B (Asset Specialist 1, Asset Manager 3, Contract Manager 2, Regional Director 1, and Configuration Manager 1).<br>• 4 at Rail (Project Manager 1, Data Scientist 2, Contract Manager 3, and Asset Manager 4).<br>• 3 at Rail A (Asset Manager 5, Contract Manager 4, and Asset Manager 6).<br>• 3 at Rail B (Asset Manager 7, Contract Manager 5, and Asset Manager 8). | Obtaining data and detailed insights into the following three aspects:<br>1. Maintenance activities and how these are affected by data *(e.g. Asset Managers and Asset Specialists)*.<br>2. Contractual agreements and relationships with suppliers *(e.g. Contract Managers and Regional Director)*.<br>3. Data gathering, sharing and transformation activities *(e.g. Data Scientists and Configuration Manager)*.<br>Triangulation with findings and insights from exploratory research stage. |

(and specific control and coordination clauses) was used to support information-processing activities.

#### *2.3.2.3 Interviews*

We conducted eight pilot interviews (over 9 h) with several advisors from both organisations that had a thorough understanding of contract management processes and/or digital technologies. We then prepared summaries of the most important points that provided us with an initial understanding of the two case organisations and their operations and helped us to uncover potential cases. During the in-depth case research stage, 20 interviews (over 18 h) were conducted with knowledgeable people (Alvesson, 2003) with different lengths of tenure in disparate hierarchical and functional roles. An interview protocol was designed (see **Appendix A**) which we refined as the research progressed and new insights emerged. Semi-structured interviews included questions to help us understand the case organisations, the infrastructural assets involved and their maintenance requirements, past and current relationships with the private maintenance suppliers in focus, information processing activities and the role of digital technologies in these processes.

#### *2.3.2.4 Validity and reliability of the study*

We applied specific criteria and measures to ensure validity and reliability of our case study findings in line with literature recommendations (e.g. Gibbert et al., 2008; McCutcheon & Meredith, 1993; Yin, 2009). More specifically, we derived a research framework from extant literature and offered clarity about how data were collected and analysed (informant and data source triangulation). In order to increase generalisability, we built on analytical generalisation by seeking to identify patterns across cases (Ellram, 1996). The lead author coded each data source individually before discussing with the other three authors. This ensured not only a high degree of inter-coder reliability but also an in-depth understanding of the data set across the author team. All interviews were recorded and transcribed and subsequently reviewed by the respective informants to check for consistency. Finally, we maintained a database with all data sources used in the analysis to increase transparency and reliability. A detailed overview is presented in **Appendix B**.

### ***2.3.3 Data analysis***

As recommended by Barratt et al. (2011) and Miles and Huberman (1994), data coding and analysis activities took place in parallel with data collection. Notes from the pilot interviews and observations, as well as archival data collected during the exploratory research stage, were assessed and discussed by the lead researcher and the second author to uncover interesting topics in the areas of digital technologies, contract management and maintenance at the case organisations. This helped in selecting the four cases and setting up the subsequent in-depth case research stage. Interview transcripts, contracts and archival data sources collected during the in-depth case research stage were subsequently coded using the data analysis software Atlas.ti.

Before we started the coding process, we identified several provisional themes (i.e. "data acquisition", "data transformation", "contractual governance" and "relational governance") from our literature review to guide our coding. As such, we ensured a clear link to prior literature, while providing flexibility to incorporate emerging themes such as "data needs", "registration of data", "bonus", "penalty" and "supplier behaviour" (i.e. open coding; Miles & Huberman, 1994). To assure the quality of the coding process, the lead researcher and the second author jointly discussed the initial open codes and established the initial coding structure, after which the lead researcher continued coding all transcripts and other documents. To enhance quality further, two research assistants each coded three transcripts from one of the cases, while the lead researcher coded all six interviews across both cases. Results between coders were compared to reduce potential biases or blindness to emerging constructs, with differences being resolved by trying to reconcile differing interpretations. For example, the codes "supplier attitude" and "supplier behaviour" were reconciled under the label "supplier behaviour". The results of this step were subsequently verified with the second author. Codes that could not be reconciled were critically evaluated by the lead researcher and the second author for their relevance (e.g. the code "replaceability of assets" was considered less relevant as it did not relate to information processing or governance; the code "maturity of system", which refers to asset management systems, was deemed relevant because it relates to information processing). In the end, 49 unique codes were identified.

Subsequently, the open codes were grouped into higher-order categories (e.g. "contract design" and "incentive schemes") using axial coding procedures. This resulted in ten second order codes capturing one or several first-order codes. Finally, the second-order codes were related to the four main concepts under study: "data gathering and sharing", "data transformation", "contractual governance" and "relational governance". The resulting final coding structure (see **Appendix C**) was used to analyse the remaining interviews, observations, contract documents and the archival data.

## 2.4 Within-case analysis: information processing in public–private relationships

This section presents the within-case analyses. The analyses outline first how DT affected the relationships in focus and then presents data on how the organisations managed their information-processing activities using both governance mechanisms.

### *2.4.1 Digital transformation in the public–private relationships at Road*

The two public–private relationships at Road included pilot projects as part of an organisation-wide digitalisation programme called "Vital Assets". In the past, Road's maintenance decision-making relied on an OEM's average life-cycle estimations and visual inspections (by Road or their private supplier). Usually, this resulted in maintenance taking place either too early or too late (e.g. a sluice door used to be maintained according to a predefined schedule or upon failure). As a result, Road's assets were either unnecessarily unavailable (because assets were being maintained while still working properly) or unexpectedly failing and causing potentially dangerous situations. Introducing sensors and advanced data analytics allowed combining sensor-generated data with data from Road's SCADA (a computerised control system used to operate assets) and asset management systems for better condition monitoring. Presenting the resulting information in a dashboard subsequently helped asset managers to handle assets more efficiently and suppliers to make more informed maintenance decisions that improved asset availability and user safety. For example, combining SCADA data on the sluice door movements with electricity usage of the door's hydraulic system provided valuable insights: "*You can see the failure and you also know what the failure is*" (Asset Specialist 1, Road B).

Having up-to-date information about their assets was essential as interviewees indicated that Road, being an executive agency of the Dutch government, had certain "extended responsibilities", meaning that they would always remain responsible for the availability and safety of their infrastructural network. Even with private suppliers maintaining the network's assets, Road should always keep itself informed about the state of the assets (e.g. to determine whether these are still safe enough to be used by the public). Road could not just point at the supplier in case a failure occurred: "*If a supplier does something wrong, you can hold it against them. However, if the failure significantly hampers operations, then Road is ultimately responsible*" (Advisor 1, Road A). Additionally, Road was obliged to work as transparently as possible as they were accountable to the government and to the public for the actions taken. As such, they required not only basic data about performed maintenance activities, but also detailed data that could help prove that assets were safe enough to be used. The "Vital Assets" programme created awareness that Road needed to keep up with the technological developments that were changing the way maintenance was being performed. Moreover, instead of trying to "reinvent the wheel", they acknowledged that capabilities and knowledge resided with their supplier. As such, they opted for developing collaborative relationships with their suppliers and changed the contracts accordingly: "*In our contracts we want to organise a different way of collaboration in the area of smart maintenance, including a different way of rewarding [suppliers] to avoid unnecessary costs and to share knowledge and data*" (Towards a vital infra sector, p. 40).

With the "Vital Assets" programme Road developed an organisation-wide vision (captured in the "Vision on Vital Assets" document) with respect to how they should address the ongoing digital transformation that, among other things, enabled smart maintenance and management. Road viewed digital transformation to be an important element of their competitive environment and considered themselves to be at a crossroad: "*It is expected that the sector will develop itself further, with or without Road. Even if Road does nothing, assets will become increasingly smarter. A lot is already happening in this area without us being aware of it*" (Vision on Vital Assets, p. 3). Furthermore, Road acknowledged that they lacked the capabilities to implement digital technologies successfully, as for years they had increasingly been passing on responsibilities to their suppliers. Under this "market unless" principle as they called it, Road limited themselves to coordinating maintenance processes and refrained from requiring detailed information about their assets and maintenance performed. Suppliers, as a result, became fully responsible for assessing the actual states of assets and planning maintenance activities accordingly, and Road lost a significant part of their technical knowledge: "*When we adopted the 'market unless' principle, it* [technological knowledge] *significantly disappeared at several places* [regional asset management departments]" (Contract Manager, Road A). As suppliers became more knowledgeable about Road's assets, Road had become increasingly dependent on them for asset-related information as well as interpretation of that information, that is, "*a possible dependence on the supplier who supplies data*" and "*a possible dependence on the supplier that performs data analyses*" (Vision on Vital Assets in relation to procurement, p. 3). To reduce these dependencies and return to being a knowledgeable partner, Road decided to become more actively involved with their suppliers and with maintenance activities: "*Now we see possibilities to build it* [being a knowledgeable partner] *up again. It is no surprise that programmes such as 'Vital Assets' triggered that old need*" (Contract Manager, Road A). As a result, collaboration with private suppliers became a strong pillar in the Vital Assets programme and the pilots.

Road A concerned a sluice that is a vital node in an important waterway corridor connecting the Netherlands with Germany and a large water pump that regulates the water levels for several eastern provinces in the Netherlands. Road A invested some of the maintenance budget in sensors to measure sluice door corrosion rates and the stretching of the chains moving the doors (Project plan: Vital Assets – Pilot Road A, p. 9). The sensor data allowed the supplier to verify their degradation models and could also be combined with SCADA data to improve asset maintenance. Road B concerned a sluice in a water way corridor that acts as a gateway between the North Sea and the Dutch/European hinterland and a large water pump that regulates water levels. Road B invested in sensors that monitored the health of the hydraulic system that moves the sluice doors (Project plan: Vital Assets – Pilot Road B, p. 9). The private maintenance supplier did not contribute to this investment but was closely involved in decision-making as they were mounting the sensors to the assets and were, next to the regional asset management team, a main user of the data.

Although both cases belonged to the same pilot project, closer inspection revealed regional differences in the levels of information asymmetry experienced. For example, while Road B found themselves confronted with issues with automated data transfer, Road A had no such problems. As a result, Road A was more able to access data and had relatively less information uncertainty than Road B. On the other hand, Road A had more difficulties with determining their information needs than Road B, leaving Road B with relatively less information equivocality. A selection of key evidence across both cases is shown in **Tables 2.3** and **Table 2.4**, which is referred to throughout the text using numbering (e.g. [3]).

**Table 2.3** Findings and key quotes from Road A

| **Road A** | |
|---|---|
| *Uncertainty* | • In order to access needed data, Road A aimed to play a central role in data gathering:<br>[1] "*Road ultimately owns the objects. I think it is good if Road obtains and manages data itself*" – Data Scientist 1.<br>[2] "*We are also looking for a link with our asset management system, which the supplier mainly works in*" – Asset Manager 2.<br>• Road A experienced difficulties with respect to determining the exact data they needed from their suppliers:<br>[3] "*That* [the availability of data] *differs per object. Usually, no explicit agreements were made about this in the past*" – Data Scientist 1. |

| | | |
|---|---|---|
| *Equivocality* | • Although Rail A possessed relevant data, their employees did not know their information needs and thus how the data should be transferred:<br>[4] "*The biggest challenge lies in determining the information needs. What is the relevant information that we need for the various processes we have?*" – Asset Manager 1.<br>[5] "*It would help if we had someone who acts as a customer, who explains how we can help him and what exactly he needs*" – Data Scientist 1.<br>• To make sense of data, Road A relied on their supplier's input:<br>[6] "*My dashboard indicates action is required within three months. 'Do you have the same experience? Does this pump show you anything that something is wrong?' You will always need each other with respect to this*" – Asset Manager 2. | |
| | ***Contractual Governance*** | ***Relational Governance*** |
| *Information Acquisition* | • Contracts stipulated that Road owns the data and that suppliers must share relevant data (i.e. control):<br>[7] "W*e have 1 main objective. We call it 'making the ABC' of our contract area. Improve the quality of documents and data*" – Asset Manager 2.<br>[8] "*The supplier must deliver area data once maintenance is completed, so that Road can perform proper management of its area*" – Contract (Annex 3, page 45).<br>• Contract prohibited (future) data sharing with other parties (control):<br>[9] "*But we want to be able to pass that data on to the next supplier*" – Asset Manager 1.<br>• Supplier takes advantage of vague agreements:<br>[10] "*The supplier tries to limit efforts as much as possible. They simply think: 'I do not really have to do that, because the contract does not exactly detail what I have to do'*" – Asset Manager 1. | • Road A's many requests for data led the supplier to think that Road A wanted to govern the maintenance activities the supplier was responsible for:<br>[11] "*There is friction between the supplier and Road. Suppliers find it strange that we want to know a lot and they say: you have us to manage that, why do you want to govern that?*" – Advisor 1.<br>• Trust was needed to ensure a supplier is not reluctant to share data:<br>[12] "*I think that it is mainly a matter of creating good connections and agreeing on what you are going to do*" – Data Scientist 1.<br>[13] "*Interpersonal aspects and acceptance of each other's qualities play an important role. We must trust and strengthen each other*" – 'The Market Vision' document (page 7). |
| *Information Transformation* | • Basic transformation activities were requested from suppliers through the contract:<br>[14] "*The supplier must provide a progress report. This is used to determine what the performance of the supplier has been*" – Contract Manager 1.<br>• Redesign of contract required to better support knowledge sharing:<br>[15] "*In our contracts, we want to organise a different way of rewarding* [suppliers] *in order to prevent unnecessary costs (including the use of capacity) and to support the sharing of knowledge and data*" – 'Towards a vital sector' document (page 40). | • Collaboration and common goals ensured most information was actually unlocked and interpreted in the same way:<br>[16] "*What I would also like to see is that market parties realise that by jointly working on this type of information, they can also organise maintenance process much more efficiently*" – Asset Manager 1.<br>[17] "*I want to discuss this with the supplier, so not simply supply the data and then have to rely entirely on the analysis that is being made.* […] *I would like to do at least some of those processes together, to avoid discussion about the used data*" – Asset Manager 1. |

*2.4.1.1 Information processing activities at Road A*

Data gathering at Road A entailed manually registering results of planned inspections or causes of unexpected failures in Road's asset management system [1]. Additionally, it included coordinating the process of setting up a direct connection with the supplier's asset management system to enable seamless data sharing as indicated by the interviewees [2]. However, interviewees also suggested, "*no explicit agreements were made*" about the data that suppliers should gather and subsequently supply to Road A, as Road A's team did not exactly know what they needed [3]. Road A therefore experienced incomplete data sets and hence rather extensive information uncertainty. Transforming data into information, on the other hand, was found to be complex and interviews with several team members showed that the team struggled in determining their information requirements [4, 5]. For example, the team did not know which behaviours of their assets were abnormal and indicated pending failures, nor what information they needed about these behaviours to predict future maintenance needs. Support from and close cooperation with the private supplier were needed to ensure that collected data were complete. The close relationship also included performing joint interpretation and transformation activities. For example, in order to develop key indicators for the performance dashboards, Asset Manager 2 set out to interpret the information shown by the dashboard jointly with his counterparts at the supplier: "*You will always need each other with respect to this*" [6]. As a result, information was less messy and information equivocality was relatively limited.

*2.4.1.2 Contractual and relational governance at Road A*

An annex of the contract specified that "*the supplier must deliver area data once maintenance is completed*" (i.e. control) and share it with Road's regional asset management team "*so that Road can properly manage* [the assets in] *its area*" [7, 8] (i.e. coordination). As the contract excerpts show, data-sharing clauses were not very precise as they referred to broader tasks (e.g. while the task "addressing failures" involved sharing data about the cause of failure and maintenance activities performed, what data was needed was not explicitly mentioned). Moreover, the contract failed to underline the importance of additional data that Road A needed to report on the degree to which they fulfil their public tasks (i.e. availability and safety of assets). The interviews confirmed the lack of explicit contractual agreements on data sharing [3] and explained that this made it difficult for Road to obtain the data they actually needed. The lack of understanding regarding what data was needed and why provided insufficient guidance and incentives for the suppliers to put in the efforts that Road A expected from them [10]. With respect to transformation, interviewees referred to a "progress report", mentioned in the contract, implying a requirement for the supplier to transform data [14]. This progress report typically contained information on the assets' health and on maintenance activities performed. No further evidence was found regarding contractually required information transformation activities. A plausible explanation was provided by the interviewees who indicated that it was difficult for the team to identify what information they needed and what the supplier should contribute [4, 5]. This then inhibited developing specific contractual agreements. In parallel, an internal report described the need to redesign the current contract and incentive scheme to support knowledge sharing between Road A and their private suppliers [15].

Interviews with Road A's regional asset management team and internal documents indicated that building a trusting relationship was expected to foster shared behavioural expectations and motivate the supplier to gather and share data they seemed hesitant to share, despite the contractual incentives in place [11, 12, 13]. For example, while the supplier aimed to maximise its value from the contract by performing a lot of maintenance activities, Road A aimed for the supplier to go beyond mere profits and become interested in the condition of the assets and start to understand the importance of sharing data: "*You want them*[private supplier] *to be pro-active and act as if they actually owned the assets in our area. That they inform us about what is happening and what should be done*" (Asset Manager 1). To facilitate information transformation activities, establishing a common goal furthermore fostered the development of shared behavioural expectations [16]. For example, interviewees described that instead of passively supplying data to suppliers so that they can verify their asset degradation models, the team aimed to analyse at least part of the data collaboratively, thus seeking to enhance both parties' understanding of maintenance needs [17]. Asset Manager 1 pointed out that this is vital "*to avoid discussion about the used data*". Stated differently, collaboratively interpreting the information derived from analytical models helped to reduce individual biases and to avoid the situation where Road A would become dependent on the private supplier to interpret information: "*You have to look out for the situation where the supplier gets the raw data and modifies it. The next could be: 'Look Road, this is interesting for you' and that they try to sell that information back to us*" (Advisor 1). Establishing a common goal (i.e. more efficiently organised maintenance) motivated both parties to invest in the collaborative information transformation activities required to achieve this goal and helped the private suppliers to maintain assets in a timely and resource efficient way while helping Road A to increase asset availability.

#### *2.4.1.3 Summary case Road A*

The findings above suggest that Road A experienced extensive information uncertainty due to difficulties in determining their exact data needs and incomplete data sets regarding their assets. A combination of imprecise contractual control and coordination clauses described mainly how suppliers were supposed to share data, as opposed to which data needed to be shared. As such, for the private supplier it was not clear what data needed to be shared. Road A tried to support their contractual agreements by building a collaborative relationship and establishing bilateral expectations as to motivate the supplier to go beyond the "letter of the contract" and focus on the "bigger societal gains" rather than merely their own goals. This included the supplier assisting Road A with their public task to offer reliable and safe infrastructures with a high level of availability. However, these relational governance mechanisms were not fully effective in complementing incomplete contract terms, resulting in only limited increases in suppliers' understanding of what data to gather and share and in Road A still missing some of the data they require.

Road A experienced limited information equivocality as they worked closely together with the private supplier to perform transformation activities effectively. As the contract only specified the requirement of progress reports to be prepared by the private supplier, joint transformation activities strongly relied on relational governance mechanisms, that is, creating a trusting and collaborative relationship and establishing common goals.

**Table 2.4** Findings and key quotes from Road B

| **Road B** | | |
|---|---|---|
| *Uncertainty* | • Road B did not receive all required information due to wrong configurations in the connection between their own system and their supplier's system and because of misunderstandings about what data were actually needed:<br>[18] "*Not enough data are being sent and we still miss a lot of things. We are working very hard on fixing this*" – Configuration Manager 1.<br>[19] "*At the beginning they filled out too little information.* […] *The data should provide us with enough information, and not just things like 'finished' and 'button pressed'*" – Contract Manager 2. | |
| *Equivocality* | • The data in Road B's database did not have the correct data format and the extended time it takes to fix the data format rendered the data useless:<br>[20] "*The information is described in the description, but that is not in the form of data. If you want to analyse that, you have to search in the text boxes and order that first*" – Asset Manager 3.<br>[21] "*It is not real-time information due to the large time difference. It is not reliable, and it is not correct anymore*" – Asset Manager 3.<br>• Road B's system could not handle all types of file formats they received:<br>[22] "*We are twenty years behind with this within Road. We 'flatten' everything to 2D* [while supplier sends 3D]. […] *We do not have the facilities to embrace 3D. You understand of course that we lose a lot of data*" – Asset Manager 3. | |
| | ***Contractual Governance*** | ***Relational Governance*** |
| *Information Acquisition* | • Contracts stipulated that Road owned the data. Suppliers had to share to avoid penalties (i.e. control); penalties were found to be ineffective:<br>[23] "*If the supplier does not want to transfer it, the supplier does not meet the contract requirements. Then you get a penalty or even a breach of contract*" – Configuration Manager 1.<br>[24] "*They do get a penalty, but that is sometimes much less than what they can save if they do nothing*" – Asset Specialist 1.<br>• Contracts also included the requirement to connect data systems (control):<br>[25] "*We have had it* [requirement to connect systems] *included in the performance contract, which will have it* [data from supplier] *transferred automatically.*" – Configuration Manager 1.<br>• Agreements about what to share were vague and inconsistent (coordination):<br>[26] "*What they have to fill out is in the agreement. But these agreements are based on a very old system*" – Configuration Manager 1. | • Suppliers seemed hesitant to share all maintenance data:<br>[27] "*But they do not put all their cards on the table. It is true.*" – Configuration Manager 1.<br>• Road invested in open communication and tried to refrain from penalising suppliers immediately to avoid a blaming game:<br>[28] "*We are open and transparent regarding the needed and available information*" – 'The Market Vision' document (page 6).<br>[29] "*What does the supplier need and what do we need? That is how we collaborate. It is no longer about point fingers to each other*" – Configuration Manager 1.<br>[30] "*Our goal now is to work more with the market. Previously, we had a more steering role*" – Contract Manager 2.<br>• Road sought to enhance current relationships through two-way sharing:<br>[31] "*We are not only knowledge seekers, but also knowledge bearers. So we can also return knowledge to them*" – Configuration Manager 1. |
| *Information Transformation* | • Misaligned contract agreements hampered transformation:<br>[32] "*The biggest problem is that internal information needs, and contract requirements are not working* | • Road sought collaboration to receive all information:<br>[34] "*That is our pilot. That they process all malfunctions directly in our system"* – Asset Manager 3. |

| | | |
|---|---|---|
| | *together. If you have specified your internal information needs, the contract should actually be accommodating to it*" – Configuration Manager 1.<br>• Contract stipulated that recurring meetings should have been organised to jointly interpret and transform information:<br>[33] "*The Principal organises one or more meetings per period to discuss the evaluation reports"* – Contract (Specification 1, page 38). | [35] "*We look at the asset in the field. Is it properly maintained, and does it* [information in the system] *match the current state of the asset? And that you then assess together*" – Contract Manager 2.<br>• Closer collaboration was also needed to induce flexibility and motivate parties to look beyond contract agreements:<br>[36] "*Not only our contracts have to change, also our behaviours and attitudes. It is not the same as five or more years ago.* […] *You have to be flexible; you cannot afford to be rigid anymore*" – Contract Manager 2. |

### *2.4.1.4 Information processing activities at Road B*

Data gathering at Road B entailed data on results of planned inspections and causes of unexpected failures. However, in contrast to Road A, Road B's supplier only needed to register these data in their own asset management system due to the direct link between their and Road B's supplier's asset management systems. Despite this direct link, certain fields in Road's databases were nevertheless left empty because the technical configuration did not allow seamless data transfer [18]. As a result, Road B experienced extensive information uncertainty (when compared to Road A). Moreover, information uncertainty resulted from differing interpretations of data completeness between the private supplier and Road B. For example, while the supplier believed that a short description of the activity performed was enough ("*button pressed*"), Road B also expected some contextual information (e.g. the cause of the failure) [19] and thus required additional data from the supplier. Information transformation activities also proved to be complex for Road B, as the data they received from the supplier was provided in the wrong format [20] and hence messy. For example, while Road B specified specific fields in a standard form to capture information (e.g. number of hours worked, type of failure), the supplier simply put all this information into the "description" field and left the other fields in the form blank. This required Road B to reorganise the supplier's data, leading to long transformation lead times and information being obsolete before it was even used [21]. Interviewees furthermore mentioned that Road B's system could not manage 3D files, forcing the team to convert these into 2D files and leading to a loss of data [22]. Road B acknowledged that reducing the messiness of the supplier's data required flexibility to deviate from the initial agreements, as these turned out to not be specific enough.

### *2.4.1.5 Contractual and relational governance at Road B*

Road B's contract had the same data-sharing clauses as found in Road A's contract, that is, control clauses to ensure data gathering and coordination clauses to govern data sharing. The contract also specified the direct link between the asset management systems of both partners, including which data fields should be connected to ensure correct and complete data [25]. The interviewees, however, indicated that the asset management system had been upgraded after the start of the contract, while the related contract clauses referred to a prior version of system

[26]. Hence, the direct link could not be established. Contract clauses related to information transformation activities were sparsely present as interviewees indicated that specifying information requirements in contracts was not easy: "*The biggest problem is that internal information needs, and contract requirements are not working together*" [32]. Road B considered clauses to "set things in stone", while flexibility was actually needed to deal with changing information needs: "*You have to be flexible; you cannot afford to be rigid anymore*" (Contract Manager 2). For example, following a major incident at one of their sluices, Road B needed additional information to demonstrate that users of the sluice had not been endangered and that sufficient actions had been taken to avoid similar issues in the future. As such situations were difficult to forecast, the contract had to allow for requiring additional information from the supplier. Lastly, the specification document of Road B's contract included clauses requiring the team to organise recurring performance evaluation meetings with the supplier [33] but did not contain any specific information on meeting content and parties' roles. As a result, Road B had to rely on other governance mechanisms to determine the roles of the parties involved and to ensure that the right information is obtained.

To promote data sharing, the supplier was penalised in case they did not deliver, but this penalty was found to be insufficient to deter divergent behaviour: "*They do get a penalty, but that was sometimes much less than what they saved if they did nothing*" (Asset Manager 3). Several members of Road B's regional asset management team however indicated to refrain from penalising suppliers as much as possible [29], as this might make the supplier hesitant to share data in the future [27]. Contract Manager 2 indicated that the team focussed instead on collaboration ("*Our goal is to collaborate with the market*"), as to build a trusting relationship and to enhance information sharing [31]. By showing that information was needed for proper asset management rather than for penalising the supplier, and that flexibility was required to respond to changing information needs [36], Road B hoped to move the supplier away from strictly following contractual agreements: "*A supplier always checks: 'what is in it for me?' They will not provide an additional service that is not prescribed in the contract*" (Contract Manager 2). Investing in collaboration also paid off with respect to Road B's information transformation activities, because the collaboration involved establishing a common goal. Contract Manager 2, for example, mentioned that Road B and the supplier started to assess data of the assets jointly [35], which helped to combine expertise and allowed for developing a shared understanding.

#### *2.4.1.6 Summary case Road B*

Overall, Road B experienced extensive information uncertainty. Road B's difficulties with determining their data needs resulted in imprecise and ineffective clauses to control access to data, while basing clauses to coordinate the data transfer (i.e. the how of data sharing) on wrong system configurations led to incomplete data sets regarding their assets. Moreover, incentive schemes appeared to be ineffective which led to additional issues with data sharing. Road B also invested substantial time in relational mechanisms including building a collaborative and trusting relationship with their supplier, which fostered open information sharing and provided flexibility to deal with gaps in contracts. Similar to Road A, Road B also experienced that relational governance was insufficient in complementing incomplete and poorly specified contractual mechanisms, causing Road B to miss data still.

Road B showed that it experienced limited information equivocality, as Road B was able to leverage their supplier's expertise for the purpose of transformation activities. The joint transformation activities were mainly supported by relational governance (including collaborative relationships, common goals and trust), while contractual governance was sparsely used to outline the basics of the joint activities (e.g. having recurring meetings).

### *2.4.2 Digital transformation in the public–private relationships at Rail*

For decades, Rail has relied on data collected by specialised inspection trains, equipped with sensors and cameras, to manage and maintain their assets. Inspection trains, however, only scan the rail network a couple of times a year, and hence, data could only be used to take preventive maintenance decisions. In order to obtain real-time data, Rail invested in sensors, mounted to the rail network and partnered up with a semi-public train operator to obtain more continuous data streams by fitting 14 passenger trains with sensors that provided Rail with daily reports from which potential "harbingers" of failures could be detected (Management Plan 2019, pp. 19–20). Furthermore, a Data Lab (established in 2017) combined different data flows and developed failure prediction algorithms. These two developments enabled Rail to "*use data in a smart way, which means that we, for example, together with suppliers prevent failures and obtain earlier insights into when an object needs to be replaced*" (Management Plan 2018, p. 39) and to manage their network: "*Without data, you have no control and no oversight. We need that data to know how our assets perform and how it affects train movements*" (Project Manager 1).

Similar to Road, Rail also faced an "extended responsibility" with respect to the availability and safety of the rail infrastructure and hence required timely and accurate information about their assets. When maintenance activities took too long or were performed too late (leading to extended periods of non-availability of railway segments and possibly to unsafe situations), both the public and the Dutch government would hold Rail accountable and not the private maintenance suppliers. As a result, Rail A's asset management team preferred to exert more control in the relationship with their private supplier: "*We have to build in even more clauses* [in the contract] *where we can take more control. This is because we are the ones who, if things go wrong, are on the evening news again and not the supplier*" (Asset Manager, Rail A). Rail B illustrated the difference between their goals and the supplier's as follows: "*The supplier has commercial interests; besides that they have heart for the railways and enjoy performing maintenance. But in the end, the supplier also looks at what they can earn with it. Rail has a different assignment. We have to keep the rail track available for carriers and travellers*" (Asset Manager, Rail B). While suppliers were satisfied with data demonstrating that they had completed their job (e.g. descriptions of failures and measures taken), both Rail A and B required additional data about the impact of maintenance on availability (e.g. length of the activity, potential differences between expected maintenance time vs actual time, etc.) to safeguard societal interests (e.g. a safe rail network).

In order to capitalise on the opportunities provided by DT, Rail took the lead in implementing digital technologies, rather than relying on suppliers or collaborating with them. Rail believed that in their specific sector they were in the best position to take the lead as they had access to more data than individual private suppliers did: "*A supplier only has data from their own area, and thus has far fewer data points than we do. So, we are the only ones in a* *position to do these predictions*" (Data Scientist). Embracing digital technologies enabled Rail to predict potential problems regarding network availability using data from their national database, for example, regarding heating elements in railroad switches: "*We built sensors in the tracks to measure the temperature of the railroad to avoid switches being flooded with snow, because otherwise you have an availability problem*" (Asset Manager, Rail B). Although Rail led the implementation of digital technologies, they still required specialised input from their private suppliers: "*As an asset manager, I would very much like to know: 'is my infrastructure deteriorating in the way we expect? And do the maintenance activities performed by a supplier benefit that pattern or does it deteriorate too much?'*" (Asset Manager 4). Private suppliers' expertise in maintenance helped Rail to understand their assets better, to smarten the actual maintenance activities and to achieve efficiency gains. Despite significant investments in digital technologies, Rail's technicians (who had been trained in the management and maintenance of technical systems) continued to be largely unfamiliar with the use of data and their potential. This resulted in a low adoption rate of data in asset management processes, and suppliers being only sparsely allowed to use their own digital technologies to smarten the maintenance of the area they were responsible for: "*I think we are still at a stage where we are slowing down the suppliers. This stems from our historical conservatism*" (Asset Manager 5, Rail A).

Rail A focussed on the north-western part of the Netherlands and included the management and maintenance of the railroad network including a pivotal central train station. A major failure at that train station would cause the majority of the Dutch timetables to be disrupted. Rail B mainly worked on railroad networks in the south-eastern part of the Netherlands that connected several major cities. Rail had centralised its maintenance service tendering process and aimed to ensure that regional asset management teams acted in a uniform way. However, closer examination of the cases revealed regional differences with respect to levels of information uncertainty and equivocality experienced and the mix of contractual and relational governance mechanisms deployed. These differences are discussed in the next sections. The evidence referred to has been captured in **Table 2.5** and **Table 2.6**.

**Table 2.5** Findings and key quotes from Rail A

| **Rail A** | |
|---|---|
| *Uncertainty* | • Rail A and their supplier jointly populated Rail's A asset management system with data:<br>[37] *"That is a system where we just share the data. They* [the supplier] *see everything in it, but I see that too*" – Asset Manager 6.<br>• The supplier also collected data about their own activities and shared data with Rail A upon request:<br>[38] "W*e want those suppliers to track and record this* [data performance maintenance activities]*, and when we say 'now I want to see it' you have to deliver it*" – Asset Manager 5.<br>• There were some concerns that the supplier did not share all data they had, and that the quality of data was not always of appropriate quality:<br>[39] "*We have experienced this every once in a while, that certain information is not provided, is not correct, is not complete or does not meet the requirements*" – Asset Manager 5. |

| | | |
|---|---|---|
| *Equivocality* | • A large part of the data in Rail A's database did not correspond to the actual situation at Rail A's assets and, hence, should have been cleaned:<br>[40] "*In the past, this* [data cleaning] *has not yet been done correctly at Rail. There are a kind of improvement steps going on now. However, you are not completely up to date in your database with respect to what is actually outside at the moment*" – Asset Manager 6.<br>• Even though they had the data, Rail A did not know what they wanted to do with the data:<br>[41] "*The question is: what will you do with it? Because yes, data are provided, but if you do not do anything else, you still do not have a KPI for your senior management and for your team*" – Contract Manager 4. | |
| | ***Contractual Governance*** | ***Relational Governance*** |
| *Information Acquisition* | • Rail specified clauses with respect to data usage (i.e. control):<br>[42] "*There is a certain clause in the PBC contract that clearly states that this and this must be reported by* [supplier] *to* [Rail]*, and then* [Rail] *must act on it*" – Asset Manager 6.<br>[43] "*It is stated there that every renovation that takes place or anything maintenance-related that is of importance for this equipment, that they must share it with us. The contract just states that they* [maintenance suppliers] *are the ones who are responsible*" – Asset Manager 6.<br>• Contract enforcement (i.e. control) was crucial, but had been deteriorating over time:<br>[44] "*Enforcement needs to be tightened, as the department that used to enforce has been cut by 50%"* – Asset Manager 6.<br>[45] "*Then the supplier's 'beeping system' comes around. I do not deliver, and I will see if I hear something*" –Contract Manager 4.<br>[46] "*Suppliers do not do as we have contracted. Sometimes they 'forget' to deliver* [data] *and keep quiet about it until we ask for it*" – Contract Manager 4. | • Afraid of the consequences (e.g. penalties in case data showed that the supplier did not achieve all contract requirements), Rail A's supplier aimed to share the minimal accepted amount of data:<br>[47] "*Data about maintenance activities is something the supplier makes a fuss about, so you have to ask for it all the time. They prefer to keep this a bit foggy*" – Asset Manager 6.<br>[48] "*Certain things that might put the organisation in a bad, or in a less good, daylight… the supplier tries to cover this a bit*" – Asset Manager 6.<br>• Transparency may lead to non-compliance with tender regulations and thus Rail and their supplier refrained from sharing all data:<br>[49] "*Transparency is not desirable. Maybe not from* [Rail] *either, but I am not sure about this*" – Contract Manager 4. |
| *Information Transformation* | • Rail A required transformed information from suppliers and strictly controlled everything they received:<br>[50] "*They have to demonstrate on a monthly basis, by means of data, that the requirements we set in the contract, that they meet them*" – Asset Manager 5.<br>[51] "*You also have to have strict control over everything that you receive. We are now trying to get more employees available to do the checks, because that is simply very important.* [We need] *to ensure that* | • Rail A distrusted any information shared by the supplier's higher-level managers:<br>[52] "*The management of such a supplier are sent to bring a certain message. They try to make things more beautiful than that they are*" – Asset Manager 6.<br>• Open communication with the supplier's operational level employees was established which led to additional information transformation:<br>[53] "*You have the technical men that try to perform their work in a way that works best for the railroad tracks. So* |

| | | |
|---|---|---|
| | *the IT guys have sufficient capacity to continue to do this well*" – Asset Manager 6. | *sometimes they say something that they perhaps should not have said*" – Asset Manager 6.<br>• Rail A refrained from establishing a common goal with the supplier to avoid non-compliance with tender regulations.<br>[54] "*I fully understand what is behind it, the compliancy issue. It just makes it very difficult for us to achieve a common goal with our supplier in a way that we would like"* – Asset Manager 6. |

### *2.4.2.1 Information processing activities at Rail A*

Both the regional asset management team and the supplier manually entered data into Rail's central asset management system [37]. These data helped with monitoring assets' conditions and the supplier's performance and allowed enriching the data Rail gathered themselves. The supplier was contractually required to collect data about their operational activities and to share that data with Rail upon request [38]. However, interviewees raised concerns about the private supplier's apparent reluctance to share data: "*Certain information is not provided, not correct, not complete, or does not meet the requirements*" [39]. Nevertheless, information uncertainty was relatively limited due to the extensive data-gathering activities performed by Rail A. Data transformation was generally performed by Rail A, but interviewees indicated challenges regarding the resources available to check and verify all supplier-provided data, which seemed uncleaned and incomplete [40]. As a result, the database looked messy and Rail A needed to perform structuring of the data, leading to a continuing discrepancy between the information in Rail A's systems and reality. Another challenge was that Rail A struggled to determine which data were crucial and how to use them [41]. Overall, Rail A faced rather extensive information equivocality.

### *2.4.2.2 Contractual and relational governance at Rail A*

The contract explicitly stipulated that the supplier should gather and share data on Rail A's assets [42, 43] (i.e. control). However, being short on capacity [44], the team was unable to check whether they received all data they required, which allowed the supplier to reduce efforts in areas that were not checked: "*Then the supplier's 'beeping system'* [acting only when the other party asks for something ('beeps')] *comes around: 'I do not deliver; and I will see if I hear something'*" (Contract Manager 4). Suppliers simply "forgot" to share gathered data when Rail A did not actively enforce the contractual agreements that stipulated data sharing [45, 46]. In order to manage data transformation activities, Asset Manager 5 indicated that he heavily relied on contractual control, with the contract stipulating that suppliers should transform maintenance and inspection data to information that demonstrates whether requirements have been met [50]. This again required Rail A to meticulously check the submission of transformation reports and their contents, which was unfeasible because of limited capacity [51].

Limited evidence was found regarding a systematic use of relational governance mechanisms in support of data gathering and sharing. In fact, rather than having a trusting relationship, interviewees indicated distrust between Rail A and their suppliers. Fearing consequences, Rail A's suppliers shared a minimal accepted amount of data (i.e. just showing enough to keep Rail A satisfied) [47] and even hid specific data that might put them in a bad daylight [48]. For example, when an inspection by the supplier revealed an issue at a specific asset that could easily be fixed, the supplier sometimes chose to fix it without reporting it to Rail A to avoid a potential penalty. While Contract Manager 4 argued that relational governance was not invoked in order to comply with European tendering regulations [49], the team did (at times) resort to relational governance mechanisms. For example, increasing collaboration and information sharing with the supplier's operational employees helped Asset Manager 6 to find out that the supplier's managers highlighted information that supported them in meeting contracted KPIs, while being less clear regarding information that was less favourable to their performance [52, 53]. Setting up joint information transformation activities through relational governance mechanisms was found to be challenging, however, because common goals and increased levels of collaboration could provide the current supplier with an advantage over competitors, which would be in conflict with tendering regulations [54].

*2.4.2.3 Summary case Rail A*

Rail A experienced limited information uncertainty due to their own extensive data-gathering activities and strong control over the data that were collected by their supplier. Control was exercised by having clear contractual agreements that indicated which data the supplier should collect and how data should be shared. Additionally, Rail A aimed to check actively the completeness and correctness of the data collected by the supplier. Staff shortages, however, prevented Rail A from checking all data, and consequently, their databases contained gaps. Relational governance was not developed as Rail A was afraid that too much collaboration and openness with the private supplier would violate EU tendering regulations. Instead, the strong focus on contractual control seemed to create distrust between Rail A and the private supplier even.

Rail A experienced extensive information equivocality as they performed most transformation activities themselves. The few transformation activities to be performed by the supplier were governed by contractual coordination clauses specifying which data needed to be transformed into what kind of information (i.e. what purposes the information would serve). As these clauses were not clear on how information would be further interpreted by both parties, the supplier presented information only selectively (to ensure that the supplier's own work was presented in the best possible light), which then required Rail A to actively check incoming information. Again, staff shortages prevented Rail A from conducting a complete and systematic check of all incoming information.

**Table 2.6** Findings and key quotes from Rail B

| **Rail B** | |
|---|---|
| *Uncertainty* | • Data about failures were directly entered into Rail B's asset management, both by their own employees as well as the supplier's employees: |

| | | |
|---|---|---|
| | [55] "*They do that, we use* [software package]. *It actually contains everything about such a failure. What happened, what they did about it*" – Asset Manager 7. | |
| *Equivocality* | • Rail B's employees tried to make sense of the data themselves but could not extract all information from the available data:<br>[56] "*I like the fact that we can now predict with data in advance which switches function and which switches do not, so that we can make adjustments*" – Asset Manager 8.<br>[57] *"I rely on data from the inspection train. It* [results from inspection train data] *is all good and we are doing pretty well in terms of failures. But I also do not have everything in sight and neither do the inspectors*" – Contract Manager 5.<br>• To assist transformation activities, Rail B's area manager reached out to the supplier at times:<br>[58] "*We have a lot of contact with each other, we look for solutions together, and I try to inform them in time when I see problems coming up*" – Asset Manager 7. | |
| | ***Contractual Governance*** | ***Relational Governance*** |
| *Information Acquisition* | • Rail B's contract stipulated that the supplier must share data upon request (i.e. control):<br>[59] "*If one of our inspectors has been outside and comes back with the message 'that does not look good', we* [Rail] *can request all their inspection reports*" – Asset Manager 8.<br>• Rail B's contract also described the role and responsibilities of the supplier (i.e. coordination):<br>[60] "*We prescribe what the standard is. The qualitative standard it* [assets and related data] *must meet and then they* [supplier] *are free to try to achieve this*" – Asset Manager 8.<br>• Rail became increasingly strict in enforcing their contracts (control):<br>[61] "*You can clearly see that Rail has also more strictly enforced these maintenance contracts in recent years*" – Contract Manager 5. | • Suppliers seemed hesitant to be completely transparent to Rail:<br>[62] "*But they* [supplier] *also see things outside that we* [Rail] *have not seen that they are not going to report. That is just how it works*" – Contract Manager 5.<br>• Rail B did not blindly enforce the contract and their penalties all the time, but aimed to keep the supplier's point of view in mind and informed them about the need of contractual agreements:<br>[63] "*I especially think deviations should not be used for all that is not good, because if you impose a deviation for everything that is incorrect, a supplier will be paid nothing*" – Contract Manager 5.<br>[64] "*We do not push the contract to the background. Of course it is important that you have a good relationship, but it is also important to clearly explain what the contract is for*" – Asset Manager 8. |
| *Information Transformation* | • Rail B required their supplier to transform data from their inspection rounds into information about assets' condition and how assets could best be maintained:<br>[65] "*Inspection reports, maintenance plans… we can request this on demand.*" – Asset Manager 8.<br>• Rail B checked all the information that was supplied by their supplier:<br>[66] "*It is about procedural matters, but also just whether the information is good*" –Contract Manager 5. | • Rail B aimed to invest in relation norms to foster open sharing of information and that motivated both parties "to go the extra mile", allowing flexible contract application:<br>[67] "*In other contract areas that have the same supplier, the teams are much stricter, but the collaboration is not going that well over there and there is a lot of hassle*" – Contract Manager 5.<br>[68] "*In any case, I like the fact that we have a good relationship with our* [maintenance] *supplier, which means that we get a lot of things done that do not happen in other regions. I think you will be better off with that in the end*" – Contract Manager 5. |

*2.4.2.4 Information processing activities at Rail B*

Similar to Rail A, Rail B used the central asset management system to store and share data regarding maintenance activities performed on assets and inspections: "*It actually contains everything about such a failure. What happened, what they did about it*." [55]. Additionally, Rail gathered data using sensors and inspection trains [56, 57]. This suggested that information-gathering activities were well developed, and that information uncertainty was relatively limited as Rail B received the required data. With respect to data transformation, Rail B relied heavily on data scientists in their Data Lab to, for instance, transform heat sensor data to predict possible freezing of railroad switches so that they could be serviced on time. However, Asset Manager 7 [58] stated that the supplier was involved in data transformation (e.g. jointly discussing performance deviations to understand better why performance was not as expected) because of limited internal resources and because inputs from the supplier were required to transform data. Considering the inputs required from the supplier, equivocality was relatively extensive.

*2.4.2.5 Contractual and relational governance at Rail B*

Contractual coordination mechanisms played a dominant role in motivating the supplier to gather and share data [59, 60], with Rail B enforcing the contractual agreements by exerting control [61]. More specifically, the regional asset management team regularly inspected their assets and occasionally (e.g. when assets were found to not have been properly maintained or when inconsistencies emerged between their database and reality) requested additional data to investigate what happened and to what extent the supplier was responsible [59]. Similar to Rail A, Rail B had not negotiated any specific contractual agreements with respect to transforming data, other than the transformations required to demonstrate contract compliance [65]. Instead, Rail B mostly relied on their own employees to perform transformation activities.

The regional asset management team felt that the supplier did not share all available data [62] and indicated that trust was limited. The team therefore opted for more flexible contract application, as to build a more trusting relationship: "*There has to be a bit of a balance in it* [enforcing penalties]*, you cannot address everything. But it* [managing incentives] *has to stay manageable*" (Contract Manager 5). Moreover, Rail B pursued openness by explaining the need for the contractual agreements [64], and how they would be applied, as to create shared behavioural expectations that could help in developing joint goals. By investing in relational norms (that acted as a reference guide on how both parties intended to collaborate with each other), the team could actively discuss and share information with the private supplier in support of the data transformation performed by Rail's employees and could motivate their supplier to go beyond the minimum requirements [63, 67, 68].

*2.4.2.6 Summary case Rail B*

Overall, Rail B experienced relatively limited information uncertainty as data sharing was effectively supported by contractual control clauses that clearly specified which data the supplier needed to collect and how they should be shared. Contractual enforcement was very strict, involving the checking of incoming data and inspecting the work suppliers performed on their assets. Because of this strict enforcement, Rail B initially experienced limited trust at the supplier. In response Rail B increased openness by explaining why data were needed and why Rail B was strict in applying the contract, but also sought to apply the contract in a more flexible way (e.g. by not directly penalising for a deviation by the supplier). Rail B thus applied relational governance to a limited extent to complement the contract.

Rail B experienced rather extensive information equivocality. As Rail B performed the majority of transformation activities themselves, the contract only included some coordination clauses that guided the transformation activities that the supplier needed to perform to demonstrate contract compliance. Rail B noted, however, that their own expertise was insufficient to effectively transform all data and hence resorted to relational governance, that is, implementing relational norms to ensure that Rail B could tap into the supplier's expertise for performing the transformations.

## 2.5 Cross-case analysis

This section presents the main findings from the cross-case analysis. The role of contractual governance in relation to information asymmetry is first analysed, followed by the role of relational governance in relation to information asymmetry. **Figure 2.1** illustrates the key concepts and their relationships as discussed in the cross-case analysis. It highlights that information gathering and sharing activities help address information uncertainty and that in IORs such activities are mainly supported by contractual mechanisms complemented with relational mechanisms. Information transformation activities help address information equivocality, and these activities are mainly supported by relational mechanisms complemented with contractual mechanisms.

### *2.5.1 The role of contractual governance in addressing information asymmetry*

Road A and B showed that ineffective contractual control and coordination caused issues with data-gathering activities, which in turn were associated with extensive information uncertainty. In contrast to the Road cases, both Rail A and B experienced limited uncertainty, as they were able to rely on effective contractual controls to manage their data gathering and sharing activities. As such, the cross-case findings demonstrated that information uncertainty was effectively addressed by using contractual control and coordination functions that allowed access to data collected at external parties. No evidence was found across the cases that contractual control and coordination could effectively be used to manage transformation activities and address information equivocality. In fact, Rail A and B experienced extensive equivocality while relying on contractual coordination to manage transformation activities, while Road A and B, which hardly relied on contractual governance, experienced limited equivocality.

Road's contracts required suppliers to share all data they collected regarding Road's assets and had incentive schemes tied to these requirements [8, 23, 24, 25]. Where Road A's contract contained provisions specifying how data should be shared, Road B's contract either lacked such provisions or contained provisions based on incorrect assumptions. Specific agreements indicating which data should be shared were lacking in both cases. Finally, both contracts

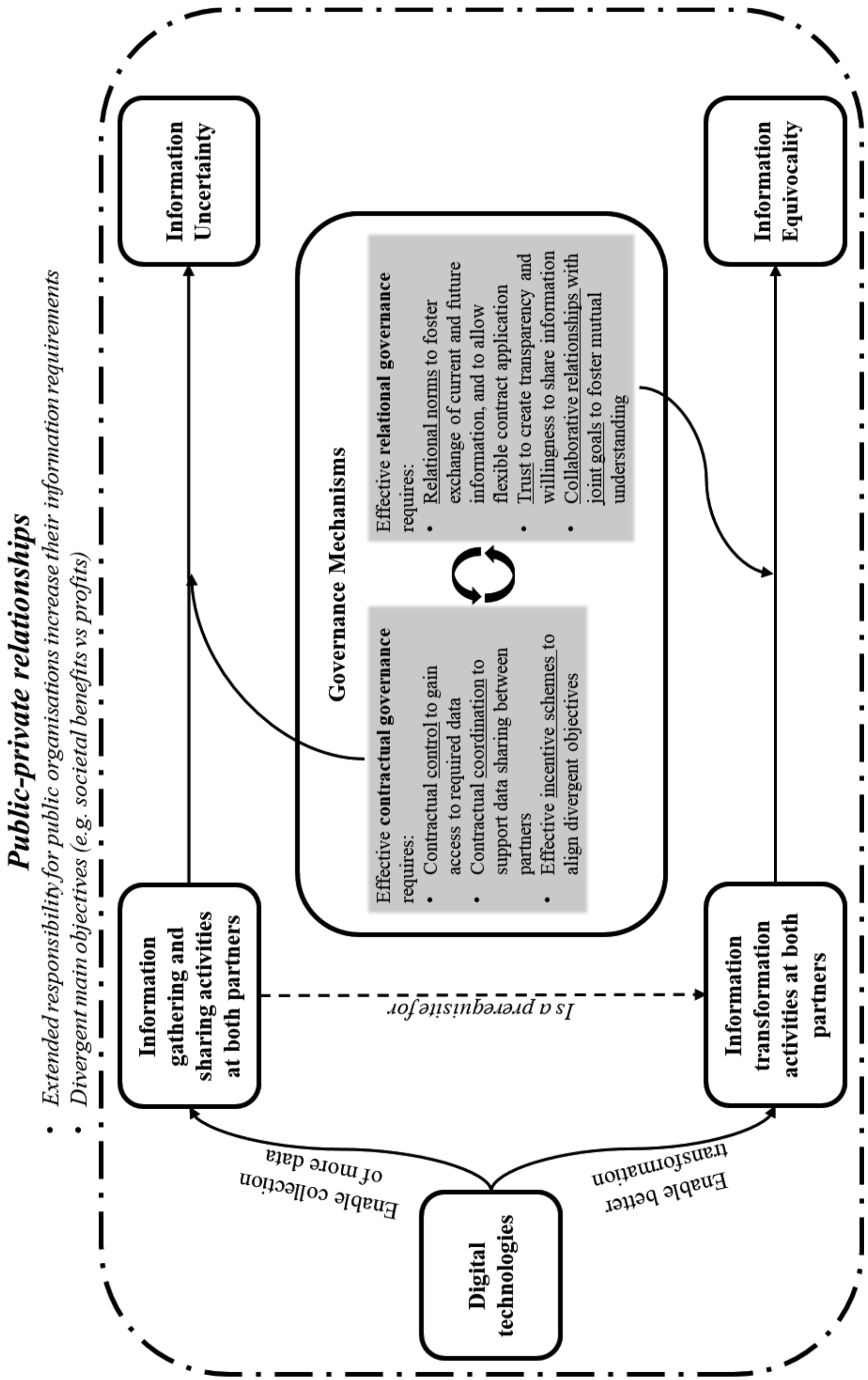


**Figure 2.1** The roles of contractual and relational governance mechanisms in managing information asymmetries

experienced issues with the designed incentive schemes since Road A's supplier preferred to pay the penalty rather than invest money to be able to meet contract requirements. While Road A expected their supplier to act as if they were the owner of the assets, which would lead them to maximise the value for society as a whole and thus actively gather and share information, the supplier (as a profit maximising private party) in that relationship aimed to maximise their profits by doing as little as possible, thereby underplaying societal benefits. Road B's supplier followed the contract to the letter, questioning each data request, fearing to be penalised as it also sought to maximise its own value. Together, the cross-case findings suggested that contracts could help in establishing processes related to data gathering and sharing, provided that sufficiently clear specifications have been developed and incentive schemes have been appropriately designed. Too much focus on control (e.g. rigidly enforcing penalties) might render contracts less efficient as evidenced by the recent shift at Road towards a more collaborative approach with respect to their suppliers: "*It is no longer about pointing fingers at each other*" (Configuration Manager 1, Road A). Rail's contracts stipulated which data suppliers should share [42, 43, 60], but Rail had difficulties in specifying data needs and capturing these needs in contract clauses. Incoming data were actively checked, and suppliers were penalised in case of non-compliance: "*Those incentives work immediately. If you hit them in their wallet, you immediately hit them hardest and they are sensitive to that*" (Asset Manager 6). This only worked, however, when contractual agreements were consistently enforced, as was the case for Rail A. Staff shortages inhibited Rail A to monitor all incoming data streams and check the completeness of data. This led to gaps in their database, as the supplier did typically not supply data that was not checked by Rail A. Rail B, on the other hand, did have sufficient resources to check all incoming data. This allowed them to enforce contracts better and to ensure that all data collected by the supplier was actually shared with Rail B.

Data transformation processes could not effectively be addressed using contractual control and coordination. Both contracts at Road required suppliers to periodically present progress reports by transforming inspection and maintenance data into asset condition information [14, 33]. Despite these provisions, both regional asset management teams felt they were not receiving what they really needed from the private supplier in terms of information. This inability to define information requirements by the public organisation inhibited capturing these requirements more explicitly in contracts [4, 32], causing the supplier to be confused about what data were required. Using the contract's control function ensured that some basic data transformation activities took place ("*the supplier must provide a progress report*", Contract Manager, Road A), but these did not necessarily address Road's information requirements. The coordination function was only sparsely used for the purpose of data transformation in both cases. The contracts outlined, for example, the basics of the collaboration by prescribing regular meetings and the attendance of both partners, but did not stipulate the specifics about, for example, which partner should perform what transformation. Rail A's contract, in contrast, had more elaborate clauses aimed at coordinating data transformation activities, including specifications of the information Rail A wanted to receive [50]. As the contract was not clear on how information would be interpreted or used by the public organisation, the private supplier tended to present information selectively according to their interests. Rail B's contract delegated few transformation activities to the supplier [65]. For the majority of data transformation activities, Rail B relied on internal resources and capabilities.

In sum, both contractual control and coordination were found to be effective in addressing information uncertainty. Formal contracts turned out, however, to be less effective in addressing information equivocality.

### *2.5.2 The role of relational governance in addressing information asymmetry*

Even though Road A and B invested in relational governance, both still experienced extensive information uncertainty. Rail A, which did not rely on relational governance, and Rail B, where relational governance played a minor role, actually experienced limited uncertainty. As such, the cross-case findings showed that information uncertainty could not effectively be addressed by investing more in relational governance. Rather, **Section 2.4.2** demonstrated that uncertainty was effectively addressed by clear contractual terms that support data sharing between partners, and this should be complemented by relational governance to foster trust to create transparency. With respect to information equivocality, the cross-case evidence suggested that relational governance was effective for addressing information equivocality. Road A and B both relied mostly on relational governance to effectively manage their transformation activities, with a complementary role for contractual governance in setting basic rules for joint activities. In turn, Road A and B experienced limited equivocality. The Rail A and B cases show that not relying on relational governance, or only to a limited extent, while extensively using contractual governance actually increased equivocality.

The limited role of relational governance in gathering data from suppliers was especially evident at Road. Motivated by the organisation-wide strategy of "collaborating with the market" [28, 29, 30], Road began transforming their transactional relationships into more collaborative ones, thereby creating bilateral expectations regarding data sharing and how data could be used to more efficiently organise maintenance activities. Road B focussed on relational norms that fostered flexibility, which was needed to improve the interpretation of contractual agreements together with their private supplier. Rather than immediately penalising the private supplier for a contract deviation, the supplier first got an opportunity to explore the deviation and address it. The fact that the private supplier was allowed this "manoeuvring space" demonstrated flexibility and made them more willing to sometimes "go beyond and above" what was stipulated in the contract. Furthermore, while merely requesting data used to result in reluctance to share data by the private supplier, explaining more about data usage (by the public organisation) was found to increase the supplier's willingness to collect and share data. Trusting relationships enabled Road to increase transparency with respect to the contract clauses, which motivated the supplier to share data more freely [12, 28]. Moreover, collaborative relationships helped both parties to build a mutual understanding and develop joint goals regarding data collection. Similar to Road B, Rail B's regional asset management team discussed deviations together with the supplier and identified joint solutions, which fostered data sharing by the supplier [58]. Discussing deviations and associated root causes built trust in the relationship and supported data acquisition and sharing activities. In contrast to the relational approach adopted by Rail B, Rail A did not rely much on relational governance mechanisms to support data gathering and sharing. For example, Rail A was afraid that if they were too transparent, they might provide too much information to their supplier (providing them with an advantage over other potential suppliers) and hence infringe on European tendering regulations. As such, Rail A rigidly enforced the contract and was unable to avert distrust. Consequently, the private supplier provided only the bare minimum in data (as per the contract), fearing that sharing too much data would be used against them by Rail A [47, 48].

Regarding transformation activities, Road's strategy to collaborate more closely with suppliers helped in building trust, which created transparency, and establishing collaborative relationships in which shared objectives could be identified. This motivated parties to engage in joint information transformation activities that helped limit the messiness of information and enabled the joint development of a dashboard to, for example, monitor the states of sluice doors with real-time information (Road B). Furthermore, both cases at Road focussed on the benefits that partners could obtain from relevant information and that simultaneously addressed their converging goals (e.g. more efficient maintenance for the supplier resulting in higher profits, more efficient asset management for Road resulting in a higher availability of the network) [16, 17, 35]. Creating such common objectives helped to motivate Road and their suppliers to transform data, both individually and jointly, thereby limiting the messiness of information. Rail, in contrast, relied heavily on internal resources for transformation activities, with limited opportunities for suppliers to engage with the public organisation in a joint transformation process. Rail A did not invest in building a trusting relationship with the supplier, since Rail A believed that any data transformation activities that the supplier could perform would only result in "*fragmented, or even tainted, information*". **Table 2.5** shows, for example, that the supplier's management and their engineers had diverging ideas about performance [53]. While the supplier's engineers tried to perform as if they "owned" the assets that they were maintaining (i.e. more aligned with Rail A's interest to lower the number of failures and thus increase availability), their management more strictly followed the contract (i.e. performing enough maintenance to meet minimum contract requirements and maximise their profit). This led to differences in how both parties interpreted information regarding the supplier's performance and the assets' availability. Rail B invested in establishing relational norms (i.e. setting up a reference guide for their intended collaboration), with the intention of motivating the private supplier to go beyond the letter of the contract and to propose possible data transformation opportunities other than those prescribed in the contract [67]. This approach was described by both parties as creating more flexibility in the relationship, which was needed to address emerging issues and to consider the relationship a partnership (rather than a transactional relationship) involving both partners to maintain the rail network as effectively as possible as to increase network availability.

In sum, relational governance mechanisms were found to be less effective when addressing information uncertainty and to – at most – complement the required contractual governance mechanisms. Relational governance mechanisms (i.e. relational norms and trust) were effective in addressing information equivocality.

## 2.6 Discussion

Drawing on IPT, we posit that information uncertainty and equivocality in relationships undergoing DT are addressed by data gathering (and sharing) and transformation activities. Our investigation of four public–private relationships shows that both contractual and relational governance mechanisms can be used, but in different roles, to manage information asymmetry.

### *2.6.1 Theoretical contributions*

This study contributes to inter-organisational governance and DT research. First, this study draws out how DT affects information uncertainty and equivocality. Digital technologies may reduce information uncertainty by enhancing both the quantity and quality of data available for decision-making (Sternberg et al., 2021). In the context of smart sensors, our findings show that they enable data to be collected in real time and that measurements tend to be more accurate. Advanced data analytics tools (Frank et al., 2019) enable combining data from different sources (e.g. SCADA and asset management systems, weather forecasts) and with expertise of relevant specialists (e.g. on asset utilisation, or the impact of weather conditions), thereby reducing equivocality. The findings, however, demonstrate that merely having these technological solutions in place does not guarantee enhanced information processing. Rather, challenges in data acquisition and transformation activities pertain to organisational aspects of implementing digital technologies and to the management of the IORs in which data from these technologies play a role. This is especially true for public–private relationships, which are characterised by different information processing needs. The public organisations in our study serve the public by providing safe, reliable and affordable transport to citizens and are held accountable by the national government in case of failures (e.g. low availability, accidents). As a result, these public organisations "need to know more than they buy" (Flowers, 2007) and hence require more information than suppliers would generally be inclined to provide (e.g. not only showing that a repair was made, but also that the failure did not impact safety). Based on our findings, we also show that public organisations and private suppliers differ in their main objectives (i.e. high availability vs maintenance volume) which, as shown in our case findings, caused both parties in the public–private relationship to make different decisions using the same information (e.g. postponing maintenance vs performing it now). We thus find that merely equipping assets with digital technologies does not yield any benefits if private suppliers fail to act upon the data these technologies generate and if data are not shared between partners. Thus, information processing activities need to be properly organised (to ensure that both partners in the relationship contribute to the effective execution of the necessary processing activities) if public–private relationships are to reap the benefits that digital technologies can provide. Governance mechanisms can play a key role by explicating rules and operating procedures as well as by providing relationship-governing guidelines for data collection, sharing and transformation.

Second, this study theoretically and empirically contributes to inter-organisational governance literature by investigating the roles of contractual and relational governance mechanisms with regard to addressing information asymmetry in relationships undergoing DT. This is important because separate, yet interdependent, data collection and analysis activities increase organisations' strategic interdependence (Mahapatra et al., 2010) in successfully exploiting data-driven decision-making. As evidenced in our cases, effective deployment of both governance mechanisms helps to address information asymmetry. However, different governance mechanisms are needed depending on the nature of information asymmetry. More specifically, information gathering and sharing between partners can be explicated and stipulated using contracts' control and coordination functions geared at supporting collecting data and sharing it with the public organisation. To be useful for both parties in the relationship, these contractual control and coordination provisions need further detail and clarification regarding, for example, the format in which data should be collected and shared and the desired levels of detail. The contractually stipulated incentive schemes also need to be proportional (Selviaridis & Van der Valk, 2019) if data gathering and sharing are to achieve the desired levels. In other words, incentive schemes need to include both penalties and bonuses, and these are required at levels that incentivise suppliers to put effort into data gathering and sharing. Furthermore, organisations might benefit from more extensive use of coordination clauses aimed at establishing communication routines (e.g. frequency and detail of regular meetings) to exchange data and increase their understanding of each other's information requirements. Contractual mechanisms are found to be less prominent in data transformation activities. One plausible explanation seems to lie in the difficulty of defining information requirements in advance of DT with both parties struggling to define and bound precise specifications for data transformation. Also, when data acquisition and sharing are not properly organised via a contract's coordination clauses, information transformation between parties is limited. Data acquisition first needs to be properly organised before organisations seek to organise transformation activities.

Our study finds that data acquisition and sharing mainly benefit from the use of relational governance such as trust and relational norms. Where trusting relationships are developed, suppliers are more open about the data they collected and engage more frequently in discussions regarding potential issues and new ideas with respect to using collected data to optimise their maintenance activities. Establishing collaboration and setting joint objectives aid partners in developing a clear perspective on what kind of data are required for what purpose. This may successfully be achieved by developing relational norms as these create a bilateral expectation (Cannon et al., 2000) that parties will proactively provide relevant (and often beyond contractually stipulated) information to their partner and thus support decision making in the relationship. Furthermore, in the presence of trust, parties are more likely to spend time collecting and sharing data (Inkpen & Tsang, 2005). Trust also plays a vital role with respect to data transformation activities by increasing collaboration and information exchange between partners, and it helps them to share objectives with each other more freely. Increasing the level of trust between partnering organisations may help organisations to actively exchange relevant information and openly discuss collected data and possible interpretations. This may also support aligning interpretations between partnering organisations and thus lead to joint synthesis of information.

### *2.6.2 Boundary conditions and further research*

In this study, the roles of governance mechanisms in addressing information asymmetry in public–private relationships during DT are closely examined. While our findings are relevant to public and private organisations beyond the investigated sectors and country, future research should compare our findings with other types of relationships (private–private or involving NGOs) and other sectors with different characteristics (e.g. different clock speed or types of products/services). This may have an impact on how information asymmetry is addressed. For instance, relationships in fast-moving product industries may not have the time to collect, analyse and transfer rich information and may rely on other means to address information asymmetry. In addition, the investigated public–private relationships are characterised by possible diverging goals and objectives (e.g. social vs economic value) which may lead to further information asymmetry and thus making them an ideal context for our study. Future research should investigate other types of relationships where goals and objectives might be more aligned (e.g. joint economic value creation and appropriation) and their impact on information asymmetry and the use of both governance mechanisms.

This study focusses on a particular type of digital technology. Other types of digital technologies, such as the use of blockchain technology to secure information transfers, should be investigated too to obtain a broader view of how different technologies affect information asymmetry. Moreover, investigating the findings in countries with different legal practices (i.e. different legal systems, importance of different contract types) may reveal the different roles both governance mechanisms play in addressing information asymmetry. Finally, this study leverages many sources of data including interviews, observations, contracts and archival data. Future studies may use behavioural experiments to uncover the role that different individuals play in using both governance mechanisms to address information asymmetry. For instance, further work should explore whom, at what level (e.g. business, corporate, subsidiary) and in what job role (e.g. legal, engineering, supply chain) uses what type of governance mechanism to gather, analyse and transfer information.

### *2.6.3 Implications for practice*

This study has important implications for organisations and managers seeking to use governance mechanisms to address information asymmetry in relationships undergoing DT. Adopting and implementing digital technologies as such will not enhance information processing capacity (as shown in the case where not enough staff was present to transform collected information) and capabilities (as specific expertise from the relationship partners needs to be combined), unless organisational and relationship management aspects associated with DT are properly dealt with. (Public) Organisations embarking on DT should therefore carefully consider how this would affect their relationships and their dealings with (private) partners, but also how processes, resources and structures may need to be adapted internally to deal with increased data and information. Our study provides valuable levers for the effective deployment of contractual and relational governance mechanisms in supporting information-processing activities and the management of information asymmetry in IORs.

In order to deploy both governance mechanisms effectively, organisations should first develop a thorough understanding of their own information requirements (including, but not limited to, questions around what, when, how, why and who) in relation to operational and contractual decision-making as well as the information requirements of partners. While information requirements may be clear in some areas, our study revealed that in most cases it is not. Public organisations may have difficulties identifying their essential information requirements. Organisations (and especially public ones) may lack crucial and specialised technical knowledge of the operational tasks of maintenance that they have outsourced to private suppliers. Additionally, public organisations typically work with tight budgets that do not allow simultaneous investments in current and new maintenance processes supported by digital technologies. Taken together, these issues inhibit organisations from developing a clear understanding of their information requirements. Increased collaboration with suppliers may foster such understanding, as suppliers are likely to be able to help establish and address information requirements based on their experiences with other customers and sectors. However, collaboration is problematic as public organisations and their private suppliers have diverging interests, leading public organisations to require higher quantities and quality of information than other (private) customers. Moreover, public organisations tend to refrain from too close collaborations with suppliers to avoid supplier lock-ins or the unintended creation of unfair competition between current and potential suppliers, thus making collaborative public–private relationships more difficult to achieve.

When information requirements are sufficiently clear, contracts should explicitly stipulate these information requirements and what data are required. Associated incentive schemes should be proportional and functional to be effective. Our research provides specific insights into how contractual and relational governance mechanisms help coordinate information processing activities. Contracts help establish data gathering and transformation processes by facilitating communication and information transfer, thereby reducing the information uncertainty that the relationship faces. Relational mechanisms may strengthen this relationship as trust, openness and establishing common goals help to refine both parties' understanding of information requirements. Relational mechanisms play an even more important role in transformation activities as strong relationships help to develop the skills required for understanding the information held jointly. Joint problem-solving helps to develop the information structuring and evaluation skills of individual decision-makers in the relationship.

## 2.7 Conclusion

This paper explored how organisations in public–private relationships use contractual and relational governance mechanisms to organise information-processing activities in addressing information uncertainty and equivocality during DT. Information gathering and sharing activities can be made explicit and can be stipulated in contracts, which mainly serve to reduce information uncertainty. Information transformation activities are predominantly supported by relational mechanisms including trust, flexibility and joint problem-solving to address information equivocality. Our findings show that organisations need to first organise data acquisition and sharing activities before they can embark on organising data transformation activities (internally and with their partner). We are hopeful that these insights will encourage further research to refine our understanding of the roles of both governance mechanisms in addressing information asymmetry during DT.

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## Appendix A

The interview protocol below lists the generic and function-specific questions that guided the semi-structured interviews.

*General Questions* (all interviewees)

1. Can you describe the total value (economically, socially, etc.) of the assets for which your organisation is responsible?
2. To what extent are data and information already utilised when performing management and maintenance activities?

*Management and Maintenance Activities* (Asset Managers and Asset Specialists).

1. Can you describe how the management and maintenance activities of the infrastructure assets are currently organised?
2. To what extent is your organisation ready for smarter maintenance methods?
3. Are there any steps left to be taken by your organisation to achieve smart management and maintenance of assets? If so, can you describe these steps?
4. Can you describe which role suppliers should play in realising smarter maintenance methods?

*Information Processing and Innovation* (Advisors, Data Scientists, Configuration Manager and Project Manager)

1. What data does your organisation (plan to) share with supplier(s) and what data does your organisation (plan to) request from supplier(s)?
2. To what extent does your organisation request supplier(s) to contribute to the implementation of digital technologies for the purpose of maintenance?
3. In your opinion, what role will data and information play regarding smarter maintenance?
4. Which party do you think should take a leading role in achieving smarter maintenance?

*Outsourcing of Maintenance* (Advisor, Regional Director and Contract Managers)

1. Can you describe the design/structure of the maintenance contract?
2. Can you describe the outsourcing process for maintenance activities?
3. Can you describe the last maintenance contract awarded by your department?
4. Can you describe the collaboration with the current supplier?
5. Can you describe what a future cooperation should look like?

## Appendix B

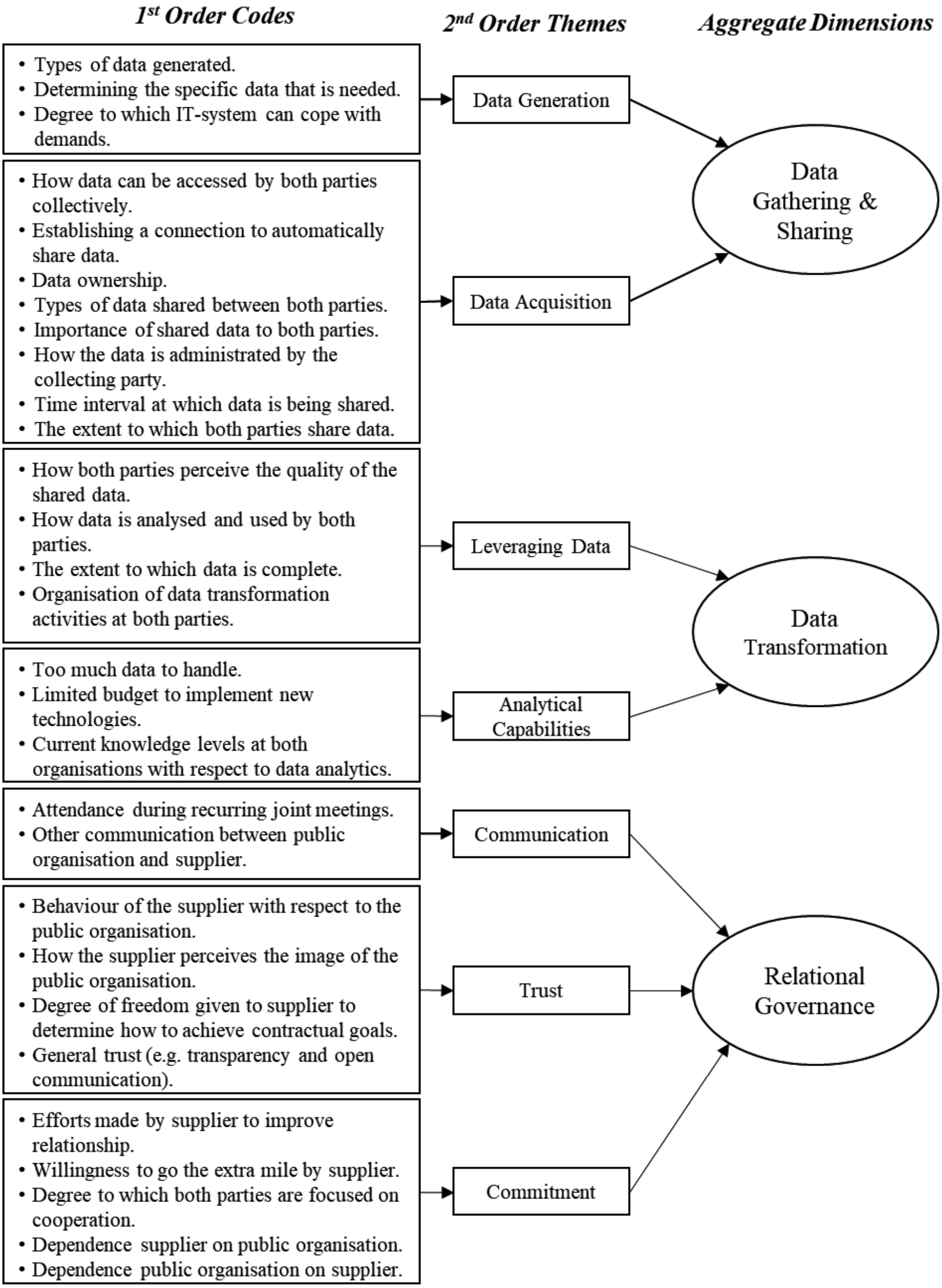
The table below summarises the different tactics and their operationalisation within our study to enhance reliability and validity.

**Table B1** Summary of research credibility (adapted from Gibbert et al., 2008; Yin, 2009)

| Test | Tactic | Research Stage | Operationalisation |
|---|---|---|---|
| ***Construct Validity*** | *Using multiple sources of evidence to enable triangulation of data* | Exploratory stage and In-depth case research stage | • Evidence was collected from multiple groups of informants at buyer side (e.g. data specialists, maintenance experts and contract managers) regarding both the buyer side as well as supplier side.<br>• Gained access to contract documents governing the relationships under investigation.<br>• Additional documentary evidence (e.g. firm documents and government reports) and observational notes were collected to support data triangulation. |
| | *Establishing a clear chain of evidence* | In-depth case research stage | • Detailed case study descriptions written, based on all sources of evidence, to uncover information processing activities and governance mechanisms used in investigated relationships.<br>• Original material (e.g. interview transcripts and documentary evidence) is referenced throughout the paper. |
| | *Letting key informants review draft reports* | In-depth case research stage | • Case study descriptions were discussed during extensive meetings that included both the two lead authors as well as a small selection of key informants from both case organisations to verify our analyses.<br>• Informal talks by the lead author with a selection of key informants to clarify interview transcripts. |
| ***(Internal and External) Validity*** | *Using replication logic in multiple case studies (pattern matching)* | In-depth case research stage | • Analysis of case studies was guided by several main concepts that were derived from existing literature (IPT and governance mechanisms).<br>• Built on "analytical generalisation" by seeking to identify patterns across the four cases.<br>• Case studies aimed to generalise to some wider theory (i.e. IPT), rather than a population. |
| ***Reliability*** | *Interview protocol* | Exploratory stage and In-depth case research stage | • Interview protocols were established based on concepts from existing literature, and they contained the procedures and questions for data collection during both research stages. |
| | *Case study database* | Exploratory stage and In-depth case research stage | • We created a case study database in Atlas.ti and Windows File Explorer while collecting data including, for instance interview transcripts, observational notes and contract documents. |

## Appendix C

The figure below presents the final coding structure that was constructed for the data analysis.



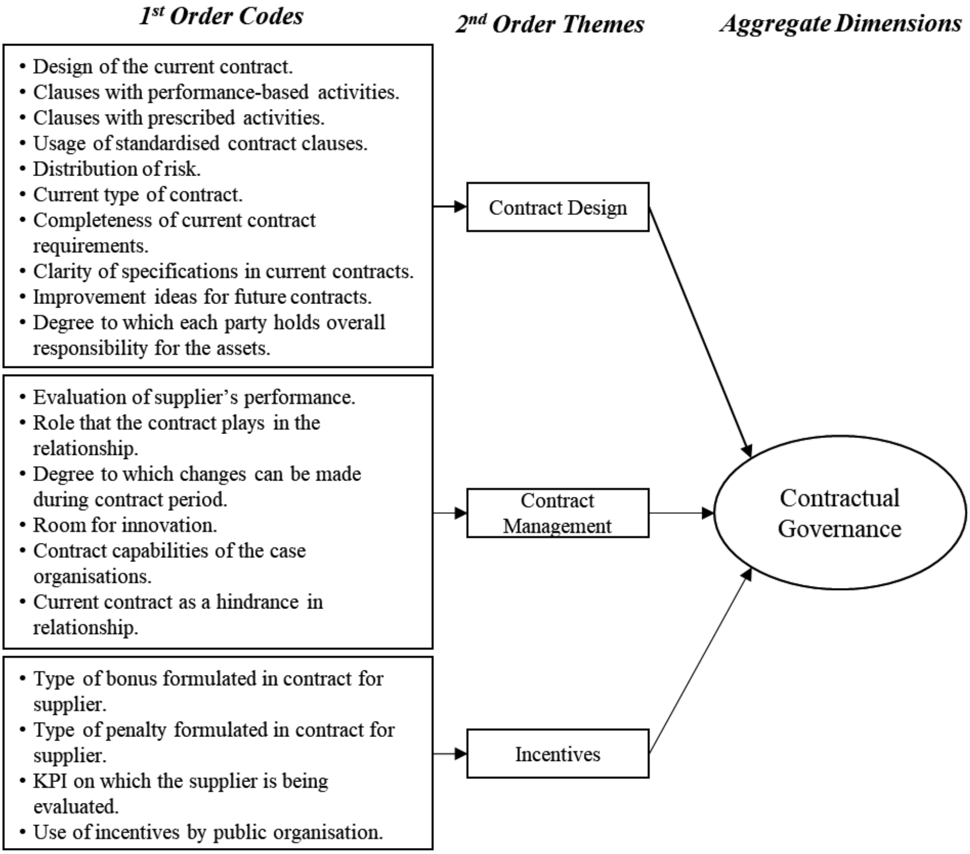



**Figure C1** Final coding scheme

# Chapter 3

## Learning to contract while digitalising:

## Joint intra-contract learning efforts in buyer–supplier relationships to develop contractual data clauses in PBCs


### Abstract

Digitalisation entails using digital technologies to fundamentally transform both intra- and inter-organisational processes of organisations, and as such also greatly impacts inter-organisational governance. Since it also involves a learning process about the new (upcoming) possibilities, the effective support of digitalisation using contractual and relational governance mechanisms is likely to require learning as well. This learning is preferably done within single contract periods because of the pressure on organisations to reap the benefits of their digitalisation efforts and because of the long-term nature of many maintenance contracts in public–private collaborations. A single longitudinal case study was investigated with two embedded cases, each focusing on a maintenance outsourcing contracts that are to be digitalised. These two embedded cases illustrate that intra-contract learning regarding digitalisation involves post-formation adjustments to both contractual governance (i.e. (re)design of contractual data clauses) and relational governance (i.e. increased formalisation of cooperative norms).



**Keywords:** *Intra-contract learning, Governance, Digital transformation, Data*



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A previous version of this conference paper was presented (April 2021) during the IPSERA 2021 conference as a 'working paper'.

## 3.1 Introduction

Inter-organisational relationships are undergoing massive changes due to the current digital transformation of the world around us. This transformation is triggered by the introduction of disruptive technologies (such as big data analytics, Internet-of-Things devices and smart sensors) and is resulting in substantial amounts of data (Holmström et al., 2019; Søgaard et al., 2019). For example, by placing (smart) sensors in critical components of their assets, asset managers are enabled to collect substantial amounts of data on their assets' health and usage, while (big) data analytics can provide these managers with opportunities to quickly transform this data (and data coming from other sources) into valuable information. These disruptive technologies thus enable the introduction of smart maintenance that can help asset managers to manage and maintain their assets more effectively (Bokrantz et al., 2020). In many sectors, including the public (infrastructure) sector, maintenance activities are largely or even fully outsourced to specialised contractors (Caldwell & Howard, 2014). To enable the implementation of smart maintenance in these outsourcing situations as well, the gathering and transformation of data needs to be managed across organisational boundaries and supported by effective governance mechanisms.

Digital transformations thus trigger the digitalisation of (inter-)organisational processes and provide organisations with both opportunities, and challenges and risks, which require the reconfiguration of processes (Aryal et al., 2018; Birkel & Hartmann, 2019). These reconfigurations also impact the use of contractual and relational governance mechanisms in buyer–supplier relationships as contracting organisations need to start to account for the possibilities provided by disruptive technologies (e.g. by designing effective data clauses for their contracts). Currently, not much is known about how governance mechanisms are affected by and can help with digitalising buyer–supplier relationships. As an exception, Aben et al. (2021) showed that contractual mechanisms are especially effective for data gathering activities (i.e. ensure access to the right data), while relational governance mechanisms are especially effective for data transformation activities (i.e. establishing a joint goal to jointly transform data into valuable information) (see **Chapter 2**). This shows that organisations undergoing a digital transformation should not only focus on designing effective contracts but should also invest in building a good relationship with their partners as not all aspects of the digitalising processes can be specified in contractual terms.

Accounting for disruptive technologies and the digitalisation of processes, however, is challenging since contracting organisations typically do not have all the knowledge regarding the use of new technologies and the data these produce. On top of that, digitalisation itself is an uncertain process that is typically not fully understood yet by contracting organisations. Since digitalisation inhibits the *ex ante* design of fully effective contracts, post-formation governance adjustments are thus likely to be necessary (Keller et al., 2021) in digitalising buyer–supplier relationships. These adjustments do not only pertain to the contractual mechanisms (i.e. changing contract clauses), but it also requires making changes to the relational mechanisms (i.e. changing joint goals that were set, managing trust between the contracting organisations). Moreover, these adjustments can also pertain to the degree of formality that is needed with respect to the two types of governance mechanisms (Keller et al., 2021). The need to make post-formation adjustments stems from experiences gained by the contracting parties after a relationship has commenced and during the implementation of (new) disruptive technologies and the usage of data from the organisations' databases. Gaining experiences and directly implementing the learnings from these during an ongoing contract period is known as 'intra-contract learning' (Lumineau et al., 2011; Reuer & Ariño, 2002).[3]

To date, not much is known about how digitalisation, and advancing knowledge about this, make post-formation adjustments to contractual and relational governance mechanisms probable and necessary. As such, we advance the following research question: *How do contracting organisations employ intra-contract learning and make adjustments to contractual and relational governance mechanisms to deal with digitalisation more effectively?* To investigate this and answer our research question, we built a single case around a public infrastructure manager (the buying organisation) that outsourced almost all of their maintenance activities to two specialised maintenance contractors (the supplying organisations). The two relationships are identified as two separate cases embedded in the single case. Our case involved a public organisation responsible for the management and maintenance of infrastructure assets in a major Western-European port and two specialised (and private) maintenance contractors of which one was hired to maintain all 'grey' assets (e.g. roads, sidewalks, road signs) of the buying organisations and the other all 'green' assets (e.g. trees, verges, removing litter). In both relationships, digital transformation provided the contracting organisations with substantial amounts of data holding the potential for more effective (i.e. smart) maintenance. We had access to individuals on both sides of the dyads and were thus able to uncover their behaviours and decisions leading up to contract adjustments during the execution period (i.e. the intra-contract learning processes). Moreover, we were able to investigate the embedded cases over a longer period of time through multiple rounds of data collection in which we not only observed the design phase of the contracts (which included a two-year design period in which the contractors had the lead), but also the first two years of the execution period of both contractors.

The rest of this paper is organised as follows. In the next section, we provide the theoretical background in which we discuss how digitalisation impacts inter-organisational relationships and governance mechanisms, and how organisations can learn from experiences gained during the execution of a contract and directly implement these (i.e. intra-contract learning). In section 3, we discuss the employed methodology for this study. Section 4 presents the findings from our single case study. This paper is concluded in section 5 in which we discuss our main findings and provide some concluding remarks.

## 3.2 Theoretical background

Digital transformations are typically the result of the introduction of disruptive technologies that trigger strategic responses from organisations and provide opportunities to alter the way value is created (Vial, 2019). These technologies do not only cause the digitalisation of intra-organisational operations, they also continuously challenge the purchasing functions of organisations by prompting the digitalisation of the management of buyer–supplier relationships and inter-organisational operations (Holmström et al., 2019; Søgaard et al., 2019). An important aspect of digitalisation is the large amount of data, which disruptive technologies tend to create and/or collect, and the tools it provides to organisations to effectively transform

[3] Learnings occurring across contract periods and implementing these in subsequent contract periods are known in the literature as 'inter-contract learnings' (Mayer & Argyres, 2004).

this data (Kache & Seuring, 2017). These substantial amounts of data that are being generated increases the level of information available in buyer–supplier relationships (Sternberg et al., 2021). However, the availability of the information is likely to be asymmetric, as one specific party typically gathers data. Consequently, one party may have access to data while the other has not. In addition, some parties may possess specific processing skills while the other does not. Hence, collaboration is required.

Recent research has shown that getting access to data collected by a partner, including data sharing, requires appropriate contractual governance, while data transformation is facilitated by appropriate relational governance (Aben et al., 2021). Contractual governance mechanisms provide contracting parties with effective tools to control access to data and to coordinate the sharing of data, thereby effectively lowering information uncertainty (i.e. the risk of not having access to specific data). These tools are typically in the form of written, legally enforceable contracts that help contracting organisations define their roles and responsibilities and support pre-determined promises and obligations regarding the resolution of disputes (Luo, 2002). Controlling access to data is typically achieved by explicitly stipulating how information exchange needs to occur between the contracting parties (Faems et al., 2008; Jayaraman et al., 2013). Coordination clauses, on the other hand, facilitate communication and the actual transfer of data (Mesquita & Brush, 2008; Zheng et al., 2008) to support the actual sharing of data between contracting organisations.

Relational governance help contract parties to build trusting relationships and identify shared goals to enable joint interpretation of data to transform it to valuable insights, thereby effectively lowering the messiness of information. Important here is the need for relational (or cooperative) norms that help with the establishment of shared goals and defining expectations regarding behaviour (Cannon et al., 2000; Heide & John, 1992). This is needed as the transformation of information requires a joint interpretation of the gathered data by the involved parties. The other important mechanisms, trust, can be defined as the expectations around the degree to which another party can be relied on, behaves as predicted and acts fairly (Poppo et al., 2008). Previous research has shown that when trust is established, contracting parties are more inclined to collaborate and share information with each other (Carey et al., 2011; Inkpen & Tsang, 2005). Combining trust with relational norms in collaborations enables the creation of strong social bonds between contracting parties that increases the mutual willingness to put in additional efforts to attain a shared goal as is needed with information transformation.

Since data collecting, sharing and transforming activities require both contractual and relational governance, this paper does not only investigate how learnings by contracting organisations lead to adjustments of current contract documents in ongoing contract periods, but also to adjustments in the relationship (specifically in the cooperative norms). While investigating the use of contractual and relational governance mechanisms, many scholars implicitly regard contractual governance as more formal and relational governance as more informal, this is not necessarily the case. Keller et al. (2021) argue that both contractual and relational governance mechanisms can be formal as well as informal. For example, contracts can include commitments that are codified in the documents, describing in detail the tasks and obligations of both parties involved (formal contractual governance), as well as uncodified commitments that only describe the intentions of both parties involved (informal contractual governance). The same holds true for relational governance mechanisms that can be either formal (e.g. expected behaviours are codified, or detailed, in procedures) or informal (e.g. trusting each other certain behaviours will be shown without specifying it in procedures).

While digital technologies are expected to provide organisations with numerous opportunities, these also provide challenges and risks such as uncertainty, costs and trust issues (Aryal et al., 2018; Birkel & Hartmann, 2019). This uncertainty also translates to the design and execution of contracts, leading to a new area in which organisations are learning-to-contract, especially regarding the management of data generated through these technologies. Since developments are going extremely fast, and since not all implications of new disruptive technologies are known upfront, it is exceedingly difficult to *ex ante* design contract documents that foresee in all potential uses of data generated by newly introduced disruptive technologies or even the introduction of new technologies in the near future. This lack of knowledge *ex ante* requires contracting parties to employ post-formation adjustments during the contract execution phase. To date, our understanding of post-formation adjustments to contractual and relational governance remains limited, especially in the context of digitalisation.

The notion that organisations can learn from their actions and experiences is well-documented in the management literature (Argote et al., 2021; Argote & Hora, 2017; Argote & Miron-Spektor, 2011; Desai, 2020; Huber, 1991; March, 1991; Pisano et al., 2001; Valentine, 2018), and it is no surprise that organisational learning also occurs in contracting situations. This learning-to-contract research stream gained a lot of attention in both the general management and the operations management literatures and has broadly identified two types of learning with respect to contracting: inter-contract learning (see e.g. Anand & Khanna, 2000; Argyres & Mayer, 2007; Dekker & Van den Abbeele, 2010; Mayer & Argyres, 2004; Ryall & Sampson, 2009; Selviaridis & Spring, 2018; Vanneste & Puranam, 2010; Wu & Chen, 2014) and intra-contract learning (Ariño & de la Torre, 1998; Doz, 1996; Lumineau et al., 2011; Reuer & Ariño, 2002; Wang et al., 2021; Xing et al., 2021; Zhang et al., 2018).

The concept of inter-contract learning views the process of learning as resulting from experiences gained in repeated partnerships that ultimately influence the design of subsequent contracts (Mayer & Argyres, 2004; Ryall & Sampson, 2009). The contract is viewed as a repository of the common knowledge that the contracting parties have gained based on their repeated interactions, and a history of multiple prior interactions often corresponds with increased levels of detail in subsequent contracts (Vanneste & Puranam, 2010). Studies into inter-contract learning have, among other things, shown that organisations learn to collaborate with each other over time by repeatedly engaging in inter-organisational transactions, and provided insights into how organisations learn from one contract cycle to another (Ryall & Sampson, 2009) and which capabilities organisations need to have to effectively learn to contract (Argyres & Mayer, 2007).

Contracting parties may also gain experience with how to prevent unforeseen events from recurring within a specific contract period or make subsequent events in the same relationship easier to deal with. This is known as the concept of intra-contract learning which aims to understand how contracting parties can leverage experiences gained during the same ongoing relationship, thus using them to adjust the current contract (Lumineau et al., 2011) and/or to adjust the norms of cooperation in such a way that it better suits their (changed) needs. Previous research with respect to intra-contract learning primarily focused on strategic alliances (e.g. Reuer & Ariño, 2002) and explains how organisations learn from the dynamics and changes that occur during their alliance, leading organisations to renegotiate contractual terms during a contract period. More recently, scholars started focusing on the more transactional buyer–supper relationships as well and found that standard contracts with boilerplate terms are being customised in different ways by different organisations and industries (Roehrich et al., 2021), and started to investigate how contract flexibility can help contracting organisations cope with uncertainty and opportunism (Wang et al., 2021).

While extant literature has advanced the notion of inter-contract learning, the notion of intra-contract learning has received much less attention to date, especially with respect to digitalisation leading to the reconfiguration of many buyer–supplier relationships. Moreover, of the limited number of studies in intra-contract learning, most primarily focus on strategic alliances and other collaborations with a long-term focus, with only a few exceptions that focus on the more transactional buyer–supplier relationships (see e.g. Wang et al., 2021; Zhang et al., 2018). At the same time, there are already studies regarding digitalisation in buyer–supplier relationships and these provide insights into which governance mechanism (contractual or relational) are most effective. However, to our understanding, it is not yet known whether and how contracting organisations need to make adjustments to the governance mechanisms, and the specific mix of these mechanisms, they employ during a contract period when learning about the implications of digitalisation on their relationships.

## 3.3 Methodology

### *3.3.1 Research design and case selection*

Given the exploratory nature of this research, and the importance of obtaining a deep understanding of the learning processes that the individuals involved experienced, a single case research strategy was considered most appropriate (Barratt et al., 2011; Ketokivi & Choi, 2014) with two embedded cases. As inter-organisational collaborations are increasingly acknowledged to be inherently unstable and subject to changes overtime (Keller et al., 2021), we specifically opted for a longitudinal case research in which both retrospective and real-time data was collected to gain an in-depth understanding of the dynamics in both observed relationships and how these contributed to intra-contract learning (Siggelkow, 2007). Moreover, it helped us to gain access to the actual contract documents used, which are typically not easily accessible for researchers, and which allows for detailed analyses (Lumineau et al., 2011). By applying the purposeful sampling method, two unique cases were selected (Dubois & Araujo, 2007).

The buying organisation is an unlisted public limited company (hereafter referred to as ‘Port’) responsible for managing and maintaining all infrastructures in a large port area in Western-Europe, including roads, greenery, quays, and public lighting. Maintenance of these assets is outsourced to specialist contractors operating on the private market. For the two embedded cases in our single case studied here, this concerns maintenance related to road infrastructure (‘Case Grey’), and the maintenance of ‘green’ assets (e.g., trees, grass fields, and litter; ‘Case Green’). Tendering and subsequent contract design was similar in both cases, and the selected contractors (hereafter referred to ‘Grey’ and ‘Green’) are both medium-sized specialist companies in their respective sectors (i.e., road construction and maintenance, and landscaping and grounds maintenance). Finally, in both embedded cases, the contractors were invited to take the lead in drawing up the contract agreement, thereby leveraging their content expertise and prior experience for the purpose of designing effective contracts.

Differences between the embedded cases occurred with regard to the contractors' prior design experience: while Green had experience in this as they had designed contracts for other clients in the past, Grey had never performed this task before. The embedded cases also differed regarding Port's prior experience with each of these contractors, since Port had two years of experience with Green, and no experience with Grey. While the similarities regarding tendering and contract design between both embedded cases helps allows us to make strong comparisons and identify the learning processes of joint contract design activities, the differences allow us to understand how and to what extent the contractor's previous knowledge and familiarity between the buying organisation and contractor influenced the amount and type of learning. For an overview of the case organisations and their characteristics, see **Table 3.1**.

**Table 3.1** Case organisation characteristics

| | **Port** | **Grey** | **Green** |
|---|---|---|---|
| *Description* | Public organisation responsible for developing, managing and maintaining a major port in Western-Europe | Medium-sized Dutch private contractor specialised in the construction and maintenance of both above-ground and underground infrastructures | Medium-sized Dutch private contractor specialised in environment management and landscaping; part of a European holding firm |
| *Type of organisation* | Unlisted public limited company with two governmental entities as shareholders | Family-owned private limited liability company | Private limited liability company owned by a private investment firm |
| *# Employees* | 1.270 | 1.100 | 500 |
| *Revenue* | €750 million | €500 million | €60 million |
| *Importance of assets involved* | Assets maintained by contractors greatly influence Port's internal as well as external connectivity and the quality of the business climate | N/a | N/a |
| *Contract size* | N/a | Significant part of the revenue for the regional department, small part of the revenue for the company overall | Significant part of the revenue for the company overall. Landmark contract (exemplary contract for other subsidiaries in the European holding) |

| | | | |
|---|---|---|---|
| *Prior relationship* | N/a | No prior relationship | Prior relationship (2 years) |
| *Experience with contract design* | Multiple contracts with varying degrees of success | Only limited experience with contract design; never had the lead | Some experience with contract design, mostly in an advising role |

### *3.3.2 Data collection and analysis*

To identify post-formation adjustments to contractual and relational governance mechanisms made during contract design and execution in both cases, we identified three distinct periods of contract learning at Port (see **Figure 3.1**). Period 0 (2009-2016) is concerned with Port's learnings from several former maintenance contracts they had that did not include Grey nor Green as contractor and from a market consultation Port performed. An analysis of this period helps explain the specific approach taken by Port in Period I as well as Port's behaviour regarding Grey and Green in Periods I and II. Period I is concerned with the learnings during the period 2017-2019 involving both inter-contractual learnings derived from various previous contracts, and intra-contractual learnings obtained while executing the cost-reimbursable contracts under which the new contractors served. Specifically, the latter type of learnings was to materialise in the form of the new performance-based contracts that the contractors developed in consultation with Port as successors to the cost-reimbursable contracts, as well as changes in the way relational governance mechanisms were employed. Moreover, this two-year transition period provided the opportunity to investigate the intentions of all parties involved. Period II involves the learnings under the performance-based contracts (starting January 2020, and still ongoing) in both cases. During this second period, we specifically focused on closely monitoring intra-contractual learnings, any subsequent changes made in the contract documents and relational governance mechanisms, and the behaviours of the employees involved on both sides of each dyadic relationship as it evolved over time.

Data was collected in three distinct rounds. In the first round (October 2018-March 2019), initial interviews were done with employees at Port to identify interesting cases and secure access to individuals at all organisations involved with the two selected cases, and related contract and internal documents. In the second round (November 2019 – May 2020), retrospective data related to Port's experiences with previous outsourcing relationships in Period 0 (explaining, among other things, their decision to engage in a two-year transition period) were collected. In parallel, both retrospective and real-time data were collected from Port, Grey and Green to obtain insights regarding the transition period (Period I). A final round (September 2020 – April 2021) focused on real-time data collection at all three organisations to obtain insights on the execution period of the newly designed performance-based contracts (Period II). Collecting data in multiple rounds helped the interviewees to focus their attention to specific learning periods and to avoid mixing memories and ideas. In total, 34 interviews (30 hours) were conducted, of which 20 with employees working at Port, nine with employees from Grey and five employees from Green. Moreover, the lead author got access to six contracts (with a total of 859 pages) and the archival data included four internal documents (with a total of 348 pages). For a detailed overview of the main data sources and how data is used, see **Table D1** in **Appendix D**. Moreover, the specific interview protocols that were used in each of the data collection rounds can be found in **Appendix E**. To clarify in which data collection round a specific quote was collected, and to which period it refers to, each quote will have the following format: ([organisation], [function of interviewee], [collection round], [period]). For example, a quote by Port's data manager, collected in the second round regarding Period 1 will be denoted as follows: (Port, data manager, R2, P1).

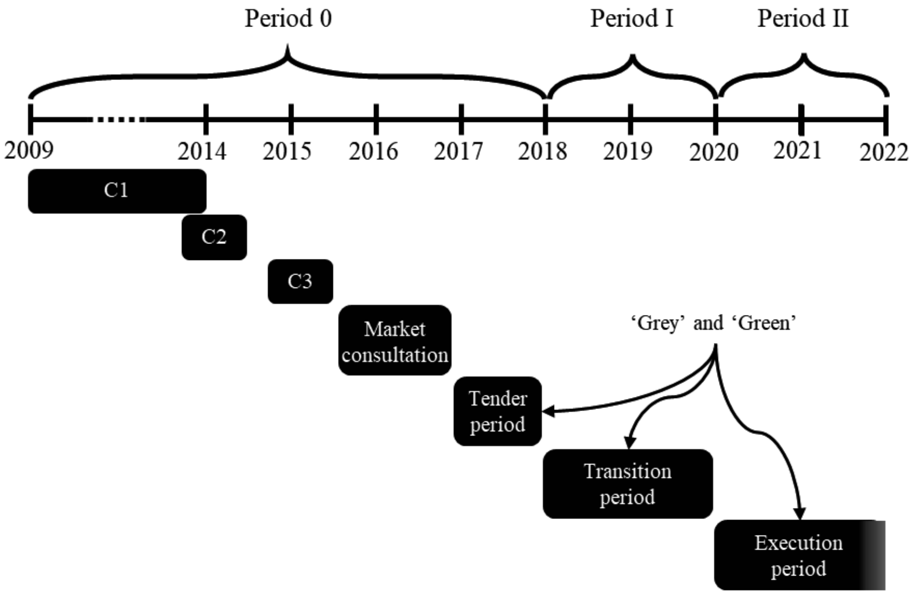


**Figure 3.1** Timeline of the three learning periods at Port

We started our data coding and analysis activities just after the first pieces of data were collected by the lead author, as recommended by Miles and Huberman (1994). All interview transcripts, contract documents and archival data were analyses using the data analysis software Atlas.ti to build and maintain an extensive database and chain of evidence. Several provisional themes, based on the theoretical background, were identified by the three authors to guide the coding process and to ensure a clear link with prior literature. These provisional themes included "data & digital technologies", "governance" (both contractual and relational) and "post-formation adjustments". Although several provisional themes were used, open coding (Miles & Huberman, 1994) was applied to incorporate emerging themes such as "behaviour", "contract design", "contract execution" and "relationship management". The lead author coded all the data that was collected, while the second author coded a small subset of the data. By comparing the results of the coding activities by the lead author and second author, potential biases were reduced. Moreover, any differences between the results of the two authors were resolved through reconciling interpretations. Overall, a total number of 68 unique first order codes were identified, which were subsequently grouped into 14 second order themes through axial coding procedures. The last step involved relating the second order themes into five aggregate dimensions that capture the main topics under study in this paper. See **Appendix F** for a detailed overview of the coding scheme and all codes that were used.

To ensure the quality and rigour of our case study, measures were applied to enhance construct validity, internal validity, external validity, and reliability (Gibbert et al., 2008; Yin, 2009). Measures adopted include theory and data triangulation to enhance construct and internal validity respectively, performing both within-case analyses and a cross-case analysis between the two embedded cases to enhance external validity, and maintaining an extensive case study database to enhance reliability (Gibbert et al., 2008).

## 3.4 Findings

In this section, the findings from the two embedded cases are presented. First, Period 0 is analysed to provide background information about previous contracting experiences of Port to explain the specifics of the contract design and execution in the subsequent periods. Secondly, the main developments in both Period I (the transition period with the cost-reimbursable contracts and the design of the new contracts) and Period II (the execution period of the newly designed contracts) are presented together with a deep dive into the learnings in case Grey and case Green through a within-case analysis for both. Finally, a cross-case analysis is presented in which the findings from case Grey are compared with the those from case Green. For both periods and cases, intra-contract learning outcomes, in the form of post-formation adjustments to both contractual and relational governance, could be identified.

### *3.4.1 Period 0: An overview of previous contracting experiences at Port*

In Period 0, which lasted from 2009 until 2017, three distinct contract cycles occurred at Port during which their infrastructure department tendered maintenance contracts with varying compositions, lengths and degrees of success. The three contract cycles can be found in **Figure 3.1** and are denoted by C1, C2 and C3. The contract(s) in each of the three cycles were all written exclusively by Port, included different contractors and all included performance-based requirements.

During the first contract cycle in Period 0 (C1), Port tendered two parallel maintenance contracts, both with a duration of five years (2009-2013). To create these two contracts, Port placed the maintenance activities for related assets into two separate groups: one for road maintenance and one for greenery maintenance. As such, each contractor became responsible for an 'integral' contract: "*the contractor had to perform all design activities to determine what maintenance activities were required and when*" (Port, contract specialist 1, R2, P0). During the execution of the contracts, there were some discussions between Port and their contractors regarding the baseline measure at the start of the contract (the assets needed to be on an acceptable level before the contractors became responsible for the assets), the justifiability of penalties given to the contractors by Port, and the effectiveness of the requirements in the contract. Especially, the latter aspect posed a large risk to Port as they failed to effectively require their contractors to share condition data regarding Port's assets: "*in retrospect, we were lucky that everything went well* [with respect to the data]*, but that is not because we arranged it well*" (Port, contract specialist 1, R2, P0). In the end, it all worked out well and the execution of both contracts was successful as both contractors served the full term.

Based on discussions with their contractors and their positive experience with the two previous integral contracts, Port changed their approach only slightly while designing the new contract for the second contract cycle (C2) that was set to start in 2014. First, an even more integral approach was taken: "*in the end, the choice was made to make one integral contract for about 90% of the assets in our port area*" (Port, contract specialist 1, R2, P0). Instead of two contracts, now one single contract was tendered as Port believed that making one contractor responsible for all 'dry' infrastructure (i.e. roads, greenery and public lighting), would increase the opportunities for achieving economies of scale as opposed to having two or more different contractors. In addition to integrating the two contracts, Port also changed the performance objectives, thereby transferring more risk to the contractor. They also initiated a two-month transition period in which the new contractor would start up their operations, while the two previous contractors finished their work. The idea was that this would ensure that the assets were well-maintained and that a solid baseline measure was in place on which the new contractor could build. Lastly, Port included a stricter requirement regarding the sharing of condition data: "*from this contract onwards we aimed to do it differently. We wanted the contractor to deliver the data in our systems directly*" (Port, contract specialist 1, R2, P0). Unfortunately, the transition period was characterised by many discussions as the new contractor was unhappy with the state in which the previous contractors left the assets: "*there was a gap between how the previous contractors left our assets and how the new contractor evaluated these. How are you going to close that gap? That was a very big problem*" (Port, contract specialist, R2, P0). Port also felt that, as a response, the new contractor seemed to aim for asking as much additional money from Port as possible to fix 'shortcomings' of the prior contractors. Since the ongoing discussions between Port and their new contractor could not be resolved, the contract was terminated after only six months (June 2014).

After the termination, Port needed to react quickly. Instead of offering a new performance-based contract, they awarded a basic cost-reimbursable contract to the contractor that submitted the second-best offer in the initial tender, thereby effectively transferring all risk back to Port. Meanwhile, Port set up a new tender (in 2015) for which they decided to adhere to the idea of an integral contract and one contractor but changed the agreements with respect to the baseline measure. As opposed to the two previous contracts (C1 and C2) in which Port was responsible for the costs to bring the condition of the assets to the baseline level, they now shifted this risk to the contractor. This meant that the contractor needed to determine the costs of bringing all assets to the baseline level before the contract even started and to incorporate these costs into their offer. However, this led to a lot of additional difficulties for potential contractors in the tendering process: "*this means that you transfer the risk to the contractor. They already need to give a price in the tender for meeting the baseline level, while they only become the actual contractor at a later time. In this period, the whole world can change. How can a contractor make estimates for this?*" (Port, contract specialist 1, R2, P0). At the same time, Port felt that the market parties, at that time, did not have enough expertise or knowledge to set up effective asset management systems: "*you expect that contractors produce key figures or something and that they have some kind of* [maintenance] *vision behind it. That* [lack of expertise] *was very disappointing*" (Port, contract specialist 2, R2, P0). These concerns eventually became reality as Port did not receive any viable proposals from potential contractors at all during the tender process for C3.

Faced with the failed tender, Port decided to take a step back and return to basic cost-reimbursable contracts once again for the time being. Moreover, Port also decided to split their assets into three distinct groups and hire a different maintenance contractor for each group of assets (one of these contractors was Green). In the meantime, Port analysed what happened and why their tender failed. In order to get the full picture, Port performed a 'market consultation' in which they spoke to potential contractors in the market, as well as observed other Dutch infrastructure managers who outsourced their maintenance activities. The market consultation made clear that Port's reputation as a customer among (potential) contractors had been severely damaged. Additionally, Port found out that not only contractors were lacking necessary knowledge and skills (i.e. asset management expertise) but that they themselves also lacked necessary skills as they were not able to accurately specify their needs: "*we actually learned that we were not very able to ask the question what it would take to keep it* [Port's assets] *maintained*" (Port, contract specialist 1, R2, P0). Lastly, Port's contract requirements were unworkable according to the market parties: "*the ultimate conclusion at the end of the journey* [market consultation] *was that we had actually gone too far in a number of aspects. The parties indicated that the requirements were very clear, but there was no room left in it*" (Port, contract specialist 1, R2, P0). Port's contracts simply became too detailed and rigid which left contractors more or less unable to earn any money on the contracts. The conclusion of the market consultation and the analyses by Port denoted the end of Period 0.

### *3.4.2 Within-case analysis: developments and learnings in case Grey and case Green*

#### *3.4.2.1 General developments in Period I*

In the tender for the transition period, Port explicitly stated their ambition to design the new performance-based and digitally informed maintenance contracts in closer collaboration with market parties. Port aimed to facilitate this process by issuing basic cost-reimbursable contracts, as to guarantee continuation of maintenance during the transition period. Port also made clear that the contract that the selected contractors would earn (and that would be designed by these contractors) would have a maximum duration of ten years, with two important milestones: 1) a successful completion of the transition period, two years into the contract; and 2) a positive evaluation of the contractor performance during the four subsequent contract years. The decision to have a two-year transition period was made following the market consultation near the end of Period 0 (as described in **Section 3.4.1**): "*from the market consultation we learned that two years is realistic, and we thus took two years for the transition period*" (Port, contract manager 1, R2, P1).

Contractor performance during the transition period was measured against outcome-based Key Performance Indicators (KPIs), while Port took all the risk: "*we rely on outcome-based requirements and with these the contractor gains experience with how they can demonstrate, verify and validate their performance*" (Port, head of subdepartment 1, R2, P1). Such experience would subsequently inform the contractor about risk allocation and associated price setting: "*in a performance-based contract, the contractor takes on a lot of risk.* […]. *If the contractor really wants to be able to incorporate that properly at a market price without risk premiums, they need to really get to know our port area thoroughly*" (Port, contract manager 1, R2, P1). Port also aimed to actively share their data with their contractors to jointly become smarter with maintenance: "*this is our* [Port] *data, indicate where it is correct and indicate* *what you* [contractor] *are missing, so that we can get better together.* […]. *We invest in improving the data quality, but they also benefit from being able to plan maintenance better*" [Port, data specialist, R2, P1). Taken together, these practices would help the contractors to, in consultation with Port, develop formal performance-based and digitally informed maintenance contracts for the two subsequent periods of four years (Period II) following the transition period, transferring risk only when and where feasible to the contractor.

*3.4.2.2 Learnings from Period I in case Grey*

During the transition period, Port employed a rather 'open' approach regarding the design of the performance-based contract and basically provided Grey with a carte blanche aside from some minor contract design guidelines. This open approach meant that Grey was rather free in interpreting their tasks themselves: "*we would use those two years to gain insight into everything, specifically to minimise risks, so that we could design a performance-based contract*" (Grey, advisor, R2, P1). Grey would thus develop a maintenance plan based on their experiences obtained in year 1, which would be validated and refined in year 2, and which would subsequently inform the final design of the contract for Period II (including the risk allocation between them and Port). At the start of the transition period, a carte blanche was expected and also proven to be challenging for Grey as they lacked experience both with contract writing and with working under performance-based contracts more generally. Grey initially assumed that they would be the ones designing the formal contract, and this assumption was reinforced by Port's initial passive stance and limited involvement. However, Grey's assumption turned out be wrong: "*during the transition period, we noticed very clearly that Port continuously monitored the content as well, while we thought the content was actually our business*" (Grey, advisor, R2, P1). The difference between the intentions of both parties led to lengthy discussions that caused delays in Grey's original planning for the transition period. At the same time, Port increasingly started to believe that Grey would not be able to finish the new contract on time and that action from their side was required: "*we slowly and surely have gone from pushing with a straw towards pushing with an iron pole*" (Port, head of subdepartment 1, R2, P1). In the end, Port did indeed intervene (September 2019, four months before the new contract was supposed to start) by organising a series of daily collaborative sessions (three weeks in total) with Grey in which the contract documents were jointly (re-)written and finished.

Important learnings in case Grey during this transition period were, first of all, concerned with the need for the buying organisation to provide a basic sense of direction to contractors regarding the type of requirements they expect in the final contract design. In hindsight, Grey found out that it needed more direction from Port: "*we got a carte blanche, without any framework. I think we needed at least some kind of framework*" (Grey, regional director, R3, P1). Port also acknowledged the importance of providing a general framework at the start of the contract design: "*in retrospect, it would have been smarter to give some more structure, rather than a carte blanche. That might have saved some time*" (Port, head of subdepartment 1, R2, P1). By having such a general framework, Port's own ideas (and wishes) would have been clearer from the start for the contract, while it could potentially have helped avoid situations where Grey is 'reinventing the wheel' and wasting valuable time. Another learning concerns the importance of open communication between the contracting parties: "*I think that* *the biggest learning point is that you have to be open and honest towards each other. And that there is room for that as well. We are not there yet*" (Grey, data specialist 1, R2, P1). Grey's contract writing team hesitated to share data with Port as they were afraid they were sharing too much and too frequently. As a result of Grey's hesitation, Port found it difficult to assess the direction Grey was taking and could not provide feedback. If both parties would have been less hesitant to share data from the start and instead actively sought to meet each other regularly, misunderstandings between them might have been avoided as illustrated by Port: *"we should have sat down with each other for a week or so to really understand each other.* [...]. *I think that if you had just sat down together like this at least three times during the design phase, we would have accomplished more*" (Port, project manager, R2, P1).

Looking specifically to the clauses regarding data and data management, Grey indicated that not much happened in this area during the transition period: "*it* [data] *has remained quite generic during the transition phase. We have mentioned and discussed some things and also wrote these down. But looking back on it later, we did not describe things detailed enough. For example, how data should be delivered back to Port?*" (Grey, data specialist 1, R2, P1). An important issue hindering the development of these data and data management clauses is the fact that both Grey and Port did not know exactly what their needs were with respect data and its management, and they did not invest a lot of time to investigate this in more detail. As indicated by Port: "*in Appendix 9 we have included how Grey should provide the data to us. There you also see, because we did not focus on this during the transition period, that we wrote down things of which we did not know how these would go. Now we see that quite a few aspects are missing here, and that these should have been written differently*" (Port, contract manager 1, R3, P1).

#### *3.4.2.3 Learnings from Period I in case Green*

Green had some experience with performance-based contract design while collaborating with other clients. However, they had never been in the lead in the design process of a new contract. Combined with the 'open approach' that Port had at the beginning of the transition period, Green's first concern was interpreting the task it received: "*the intention is that we as a contractor become familiar with Port's area as well as possible so that we can write a contract ourselves and that we both can agree on an amount and performance level with as little risk as possible*" (Green, project manager, R2, P1). Initially, Green believed that they were completely free regarding the design of the contract documents. However, over time, they learned that Port had quite specific ideas about the contract being designed: "*at a certain point it became clear that Port also had a certain, different, type of contract in mind*" (Green, project manager, R2, P1). Although both contracting parties worked with performance-based contracts before, they had different ideas of what such type of contract entails. As such, they were not on the same page: "*what a bigger problem for me was that we did not always fully understand each other. Or did not ask enough questions*" (Port, contract manager 2, R2, P1). Rather than meeting in person, Green and Port initially tried to resolve their different views via e-mail communication. However, the misunderstanding between the two contracting parties persisted and Port decided to intervene by setting up a series of collaborative sessions (one week in total) with Green to jointly finish the contract documents. These sessions eventually resulted in near complete contract documents.

An important learning point in case Green was the importance of mutually understanding each other, especially if you intend to jointly design a (new) contract. It is important to avoid any (major) misunderstandings: *"perhaps the most important word is 'perception'. Do you always have the same in mind? I often noticed that we had been talking for 2 hours about a contract piece Green would deliver and, in the end, I thought: 'in two weeks we will get a piece that is green'. And then, two weeks later, it turned out to be red. How is this possible? So, in turns out that you misunderstood each other*" (Port, contract manager 2, R2, P1). Reflecting on the transition period, both Green and Port felt that misunderstandings could have been avoided if their meetings had not only focused on discussions regarding the content of the contract, but also on each party's expectations: "*the pressure that arose at the end of the transition period could have been prevented by expressing expectations to each other earlier in the process*" (Green, maintenance specialist, R3, P1). As a result, the new performance-based contract included clauses specifying the organisation of recurring joint meetings, as well as a more formalised description of the intended relationship. This ensured awareness among all involved and enhanced the transferability of these notions to newcomers. A second learning point that emerged was related to the collaboration itself and the role each party should play: "*specifically at the beginning of the process, to arrive to a finished performance-based contract, it was not clear what the role, the input and the approval of Port would be*" (Green, project manager, R2, P1). Unclarity with respect to each other's roles led to additional misunderstandings, as well as unnecessary irritations.

When zooming in on the data and data management clauses that also needed to be developed during the transition period, it became clear that these areas initially did not receive much attention in case Green: "*we already worked on that* [data] *in the transition phase. However, it sometimes did not receive the attention it needed, so at the end of the transition period, it was not what we wanted it to be*" (Green, maintenance specialist, R3, P1). Both contracting parties underestimated the effort it took to design effective data management processes and instead turned their attention mostly to other aspects of the contract (e.g. maintenance plans and the development of KPIs). This underestimation was a result of the contracting parties' missing knowledge regarding data (and its future uses): "*we are currently in a learning process, and we do not know where it will end.* […]. *It could be that it will be completely different soon*" (Green, data specialist, R2, P1). In hindsight, both Green and Port realised that they should have given the data processes a more central role, rather than viewing it simply as a 'by-product'.

#### *3.4.2.4 General developments in Period II*

At the end of the transition period, both Grey and Green had finished a contract with performance-based elements that was also approved by Port. As such, both contractors successfully completed the transition period and on January 1, 2020, both performance-based contracts were implemented. The start of the implementation was difficult for both contractors, as the new contract had only been signed days before or even after January 1. As a result, there hardly was any time for Grey and Green to prepare their organisations for the new contract and the new way of working (e.g. with the new contract, the contractors took upon more risk than during the transition period and would thus need to show more ownership). Instead, they immediately needed to start working with the new contracts: "*when we started, after the* *transition period, we were actually not ready for it yet. Not us, not Port… It was because the signing of the final contract took three months longer than we initially thought*" (Grey, contract manager 2, R3, P2). Similarly, Green indicated: "*the execution had to start immediately while we might have preferred to have some preparation time in November and December before the start*" (maintenance specialist Green, R3, P2).

### *3.4.2.5 Learnings from Period II in case Grey*

After officially signing the new contract, the collaboration between Grey and Port entered into a negative spiral during the first half year. Unmet expectations regarding the cooperative relationship that had been agreed upon during the transition period resulted in a major escalation seven months into the contract period. The major escalation was the result of some of Grey's employees having let their own interests prevail over mutual interests, thereby slipping back to the traditional profit-maximising behaviour that hurt the intended collaborative approach. Grey was eventually forced to change the people involved with Port's contract: "*the situation* [Grey's employees giving priority to their own interests] *forced me to change the team. In fact, things have gotten better from that moment onwards and we started to behave more in line with what we agreed in the contract*" (Grey, regional director, R3, P2). Port confirmed that this change in personnel helped to restore the relationship between both organisations: "*Grey is now better able to put themselves in our shoes and the relationship is back on track. Actually, it is better than it ever was before*" (Port, contract manager 1, R3, P2).

During the first couple of months, both contracting organisations needed to adjust to the new contract and their new roles. Grey now had the lead in various maintenance tasks and were responsible for ensuring these were performed on time. Moreover, it was expected that Grey changed from a traditionally 'reactive' contractor (solely focused on profit) to a 'proactive' manager of Port's assets: "*money cannot be the issue in this contract, because we have agreed on a fixed percentage of profit. The old contractor's behaviour is profit maximisation and of course I emphasised a lot that this old behaviour is not desirable in this contract*" (Grey, regional director, R3, P2). Slowly but gradually Grey adjusted to their new role in which they should take ownership of the work they provided and the end result: "*I now notice, with the new project leader, that Grey is trying to become more proactive*" (Port, contract manager 1, R3, P2). Grey even went beyond their traditional profit-maximising approach over time: "*there is also a kind of ownership developing. You are a kind of co-owner of the port area. It is your business card, so you want it to look good and be reliable*" (Grey, data specialist 2, R3, P2). Not only Grey needed to adjust to the new contract and behave accordingly, also Port struggled with behaving in line with the intended collaboration. During the first couple of months, Grey noticed that: "*Port did not 'sit on their hands'. They were constantly checking behind the scenes and checking us*" (Grey, regional director, R3, P2). Port admitted that "*it is difficult now that we focus more on output and the relationship rather than on the actual contractual framework. And I think that is challenging for us*" (Port, maintenance specialist, R3, P2).

Apart from the steep learning curve in the initial months of the contract period, there were also several learnings that led to adjustments in the contract documents that were being executed. First, Grey had become more experienced with organising the maintenance activities to be performed more efficiently: "*we had produced extensive maintenance plans. During the execution phase we found out that some plans were too detailed or too large. So, we managed* *to find significant savings in financial terms*" (Grey, contract manager 2, R3, P2). Furthermore, the two contracting organisations found out that not all KPIs in the contract were relevant. As such, critical changes to the KPIs that had been put in place in the transition period were proposed: "*we have drawn up new KPIs for the new year. During the current year we found out that the KPIs were not met. However, my boss did not call me to ask what happened. Also no one from Port called. So, if KPIs are not met, and nobody seems to care about this, then maybe we chose the wrong KPIs*" (Grey, contract manager 2, R3, P2). After Port and Grey realised that Grey's performance was satisfactory, even though contract KPIs suggested otherwise, they jointly decided to introduce a new set of KPIs that better reflected the desired performance. These new KPIs would be revaluated annually.

Finally, there were also developments regarding the data and data management clauses of the contract. The original clauses did not provide much direction on how to share and manage data between the two contracting organisations. Moreover, Grey struggled with getting the data part of the contract up and running in the beginning of the execution period: "*the first two or three months was a really steep learning curve, also regarding collecting and sharing data*" (Grey, data specialist 1, R2, P2). Along the way, both contracting organisations became more familiar with their own needs as well as data management processes and sought to incorporate these learnings in the existing contract: "*we will have a meeting about that next week, to update Annex 9* [data management annex]. *We will check how it is written now and whether the current text is still good, or whether we have become smarter and more practical* [with data] *and hence should write it down differently*" (Port, contract manager 1, R3, P2). As such, the joint learnings regarding data and data management led to an improved specification of related clauses: "*we had an information protocol in which we specified when we wanted to transfer or exchange information, in which format, via what programmes and what the expected content should be. Later, it turned out that what was initially written and agreed upon was not quite as how it was interpreted in practice, so we revised that with the client*" (Grey, data specialist 2, R3, P2).

#### *3.4.2.6 Learning from Period II in case Green*

Although the start of the execution period was hectic, Green was found to thrive under the increased responsibility that they could take under the performance-based contract: "*what struck me from the start is that Green feels more comfortable with a performance-based contract. It is their call now. Of course, more risks now lie with Green, but they really enjoy organising the maintenance activities themselves and I see them really flourish*" (Port, contract manager 2, R3, P2). This confirmed the expectations Port had of Green before the start of the execution period: "*that* [contract execution] *naturally went more smoothly as Green had a different starting level when looking at the quality*" (Port, head of subdepartment 1, R3, P2). Green's 'higher quality' was the result of their previous experiences with working under performance-based contracts while collaborating with other clients. Apart from Green's experience with the type of contract, the employees of the two contracting organisations also connected on a personal level with each other: "*I think we really click. We are both having a good time and we like what we do. We just get along very well and even if it is not about work, we know where to find each other*" (Green, contract manager, R3, P2). As a result of these good relations between the employees of both contracting organisations, the collaboration as a whole thrived: "*if you look at Green's organisation, and how we collaborate and assess each other,* *that is quite positive*" (Port, contract manager 2, R3, P2). This translated into stable relationships between the employees of both organisations, without any personnel changes at either side during the execution period.

Despite having experience with working under performance-based contracts, Green was still unfamiliar with the way Port would behave during the execution period. Green did not know what to expect at the start: "*when we started last year, we were very unsure as a lot was coming our way with the new contract. What do we need to comply with? How strict is Port? We did not really know where we were going*" (Green, contract manager, R3, P2). Later on in the execution period, Green observed the following: "*I expected that Port would be much stricter with enforcing the contract. However, this turns out to be much less than expected*" (Green, contract manager, R3, P2). Looking from the outside, Green found that Port behaved less strict than expected and was generally happy with their behaviour. Internally, however, Port had struggled to develop realistic expectations and act accordingly: "[in the beginning] *as soon as there was a minor deviation in quality or a disagreement, we internally discussed it with the idea that 'for this amount of money, Green should deliver'. But you should not do this. You must be willing to award something based on the proposed criteria, but you cannot hold it against them if they do not deliver more than proposed*" (Port, project manager, R3, P2).

During the first two years of the execution period, learnings occurred in the collaboration between Green and Port that already led to several adjustments made to the formal contract. One adjustment made in the contract was regarding the assets in scope: "*there have been some adjustments for sure. Parts and assets have been added, quantities have been recalibrated*" (Green, contract manager, R3, P2). While executing the contract, Green found out that not all greenery assets were included in the scope of the contract and that for some asset types, more assets were actually in Port's area than initially thought. To cover the additional costs and work, the contract was adjusted accordingly. Moreover, Green and Port had structural evaluations of KPIs in place: "*in several areas we have lowered the standard for the grass length to 20 cm, because this poses no risk at all and is cheaper since Green has to mow less. So, the performance requirements have been adjusted, yes*" (Port, contract manager 2, R3, P2). These structural evaluations ensured that the KPIs remained relevant and that the contract overall remained workable and profitable for both contracting parties.

There have also been developments regarding the data and data management clauses of the contract between Green and Port during the first two years of the execution period. Already at the start of the execution period, Port concluded that they were not able to clearly what data needs they had: "*I think a weak point is still the data part. This entire data part, including supplying data and understanding what we* [Port] *want*" (Port, contract manager 2, R3, P2). This translated into vague and generic data and data management clauses that not necessarily reflected the reality. Moreover, these generic clauses also hampered the development of connections between the IT-systems of both contracting organisations to automatically transfer data. The connection itself, as well as any agreements, needed to be discussed while the contract was being executed already: "*as far as I know this connection is non-existent. We have a deadline for developing this on, I think, 1 July 2020*" (Green, project manager, R2, P2). This meant that during the first part of the execution period, no data was shared between Green and Port: "*we have actually not received any data until now. The project leaders* [from Green and Port] *thought they did, but that is not the case. Luckily, Green is willing supply this data reactively* [in response to Port's requests]" (Port, data specialist, R3, P2). Green confirmed this as well: "*basically, we share everything. All data that we generate, all data that we register will be transferred to Port*" (Green, data specialist, R2, P2). Along the way, both contracting organisations became better in understanding in each other's data needs and committed themselves to continuously update the data and data management clauses to ensure these clauses became increasingly effective.

### *3.4.3 Cross-case analysis: comparing case Grey with case Green*

The main symptoms (actions and behaviours that triggered intra-contract learnings) and observations (the actual intra-contract learnings that were recorded in each phase) from the two embedded cases have been captured in **Table 3.2**. The results from these two embedded cases show that Port and their contractors during specific contract periods made various post-formation adjustments to both contractual and relational governance. Both cases seem to reveal a pattern involving increased formal contractual governance, in the form of additional, as well as more refined contractual clauses, and increased formal relational governance in the form of explicated and codified patterns of expected behaviours. This pattern of increased formality was triggered by Port as it was seeking for contracts with a stronger 'legal' basis and a clearer definition of behaviours as to lower potential risks on their side. Grey and Green in turn aimed for 'leaner' and less formalised contracts that focused on easy execution and a more informal relationship with Port. As the performance-based contract was operationalised during Phase II, further adjustments took place regarding the actual behaviours displayed by the three parties involved, in conformance with what had been codified in the formal contract.

**Table 3.2** Main observations from Grey and Green

<table>
<tr><th></th><th></th><th>Grey</th><th>Green</th></tr>
<tr><td rowspan="3">Period I</td><td rowspan="2">Generic</td><td>Symptoms:<br>• No experience in designing PBC contracts.<br>• Lack of direction for designing a PBC contract.<br>• Draft contracts with insufficient legal basis and PBC elements.<br>• No open communication between Port and Grey.<br>• Intervention by Port: 15 days of joint writing sessions.</td><td>Symptoms:<br>• Some experience in designing PBC contracts.<br>• Lack of direction for designing a PBC contract.<br>• Draft contracts with insufficient legal basis.<br>• Misunderstandings that caused rework.<br>• Unclarity regarding roles.<br>• Intervention by Port: 5 days of joint writing sessions.</td></tr>
<tr><td colspan="2">Intra-contract learning outcomes observed:<br>• Incorporating contract clauses that specify recurring meetings between the contracting parties.<br>• Formalising intended relationship by explicating it in writing.</td></tr>
<tr><td>Data</td><td colspan="2">Symptoms:<br>• Generic clauses, lacking a sufficient level of detail.<br>• Data part in contract far from complete.<br>• Underestimation of the work needed to complete data clauses.</td></tr>
</table>

| | | | |
|---|---|---|---|
| | | **Intra-contract learning outcomes observed:**<br>• Not applicable | |
| **Period II** | *Generic* | **Symptoms:**<br>• Major escalation: employees not behaving as expected.<br>• Port intervening in what maintenance activities need to be performed.<br>• Specified maintenance turned out to not correspond well with practice. | **Symptoms:**<br>• Port struggling 'behind the scenes' but being lenient in terms of contract enforcement.<br>• Scope of contract did not correspond with reality.<br>• Structural evaluation of KPIs in contract. |
| | | **Intra-contract learning outcomes observed:**<br>• Shaping the relationship in line with patterns of expected behaviour as codified in the contract.<br>• Adjustments to contract specifications (e.g. scheduled maintenance activities, assets in scope) and to KPIs. | |
| | *Data* | **Symptoms:**<br>• Contracting parties have difficulties identifying and explicating their data requirements.<br><br>**Intra-contract learning outcomes observed:**<br>• Developing a mutual understanding regarding specific actions needed based on generic data clauses.<br>• Revision of data clause to reflect the 'true' way of working that developed during contract execution. | |

*3.4.3.1 (Post-formation) adjustments made to contractual governance mechanisms*

In both periods, the case organisations made (post-formation) adjustments to the contract documents with the aim to directly include learnings from the experiences they jointly gained. Near the end of the first period, it became clear that the expectations of Port and the expectations of the contractors were far apart, requiring Port to manage the relationship with both contractors by staging an intervention and changing the contractual agreements between them. As Grey and Green received a carte blanche and interpreted the 'assignment' of Port in their own way, while Port remained passive in the beginning, the contract design phase was challenging for both contractors. When the drafts became increasingly detailed along the way, Port increasingly voiced their concerns that the designs were not what they intended them to be (especially the degree of formality in the contracts was too low in the eyes of Port), which eventually triggered them to intervene in both cases. Due to Port's passive stance and Grey's and Green's determination to show their abilities to meet Port's requirements, discussions between the parties took place irregularly and communication was deficient. Port's intervention therefore entailed engaging in joint discussions and collaborative writing sessions with each individual contractor to align ideas and interests. These interventions demonstrated the importance of regular discussion and mutual understanding, which inspired Port, Grey and Green to formalise their relational governance mechanisms by ensuring that agreements were included which specified that regular meetings would be organised during the execution phase.

Including clauses regarding data and data processing activities into the contracts during the contract design phase proved to be challenging in both cases. Further investigations revealed that the design of such clauses was only considered towards the very end of the first period as other aspects continuously demanded the attention of both contracting parties, such as, for example, the maintenance plans and KPIs. This came at the expense of designing effective data (management) clauses, as in neither of the cases were the parties actively discussing questions related to data being generated and required for the maintenance of Port's assets, nor how data processing activities could be managed between the two parties. Unintendedly, data had thus become a 'by-product' rather than a core element of the outsourced maintenance process, which led to relatively 'generic' contract clauses being included in both cases (i.e. a fairly informal contractual governance mechanism), with neither of the organisations knowing for sure what data they needed and how to process them to obtain meaningful information. During the second period, attention for data increased since the initial months of contract implementation were associated with shaping both parties' behaviours in correspondence with the expectations as explicated in the formal contract. Grey, Green and Port realised they needed to jointly learn about their own and each other's data needs and how these needs can effectively be satisfied as they continued to struggle with how to manage data and data management. The resulting learnings directly led to adjustments to those clauses and annexes that focused on data in an attempt to better reflect the actual practices performed by the parties involved (i.e. formalising the contractual governance mechanism). This suggests that thinking about managing data and the related processing activities during buyer–supplier relationships cannot simply be done near the end of a design phase or quickly in between. Rather, building and implementing data processing activities requires joint learning and these processes must be given a more central role during the design and subsequent execution phase.

#### *3.4.3.2 (Post-formation) adjustments made to relational governance mechanisms*

Next to the (post-formation) adjustments made to the contractual governance mechanisms, the case organisations also adjusted their relational governance mechanisms following learnings in both periods. A key difference between the two contractors was their level of experience: while Green already had experience with (co-)writing performance-based contract clauses, Grey did not have such experience. Since Green had more experience with writing the type of contract the buyer was aiming for (in this case a performance-based contract) helped them to better serve their buyer. This was reflected in the extensiveness of the intervention (a joint writing session lasting for seven days with Green versus fifteen days with Grey), because Port was more satisfied with the number and quality of performance-based clauses that had already been designed by Green. In contrast, Grey's design resembled that of the cost reimbursable contract that governed the transition phase. At the same time, as Green was more experienced, higher levels of trust were observed between Green and Port. Trust between Port and Grey, on the other hand, declined as it became increasingly apparent Grey required more guidance during the design phase. Acknowledging experience levels upfront, and adapting expectations to these levels, helps keep trust high between contracting organisations.

Another aspect that stood out were events on an individual level and the degree to which a joint goal was (or was not) pursued. While no personnel changes occurred in case Green, case Grey involved several changes on both sides of the dyad, in both Periods I and II. In case Green, individuals had good relations with each other on all organisational levels. Although there were some highs and lows along the way, the relationship between Green and Port remained good on average and improved throughout the two periods. A key aspect is that the employees at both Green and Port had a clear joint goal in mind and were willing to invest in a relationship where the care for Port's assets was priority number one for both organisations. In case Grey, a different picture emerged. While the individuals at the managerial level from both Grey and Port established and maintained good relations, there were several conflicts at the 'operational level' (i.e., the contract writers and managers). Grey's employees responsible for the contract took a more traditional approach and valued pursuing their own interests higher than working towards achieving a mutual goal. This conflicted with the position of Port's employees that hoped to have a more trusting relationship where a mutual goal would take precedence over individual company goals. It took some time before Grey found the right person to manage the contract with Port and who could restore the trust of Port in Grey that they would focus again on the mutual goals rather than individual ones. At the same time, Port also made changes to their employees. In addition to the challenge of finding the right persons for Grey's contract, the contract itself contained fewer performance-based clauses than Port initially envisaged, especially compared to Green's contract. However, after the right persons had been identified and appointed, Grey was able to pick up the pace and started to learn more about the performance-based concepts.

## 3.5 Conclusion

In this paper we explored how intra-contract learning takes place between contracting organisations that are undergoing a digital transformation and how they employ this learning to make post-formation adjustments to both contractual and relational governance mechanisms. Digitalisation of operations triggers digital transformations within organisations and their relationships that bring along fundamental questions and challenges, including those related to the management of data. As contracting organisations are not able to oversee all implications a digital transformation may have for their relationships, they cannot develop fully effective contracts and relational governance mechanisms *ex ante*. It is thus no surprise that organisations in digitalising buyer–supplier relationships are required to make post-formation adjustments to their governance mechanisms by jointly learning with their partners about the implications of digitalisation that expose themselves over time and to subsequently adjust the contract agreement and relational governance mechanisms as to tailor better to new situations or incorporate insights from new experiences. Additionally, a 'match' between not only the individuals from both sides of the dyad, but also between the involved individuals and the overall goal of the contracting parties influence the rate of intra-contract learning. Misalignments between the individuals' goals from both sides of the dyad (i.e. individuals pursuing other (individual) goals rather than the joint goals that were set out for the overall relationship) may lead to annoyances and cause disruptions and delays in the learning processes.

This study makes three contributions to the literature. First, this study contributes to our growing understanding of how digitalisation influences operational activities, specifically the procurement activities (which includes contract design and managing ongoing relationships) of organisations that need to carefully manage data and the related processing activities within buyer–supplier relationships (Holmström et al., 2019; Søgaard et al., 2019). Secondly, it contributes to the literature related to learning-to-contract by examining how intra-contract learning processes enable contracting organisations to make post-formation adjustments to their contractual and relational governance mechanisms in order to cope with the digitalisation of their buyer–supplier relationships. By taking a longitudinal approach, this paper satisfies the need for more longitudinal research in buyer–supplier relationships that provides in-depth insights into the dynamics in these relationships that are increasingly seen as non-static (Keller et al., 2021), brought about by the unpredictable implications of digitalisation. Thirdly, this paper contributes to the discussion about regarding the formality of each type of governance mechanisms as more fluid rather than static. In their recent paper, Keller et al. (2021) argues that contractual governance mechanisms do not necessarily have to be formal and relational governance mechanisms informal. Instead, both governance mechanisms can have different degrees of formality. Also in our paper, we found evidence that the degree of formality of a specific governance mechanism can change over time from more informal to more formal.

This study also has important implications for practice. First, our paper demonstrates that buyer–supplier relationships undergoing digitalisation are typically unable to write effective contracts and employ the 'right' relational governance mechanisms *ex ante*. Rather, as digitalisation provides uncertainties regarding new technological developments and potential new data streams, it is important that contracting organisations create an environment in which they can jointly learn from their experiences with new technologies and/or data streams that are introduced during their contract period and directly implement these learnings by making adjustments to their contracts and relational governance mechanisms (specifically cooperative norms) during an ongoing relationship. Secondly, our paper shows that contractual governance does not necessarily have to be very formal (and can be rather informal as well), while relational governance is necessarily informal (and can potentially be more formalised as well). This implies that organisations should not only carefully consider the mix of contractual and relational governance when designing effective collaboration and adjustments to this mix during an going relationship, but also should take into account the degree of formality that is needed from each type of governance at the beginning of a relationship and that this degree of formality can change over time (also after the contract has been signed). Lastly, the case clearly demonstrates that developing data clauses is a complex venture that contracting organisations should not take up lightly. Rather, it should be given a central role during the design phase of the contract.

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## Appendix D

**Table D1** Main data sources and use of data

| Data source | Type of data | Use in analysis | Period | | |
|---|---|---|---|---|---|
| | | | 0 | I | II |
| **Data collection round 1** | | | | | |
| *Interviews* | 6 interviews at Port *(280 minutes)*<br>• Head of department<br>• Subdepartment head 1 *(main responsible for contract Grey and Green)*<br>• Subdepartment head 2<br>• Subdepartment head 3<br>• Subdepartment head 4<br>• Project manager | Understanding Port's history with respect to outsourcing the maintenance of their assets.<br>Overview of the data management experience at Port and their requirements. | X | | |
| *Internal documents* | Various internal documents from Port *(348 pages)*<br>• Documents about Port's sourcing strategy<br>• Documents about Port's digitalisation strategy<br>• Documents about data management at Port<br>• Documents with Port's company information | Understanding Port's intended digital direction.<br>Understanding Port's data requirements, how they manage data, and data sharing principles.<br>In-depth understanding into Port's approach towards the contractor's market. | X | X | X |
| **Data collection round 2** | | | | | |
| *Interviews* | 8 interviews at Port *(475 minutes)*<br>• Subdepartment head 1 *(main responsible for contract Grey and Green)*<br>• Contract manager 1 *(managing contract Grey)*<br>• Contract manager 2 *(managing contract Green)*<br>• Project manager<br>• Maintenance specialist<br>• Data specialist<br>• Contract specialist 1<br>• Contract specialist 2 | Insights from contract design phase (as seen from the Port's point of view).<br>In-depth understanding of the individual behaviours at Port with respect to the relationships with Grey and Green. | X | X | |
| | 4 interviews at Grey *(215 minutes)*<br>• Regional director *(main responsible for contract Grey)*<br>• Contract manager 1 *(managing contract Grey)*<br>• Data specialist 1<br>• Advisor | Insights from the contract design phase (as seen from Grey's point of view). | | X | |

| | | | | | |
|---|---|---|---|---|---|
| | 3 interviews at Green *(170 minutes*)<br>• Regional director *(main responsible for contract Green)*<br>• Project manager<br>• Data specialist | Insights from the contract design phase (as seen from Green's point of view). | | X | |
| *Contracts* | Contracts of Port's previous outsourcing relationships *(178 pages)*<br>• 4 contracts<br>• Executed between 2009 & 2016 | In-dept review of contractual clauses from Port's previous outsourcing relationships. | | | |
| | Contract documents for contract Grey *(216 pages)*<br>• 60% version<br>• 80% version | Development of the contractual clauses. | | X | |
| | Contract documents for contract Green *(245 pages)*<br>• 60% version<br>• 80% version | Development of the contractual clauses. | | X | |
| Data collection round 3 | | | | | |
| *Interviews* | 6 interviews at Port *(275 minutes)*<br>• Subdepartment head 1 *(main responsible for contract Grey and Green)*<br>• Contract manager 1 *(managing contract Grey)*<br>• Contract manager 2 *(managing contract Green)*<br>• Project manager<br>• Maintenance specialist<br>• Data specialist | Insights from the contract execution phase (as seen from Port's point of view).<br>In-depth understanding of the individual behaviours at Port with respect to the relationships with Grey and Green. | | X | X |
| | 5 interviews at Grey *(230 minutes)*<br>• Regional director *(main responsible for contract Grey)*<br>• Contract manager 2 *(managing contract Grey)*<br>• Contract specialist<br>• Data specialist 2<br>• System specialist | Insights from the contract execution phase (as seen from Grey's point of view).<br>In-depth understanding of the individual behaviours at Grey with respect to the relationship with Port. | | X | X |
| | 2 interviews at Green *(115 minutes)*<br>• Contract manager *(managing contract Green)*<br>• Maintenance specialist | Insights from the contract execution phase (as seen from Green's point of view).<br>In-depth understanding of the individual behaviours at | | X | X |

| | | | | | |
|---|---|---|---|---|---|
| | | Green with respect to the relationship with Port. | | | |
| *Contracts* | Contract documents for contract Grey *(118 pages)*<br>• Final version | In-depth review of contractual clauses of contract 'Grey'. | | | X |
| | Contract documents for contract 'Green' *(102 pages)*<br>• Final version | In-depth review of contractual clauses of contract 'Green'. | | | X |

## Appendix E

In this appendix, the interview protocols for the three rounds of interviews are provided. First, the questions that guided the semi-structured interviews in the first round are presented. These interviews only included employees of Port of Rotterdam in management positions (i.e., those with the role of 'head of department' and 'subdepartment head') with the aim to obtain a global overview of the organisation's activities with respect to innovation and the management of assets and uncover interesting cases.

*Organisation questions*

1. In what department are you working?
2. What is your position?
3. How many people are working in your department?
4. How does your department relate to other departments in your organisation?

*Management & maintenance activities*

1. Is your department responsible for the management and/or maintenance of assets?
2. Can you provide examples of assets that your department is responsible for?
3. What is the total worth of the assets your department is responsible for?
4. How does your department organise the maintenance activities?

In case outsourcing of activities took place:

5. To what type of organisation are the maintenance activities outsourced?
6. What is the average length of these outsourcing relationships?
7. To what extent does the exchange of data play a role in the relationship with the service provider(s)?

*Data and data-driven innovations*

1. Does your department use data-driven innovations (e.g. smart sensors, smart meters, IoT, cloud computing)?
2. Can you give examples of the data-driven innovations your department is using?
3. Where does your department use these innovations for?
4. To what extent does it involve the collection of data?
5. Did your department (recently) decide to implement data-driven innovations and (big) data tools with the aim to improve the management and/or maintenance of assets?
6. Do you have an example of a successful implementation?
7. Do you have an example of a less successful implementation?

Secondly, the questions that guided the semi-structured interviews in the second round are presented. These interviews included employees from Port, Grey and Green with various roles from various levels with the aim to obtain 1) information about Port's previous outsourcing relationships and 2) both retrospective and real-time data regarding the transition period Port, Grey and Green were undergoing.

First, the interview protocol for interviewees from Port is presented.

*Organisational questions* (all interviewees)

1. In which department are you working?
2. What is your current position within your organisation?
3. In what way were you involved in the tender for contract 'Grey'/ 'Green'?

*Questions regarding the transition period* (all interviewees)

1. Why did your organisation opt for a two-year period to design a new contract in collaboration with the contractor?
2. Can you describe the period from awarding the tender to the contractor until now?
3. How has the relationship between the contractor and your organisation developed over the past two years?
4. What are the most important learning points from this 'transition period'?

Specific questions about the transition period for interviewees with the roles 'subdepartment head', 'project manager', 'contract manager', and 'maintenance specialist'.

1. Can you indicate what the 'Grey'/ 'Green' contract includes?
2. How has the contractor currently organised their maintenance activities?

Specific questions about the transition period for interviewees with the role 'data specialist'.

1. What role has data played during the transition period?
2. Which specific (financial) agreements have been made in the contract used during the transition period regarding data?
3. How do the two organisations use the data that they are sharing?

*Questions regarding the new contract design* (all interviewees)

1. Can you describe the ideal collaboration with your contractor?
2. What role will the new contract play in this collaboration?

Specific questions about the contract design for interviewees with the roles 'subdepartment head', 'project manager', 'contract manager', 'contract specialist', and 'maintenance specialist'.

1. Can you describe the ideal design for a new contract?
2. On what is the new contract design based?

3. In which way does the new contract affect the way in which maintenance activities are performed by the contractor?

Specific questions about the contract design for interviewees with the role ‘data specialist’.

1. How is the sharing of data between the two organisations guaranteed in the new contract?
2. How does the new foresee any changing needs regarding data in the future?
3. How will the data be used by the organisations that is being shared during the time the new contract runs?

*Questions regarding previous contract periods* (interviewees with the role ‘contract specialist’)

1. Can you describe the tenders and contracts regarding maintenance from 2009 up until the market consultation in 2016 in which your organisation was involved?
2. Can you describe the market consultation and the related results that Port performed in 2016?

Below, the interview protocol for interviewees working at Grey and Green is presented.

*Organisational questions* (all interviewees)

1. In which department are you working?
2. What is your current position within your organisation?
3. In what way were you involved in the tender for contract ‘Grey’/ ‘Green’?

*Questions regarding the transition period* (all interviewees)

1. Can you describe the assignment formulated by Port for this specific tender?
2. Why did Port opt for a two-year period to design a new contract in collaboration with your organisation?
3. Can you describe the period from the moment you were awarded the tender until now?
4. How has the relationship between Port and your organisation developed over the past two years?
5. What are the most important learning points from this ‘transition period’?

Specific questions about the transition period for interviewees with the roles ‘regional director’, ‘advisor’, ‘contract manager’, ‘project manager’, and ‘maintenance specialist’.

1. Can you indicate what the ‘Grey’/ ‘Green’ contract includes?
2. In what way have you currently organised the maintenance activities that you conduct for Port?

Specific questions about the transition period for interviewees with the roles 'data specialist' and 'system specialist'.

1. What role has data played during the transition period?
2. Which specific (financial) agreements have been made in the contract used during the transition period regarding data?
3. How do the two organisations use the data that they are sharing?

*Questions regarding the new contract design* (all interviewees)

1. Can you describe the ideal collaboration with Port?
2. What role will the new contract play in this collaboration?

Specific questions about the transition period for interviewees with the roles 'regional director', 'advisor', 'contract manager', 'project manager', 'maintenance specialist', and 'contract specialist'.

1. Can you describe the ideal design for a new contract?
2. On what is the new contract design based?
3. In which way does the new contract affect the way in which maintenance activities are performed by your organisation?

Specific questions about the contract design for interviewees with the role 'data specialist' and 'system specialist'.

1. How is the sharing of data between the two organisations guaranteed in the new contract?
2. How does the new foresee any changing needs regarding data in the future?
3. How will the data be used by the organisations that is being shared during the time the new contract runs?

Finally, the questions that guided the semi-structured interviews in the third and final round are presented. These interviews included employees from Port, Grey and Green with again various roles from various levels with the aim to obtain real-time data regarding the execution phase of the newly designed contracts.

First, the interview protocol for interviewees from Port is presented.

*Questions regarding the development of the relationship* (all interviewees)

1. How has your organisation experienced the collaboration between Port and the two contractors so far?
2. What role have the contractual agreements played so far?
3. How would you characterise the contractor's behaviour to date?
4. How does your organisation experience the current division of roles in the relationship?

*Questions regarding data and IT systems* (all interviewees)

1. Can you describe how the data sharing between your organisation and the two contractors went so far?
2. To what extent are both parties motivated to share data?
3. Can you describe the most important developments regarding data and IT systems?
4. What role has data played in the collaboration so far?
5. Does the contract sufficiently meet the current data needs?
6. How has the shared data been used so far?

*Questions regarding maintenance activities* (interviewees with the roles 'subdepartment head, 'project manager', 'contract manager', and 'maintenance specialist')

1. How have the maintenance activities been performed in recent months?
2. To what extent do the contractors meet the contract requirements regarding the maintenance for which they are responsible?
3. To what extent does your organisation have confidence in the contractors' knowledge and skill so far?

*Questions regarding the contracts* (interviewees with the roles 'subdepartment head', 'project manager', and 'contract manager')

1. What changes have been (or will be) made to the current contracts?
2. Who had the lead while writing the initial contracts?
3. Who has the lead in proposing/making adjustments in the contracts?
4. What was the decisive factor that motivated you to choose for Grey and Green?

Below, the interview protocol for interviewees working at Grey and Green is presented.

*Questions regarding the development of the relationship* (all interviewees)

1. How has your organisation experienced the collaboration with Port so far?
2. What role have the contractual agreements played so far?
3. How would you characterise Port's behaviour to date?

*Questions regarding data and IT systems* (all interviewees)

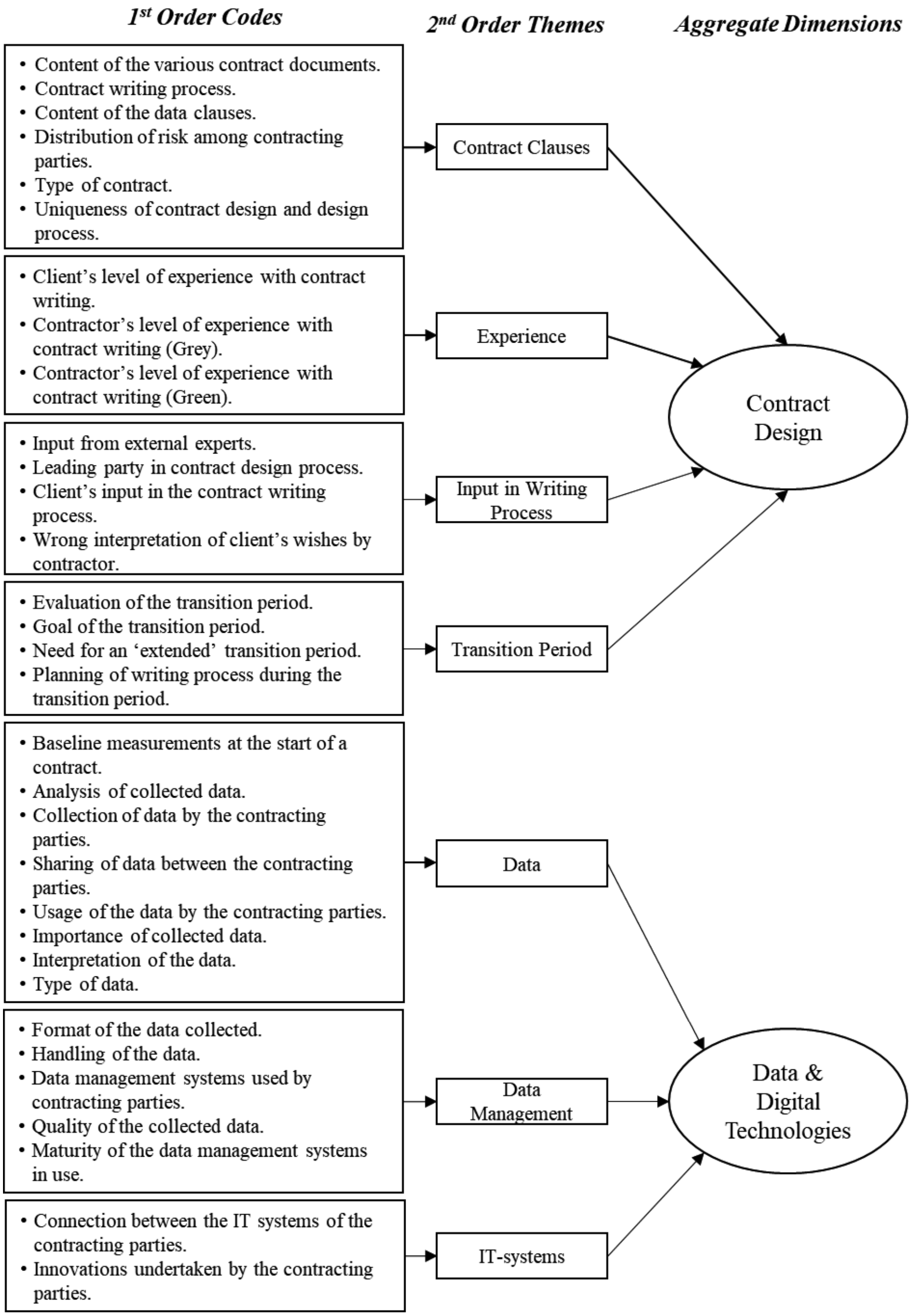
1. Can you describe how the data sharing between your organisation and Port went so far?
2. To what extent are both parties motivated to share data?
3. Can you describe the most important developments regarding data and IT systems?
4. What role has data played in the collaboration so far?
5. Does the contract sufficiently meet the current data needs?
6. How has the shared data been used so far?

*Questions regarding the contracts* (interviewees with the roles 'regional director', 'project manager', 'contract manager', and 'contract specialist')

1. What changes have been (or will be) made to the current contracts?
2. Who has the lead in proposing/making adjustments in the contracts?

## Appendix F

In the figure below, the final coding scheme is presented that was constructed for the data analysis of this paper.



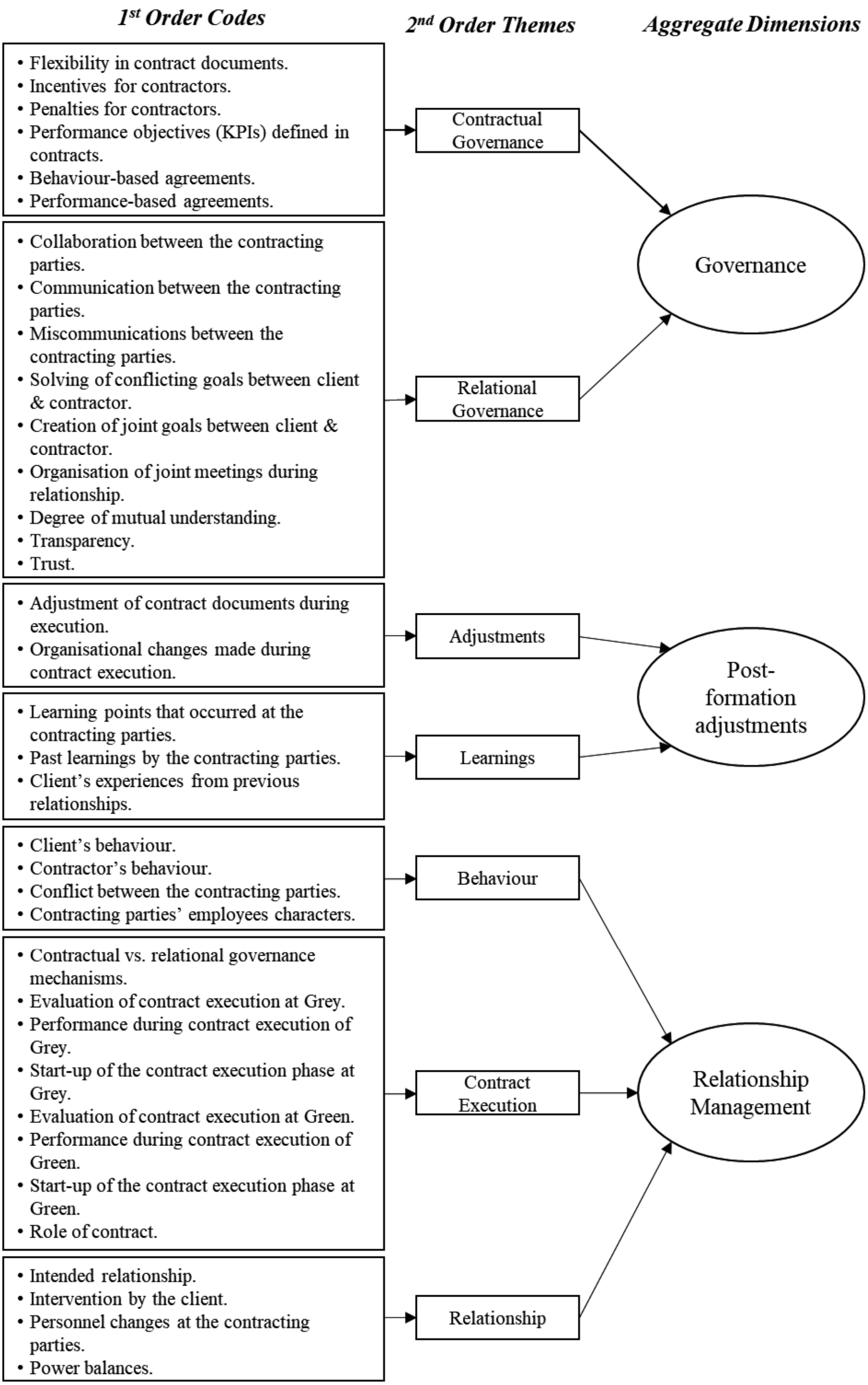



**Figure F1** Coding scheme used for data analysis

# Chapter 4

## Smart meters, smart grids?

## Lessons from digital transformation policy efforts in the Dutch energy transition


### Abstract

The energy transition is posing major challenges to society, such as the design of a sustainable energy service network. In public utilities, digitalisation promises to be a major enabler for the energy transition. Detailed energy data, or so-called smart meter data, can help grid managers better match demand and capacity, so that the electricity grid is operated with increased reliability and at a lower cost, even with increasing use of solar panels, wind turbines and electric vehicles. This is called smart grid management. So far, efforts in the electricity sector to digitalise are faltering. Thus, there is an urgent need to learn about these efforts to improve. First, it is important to learn from past efforts to leverage smart meter data to inform future attempts to implement smart energy grids. Second, digitalisation also affects the structural arrangements between the actors involved in the energy service network and how it operates as a whole. Effective governance of the relationships between actors becomes vital to deal with the growing risks inherent to the complexities and uncertainties of sustainable energy networks. Therefore, it is also important to learn how best to orchestrate the efforts of the public and private parties involved in the digitisation of the energy service network. To address both learning needs, we investigate a single case of a digital transformation policy failure related to the rollout of smart meters in the Dutch electricity sector. Drawing on a rich database comprising data from the start of the rollout in 2010 to 2021, we highlight several challenges that arose both in relation to smart grid management and network governance. We use these insights to develop a preliminary research framework and corresponding propositions on both concepts in the context of digitalisation.



**Keywords:** *Digital transformation, Smart meters, Smart grids, Network governance, Case study*



This chapter is based on a paper co-authored with dr. Martijn Jonker (Alliander/Delft University of Technology), Prof. Henk Akkermans (Tilburg University) and Prof. Wendy van der Valk (Tilburg University).

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## 4.1 Introduction

Climate change is forcing the world to use its energy sources more sustainably. Doing so entails a shift from fossil-fuel energy sources to more renewable sources (e.g. solar panels, wind turbines), as well as in the thinking about energy usage behaviour and associated consumption. From an operations management (OM) perspective, this shift implies a move from centralised generation and top-down distribution of energy to a distributed and networked architecture for smart grid management (Giordano & Fulli, 2012). At the same time, the current wave of digitalisation provides organisations with digital technologies (e.g. smart meters), enabling them to fundamentally revisit their operations (Holmström et al., 2019), including the (smart) management of electricity grids. Decentralised generation and distribution affect the sustainable production of energy, while data from smart meters help reduce energy consumption. Meanwhile, these new ways of energy production and consumption must be accommodated within existing grids, which have limited capacity.

Historically, the realisation of responsible consumption and production of energy (United Nations' Sustainable Development Goal 12) first resonated with a focus on reducing consumption. Countries in the European Union (triggered by a 2009 EU Directive that required them to equip 80% of households with a smart meter by 2020 [Van Aubel & Poll, 2019]) have hence rolled out smart meters to provide consumers with detailed usage data, so that they can adjust their energy usage behaviour and thereby curb energy consumption. Presently, the emergence of new forms of energy supply (e.g. solar panels) and new forms of demand (e.g. charging electric vehicles) is causing the focus to shift. To accommodate larger and more localised surges in energy supply and demand, smart grid management is becoming essential. This requires a new and digitally enabled grid architecture that can use constrained capacity more smartly to balance demand, reduce operation costs and allow new business models and actors into the energy market (Giordano & Fulli, 2012). Here, smart meter data are essential for smart grid management. Nevertheless, studies on the use of smart meter data for smart grid management purposes in the OM field seem to be virtually absent (Parker et al., 2019).

Digitalisation and the resulting digital technologies (e.g. smart meter) that support the transition to smart grids affect more than demand and supply management; they also affect the inter-organisational (governance) processes between the various smart grid stakeholders involved (Holmström et al., 2019). (Re)designing the large-scale and complex network architecture for sustainable energy production and consumption calls for the participation of many public and private actors in an extended system-oriented network (Nowell & Milward, 2022), which is a network associated with the system of providing energy services, as well as with managing the digital transformation of these services. It requires OM researchers to broaden their perspective as well. We come from the position of a (supply) network that "consists of inter-connected firms" (Kim et al., 2011, p. 195) that ideally should be "mutually and co-operatively working together to control, manage and improve the flow of materials and information from suppliers to end users" (Aitken, 1998, p. 2). However, a more extended notion of a network of organisations that is wider in scope and more fluid (Spring et al., 2017) and explicitly also includes end users and governmental institutions may now be required. For such networks to become effective, widespread awareness of technical interdependence and complementarities between actors appears essential, as does the notion of an overarching purpose (Shipilov & Gawer, 2020). The enhanced design of networks will also help ensure that while developing public goods and services (such as energy) the end consumer's input is not neglected in the development process (Trischler & Westman Trischler, 2021).

The energy transition makes network failures more likely, in both senses of the word 'network'. First, there is the electricity demand and supply network and how this functions dynamically. Here, more unexpected events can occur, so more can go wrong. Second, there is also the organisational network, or the structural arrangements between the organisations involved in the energy service network. Here, digitalisation changes the ways the efforts of participants in networks can effectively be orchestrated (Field et al., 2021). The governance of the relationships between network actors is vital to handle risk and to coordinate tasks and activities (Johnson et al., 2021).

Despite the large body of research on contractual and relational governance in inter-organisational relationships (e.g. Cao & Lumineau, 2015; Roehrich et al., 2020), governance arrangements for these relationships, specifically within (system-oriented) networks that include actors not involved in one or more particular buyer–supplier dyads, are a new and important area for research (Jacobides et al., 2018; Johnson et al., 2021). However, research explaining how the governance of such networks works in practice is limited to date (e.g. Bastl et al., 2019; Roehrich et al., 2020). More specifically, governance mechanisms, such as cooperation between firms to access resources (Hannah & Eisenhardt, 2018) and control and coordination to mitigate risk (Bastl et al., 2019), need to be understood in the specific context in which relationships—even those involving dyadic (contractual) arrangements—are interdependent. As such, their alignment is vital if the intended value proposition is to be realised (Moore, 2006). Current network governance literature (e.g., Provan & Kenis, 2008) already stresses the importance of alignment, and advances network goal consensus as critical to achieving positive network-level outcomes.

Thus, further understanding of the smart use of data obtained from digital technologies for smart grid management and how the governance of the energy service network (involving public and private actors) can be designed to lead to positive outcomes is necessary. In this vein, the rollout of smart meters in the Dutch electricity sector in the past decade can be highly informative, as this case is not yet a success story. Ten years after the start of the rollout of smart meters in the Netherlands, the effects on consumer energy consumption remain marginal, while the potential benefits of the use of data for enhanced operations of the energy grid are not fully reaped. We evaluate this case from two angles: that of smart grid management and that of network orchestration and governance. For this, the following to research questions were developed: 1) *how to use smart meter data to support smart grid decisions within the supply network*? and 2) *how to orchestrate governance in such a way that network actors are indeed incentivised to make those smarter decision?*

This study is best labelled as pre-theoretical research (Browning & de Treville, 2018; Hambrick, 2007), being theoretically interesting rather than theory-driven (Baker & Pollock, 2007), as it aims to stimulate theory development in both areas. Our main objective is to learn from the recent past to inform future policy and operations. This study develops a preliminary research framework and corresponding propositions on the effective functioning of energy service networks and enhanced operational decision-making through smart grid management in the context of digitalisation. These aim to help OM researchers and practitioners focus their efforts on further understanding (e.g. Collins & Browning, 2019) how to make smart use of smart meters. As such, this study retains the real-life details that are necessary for the framework to be relevant in an industry context and aims to provide the industry with relevant decision-making support (Parker et al., 2019).

Our intended contributions are threefold. First, we aim to contribute to the literature on digital transformation of operations by empirically studying the actions and effects in relation to the digitalisation of the Dutch electricity sector. To date, a lack of in-depth qualitative studies, particularly with a longitudinal character, inhibits our understanding of smart meter implementations and their impact on smart grid management. We identify why digital transformation has not (yet) taken place and advance recommendations targeting the OM–policy interface to inform both public and private parties embarking on smart utility implementation or enhancement (Helper et al., 2021). Second, we aim to contribute to theoretical thinking on the governance and management of a network of interdependent and complementary relationships, including the public sector, which deal with 'wicked' problems (Helper et al., 2021). How actors effectively operate in, and govern, system-oriented networks (such as the electricity network) is a topic that has received limited attention to date. We add to the current understanding of how networks (involving public and private actors) striving for innovation function (Johnson et al., 2021) and focus on how the activities of these actors can effectively be coordinated through network governance. Third, we contribute to the literature on smart grids, particularly how smart meter data can be used (as opposed to obtained), both in terms of operational decision-making (e.g. congestion management, outage localisation, theft detection) and for strategic decisions in capacity investment. In doing so, we add to the current understanding of how data from digital technologies aid network actors in making smarter operational decisions.

## 4.2 Theoretical background

### *4.2.1 Overview of extant literature on digitalisation in the electricity sector*

We conducted a comprehensive review of the OM and energy literature to enhance our understanding of digitalisation (particularly the use of smart meters) in the electricity sector, as well as in other sectors (e.g. water, telecommunications), and of digitalisation in supply networks and the related network governance (see **Appendix G** for an overview of findings).

Assessing the state of the art literature resulted in the identification of three distinct research gaps. First, a lack of in-depth, qualitative studies, particularly with a longitudinal character, has limited the understanding of smart meter implementation and how it affects smart(er) grids and their management. The second gap is a lack of attention on sets of actors operating in networks. Research in OM and energy tends to focus on a small number of actors (e.g. the consumer, the distribution system operator [DSO] or on dyads). The notion that the development of the electricity sector involves sets of actors operating in networks is largely neglected (with Chen et al. [2021] as a notable exception). The third gap is a lack of studies on how smart meter data can help smart grid management. Current research on smart meter data largely focuses on implementation challenges, not on how network actors can leverage these data. Therefore, we turn to a more elaborated discussion of the literature on smart grids and network governance, with the aim to understand how these concepts may inform the redesign of grid and electricity markets to transition to a more sustainable electric power industry (Parker et al., 2019).

### *4.2.2 Smart grid management*

Over the course of several decades, the traditional energy system evolved into a system in which electrical energy was generated at a centralised location using fossil fuels (e.g. oil, coal, gas) and then transported in one direction via the high- and medium-voltage grid to the low-voltage grid, where companies and households consumed the energy. These electricity grids were built for many decades and dimensioned so that a steady growth in demand could be accommodated. Moreover, the functions of generating and transporting electricity were established in a coordinated manner, as both functions typically were vertically integrated in a single organisation.

In recent years, the centralised energy generation has become more diversified as part of the energy transition, through solar farms and windmills. It is also rapidly being complemented with decentralised electricity generation at the low-voltage grid level, as households increasingly install sustainable generation units such as solar panels and batteries, allowing them to feed energy back to the grid. Consumers' roles are thus changing from purely consuming energy to also producing it (i.e. 'prosumers'; Pereira et al., 2018). This development is likely to continue, as electric vehicle batteries also to be used to feed energy back to the grid (Kahlen et al., 2018). At the same time, increased electric driving poses new demands on the grid (often claiming a large energy capacity), while the shift from gas heating to electric heating also affects grid utilisation. These developments are accompanied by the emergence of new actors in the electricity sector (e.g. charge-point operators for electric vehicles, heat pump suppliers, energy service organisations), while the previously vertically integrated energy companies are unbundling (Meeus & Glachant, 2018). Both traditional and new actors are contributing to the emergence of new electricity patterns in the low-voltage network, creating important operational challenges for the DSO (Parker et al., 2019).

A smart grid is necessary to control the distribution grid and to safeguard its operation and stability (Depuru et al., 2011; European Commission, 2011). A smart grid is "an electricity network that can cost-efficiently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – as to ensure economically efficient, sustainable power system with low losses, and high levels of quality and security of supply and safety" (European Commission, 2011, p. 2). Whereas the physical grid refers to the transmission lines, substations, transformers and cables, the 'smart' part refers to a digital layer in which data from various sensors, controls and automation in the grid enable a DSO to make better operational decisions to facilitate the developments accompanying the energy transition.

Smart grids are foremost a way to facilitate future developments in decentralised electricity generation (e.g. solar panels in households, wind turbines), next to the large-scale introduction of electric transportation. For example, congestion of the electricity distribution grid is a problem caused by the unrestrained and swift installation of energy production capacity. This can be problematic given the long lead times to install or upgrade electricity grids (Voogd, 2021). DSOs tackle these challenges by expanding the capacity of the grid (Barber, 2021). Moreover, DSOs make efforts to use the current electricity grid's capacity more efficiently. To do so, they must accurately monitor critical locations in the grid on a real-time basis and know exactly where issues in the grid may potentially arise. Such data are important for operational decisions related to controlling or switching the network in the event of an acute grid overload, but also to inform strategic decision-making, such as investment decisions within a certain congestion area.

The smart meter is therefore a key enabler of the transition to smart grids (Cooper, 2016; Ministerie van Economische Zaken, 2011). Smart meters installed in consumer homes measure local energy usage in seconds, providing real-time data with high granularity (Hu et al., 2015). These meters also measure the voltage quality and record data on specific events (e.g. sudden drops or surges in voltages). In this sense, smart meters can function as a large set of sensors for DSOs at the deepest end of the low-voltage level for grid optimisation. Although this may not have been the initial purpose of the smart meter, it is clear that smart meter data can provide a variety of additional benefits for smart grid management (Gouveia et al., 2017; Jenkins et al., 2015; Sovacool et al., 2017).

A first example of how smart meter data may benefit operational decision-making is improved congestion management. To avoid thermal overload or congestion of network components, a trigger that controls the load of the grid is required. Combining the smart meter with a home energy management system, for example, enables optimising the household's energy use based on the actual capacity of the grid (Haque, 2017). A second example involves smart meters allowing grid operators to determine the location of outages. Traditional outage processes are reactive as they largely rely on calls from consumers after which the engineers need to specify the location of the outage in person. By polling specific smart meters, the location of the outage can be found more quickly and thus be fixed sooner (Jiang et al., 2016; Yuan et al., 2020), while enabling the DSO's service policy to become more proactive and independent of consumer calls. A third example is energy theft detection (Ahmad et al., 2018; Chakraborty et al., 2021). If a large voltage drop from one household to another occurs, with no substantial energy usage, this can point to either an energy leakage or consumer theft.

Furthermore, smart meter data provide historical and actual data on energy usage, enabling end users to make better informed decisions about their energy management. For example, they can use the meter readings to leverage flexible energy prices and to engage in demand management, provided that energy prices or flexible transport tariffs are communicated regularly (Buchanan et al., 2016; Kiguchi et al., 2019). Smart meters also have benefits for strategic decisions, as they allow for more accurately assessing the actual utilisation and degradation of component health, providing enhanced information for investing in new assets (Thomas & Jenkins, 2012) and to individual energy end users, such as companies and households. This differs greatly from the traditional approach of periodically replacing components depending on their age and generic load profiles.

Despite these benefits and their importance, literature on smart grids (for a review, see Vakulenko et al., 2021) has mainly focused on technical aspects of the development and improvement of energy technologies and the introduction of information systems to manage the electricity grid and monitor energy consumption, often in the context of alternative energy and decarbonisation of the economy. Several studies take a broader perspective on smart grids by focusing less on specific benefits and more on the actors involved (e.g. Dehdarian & Tucci, 2021; Rohde & Hielscher, 2021). Regarding smart meters, the concept of net metering has received scant attention (Parker et al., 2019), especially in the OM literature (with Hu et al. [2015] as a notable exception). Thus, a clear research gap is how to effectively implement smart meters with the aim to successfully transition to smart grids and their effective management.

#### *4.2.3 Network governance*

To realise the digital transformation of an entire sector, organisations and institutions in that sector cannot operate in a vacuum. The literature on network governance acknowledges the importance of collaboration in networked structures, in which organisations engage in frequent and repeated exchanges over time (Jones et al., 1997) to attain positive network-level outcomes that cannot normally be achieved when acting alone (Provan & Kenis, 2008). Networks typically consist of inter-connected actors that collaborate to jointly control material and information flows between the source and the end user (Aitken, 1998; Kim et al., 2011). The notion of system-oriented networks (Nowell & Milward, 2022) has only recently gained attention in OSCM literature (Johnson et al., 2021), and emphasises the importance of including relevant actors and their interrelationships, including the end user, as well as the institutional context in which the network operates (Trischler & Westman Trischler, 2021).

The (system-oriented) network organisational form (hereinafter referred to as network) has been advanced as the third pillar of modern business thinking (Moore, 2006; Powell, 1990), next to organisations and markets. To enable continuous innovation, organisations need to shape not only the product or service made possible by the innovation but also the needed infrastructure and complementary products or services that make the innovation more interesting to end users. Shipilov and Gawer (2020) argue that networks cannot be reduced to a set of inter-organisational alliances, or a group of dyadic relationships. Network members may or may not have alliances among themselves, but it is foremost their alignment that is critical for the value proposition to be realised. As such, networks typically do not rely on hierarchical or arm's-length relationships between members (Jacobides et al., 2018). Furthermore, networks focus on the focal offering (in our context, smart meters) (Shipilov & Gawer, 2020) or a system for managing an issue of public concern (in our context, digital transformation policy) (Nowell & Milward, 2022), whereby organisations are dependent on all others and typically form a group of loosely coupled entities (including governments, universities, industry associations, and [end] consumers) that share a common fate (Rong et al., 2015). As such, networks provide organisations with a view of cross-industry collaboration that goes beyond collaboration with directly linked partners (Rong et al., 2015). Thus, research and practice need models of effective networks, as well as networks that fail "through which actions and effects in a case can be examined, and for which remedies can be devised and tried" (Moore, 2006, p. 36).

A particular literature stream focuses on networks in which innovations occur and the set of components (upstream) and complements (downstream) that support it (Jacobides et al., 2018). This stream views networks as "the collaborative arrangements through which firms combine their individual offerings into a coherent, customer-facing solution" (Adner, 2006, p. 98), and the focus is on understanding how interdependent actors interact to develop and implement innovations that benefit the customer. Adequate coordination is critical here, as in its absence innovations will fail (Adner & Kapoor, 2010; Kapoor & Lee, 2013). Also, in the creation of (innovative) public services a network of actors connected at different levels is required. Trischler and Westman Trischler (2021) show that a constellation of multiple actors on the meso-level of co-creation connects on the one hand to the micro-level value creation by users of digital products/services (i.e. consumers) and on the other hand to the macro-level institutional arrangements that guide value-creation activities.

The literature advances three main forms of network governance along with four structural and relational predictors of the effectiveness (i.e. the extent to which positive network-level outcomes are achieved) of each form (Provan & Kenis, 2008): (1) shared networks that are participant-governed and highly decentralised, (2) participant-governed networks that are more centralised and have one member organisation taking the lead in governing the network and (3) the network administrative organisation (NAO) model that involves the creation of a separate entity exclusively for the purpose of network governance. The effectiveness of each form depends on the trust in the network, the size of the network, the level of goal consensus between parties and the extent to which network-level competences are required. For example, shared governance is considered effective under low levels of trust, few network participants, high goal consensus and low levels of network-level competences required. By contrast, larger networks are effective under lead-organisation governance when involving moderate goal consensus and requiring moderate network-level competences, and under the NAO model when goal consensus and competence requirements are high (Provan & Kenis, 2008).

Although network governance is widely considered to produce important economic benefits, "the mechanisms that produce these benefits are vaguely specified and empirically still incipient" (Uzzi, 1996, p. 677). As such, what network governance is, when it is likely to occur and how it helps firms (and non-profit agencies) resolve problems of adapting, coordinating and safeguarding exchanges remains unclear (Jones et al., 1997). However, defining specific governance structures is often challenging, with questions on how governance should be executed, who should constitute the governance structure and what checks and balances exist being key. Thus, a key challenge for OM researchers is to enhance understanding of how to effectively orchestrate the efforts of participants in networks to achieve common strategic objectives (Field et al., 2021; Rong et al., 2015).

Effective use of contractual and relational governance mechanisms in interdependent relationships is imperative to help network participants access key resources of others in the network, deal with risk and coordinate tasks and activities (Johnson et al., 2021). How the governance of supply networks works in practice is a fruitful (Johnson et al., 2021) but understudied (e.g. Bastl et al., 2019; Roehrich et al., 2020) research area. Moreover, regulators need to recognise the network-organisational form, appreciate its nature, structure and operation, and seek to support its contributions to procompetitive and pro-innovative social outcomes (Moore, 2006). This, for example, involves the design and implementation of government and public sector policies to promote sustainable practices (e.g. those that allow to fulfil today's needs without compromising those of tomorrow), the encouragement and incentivisation of private sector parties and social entrepreneurs to invest in building sustainable (i.e. lasting) and resilient service systems, and the structuring of public–private partnerships in a way that improves both process and outcome efficacy (Field et al., 2021). Studying in more detail the collaboration mechanisms and the governance system through which different types of supply network actors (e.g. government, industrial associations and other relevant organisations that contribute to the operation of the supply network) effectively interact at the three levels Trischler and Westman Trischler (2021) identify is therefore critical to enhance understanding of how extended networks, especially those undergoing digital transformation and involving both public and private actors, function and to what performance effects.

## 4.3 Methodology

### *4.3.1 A case study research design*

We employed a single-case design around a theoretically interesting case to trigger theory building in the specific context of a digital transformation affecting operations in the electricity sector. Although OM researchers have investigated how smart meter data can help actors to make better operational decisions, they have not explored how the actors in the electricity sector, and the relationships between them that jointly form a network, can effectively be governed to use such data to help societies transform to a cleaner and more efficiently managed electricity grid (Parker et al., 2019), also known as smart grid management. This is striking because in various countries, many sectors (and particularly the electricity sector) are facing a major transition as they undergo digital transformations that involve massive investments. For example, the Dutch government expected to spend €3.3 billion on rolling out smart meters (Van Aubel & Poll, 2019), while the United Kingdom expected to spend £8.6 billion (€10 billion; KEMA, 2010). Given the lack of scholarly research in this area, we adopt an exploratory approach (Barratt et al., 2011) to a theoretically interesting case to uncover "compelling empirical patterns that cry out for future research and theorizing" (Hambrick, 2007). Although relevant literature on a priori key constructs exists, the novelty and unfamiliarity of the current setting warrants that we avoid undue bias that may result from privileging one or more pre-selected theories (Martin & Eisenhardt, 2010). Therefore, explanation derives from exploration in this research (Ketokivi & Choi, 2014).

We want to understand why the Dutch government and other actors in the electricity sector were unable to achieve the intended smart management of the electricity grid and energy savings, by exploring a single, longitudinal case study (mostly retrospective but also in real time) of the smart meter rollout in the Netherlands. With this exploration, we aim to spark theory building, which is appropriate when the context and experiences of parties (especially managers) are critical (Barratt et al., 2011), as this helps increase the practical relevance of the findings (Fisher, 2007). After building the case, we compare the emerging theoretical insights with extant literature in the areas of smart grid management and network governance to establish a sense of generality.

Our arguments for opting for a single case study were twofold. First, the Dutch setting offers a unique and highly specific context, which is critical for our findings. The context of our case shows how (inter)national regulations trigger a digital transformation through the adoption of smart meters in the Dutch electricity sector, in which different public and private actors (often with conflicting goals) need to work together and with their broader context (i.e. end users and institution context) to attain the common goal of making smart use of smart meter data to achieve smart grid management. In this unsuccessful case, we uncovered theoretically interesting dynamics that explain why it was not successful, resulting in thought-provoking propositions that include improvements for this failing network that can be tested in future research. To keep the specific context of our case in mind during the investigation, a single case design is our best option (Gibbert et al., 2008; Voss et al., 2002). The specificity of the (legal and political) context in our study also made it problematic to compare our case with cases of smart meter rollouts in other countries.

Second, the richness of a single case facilitates the in-depth study of the phenomenon and the drawing of deep insights (Voss et al., 2002). One clear benefit from the public setting of our study is that most data are, indeed, public. This offers accessibility to myriad (archival) sources, providing extraordinarily rich data. Many major events and (governmental) decisions spanning more than a decade were well-documented, thereby allowing a longitudinal analysis (see Narasimhan & Jayaram, 1998; Voss et al., 2002). The governmental records and reports describe in detail why certain decisions were made over time, precisely because the discussion was public. Such inner motivations for policy choices are often extremely difficult to find in private sector studies. Additionally, we had unusual access because one of the authors is employed by an organisation operating in the sector and liaises with national associations related to the sector. Such access provided us with a unique opportunity to gain deep insights into undocumented sector knowledge. Again, this resulted in rich data from interviews with all relevant parties, which also helped corroborate our findings from the other data sources (Barratt et al., 2011).

### *4.3.2 Case setting*

The electricity sector in the Netherlands is a heavily regulated sector involving a mix of (semi-)governmental and commercial organisations, including DSOs, energy suppliers, independent service providers (ISPs) and governmental institutions (and industry associations). DSOs are semi-public organisations to which the Dutch government granted both the legal task and exclusive rights of designing, maintaining, developing and operating the electricity distribution systems in a specific geographic region in the Netherlands. Energy suppliers are commercial organisations involved in generating and/or procuring electricity to be sold to end users and supplied through electricity grids. ISPs are commercial organisations that provide analytical services related to electricity consumption and management to end users. Finally, the government includes the responsible ministry (Economic Affairs & Climate Policy) and several independent regulating bodies (e.g. Dutch Authority for Consumers and Markets [Autoriteit Consument & Markt], which oversees the market and enforces consumer protection laws; Dutch Data Protection Authority [Autoriteit Persoonsgegevens], which oversees the processing of personal data). **Figure 4.1** provides an overview of the four key actors in our case and their relationship with end users (e.g. consumers and small business owners).

**Figure 4.1** also shows how the energy supplier supplies electricity to end users through the grid of the DSOs. End users may also supply electricity back to the grid (e.g. surplus electricity generated with solar panels). Smart meters collect data on energy consumption, thereby creating flows of data that are directly fed back to end users (e.g. via in-home displays) and the DSOs. Being responsible for managing and sharing smart meter data with eligible parties, DSOs are obligated to share it with energy suppliers for the purposes of billing, changes of residence and changes of supplier. Energy suppliers may also offer time-dependent rates or pre-payment structures, in which an insufficient balance automatically triggers a response. In addition, DSOs must grant third parties (e.g. ISPs) access to smart meter data, provided they receive consent from the end user, to abide by the General Data Protection Regulation. Data flows may also be indirect, as is the case when energy suppliers or ISPs transform the data obtained from DSOs before sharing it with end users (provided they have permission). End users receive such data (e.g. daily overviews of the amount of electricity used) at a later point in time, for example, on invoices, a website and, more recently, mobile apps.

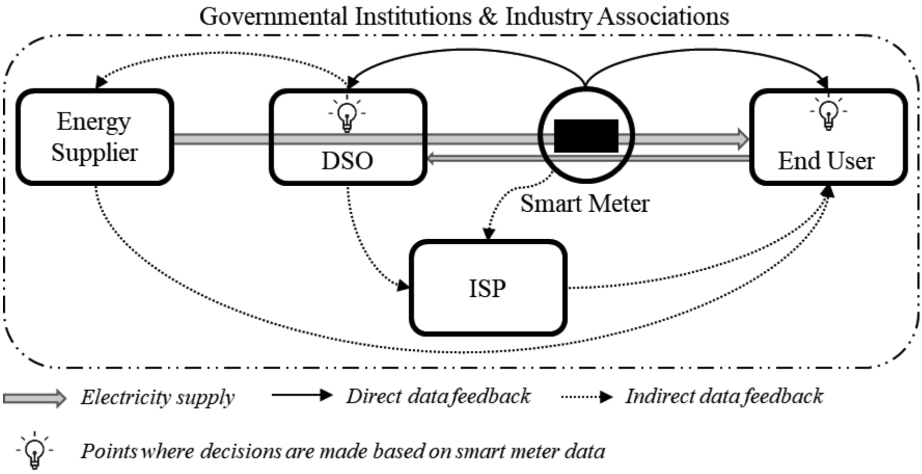


**Figure 4.1** Schematic overview of flows between key actors in the Dutch electricity sector

### *4.3.3 Data sources*

We used multiple sources of data covering the period from the start of the rollout in 2010 to mid-2021 (see **Table 4.1** for details). We analysed 64 documents (1,860 pages in total), including legal bills, governmental documents (e.g. letters, parliamentary papers), the covenant agreement, various monitoring reports and various related writings that appeared on relevant websites or in newspaper articles. Moreover, we conducted 13 interviews (duration: 11 hours) with key representatives of three DSOs (denoted as DSO.A, DSO.B and DSO.C), three electricity suppliers (denoted as ES.A, ES.B and ES.C) and two ISPs (denoted as ISP.A and ISP.B).

**Table 4.1** Types of data sources and their relevance for the study

| **Data source** | **Relevance for study** |
|---|---|
| *Archival data – legal documents* | Understanding of the EU regulations that triggered the smart meters rollout and the Dutch regulations that shaped and guided the rollout. |
| *Archival data – governmental documents* | Actions undertaken by the Dutch government regarding the smart meter rollout.<br>Decisions taken about the specific roles of each of the parties.<br>Attempts taken to motivate end users to start saving energy through smart meter data. |
| *Archival data – covenant documents* | Detailed information about the 2017 covenant agreement signed by representatives of the government, energy suppliers and DSOs. |
| *Archival data – reports* | Evaluation of the results of the collective actions undertaken by all parties to motivate end users to save energy. |
| *Archival data – newspaper articles* | Understanding of how the mutual relationships between the actors evolved during the rollout. |

| | |
|---|---|
| | Understanding of end users' perspectives of the rollout and the services/tools developed for energy savings. |
| *Interviews with employees from energy suppliers and ISPs* | Insights into the commercial activities involving smart meter data that were implemented to change end users' behaviours.<br>Insights into the impediments that hindered the widespread introduction of these commercial activities. |
| *Interviews with employees from DSOs* | Insights into the different pilots to improve the processes of their organisation with respect to the management and maintenance of electricity grids, including impediments hindering the execution or scale up of these pilots. |

The large amount and wide range of publicly available archival sources in which key facts and the chronology of events were extensively documented strengthened the empirical basis of the study (**Table 4.2** lists all included documents). The interview data helped us better understand the contingencies and mechanisms that led to the facts and results as presented in archival sources, as well as the critical experiences of the various parties involved, and enabled data triangulation.

### *4.3.4 Data analysis*

We conducted data analysis and coding in parallel with data collection (Barratt et al., 2011; Miles & Huberman, 1994). As such, we first employed open coding during data analysis, which was guided by the main takeaways obtained during data collection and general insights from the literature in the areas of smart grid management and network governance. This enabled us to explore the rich data while ensuring a link with extant literature. We then applied axial coding (Miles & Huberman, 1994) to group our data into higher-order categories, to identify emerging trends. Part of the resulting higher-order categories were connected with the dimensions of smart grid management (e.g. 'grid management', 'tools for grid management') and network governance (e.g. 'multi-party collaboration', 'incentives'), two concepts found in the OM literature. We grouped the remaining categories into two emerging dimensions that were not connected to any concept from the OM literature: 'end users' life world' (e.g. 'nudging', 'smart products') and 'governmental and institutional context' (e.g. 'government policy', 'societal implications'). The final coding scheme is available in **Appendix H**.

After data analysis, the first author wrote a detailed case narrative featuring the course of the rollout. This was then extensively discussed by the first and second authors. These discussions helped us refine the key findings in the narrative and ensure that it was based on facts and free from subjective interpretations. During the last step, the authors tied back the findings to the theoretical concepts of smart grid management and network governance, but also to the emerging concepts of the 'end users' life world' and 'governmental and institutional context'.

Following Gibbert et al.'s (2008) and Yin's (2009) suggestions, we employed several tactics to enhance construct validity, internal and external validity, and reliability to ensure the quality and rigor of our study. To enhance construct validity, we collected data from various sources to enable data source triangulation and established a clear chain of evidence by writing a detailed narrative of our case based on all data sources. Internal and external validity was enhanced by establishing a close connection between our study and our findings on the one hand and existing literature on the other hand. Finally, to enhance reliability, we created interview protocols (based on concepts from existing literature) to guide the semi-structured interviews and to manage an extensive case study database.

**Table 4.2** Public data sources referenced

| | | | |
|---|---|---|---|
| **Legal documents** | | | |
| LEG01 | Directive 2006/32/EC on energy end-use efficiency and energy services | LEG02 | Directive 2009/72/EC concerning rules for the internal market in electricity |
| **Governmental documents** | | | |
| GOV01 | European Union (2011) – *Definition, expected services, functionalities and benefits of smart grids* | GOV04 | Parliamentary Paper 29 023 no. 160 (2014) – *Energy provision and security of supply: Letter from the Minister of Economic Affairs* |
| GOV02 | Parliamentary Paper 31 374 no. 13 (2008) – *Shorthand report of a legislative meeting of the standing committee on Economic Affairs* | GOV05 | Parliamentary Paper 29 023 no. 163 (2014) – *Energy provision and security of supply: List of questions and answers* |
| GOV03 | Parliamentary Paper 32 374 no. 3 (2010) – *Amendment of the Act amending the Electricity Act 1998 and the Gas Act to improve the functioning of the electricity and gas market* | GOV06 | Ministry of Economic Affairs (2011) – *Towards smart grids in the Netherlands: Concluding document from the taskforce smart grids* |
| | | GOV07 | Rijksoverheid (2011) – *Decree on remotely readable measuring devices* |
| **Covenant agreement documents** | | | |
| CAD01 | Covenant 10 PJ energy savings (2017) – *Covenant 10 PJ energy savings built environment* | CAD05 | RVO [Netherlands Enterprise Agency] (2020) – *Monitoring report 2019 covenant built environment* |
| CAD02 | Ministry of Economic Affairs (2019) – *Letter to Parliament: Monitoring report 2018 Covenant 10 PJ energy saving built environment* | CAD06 | Ministry of Economic Affairs (2021) – *Letter to Parliament: Monitoring report 2020 Covenant 10 PJ energy saving built environment* |
| CAD03 | RVO [Netherlands Enterprise Agency] (2019) – *Monitoring report 2018 covenant built environment* | CAD07 | RVO [Netherlands Enterprise Agency] (2021) – *Monitoring report 2020 covenant built environment* |
| CAD04 | Ministry of Economic Affairs (2020) – *Letter to Parliament: Monitoring report 2019 Covenant 10 PJ energy saving built environment* | CAD08 | Rijksoverheid (2021) – *Conclusion of the 10 PJ energy saving covenant: Lessons learned and advice* |
| **Reports** | | | |
| REP01 | KEMA (2010) – *Smart meters in the Netherlands: Revised financial analysis and policy advice* | REP14 | TNO (2017) – *Saving effects of smart meters with feedback systems and smart thermostats* |
| REP02 | KEMA (2012) – *Societal costs and benefits of intelligent grids* | REP15 | TNO (2020) – *Effect measurement improved Consumption and Cost Overview* |
| REP03 | RVO [Netherlands Enterprise Agency] (2014) – *Monitor energy saving smart meters (saving monitor)* | REP16 | ACM [Authority for Consumers & Markets] (2012) – *A first impression of the small-scale rollout of smart energy meters in the Netherlands* |
| REP04 | RVO [Netherlands Enterprise Agency] (2016) – *Market analysis rollout smart meters: 2015 progress report* | REP17 | ACM [Authority for Consumers & Markets] (2013) – *Monitoring report on small-scale smart meter offer* |
| REP05 | RVO [Netherlands Enterprise Agency] (2017) – *Market analysis rollout smart meters: 2016 progress report* | REP18 | ACM [Authority for Consumers & Markets] (2020) – *Energy monitor 2020: Consumer market electricity and gas* |
| REP06 | RVO [Netherlands Enterprise Agency] | | |

(2018) – *Market analysis rollout smart meters: 2017 progress report*

REP07 RVO [Netherlands Enterprise Agency] (2019) – *Market analysis rollout smart meters: 2018 progress report*

REP08 RVO [Netherlands Enterprise Agency] (2020) – *Market analysis rollout smart meters: 2019 progress report*

REP09 Netbeheer Nederland [Grid Operators Association] (2019) – *Energy infrastructure basics*

REP10 Netbeheer Nederland [Grid Operators Association] (2020) – *Research into real-time data access smart meters: Evaluation and improvement*

REP11 PBL [Environmental Assessment Agency] (2014) – *Saving energy does not happen by itself: Evaluation of the energy saving policy*

*REP12 PBL [Environmental Assessment Agency] (2016) – The smart meter, electedly energy(-etic?)*

REP13 PBL [Environmental Assessment Agency] (2021) – *Energy consumption managers in the Netherlands: Saving energy with the smart meter*

REP19 TILT [Tilburg Institute for Law, Technology and Society] (2008) – *The 'smart meters' bill: A privacy check based on Article 8 ECHR*

REP20 Uitzinger, J. & Uitdenbogerd, D. (2014) – *Monitoring and evaluation of the smart meter and the bimonthly consumption overview*

REP21 VEH [Homeowners Association] (2010) – *Energy suppliers report January 2010*

REP22 IEI [Institute for Electric Innovation] (2016) – *Electric company smart meter deployments: Foundation for a smart grid*

*REP23 Ecorys (2017) – Performance of grid operators: Managing to facilitate the energy transition*

REP24 CSE [Centre for Sustainable Energy] (2003) – *Towards effective energy information: Improving consumer feedback on energy consumption*

REP25 SER [Social and Economic Council] (2013) – *Energy agreement for sustainable growth*

REP26 Thomas, L. & Jenkins, N. (2012) – *Smart metering for the UK*


## Newspaper articles


NEW01 Duijnmayer, D. (July 8, 2016) – *It is not going very smoothly with savings as a result of smart meters*

NEW02 De Ronde, K. (November 10, 2016) – *Smart meter business case falters*

NEW03 De Ronde, K. (November 22, 2016) – *Do not focus on smart meters, but on making energy managers better known*

NEW04 Savelkouls, J. (May 23, 2017) – *Six parties enter into a covenant on 10 PJ energy savings*

NEW05 De Ronde, K. (February 11, 2020) – *Ministry of Economic Affairs wants to increase awareness of energy consumption managers*

NEW06 Duijnmayer, D. (March 17, 2020) – *Smart meter rollout has come to a stillstand, only urgent jobs for the time being*

NEW07 Duijnmayer, D. (June 9, 2020) – *Only 6% of households receive an offer for an energy consumption manager with the smart meter*

NEW08 De Ronde, K. (October 13, 2020) – *Energy-saving effect of insight into energy consumption is disappointing*

NEW09 Duijnmayer, D. (December 3, 2020) – *Behavioral interventions have limited effect on the use of energy consumption managers*

NEW10 De Ronde, K. (March 19, 2021) – *Ollongren: Heat of 50°C should be sufficient for houses built after 1945*

NEW11 De Ronde, K. (April 13, 2021) – *Smart meter business case still faltering, despite apps and displays*

NEW12 De Ronde, K. (June 30, 2021) – *End result of the energy saving covenant for households: not 10 PJ but 2 PJ*

NEW13 De Ronde, K. (July 20, 2021) – *Tenants and housing associations want to make progress with energy displays in rental properties*

NEW14 Van Wijnen, J.F. (May 5, 2020) – *Grid operators fear a smart meter fiasco*

NEW15 Van Wijnen, J.F. (May 29, 2020) – *Millions of smart meters unsuitable for energy transition*

NEW16 Bouman, M. (June 13, 2020) – *Faster energy transition thanks to corona? You have to be very optimistic to believe that*

NEW17 Van Wijnen, J.F. (June 20, 2021) – *Grid operators deliberately took a billion-dollar risk with smart meters*

NEW18 Van Wijnen, J.F. (July 4, 2021) – *Smart meters cause problems more often than is allowed*

NEW19 Emerce (June 11, 2020) – *P1 gate smart meter rarely used*

NEW20 VEH [Homeowners Association] (November 22, 2016) – *Committee needed for smart meter problems*

NEW21 Grol (January 5, 2022) – *Expansion of electricity grid is going too slowly; warn provinces*

## 4.4 Case Findings

We aim to offer guidance for the future by looking back into the past. In doing so, we find four key periods in evolution of smart meters in the Netherlands: a preparation period, a small-scale rollout, a large-scale rollout before the covenant 10 petajoule (PJ) and a phase of further service development for smart meters installed after the covenant 10 PJ. After explaining the context, we organise the case description along these four periods. This description chronologically outlines the main developments in the periods, thereby addressing the role of the Dutch government in shaping the context and creating the conditions under which the rollouts should occur; the role of the sector, including the DSOs, energy suppliers and ISPs; and the role of end user as main actors. Whereas the first four sections focus on the objective of energy savings, the last section focuses on the large-scale rollout from the perspective of network optimisation.

### *4.4.1 Preparation period (2008-2012)*

Following EU Directive 2006/32/EC, which required all EU members to take measures to enhance end-user energy efficiency by stimulating the use of energy services, the Minister of Economic Affairs issued a bill in 2008 advocating amending the Dutch Electricity Act of 1998 to "*improve the operations of the electricity market*" (GOV03, p. 1). Member States should ensure that "*final consumers are provided with competitively priced individual meters that accurately reflect the final consumer's actual energy consumption and that provide information on actual time of use*" (LEG01). The Dutch government added the coordinated rollout of the smart meter to the legal tasks of DSOs in Article 26a of the Electricity Act. Furthermore, EU Directive 2009/72/EC imposed a target of equipping 80% of consumers with a smart meter by 2020.

For the Netherlands, the introduction of the smart meter would, according to a government-ordered social cost–benefit analysis, lead to an estimated national energy savings of 3.2% for electricity (REP01) through two parallel routes. First, smart meter data would increase consumers' understanding of their energy consumption and thus trigger behavioural changes in energy use. Second, "[t]*he smart meter also ensures more efficient grid management and facilitates future (smart) grids*" (GOV04, p. 1). In other words, smart meters would enhance DSOs' understanding of the condition of their energy grids, thereby enabling more efficient management and maintenance of these grids. Overall savings were estimated at €4.1 billion (vs. estimated costs of €3.3 billion; REP01) if adoption of smart meters was made mandatory for consumers. However, security issues (e.g. smart meter data on presence/absence of hacking by thieves; GOV02) and other data protection issues (REP19) led to political resistance and eventually to a voluntary rather than mandatory rollout (GOV03).

Important pre-conditions for achieving the estimated benefits also included providing both direct and indirect feedback to consumers. Direct feedback includes, for example, an in-room digital display showing real-time energy use. Indirect feedback includes monthly energy usage reports sent to customers. Darby (2006) finds that the savings potential of direct feedback (5–15%) exceeds that of indirect feedback (0–10%). The estimates of the aforementioned social cost–benefit analysis included only the benefits of indirect feedback; direct feedback was expected to result in an additional reduction of 3.2% for electricity usage (REP01, p. 58). The analysis also indicated that "*for direct feedback an investment in an in-home display is required. A display may cost a maximum of 140 euros to (socially) outweigh the savings of direct feedback*" (REP01, p. 55).

#### *4.4.2 Small-scale rollout (2012–2014)*

The implementation of the smart meter formally started in 2012, with a small-scale three-year rollout as per governmental decree. During this rollout, the sector would "*gain experience with the remotely readable meter*" (GOV03, p. 2). In anticipation of formally receiving the legal task to install smart meters, the DSOs had already made extensive preparations (i.e. determining the requirements for the smart meter, developing rollout scenarios and designing the installation process). Meanwhile, the decision that the adoption of the smart meter would be voluntary required the DSOs to also focus on promoting the smart meter. Energy suppliers were required to provide smart meter adopters a bi-monthly energy consumption overview (ECO) to stimulate behavioural changes in energy consumption. To gain experience with feedback mechanisms and to develop tools and services for consumers, the DSOs, energy suppliers and ISPs initiated various pilots.

In 2012–2013, more than half a million households received a smart meter through a process that was considered consumer friendly (REP17). Only 2% of consumers who were offered a smart meter refused it. At the same time, the Dutch Authority Consumer and Market claimed that energy suppliers' smart meter information provision to consumers in general was insufficient and in need of improvement (REP17), while in-home displays were hardly offered at all. Both energy suppliers and ISPs responded by noting that late (for energy suppliers) or no (for ISPs) information on smart meter installation hampered the process of offering energy-saving tools and services to adopters of smart meters (REP16, 17). Furthermore, the assortment of energy-saving devices and services continued to be limited, despite the pilots that both DSOs and commercial organisations (e.g. energy suppliers, ISPs) had initiated (REP03).

Finally, there was a need for more indirect feedback to consumers about energy-saving opportunities with smart meter data (REP03). Only 76% of smart meter adopters received the bi-monthly ECO that energy suppliers were required to send. Some of these ECOs did not meet all legal requirements, and none included a comparison with energy consumption from the past or from peers (REP20). Taken together, the total energy saving achieved by consumers who participated in the small-scale rollout was less than 1% (REP20), well below the target of 3.2% indicated in the cost–benefit analysis. The Dutch Minister of Economic Affairs explained this performance shortfall by noting that the smart meter had only been in use for a brief time and, therefore, that energy services were just emerging (REP12). Furthermore, the Minister reported that "*DSOs have made preparations to offer the smart meter on a large scale and indicate that their organisations are ready for it*" (GOV14, p. 2). Consequently, the large-scale rollout was considered good to go, and the Minister drafted a statutory instrument ordering DSOs to start the implementation.

### *4.4.3 Large-scale rollout before covenant 10 PJ (2015–2017)*

While a top-down approach was used for the large-scale smart meter rollout, a bottom-up approach was pursued for analytics tools and services. The Ministry of Economic Affairs expected that "*the number of market parties and energy savings services in this market will increase during the large-scale rollout. A tour among several market parties suggests that energy savings are high on the agenda and the rollout of the smart meter provides them with a unique opportunity to approach consumers with the services they wish to invest in*" (GOV05). The desired situation was more specifically stated as follows: "*This full-scale offering of smart meters has been entrusted by the government to the DSOs. Stimulating the use of smart meters for energy saving through feedback of information about their* [consumers'] *own energy consumption is left to energy suppliers and ISPs*" (REP19, p. 33).

At this time, the DSOs had been explicitly excluded from developing tools and services for the consumers, thereby limiting their responsibility to rolling out the smart meters and grid management and maintenance. The government monitored the smart meter rollout and the development of tools and services by commercial organisations by means of an annual progress report (a market barometer) (REP03). In 2015, the market for energy consumption managers complementing the smart meter was still on the rise (REP04), with 40 active providers, mostly small ISPs with limited opportunities for large-scale marketing and deployment. Energy suppliers also did not yet have a large supply of energy consumption managers (only 10) or in-home displays. Moreover, online tools still mainly focused on detailed analysis of the energy consumption for energy and tech-savvy consumers.

By 2016, most Dutch households had accepted the smart meter (REP05); yet, at the same time, "*consumers are* [still] *unfamiliar with their own energy consumption, how they can reduce energy consumption, how they are able to earn back the financial investment, and how to assess the social benefits. In general, energy is used on a routine basis and when purchasing appliances, the costs and benefits of energy consumption are not properly accounted. Moreover, investments to achieve energy savings are overestimated compared to energy savings*" (REP12, p. 21). Furthermore, the number of providers offering energy consumption managers for direct feedback had hardly increased and still mainly involved smaller ISPs and a few energy suppliers. Even fewer energy suppliers campaigned for increasing the use of energy consumption managers (REP05). In 2015 and 2016, only 50% of consumers were aware of the extended ECO (REP04, 05). Furthermore, up till then ECOs had resulted in only limited energy savings, as consumers found them difficult to understand and therefore difficult to translate into changed consumer behaviour (NEW20). PBL, a Dutch governmental research organisation, thus recommended collectively rolling out the smart meter and in-home displays, viewing this "*as the best choice if the government on the one hand wants to maximise energy savings and, on the other hand, wants to offer the market room to continue to innovate*" as this mitigates market parties' uncertainty in marketing their energy-saving tools and services (REP12, p. 23).

### *4.4.4 Service enhancements for smart meters after covenant 10 PJ (2017–2021)*

In May 2017, the government deemed an extra measure necessary to reach the 10-year goals of the energy agreement (REP25) signed in 2013. Therefore, the trade associations for energy suppliers, grid managers and the installation industry and technical retail sector, the Dutch Association for Durable Energy, and the government signed the ‘Covenant 10 PJ energy savings built environment’ (CAD08). The covenant had the ambition to achieve 10 PJ energy savings mainly for Dutch households. The covenant formalised the activities to be undertaken, as well as the roles of the covenant parties in achieving the targeted energy savings and was governed by a formal board consisting of representatives of all network members (i.e. the NAO model; Provan & Kenis, 2008). There was no direct consumer representation among parties of the covenant.

Achieving the energy-saving target involved enhancing both indirect and direct feedback. Regarding indirect feedback, the trade association for energy suppliers took the lead to carry the costs to provide the extended ECO more frequently and to improve its content, to address specific consumer target groups. Regarding direct feedback, a ‘best-effort obligation’ (i.e. a behaviour-based agreement; Eisenhardt, 1989) was established requiring energy suppliers to try to (by the end of 2020) provide all consumers who had adopted the smart meter with (information on) targeted analytics tools and services (e.g. [subsidised] smart thermostats, free or paid energy management services) one or more times (CAD01). The target was to have 750,000 of these smart meter adopters with these tools and services installed and activated by 2020. The trade association for energy suppliers was also required to (at its own cost) monitor the extent to which these goals were achieved and to take any necessary actions. In addition, all covenant parties were required to encourage ISPs to intensify (the marketing of) their offerings. To stimulate adoption, analytics tools, and services such as feedback systems and smart thermostats would be included in existing subsidy schemes.

The end of the covenant in 2020, however, was mostly marked by the failure to achieve the targets. At that time, only 2 of the 10 intended PJ had been realised. The secretary of state for Economic Affairs and Climate Policy wrote to the House of Representatives: “*The goal to achieve 10 PJ energy savings in the built environment has not been achieved, despite all parties putting in the agreed efforts*” (NEW12). More specifically, between 2017 and 2019, the market had not developed, as the total number of tools and services providers had remained rather stable (REP08). Energy suppliers noted the difficulties in selling energy consumption savings tools and services, as consumers were reluctant to pay money to save money: “*to save energy you have to pay something, which of course feels a bit strange*” (ES.A’s adviser). Similarly, ES.C’s market regulation specialist indicated: “*That* [device developed by ES.C] *was a paid service. We could see that there was no basis for it. So, we also stopped it quite quickly*”. The trade association for grid managers concluded that “[t]*oo few products and services exist that meet the wishes of the consumer*” and furthermore “[c]*onsumers have little interest in getting started with saving energy themselves by using real-time data. Mainly hobbyists are interested in this*” (REP10, p. 6). This is clearly reflected in the low adoption rate of tools and services for direct feedback such as energy consumption managers (20% of smart meter adopters in 2018, REP10, p. 10). Furthermore, the strictness of privacy laws was mentioned as an inhibiting factor in developing market offerings. Only 4% of consumers in the Netherlands owned an in-home display at the end of 2020 (CAD07).

Moreover, as most of the in-house displays that had become available did not list energy consumption in real time and/or were not located in an easily accessible location (REP14), they did not effectively stimulate consumers to reflect on and adjust their energy consumption behaviours. Regarding indirect feedback, although an increasing percentage of consumers received an extended ECO, an evaluation report by TNO (REP15) indicates that, while consumers read the ECO more frequently and more elaborately than before, it had not resulted in significant savings or increased the use of analytics tools and services. The Ministry of Economic Affairs also concluded that more direct feedback would be necessary to achieve the targeted energy savings (CAD05, p. 16): "*Additional research* […] *makes it clear that the actual saving behaviour of households is mainly determined by factors other than the ECO. […]. It is possible that more savings can be achieved with direct feedback systems that provide real-time feedback, such as apps and in-home displays*". By now, the energy suppliers had noted the criticality of adding services with features to activate consumers: "*the smart meter will only prove its usefulness in the coming years. If we start using more things like smart meter* [energy] *allocation and dynamic* [energy] *rates. Only that can be an incentive* [for consumers] *to move electricity usage to times with high levels of electricity production*" (market regulation specialist, ES.C.). Recently, housing corporations and the tenant's association have suggested a coordinated rollout of in-home displays for households, starting with rental houses (NEW13).

#### *4.4.5 Smart meter rollout for smart grid management*

From the beginning, the use of smart meter data to support sustainable energy production and smart grids has been another explicit governmental goal of the smart meter rollout. During the large-scale rollout to consumers, the DSOs also focused on developing software and algorithms (e.g. for analysing [aggregated] smart meter data, detecting anomalies and making predictions) that could provide advanced insights into the condition of the grids and thus enable improved grid management and maintenance decision-making. Employees attempted to draft business cases *ex ante*, to ensure that the benefits outweighed the costs: "*We roughly know what data is available and what we want. Now it is a matter of developing use cases to leverage that data*" (adviser internal processes, DSO.B). However, this turned out to be difficult. Many of the problems encountered had legal elements, in addition to obvious technological challenges.

The legal tasks of DSOs as defined in Article 16 of the Electricity Act 1998 state that a DSO is required to "*operate and maintain the network it manages*" and "*to guarantee the safety and reliability of the grids and of the transmission of electricity over the grids in the most efficient way*". So, all activities performed by a DSO should be geared toward meeting these Article 16 requirements. In addition, regarding the use of (smart meter) data, Article 26 of the act states: "*A DSO only collects data regarding consumers if this is necessary for the tasks of the DSO, as referred to in Article 16*". This implies that, legally, DSOs are only allowed to use smart meter data when necessary to ensure, for example, the safe delivery of electricity to consumer households. Although "*within the current legislation and regulations, DSOs can still make progress with the data they now have*" (DSO.A senior project manager), there is also a call for more flexibility in the interpretation and application of the Electricity Act 1998. As DSO.B's adviser internal processes stated, "[l]*ooking at the grid management activities, we would like to have some room for the smart meter data, because we see very clear use cases that benefit the consumer*".

An example of a potential use case that would benefit consumers, but is not yet allowed, is immediately reading the smart meters of all consumers in a specific area after a consumer reports a power failure. By also reading neighbouring smart meters, a DSO can more quickly determine whether the outage is a collective power failure (triggering the need for maintaining the local grid) or is restricted to the one consumer. Stricter privacy regulations have turned out to be an important barrier: "*Legislation and regulations in the area of privacy are the most important barriers at the moment that prevent us from realising the value we have in mind*" (project manager, DSO.A).

Privacy legislation is problematic for smart meter data use. While some smart meter data (e.g. event data, voltages) are quite generic and, thus, more or less anonymous, other data such as electric current data allow determining actual use and the timing of that use, which provides information on consumers' personal behaviours. Such data are therefore protected by privacy laws: "*We are now unable to use data regarding electric currents, because it is seen as privacy-sensitive*" (product owner, DSO.A). Public opinion also has played a role here: "*I think that the most important barrier is not necessarily technology, but rather the discussion regarding the usage of data and the privacy invasion you would or would not commit by using it*" (product owner, DSO.A).

Not having access to electric current data prevents the DSOs from more accurately predicting (future) electricity demands and more directly pinpointing failures in their grids. In the absence of viable business cases, moving ahead with smart meter data has proved difficult for the DSOs: "*With a lot of things we are still in a research phase. I estimate that we are still not ready to integrate these in our operational processes*" (adviser internal processes, DSO.B). Furthermore, realising the various efficiency gains identified (e.g. reduced response time in case of power outages, more efficient maintenance) is challenging: "*When you asked the intelligent grid department, 'what are the benefits and how are you going to achieve it?' they did not have a complete answer yet*" (senior project adviser, DSO.A). Thus, although there are already various potential uses for smart data in network optimisation, there is also the potential for further optimisation if use cases can find the right balance between consumer privacy and benefits for the DSO or society.

## 4.5 Case analysis

Featuring the course of the smart meter rollout, our extensive case narrative reveals that after more than a decade, usage of smart meter data for curbing energy consumption and smart grid management has insufficiently materialised. The original objectives have not been achieved: in households, energy saving from using granular and timely smart meter data has been negligible. Similarly, opportunities for smart grid management using smart meter data have hardly been reaped. The Netherlands is increasingly suffering from capacity issues in the energy grid, at both a regional and national level (e.g. Grol, 2022), and this is likely to get worse as new forms of energy supply (e.g. solar panels) and new forms of demand (e.g. charging electric vehicles) continue to emerge and develop.

Our data analysis (see **Section 4.3.4**) allowed us to identify four aggregate dimensions that fit with the framework for value creation using digital technology in the public services domain (Trischler & Westman Trischler, 2021). Two focal dimensions relate to the meso-level (i.e. constellations of organisations, digital technology and consumers), while the 'end users' life world' and 'governmental and institutional context' refer to the micro- and macro-levels, respectively. Together, these elements constitute the energy service network, in which public and private actors "connected by shared institutional arrangements and mutual value creation through service exchange" (Field et al., 2021, p. 464) integrate resources for the purpose of responsible production and consumption of energy (which is related United Nations' Sustainable Development Goal 12).

Our case analysis clearly reveals root causes for a lack of value creation (i.e. smarter grid operations, energy consumption savings) using smart meter data and complementary digital devices (e.g. in-home displays). Such root causes emerge at each of the three levels (macro, meso and micro) but also cut across levels. Therefore, in this section we summarise our findings as propositions, to be refined and improved by further research at these three levels. The propositions developed on the basis of our descriptive research are normative in nature, reflecting key recommendations, precisely because of the forward-looking nature of our work. We are mindful of the remarks of Helper et al. (2021, p. 791), who note that "OM researchers would often choose not to provide public-policy recommendations from their work, even when such recommendations seemed to us highly warranted. Such instances reveal potentially missed opportunities by otherwise excellent OM contributions to add to our understanding of public policy".

#### *4.5.1 Meso-level root causes*

Starting at the meso-level, which is where the concepts primarily studied reside, various root causes related to smart grid management and network governance become apparent. Considering smart grid management, our analysis first revealed that while DSOs already measure their high-voltage grids in real time and increasingly do the same for their medium-voltage grids, this is not yet the case for the low-voltage grids, despite the major changes taking place particularly there (e.g. prosumers delivering solar-panel energy back to the grid, increased charging of electric vehicles possibly at specific times of the day). As such, we advance the following proposition:

> **Proposition 1.** *At the meso-level, ensuring that DSOs have responsible access to granular and timely smart meter data of the local grid is critical for smart grid management (i.e. improved operational decisions and strategic investment decisions).*

Turning to network governance, first, the NAO governance form adopted in the Netherlands can be questioned, as network-level competences and particularly goal consensus appear inconsistent with the NAO form. Given the high need (but low presence) of network-level competences such as network-level coordinating skills geared toward facilitating interdependent actions from network members, combined with the moderate level of goal consensus, a lead organisation model is likely to be more effective. Alternatively, competence development and goal alignment spurred by back-to-back outcome-based agreements could have made the NAO model more feasible. Second, and more important, it is clear that the actions of network members were coordinated using input-based best-effort agreements. As a result, none of the network members could be held accountable for the lagging results: all parties had done their bit, there just were no results. Network members were incentivised by the suggestion that they would be engaging in new business development in the area of responsible energy management, but they found limited consumer interest and had to cover any investments with their own funds. Furthermore, any increased adoption of tools and services would lead to a decrease in demand for energy, and thus less sales. Taken together, network members were actually disincentivised to develop tools and services. As such, we advance the following proposition:

**Proposition 2.** *At the meso-level, the use of outcome-based incentives for the availability and use of smart meter data is critical to aligning the goals of individual network members with the overall goal of curbing energy consumption.*

Finally, network composition was flawed. The government did not allow the DSOs to be involved with offering commercial products and/or services to end users, and end-user representation was completely absent in the network. In the terminology of Spring et al. (2017), the network was defined too narrowly. Instead, practitioners and researchers should take a broader perspective and "incorporate and theorise networks wider in scope and more fluid than the firms, supply chains and markets with which [they are] familiar" (Spring et al., 2017, p. 17). The absence of the end user is particularly counterintuitive, as one ambition for the smart meter was to give end users more control. In reality, the Dutch government and network members developed services for end users without directly consulting them. In line with Trischler and Westman Trischler (2021), who denote the end user as an important meso-level actor, we advance the following proposition:

**Proposition 3.** *At the meso-level, involving the end user and designing the offerings involved with responsible energy management are critical to the acceptance, adoption and use of these offerings and to realising permanent changes in behaviour.*

### *4.5.2 Micro-level root causes*

Regarding the end users' life world, the meso-level root causes have led to only a small fraction of individual end users having access to the timely, convenient (e.g. in-room displays) and granular energy consumption data that they need to make better operational decisions and/or curb their energy consumption. That these are what end users need is not a new theoretical insight (see Abrahamse et al., 2005; Allcott, 2011; Allcott & Rogers, 2014), but they remain issues that have proved difficult to implement in practice so far. Without such data, end users are left groping in the dark regarding a topic they do not think about much anyway, as "electricity consumption is not perceived as a coherent field of action by consumers" (Fischer, 2008, p. 80). As such, we advance the following proposition:

**Proposition 4.** *At the micro-level, only if end users have real-time and highly granular smart meter data available in their immediate environment can they make better operational decisions in their energy consumption.*

Furthermore, smart meters need to be viewed as part of a broader range of government measures. Their fine-grained data can help raise awareness of the importance of energy-saving decisions, but economic incentives can help as well. Subsidies for, for example, home insulation and solar panels, can also help end users make energy-saving investment decisions. Smart meter data can help put these investments to good use, such as by charging end users' electric vehicles while their solar panels are generating energy, rather than at night when the sun is not shining. So far, in the Dutch case, with so few end users actively using smart meter data, such integrated decision-making is not yet happening. This needs to change. As such, we advance the following proposition:

**Proposition 5.** *At the micro-level increased energy awareness and financial incentives for energy-saving tools and investments, next to smart meter data, are necessary for individual end users to implement energy-saving behaviours.*

### *4.5.3 Macro-level root causes*

At the macro-level, the Dutch government's policy clearly worked out differently in practice than was envisioned or intended. The relatively loose approach taken by the Dutch government at the outset is understandable when considering that there were no pressing capacity issues at the start of the smart meter rollout over a decade ago. Only in the last one to two years has it become increasingly clear that the new energy reality is one where both energy "supply and demand have stochastic and controllable components, adding to the complexity of ensuring reliable electric service" (Parker et al., 2019, p. 2738). The breakdown of the electricity system in Texas in the winter of 2021 illustrates that an entire region can come to a standstill, calling for immediate action at the macro- or institutional level. Multiple modes of energy production and use co-exist. At the macro-level, trade-offs increasingly need to be made among natural gas, coal, solar and wind as energy sources; among fossil fuel, electricity and green hydrogen as energy carriers; and electric car batteries as energy buffers. Society is moving to an era when it requires energy-intensive companies to reduce production rates in favour of consumers on days when energy supply is lower than demand. Economic incentives such as pricing will help curb demand. More specific data such as those coming from smart meters will help make more exact and thus less disruptive decisions in such future times. As such, we advance the following proposition:

**Proposition 6.** *At the macro-level, governments and institutions will benefit from smart meter data for statistical and energy policy purposes to make better decisions from a holistic perspective, so across different energy systems.*

So far, innovation in smart grid management that leverages smart meter data is not employed to its full capacity, not because of technical challenges but because of legal impediments. As DSOs can only perform activities that are described in the law, the current legal provisions need to be broadened to provide DSOs with the space to define their specific data use for smart grids. A prominent issue here is the well-intended privacy regulation that has effectively banned DSOs from leveraging the specific data they could use to improve their smart grid management. Although there is vast literature on changes in the electricity sector, including smart grid management, attention paid to the use of smart meter data for this purpose has so far been limited. Although privacy concerns are valid and important, applying legal and technical checks and balances is feasible to enable privacy guarantees in concurrence with improved operational decisions. These regulations have valid societal reasons but have not been thought out in balance with the societal urgency regarding energy transition. DSOs need a legal opening for future data, which is yet undefined by the law, so that they can develop more concrete use cases. This is yet another example of inherently 'wicked' challenges in public policy "since they are complex, interconnected, difficult to define, involve many stakeholders, and can typically be addressed only through trial and error" (Helper et al., 2021, p. 780). As Helper et al. (2021) go on to stress, OM scholars should help address this wickedness by becoming more active contributors to the public policy dialogue. Balancing multiple, conflicting goals is an area in which OM has long excelled. By developing a combination of legal, technical and organisational solutions, smart grid management may be realised without sacrificing privacy. The final proposition thus is as follows:

> **Proposition 7.** *At the macro-level, bringing societal needs for privacy and market legislation related to smart meter data in line with the societal needs for improved smart grid performance is critical to achieve both.*

These seven propositions arise from the specific case of the Dutch smart meter rollout; yet we can expect many of them to be applicable in similar cases in other countries and regions. In public service settings, value creation typically occurs within a constellation of actors, often with limited consumer involvement (e.g. health care), in which (inter)national legislation provides important frames for the activities to be undertaken. Privacy concerns are increasingly impeding progress: they prevent, for example, criminal intelligence from being shared across the entities involved; yet those entities are responsible for the safety of individual citizens. Employers are not legally allowed to ask for their employees' COVID-19 vaccination status; yet they are also legally required to ensure a safe working environment. It seems that many of our propositions' recommendations may have value in settings other than just that of the electricity sector. An OM perspective on a public undertaking such as the smart meter rollout adds to our understanding of public policy.

## 4.6 Discussion and conclusion

### *4.6.1 Theoretical contributions*

After more than a decade, we can safely conclude that the smart meter rollout in the Netherlands has not achieved its original objectives. The government's realised strategy has been precisely the opposite of its intended strategy, as was already observed in the private sector decades ago (Mintzberg, 1978), and is noted as a recurrent problem in the interactions between public policy and OM (Helper et al., 2021). If the overarching question of this research is how to learn from the past decade to improve in the coming decade, we need to consider this theoretically interesting case from an integrated, system-oriented network perspective, encompassing the meso-, micro- and macro-levels. Furthermore, we need to examine it both from both an operational decision-making perspective and a governance perspective, in line with our two research angles.

From the angle of smart grid management, the use of smart meter data, brought about by the digital transformation of electricity sectors in support of smart grid decisions, warrants increased and real-time monitoring of local grids. Furthermore, smart meter-based decision-making should take a holistic approach, covering multiple energy systems. The possibilities for leveraging smart meter data for smart grid management are so far limited, however, by the prevalence of privacy concerns over energy concerns, preventing certain data from being used or certain actors from accessing data. The possibilities of leveraging smart meter data to curb energy consumption are hampered by limited availability of (affordable) tools and devices that help end users make responsible energy decisions.

From the angle of network orchestration and governance, properly developed agreements and associated incentive schemes can have substantial merit in coordinating the actions of network members toward the main objectives of the rollout. Moving to more outcome-based agreements will remove the non-committal nature of being a network member, merely exerting basic efforts and not stepping these up when results are not achieved. Under outcome-based agreements, network members can be held accountable, and attention can be focused to those that fall short. Such an approach needs to be accompanied by proper incentive schemes (i.e. removing incentives that 'force' network members into their old habits and advancing incentives that are proportional to and make it worthwhile to step up to the mark) (Selviaridis & van der Valk, 2019). Also, end users, as part of the constellation of actors that make up the network, can be encouraged and incentivised in a comparable manner. Involving end users more strongly in the development of energy management services and the tools and devices supporting those (Trischler & Westman Trischler, 2021) will contribute to the acceptance, adoption and use of these public goods and services, and thus to permanent changes in energy consumption behaviour.

In summary, our research holds three theoretical contributions, residing in the seven propositions advanced for our two research angles at each of the three abstraction levels (micro, meso and macro). First, as a contribution to the literature on digital transformation, our in-depth qualitative analysis of the course of the smart meter rollout in the Netherlands over a decade reveals actions, both undertaken and left out, in relation to the digitalisation of the Dutch electricity sector and their effects (or lack thereof). Digitalisation of the electricity sector requires leveraging the potential of digital technologies, which are increasingly available, and of the data they generate, but it also requires OM insights and techniques to ensure intended strategies meet realised strategies. Here the OM concepts of contractual and relational governance can help improve the sharing (through contractual control) and leveraging (through relational norms and trust) of data (Aben et al., 2021) among collaborating (network) actors.

Second, our findings regarding the effective orchestration of the actors involved in the energy service network constitute a contribution to network governance literature, which has received limited empirical attention to date. While most OM research tends to focus exclusively on a supply network with a limited number of actors, we regarded the network with reference to a specific system (i.e. the system that provides energy services), thereby considering additional and different types of actors. The notion of system-oriented networks is becoming increasingly relevant and prevalent in practice. More specifically, we view the network as a meso-level entity, which influences and is influenced by both micro-level consumer behaviour and macro-level government policy and institutional context. It also draws attention to both end users and digital technologies as meso-level actors, underscoring the importance of considering the three collectively, not only as relevant stakeholders but also as active participants in speeding up the energy transition through digitalisation.

Third, adopting an OM perspective on the production and consumption of energy adds to the understanding of the potential of data-driven operational decision-making for the energy network. Although electricity grids 'transport' electrons rather than products, they act in many ways the same as any other supply chain. More specifically, we show that once privacy restrictions are alleviated and the roles of network members (particularly the DSOs) adjusted, data can be leveraged for purposes of congestion management or grid condition monitoring (e.g. identifying 'leaks'). As such, we go beyond current research, which largely focuses on implementation challenges related to digital technologies, by investigating how network actors can actually leverage data from these technologies.

On a broader note, this research focuses on a new and under-researched application domain for OM: digital transformation in a sector that in the near future will be undergoing a massive transition—that is, the electricity sector, which accounts for just 4% of industry studies in OM (Joglekar et al., 2016). More generally, public utilities and infrastructures are undergoing major restructuring as they transition (with aging assets and climate change) to a sustainable society. Digital transformation is paramount in all these transitions. We show that at least in the case of smart meters, policy makers should design policies with an operational mindset as an additional relevant perspective in policy-development, to avoid outcomes of digital transformation of the electricity sector not being achieved, as has happened so far. OM studies such as ours advance important insights for public policy and allow OM scholars to become more active contributors to the public policy dialogue, thereby helping to address the wickedness of public policy challenges (Helper et al., 2021).

### *4.6.2 Managerial implications*

What should managers do at the different levels? Here, we refer to the seven propositions from our case analysis, which are already inherently normative. Regarding our first research angle, related to smart grid management, our case shows that before constructing the national policies on smart meters, an assessment of the micro- and meso-levels should have been conducted to identify potential barriers. More specifically, we recommend to the actors in the energy service network:

- *To provide end-users with real-time and highly granular smart meter data in their immediate environment, for example, by in-room displays* (P4; micro-level).

And to policymakers:

- *To allow real-time measurement of the local grid by DSOs, including end-user smart meter data for smart grid management* (P1; meso-level); and
- *To provide governments and institutions with access to smart meter data for statistical and energy policy purposes* (P6; macro-level).

Regarding network governance, our case illustrates that the market paradigm was dominant during the smart meter rollout and that the ‘invisible hand’ was thought to step in to provide essential services and tools to make smart use of smart meter data. However, this hardly happened, and guidance from the institutional context is required. More specifically, we recommend to the actors in the energy service network:

- *To use outcome-based incentives for individual network members on availability and using smart meter data to align their goals with the overall goal of curbing energy consumption* (P2; meso-level); and
- *To involve end users in designing the offerings involved with responsible energy management* (P3; meso-level).

And to policymakers:

- *To promote increased energy awareness and financial incentives for energy-saving behaviours and investments for individual end users* (P5; micro-level); and

- *To bring societal needs for privacy and market legislation related to smart meter data in line with the societal needs for improved smart grid performance* (P7; macro-level).

#### *4.6.3 Research limitations*

This study "reveals and proposes phenomena of interest" (Collins & Browning, 2019, p. 236), and as such comes with certain limitations. First, we rely on a single, longitudinal case study into the rollout of the smart meter in the specific context of the Netherlands. This study's results are therefore analytically rather than statistically generalisable. Our propositions are indeed also presented from this perspective, in which we expect many of the issues encountered to be applicable (though possibly to different degrees) in other countries and in other (public) sectors undergoing digital transformation. We furthermore built on a rich and longitudinal dataset stretching over a decade and grounded our findings in extant literature to allow for theory development. Future research needs to be performed in other countries, involving other (public) sectors undergoing digital transformation, to further investigate the need for a (extended) network of actors to enable the transition to a digital future and the governance of such network of actors.

Second, despite the long time-horizon of our study, this case is not finished yet. It will only be finished when the digital transformation occurred, when smart use is made of smart meters. That may well take another decade, or it may never happen. Thus, our relevant time horizon is much longer than the average empirical research project. However, we cannot limit our study of OM phenomena to those that are "high-frequency, relatively low-impact" (Hora & Klassen, 2013). Some high-impact OM research issues occur only every other decade (Akkermans & Van Wassenhove, 2018), as is true for a major transition such as the digitalisation of the electricity sector. Validating our propositions in future studies will help the field of OM to make a difference in the digitally transformed future, so that societies can indeed make smart use of the wealth of data generated by digitalisation.

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## Appendix G

The two tables in this appendix show the results of our comprehensive literature review. **Table G1** shows an overview of the key studies on digitalisation and the energy sector in the OM literature, while **Table G2** shows an overview of key studies on the same topic in the energy literature.

**Table G1** Key studies on digitalisation and the electricity sector (OM journals)

| Study | Research focus/question | Methods | Findings (as defined in the study) |
|---|---|---|---|
| Wirl (1996) *Management Science* | "This study derives incentive compatible conservation schemes that mitigate strategic behaviour related to the practice of utility demand side conservation programs." | empirical analysis | (1) Optimal incentive schemes justify, contrary to the conventional least cost planning analysis, large costs for megawatts. The reason is that this scheme "bribes" consumers for incremental conservation yet deters at the same time strategic reactions. (2) Even though there are high costs for incremental conservation, this does not necessarily mean that conservation as such is large. (3) Optimal and incentive-compatible conservation schemes should be such that the highest subsidies should go to consumer with low subjective discount rates and to consumer with a high demand. |
| Terjesen, Patel, & Covin (2011) *Journal of Operations Management* | "The current study examines the relationship between manufacturing capabilities (in particular, those contributing to low operating costs and product quality) and venture performance." | survey; sample of 167 UK-based, high technology manufacturing ventures | Some of the same manufacturing capabilities that promote performance among older, more established manufacturers also do so among young firms. |
| McAdam, Hazlett, & Galbraith (2014) *International Journal of Operations & Production Management* | "Given the lack of overarching theory, the paper begins by borrowing from contingency, dynamic capability and organisational learning constructs, to explore the role that performance measurement models can bring to improve the alignment between business strategy and functional strategy (level 1 alignment). Second, the paper analyses the role of performance measurement models in developing functional practices aligned with supply chain management (SCM) strategies (level 2 alignment)." | case studies; interviews; focus groups; observations; archival study | (1) Performance measurement models applied within an organisational programme context can be used to improve strategic or level 1 alignment (i.e. between business strategy and SCM strategy). (2) Influencing process requires a reframing and contextualisation of existing performance measurement models to include strategy and lead measurement elements, rather than an extrapolation of existing approaches. (3) Performance measurement models and methods must recognise the multi-level nature of alignment and hence the difference between the need for both level 1 and level 2 alignments. (4) Performance measurement models can be used to improve alignment at level 2 after effective alignment at level 1. |
| Avci, Girotra, & Netessine (2015) *Management Science* | "The study offers an analysis or comparison of the new mobility system of switching electric vehicle (EV) batteries with the more conventional fixed-battery powered EV systems in terms of their ability to reduce oil dependence and carbon emissions." | literature review | An increase in gasoline price (by imposing taxes) is much more effective in reducing carbon emissions, whereas battery-price reducing policy interventions are more effective for reducing oil dependence. In fact, battery-price reductions (by way of purchase/research/manufacturing subsidies) and/or technology improvements may be inimical to reducing emissions in the case of switching-station systems, and they generally enhance misalignment between objectives. |

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| Hu, Souza, Ferguson, & Wang (2015) *Manufacturing & Service Operations Management* | "This study focuses on an organisation's one-time capacity investment in a renewable energy-producing technology with supply intermittency and net metering compensation." | case study; decision support model | (1) The optimal capacity level for the renewable energy technology depends significantly on the interplay between the energy demand and the random yield as measured by very small time intervals such as hourly. (2) From a policy perspective, firms may rely on governmental subsidies to justify investments in renewable energy, as they play a role in determining the optimal investment level through the unit investment cost. |
| Alizamir, de Véricourt, & Sun (2016) *Operations Research* | "How should feed-in-tariffs (FITs) for a renewable energy technology be set in order to accelerate its deployment, while optimising specific policy objectives?" | literature review; qualitative data collection | (1) Maintaining profitability at a constant level is in theory rarely optimal. (2) When the regulator also requires the policy to prevent any strategic delays, the constant profitability index policy is optimal if the diffusion and learning rates fall outside the no-delay region. |
| Joglekar, Davies, & Anderson (2016) *Production and Operations Management* | "The research domain Industry Studies and Public Policy (IS&PP) seeks to further our understanding of industrial practices and managerial challenges by explicitly considering contextual details in the design and interpretation of research studies." | literature review; sample of 180 papers | (1) Studies in different industries emphasise different themes of operational decisions. (2) Analysis of the sample yields methodological differences and gaps. Early studies (1992–2002) contain a mix of benchmarks and inter-industry comparisons, while later studies (2003–2014) are dominated by intra-industry research. (3) The authors also observed empirics → analytics → empirics cycles, with successive papers building on findings within a single industry that are derived from distinct methodologies. (4) The relationship between operations management and public policy is bi-directional. |
| Aflaki & Netessine (2017) *Manufacturing & Service Operations Management* | "A main goal of this paper is to investigate the effect of generation intermittency on investment in renewable capacity." | analytical model; secondary data | (1) Although increasing the price of carbon emissions does lead to lower total emissions, this policy is not a good way to promote investment in renewables. (2) Long-term electricity contracts, which offer fixed feed-in tariffs to owners of renewable generation capacity, do ameliorate some disadvantages of the liberalised markets. (3) Intermittency of renewable energy sources could well be a problematic feature that handicaps investment decisions in these technologies. (4) There are various options for reducing the intermittency of renewables. |
| Chhaochharia, Grinstein, Grullon, & Michaely (2017) *Management Science* | "This paper uses the Sarbanes–Oxley Act of 2002 (SOX) as a quasi-natural experiment to examine the link between product market competition and internal governance mechanisms." | analytical model; quasi-natural experiment; data consists of the entire Compustat database over the period 2000-2006 | (1) The SOX was indeed associated with significantly larger increases in efficiency gains in firms that belong to less competitive industries. (2) The source of the gains in efficiency stems from increased operational efficiency. (3) The utility deregulation event in the United States in the 1990s was followed by a notable increase in operating performance among firms that lacked governance mechanisms in place, suggesting that greater product market competition following deregulation played a significant role when corporate governance mechanisms were not well developed. |

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| Rafique, Mun, & Zhao (2017) *Production and Operations Management* | "This paper applies SC design and location optimisation models to address the unique features of the energy sector and present a new class of mathematical models for designing coal-fired energy SCs. The model captures interaction among different parts of an integrated energy SC, the unique economics of power transmission such as yield losses, political issues associated with equity, and dynamic interaction among energy consumption, economy and budget." | supply chain design & location optimisation models | (1) A key to resolving the energy deficiency (and therefore economic crises) is the design of energy supply chains to utilise these sources effectively under limited budgets. (2) The concept of energy supply chains and the modelling framework can be extended from coal to these energy resources where new models need to be developed to account for their distinct features and economics, and to optimally balance the energy mix from the available sources. |
| Kahlen, Ketter, & Van Dalen (2018) *Production and Operations Management* | "This paper studies the management of electric vehicle fleets organised in virtual power plants as a way to address the challenges posed by the inflexible energy supply of renewable sources. In particular, we analyse the potential of parked electrical vehicles to absorb electricity from the grid and provide electricity back to the grid when needed." | analytical model; real-life data about vehicle rental and energy market trading | (1) Increasing volatility in energy production due to distributed sources of renewable energy creates challenges, but also provides scope for new business models. (2) The proposed mixed rental-trading strategy allows fleet owners to charge their electric vehicles more cheaply, use their storage capacity for arbitrage trading, and rent out these vehicles as usual. |
| Tiefenbeck, Goette, Degen, Tasic, Fleisch, Lalive, & Staake (2018) *Management Science* | "This paper attempts to directly address salience bias in the context of resource conservation." | large-scale field experiment | (1) Real-time feedback on a specific behaviour can induce large behavioural changes. (2) A novel strategy for behavioural interventions in resource conservation is suggested: the focus on a specific behaviour and real-time feedback can yield a far greater effect than the provision of broader feedback. |
| Cui & Lu (2019) *Manufacturing & Service Operations Management* | "This paper studies how the government of a developing country optimises its local content requirement (LCR) policy to maximise social welfare in a setting where foreign OEMs produce and sell multicomponent products in the developing country." | stylised modelling with a Stackelberg game | (1) Product-level LCR policies are as effective as component-level LCR policies by achieving the same maximum social welfare. (2) When replacing a product-level LCR policy with a component-level one, a government should increase (decrease) the LCR for low-gap (high-gap) components. |
| Goodarzi, Aflaki, & Masini (2019) *Production and Operations Management* | "This study models a multi-player environment consisting of a grid operator responsible for meeting electricity demands, a photovoltaic (PV) manufacturer, customers who might install (solar) PV systems and a regulator who must set an optimal feed-in tariff (FIT)." | multi-player model game | Regulators, when designing incentive schemes, should be aware of and account for competitive dynamics in the technology manufacturing market. (2) Guidelines on how policy makers should adjust the FIT (t) in response to changes in technology (as might affect the cost c or efficiency l of manufactured PV panels) and also to changes in market factors (e.g. competition m), customer decision factors that determine PV demand q (e.g. investment myopia k) and the status quo vis-a-vis supplies of non-renewable energy (k). |
| Guajardo (2019) *Production and Operations Management* | "This study empirically analyses how consumer usage and payment behaviours interact in an application of rent-to-own (RTO) to the distribution of solar lamps in developing countries." | econometric models; longitudinal variation; observational data | (1) Documentation of an engagement effect, that is, higher usage rates led to lower probability of late payments by customers. (2) Reflecting the inherent flexibility given to users in RTO settings, customers often "bundled" payments, making advance payments for future product access. (3) Building on the insights derived from econometric models, predictive models of default were developed. |

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| Holmström, Holweg, Lawson, Pil, & Wagner (2019) *Journal of Operations Management* | "This essay summarises the contributions of the special issue articles, highlighting their focus on additive manufacturing and the encapsulation of design and production information in a digital artifact." | literature review | (1) Digital encapsulation allows each unique digitally encapsulated artifact to be acted on independently by operations and supply chain management systems. (2) Digital encapsulation enables the redistribution of activities across organisational and geographic landscapes. (3) Digital encapsulation facilitates interactivity of the digital artifact with external environment inputs. |
| Parker, Tan, & Kazan (2019) *Production and Operations Management* | "This study provides a structured review of the operations research and management science (OR/MS) literatures to describe the current operational and policy issues in the electric power industry, with a particular focus on issues surrounding electricity market design, renewable integration, effects of climate policy on electric power infrastructure, rise of electric powered vehicles, energy storage, and the growing interdependence between natural gas and electric power sectors." | literature review | (1) The OR/MS community is in a strong position to provide valuable decision-making support by bringing the necessary operational considerations into the discussion of electric power policy matters. (2) One criticism of OR/MS research is that real life details are often abstracted away in the pursuit of creating elegant models. More research that retains the necessary detail to be relevant in an industry context is encouraged. (3) Large literatures on electric power industry exist at both the technical and policy levels, but OR/MS scholars are particularly well placed to bridge these focal areas. (4) The potential for dual causality between operations and public policy decisions is especially strong in the electric power industry. (5) There is one overarching research question related to all these changes: How to redesign the grid and electricity markets to help society transition to a cleaner and more efficient electric power industry? |
| Uppari, Popescu, & Netessine (2019) *Manufacturing & Service Operations Management* | "Understanding why poor people prefer one technology over another is crucial in designing effective policies and implementing suitable business models. Many technologies, although perceived at the outset to be beneficial to the poor, are not easily adopted. This study explains preferences for light sources at the *bottom of the pyramid* and designing strategies to increase adoption of clean alternatives." | stylised consumer behaviour model | (1) Rechargeable bulbs are a viable market alternative only if they are offered at a lower marginal price than kerosene. (2) Consumers who are strongly averse either to blackouts. or to recharge inconvenience will continue to prefer kerosene. (3) Consumers might prefer kerosene even when behavioural factors (e.g. ignorance, trust, habits) do not play a role. |
| Angelus (2020) *Production and Operations Management* | "This study addresses the problem of how a consumer should invest in distributed renewable generation to minimise the total expected cost of meeting his electricity demand." | infinite-horizon, continuous-time model | The resulting partial differential equation with a time-dependent free boundary represents a problem whose general solution is presently not known. Despite some of its simplifying assumptions, our model was able to generate novel insights regarding optimal capacity investments and revenue-maximising prices of electricity. |
| Choi, Lim, Murali, & Thomas (2020) *Production and Operations Management* | "Why are time-based electricity rate programmes falling short in the residential sector?" | game-theoretic model; data acquired from the US residential electricity market | (1) Identification of the key factors that determine the viability of voluntary Time-of Use (TOU) tariff deployment and adoption in the residential sector. (2) Degree of voluntary TOU deployment in the residential market by utility firms will always lag the socially optimal adoption level desired by regulatory bodies like public utilities commissions. (3) Evaluation of the degree of cross-subsidisation to identify the implications for equity under voluntary TOU tariffs relative to the default fixed flat rate (FFR) tariffs. |

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|---|---|---|---|
| Chen, Visnjic, Parida, & Zhang (2021) *International Journal of Operations & Production Management* | "How does the business model change as a traditional product manufacturer pursues digital servitization? The paper seeks to understand the process of digital servitization as a shift of manufacturing companies from the provision of standard products and services to smart solutions." | single case study; longitudinal | To successfully offer smart solution value propositions, a manufacturer needs an ecosystem value delivery system composed of suppliers, distributors, partners and customers. Once the ecosystem relationships are well aligned, the manufacturer gains value with multiple value capture mechanisms (i.e. efficiency, accountability, shared customer value and novelty). To arrive at this point, a manufacturer must pass through different stages that are characterised by both discontinuous and continuous interplay between business models and digital technologies. |
| Dhanorkar & Siemsen (2021) *Production and Operations Management* | "This study shows how nudges in the form of reminders can serve as a simple yet powerful managerial lever to focus attention on such tasks and increase the likelihood that these tasks will be completed. It also studies the effectiveness of reminders in the context of energy efficiency tasks in manufacturing facilities." | archival data study; field study | (1) Reminders work more broadly: they influence decision-making even if the recipients of these reminders are not direct subordinates who work for the same organisation, and even if the underlying tasks involve significant resource commitments. (2) Government agencies can affectively use reminders to steer firms. (3) Reminders can focus attention on discretionary energy efficiency initiatives and as a result increase the implementation rate. (4) Reminders are especially useful when multiple parallel unrelated projects (i.e. high scope) or multiple tasks (i.e. high scale) are being undertaken simultaneously. |
| Drake & York (2021) *Production and Operations Management* | "To improve our understanding of this environmental technology transition (from coal to other energy sources), it is important to determine the extent to which each of these factors has accelerated coal unit retirements." | accelerated failure time model; data on US coal-fired generating units from 2008 through 2016 | (1) Results indicate that federal regulation, renewable utilisation, and Sierra Club activism have had the most substantial effect in accelerating coal unit retirement rates. (2) Natural gas prices have been demonstrated to contribute to the adoption of gas capacity as an alternative to the adoption of coal capacity. |
| Feng, He, & Ma (2021) *Decision Sciences* | "How many households will adopt solar panels in equilibrium and what are their equilibrium payoffs? How should the government design the subsidy to reach the socially optimal adoption number? How should public private partnership (PPP) scheme compare to the traditional scheme in terms of the adoption number and households' payoffs?" | game-theoretical models | (1) The private firm tends to require larger revenue share than cost share under PPP scheme. (2) PPP scheme leads to both a smaller adoption number and lower payoffs of households compared to the traditional scheme in the absence of government subsidy. (3) PPP scheme leads to a larger adoption number and higher payoffs of households as well as a positive firm profit when government subsidy is present. (4) The subsidy required to achieve a socially optimal adoption number is larger under the PPP scheme than that under the traditional scheme. (5) The comparison between PPP scheme and the traditional scheme is independent of subsidy forms. |
| Johnson, Roehrich, Chakkol, & Davies (2021) *International Journal of Operations Management* | "This paper analysed the similarities and key differences between product-service systems (PSS) and integrated solutions (IS) to establish propositions and advance a comprehensive research agenda on servitization." | literature review; conceptual paper | By reviewing and synthesizing extant PSS and IS research, this article identified five core themes – namely modularity, platforms, ecosystems, risks and governance. The importance of these five themes and their linkages to PSS and IS are examined and a theoretical framework with a future research agenda to advance servitization is proposed. |

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| Jung, Cho, & Shin (2021) *Production and Operations Management* | "This study aims to deepen the understanding of personalised digital nudges by evaluating their effects on energy-saving behaviour." | field experiment; data from a smart metering company in South Korea | (1) Misperception serves as a significant moderator for making heterogeneous responses toward an externally imposed goal, given that the misperception makes subjects evaluate their goal differently based on their perception. (2) Underestimating subjects reduced their energy consumption only under a goal setting with feedback. (3) Personalised features based on individual data should be carefully implemented because target audiences can have biased perceptions of their past performance. |
| Lin, Schmid, & Weisbach (2021) *Management Science* | "This paper analyses the impact of a particular source of risk on firms' liquidity management. It focuses on the risk that product price movements can lead to cash flow shortfalls in the electricity-generating industry." | empirical analysis; data from 50,000 individual power plants | (1) Firms' cash holdings are positively related to product price fluctuations. (2) Wholesale price volatility appears to increase the risk faced by electricity producers, who compensate by holding more cash on their balance sheets. (3) Firms with more inflexible production technologies tend to hold more cash in markets with more volatile electricity prices. (4) Product price volatility can be an important factor affecting firms' liquidity choices. |
| Micheli & Muctor (2021) *International Journal of Operations & Production Management* | "The study aims to address the roles of organisational performance measurement and management (PMM) practices in the development and implementation of business ecosystem strategies." | case study; longitudinal; interview, observation, and archival data | (1) The process of developing and implementing the ecosystem strategy was emergent and highly iterative, rather than planned and linear, eventually requiring key decision-makers in the company to challenge some of their deeply held assumptions. (2) PMM practices first acted as barriers to ecosystem development by promoting an excessive focus on revenue generation. Once modified, PMM helped capture, convey and reassess the ecosystem strategy. (3) Performance targets, indicators and strategy maps were not just data gathering and reporting mechanisms but key means to express competing perspectives. |
| Peura & Bunn (2021) *Management Science* | "This paper investigates how intermittently available wind generation affects electricity prices in the presence of forward markets, which are widely used by power companies to hedge against revenue variability ahead of near-real-time spot trading." | game-theoretic model | (1) An apparent paradox is demonstrated in power pricing: combining two procompetitive forces, forward trading and low-cost competition from wind power, may cause prices to increase when we consider the variability of the wind resource. (2) Reconciliation of contradicting observed pricing phenomena while suggesting new empirical research questions. |
| Sunar & Swaminathan (2021) *Management Science* | "This paper studies the impact of distributed renewable energy (DRE) on utility profits and social welfare under net metering, which is a widespread policy in the United States." | supply function competition model | (1) When wholesale market dynamics are considered, net-metered DRE may be a positive for utilities. (2) Utilities might benefit from emerging business strategies that motivate their customers to install solar panels. |
| Vedantam & Iyer (2021) *Production and Operations Management* | "This paper studies a manufacturer who makes capacity investment decisions concurrent with a research and technology project, so that the required capacity is available to deploy as soon as the technology is available." | stochastic dynamic program with Bayesian updates | Description a model of an R&D project with uncertain technology outcomes, where the reports of a project's progress are shared at reporting periods with a downstream manufacturer who could use the technology. The manufacturer uses the project updates to optimally add capacity so that the technology can be deployed immediately at project completion. |

**Table G2** Key studies on digitalisation and the electricity sector (energy journals)

| Study | Research focus/question | Methods | Findings (as defined in the study) |
|---|---|---|---|
| Peláez-Samaniego, Garcia-Perez, Cortez, Oscullo, & Olmedo (2007) *Energy Policy* | "This paper describes the current energy sector in Ecuador, its present structure, the oil industry, subsidies, and renewable energy, focusing on the evolution and reform of the electricity sector." | case study | (1) Expansion of electricity generation capacity in Ecuador has been at lower pace than demand, exposing the country to possible shortages in adverse climatic conditions. (2) The oil sector also presents problems with the reduction in production capacity, which is the consequence of poor investment due to lack of policies that promote private investment. (3) A new plan to reformulate fuel subsidies is also under consideration to ensure it benefits those in real need. (4) In 2005, there was an increase of 5.82% of power generation by self-producers and independent producers. |
| Pokharel (2007) *Energy Policy* | "In this paper, Nepal's current contribution to greenhouse gas (GHG) due to energy consumption is evaluated. Options for promoting more sustainable and environmentally friendly projects have also been discussed." | literature review; archival data analysis | (1) Nepal's current GHG production is one of the lowest in the world. However, with the growth in energy use, GHG emission will also grow. (2) Programmes must be developed as soon as possible to augment supply and to manage demand. (3) Carbon trading is in Nepal's favour. |
| Prasad (2008) *Energy Policy* | "This paper investigates what works for the poor and which type of reforms and implementation are effective and lead to a transition to more efficient and clean fuels from which the poor benefit." | survey | (1) Reforms do not necessarily benefit poor people, but when they cater to their conditions and affordability, there can be a positive impact on access to and use of clean, safe and efficient fuels. (2) Overall policies encouraging the use of more efficient and cleaner fuels are successful. (3) Information and education on energy policies and projects must be clearly and repeatedly communicated to households and communities. |
| Do & Sharma (2011) *Energy Policy* | "This paper provides an overview of the current energy policies with a view to identify areas where further policy effort is needed in order to facilitate a sustainable development of the Vietnamese energy sector." | literature review; policy analysis | (1) Given the modest availability of indigenous energy resources, poor energy infrastructure and the vulnerability of global sources of energy supply, the security of energy supply is likely to remain an issue of utmost importance for the Vietnamese policy makers. (2) There are three main areas that need to be specifically improved in existing energy policies: market-based energy pricing, energy efficiency and coordination of energy plans with other programmes. |
| Von Hippel & Hayes (2011) *Energy Policy* | "Which types of energy assistance activities are likely to be good candidates for support by members of the international community, individually or in partnerships?" | archival data analysis; interviews; observations | (1) The Democratic People's Republic of Korea (DPRK) will insist that light-water reactor provision be "on the table", so other parties should be ready to address that demand. (2) Options that involve energy efficiency and renewable energy initiatives are generally "robust" for application in the DPRK, fulfilling many different considerations with few "downsides". (3) Larger-scale options that contribute to regional economic integration as well as economic integration of the Koreas, may have significant benefits, but will likely be candidates for longer-term application, set up by smaller, local projects and extensive human capacity-building. |

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| Giordano & Fulli (2012) *Energy Policy* | "This paper presents a systemic perspective aimed at establishing technical and economic synergies that may improve the business cases of individual different Smart Grid technologies and contribute to reverse the consumption-driven paradigm of the electricity sector." | literature review; case study | (1) New business arrangements might leverage technological/business synergies, foster investments and shift business value to electricity services in line with the notions of efficiency, conservation and sustainability. (2) It is necessary to anticipate and tackle from an early-stage downsides and possible distortions that come with the establishment of new technological and business arrangements, such as privacy concerns, dominant positions in new business platforms and demanding behavioural changes from consumers. |
| Krishnamurti, Schwartz, Davis, Fischhoff, De Bruine, Lave, & Wang (2012) *Energy Policy* | "This paper uses methods from behavioural decision research to understand consumer beliefs about smart meters including in-depth mental models interviews and a follow-up survey with a sample of potential smart meter customers of a major United States mod-Atlantic electricity utility." | behaviour decision model; interviews; survey | (1) Consumers are positively predisposed toward smart meters. However, those attitudes are based on expectations about smart meters that are likely to be disappointed. (2) A significant minority of consumers expressed fears regarding privacy and loss of control, including utilities' ability to shut off service. (3) Electric utilities can address misconceptions about the benefits of smart meters in two ways. (4) Electric utilities can address concerns about the risks of smart meters in the same two ways: explaining them better and making them better (i.e. smaller). |
| Gerpott & Paukert (2013) *Energy Policy* | "This study explores antecedents of willingness to pay (WTP) different price facets for smart meters" | surveys; PLS analysis; sample of 453 German-speaking residential electricity customers | (1) Deployment and use of smart meters cause substantial costs. (2) Suppliers can try to recoup costs by letting residential customers partly pay for smart meters. |
| Jennings (2013) *Energy Policy* | "The thrust of this paper is that the purpose of smart meters will define how best to arrange their deployment. The approach taken in this paper is to use insights from innovation theory to deconstruct the logical conclusions of the current policy plans." | literature review | (1) Rather than a "one shoe fits all" policy, it is recommended that metering innovation policy tacks in one direction towards one purpose. (2) The twin purposes of managing demand and accurate invoices do not necessarily align. (3) Management of demand should be placed at the feet of the end user category that is defined by consuming a large share of total demand and a small proportion of total customer share. Large predictable loads are more attractive to the distribution network operator towards the end of managing peak demand then a large set of heterogeneous domestic demand profiles. (4) It is recommended then where the end-goal of public policy is to manage demand that the focus be kept on the building sector closest in annual consumption to the daily metered segment. |
| Lee & Lee (2013) *Energy Policy* | "This study aims to explore patterns of innovation and of evolution in energy technologies, particularly focusing on similarities and differences across technologies." | literature review; patent data analysis | The results show that, while each energy technology's innovation and evolution patterns had different characteristics, they all showed a decrease in technology-developer intensity, indicating that, as they evolve, more innovation actors participate in their development. |
| McHenry (2013) *Energy Policy* | "This work seeks to clarify Advanced Metering Infrastructure (AMI) fundamentals and discusses the technical and related governance considerations from a dispassionate perspective, yet acknowledges many stakeholders tend to dichotomise debate and obfuscate both advantages and benefits, and the converse." | literature review | (1) There is relatively high confidence in the magnitude of benefits from improved network operation and metering efficiencies from AMI investments. (2) Whilst the potential benefits from AMI investments are very large, yet the 'additional' and more uncertain benefit components are highly sensitive. |

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| Buchanan, Russo, & Anderson (2015) *Energy Policy* | "With smart metering initiatives gaining increasing global popularity, the present paper seeks to challenge the increasingly entrenched view that providing householders with feedback about their energy usage, via an in home-display, will lead them to substantially reduce their energy consumption." | literature review | (1) Limited evidence is found of the efficacy of feedback in reducing energy consumption. (2) Problematically the success of in-home-displays (IHDs) depends entirely on user engagement. (3) The unintended consequence of IHDs may undermine their energy reduction capabilities. |
| Buchanan, Banks, Preston, & Russo (2016) *Energy Policy* | "This paper examines the British public's responses to (i) smart meters and (ii) three 'smart service' concepts: automation, community rewards and gamification." | interviews; focus groups | (1) Initial reactions to the automation concept were mixed, with some participants declaring that it was a "good idea" that was "quite sensible" and "straightforward", and others denouncing it as "horrible" and requiring a lot of (mental) "energy", as well as having the "potential to be wrong a lot of the time". (2) The idea of community rewards inevitably raised issues regarding what was meant by 'community' and if such a thing even still existed, or the mechanisms via which the proposed scheme could be achieved. (3) The feedback we got from our focus groups suggests that on the whole gamification of energy was not something that would personally interest them ("I wouldn't have any interest in it whatsoever"). |
| Brutschin & Fleig (2016) *Energy Policy* | "This paper analyses the effects of fossil fuel rents on R&D expenditures and patent grants in the field of energy-related technology." | empirical analysis | (1) High oil prices induce increased R&D expenditures in developed countries. (2) Fossil rents are associated with decreasing patent grants when developing economies are included. |
| Knuckles (2016) *Energy for Sustainable Development* | "This research project develops a business model framework based on the robust management literature on business models and uses the framework to analyse 24 mini-grid business models that serve *base of the pyramid* markets." | literature review; case studies | (1) The results of this study suggest that the configuration of elements across the four dimensions of a business model is an important variable to consider when studying what makes mini-grids successful. (2) The main observations and findings, summarised above, have important implications for mini-grid developers, policymakers and regulators, and researchers. |
| Gouveia, Seixas, & Mestre (2017) *Energy* | "Daily electricity consumption profiles from smart meters are explored as proxies of active behaviour regarding space heating and cooling." | surveys | (1) The assessment of temperature-driven daily load curve changes as proxies for active cooling and heating demand behaviour shed the light on important issues on energy use for indoor thermal comfort. (2) The load curve (either as a total, per household or cluster of households) may be explained by the ownership of heating and cooling equipment, the income level, the house bearing structure but also from consumer behaviour for climatization purposes during the day. (3) The combination of smart meters with surveys produces knowledge on how, when and why people consume electricity, to inform policy makers and distinct energy stakeholders. |
| Hennessey, Pittman, Morand, & Douglas (2017) *Energy Policy* | "Integration of climate change adaptation and mitigation to provide co-benefits in the energy sector." | case studies; qualitative comparative analysis | (1) Integration is an effective means of generating co-benefits that contribute positively to project outcomes. (2) Effective leadership support is one means of achieving explicit integration. (3) Energy policy, in the form of voluntary instruments and incentives, is recommended to build necessary public-private partnerships and support leadership. |

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| Kipping & Trømborg (2017) *Energy* | "The overall objective of this study is to model hourly consumption of district heat (DH) and electricity (EL) in buildings within the Norwegian service sector. Moreover, differences in total modelled hourly energy consumption in buildings with direct electric heating and non-electric hydronic heating are analysed." | empirical analysis; panel data | (1) Comparing modelled total hourly energy consumption in buildings with direct electric heating (DEH) and non-electric hydronic heating (OHH) illustrates differences over the course of the day, which can partly be explained by differences in heat transport within the building (direct vs central heating system) and in corresponding control systems. (2) A comparison of modelled disaggregate energy consumption in a normal year indicates that schools with OHH supplied by DH use the main part of total energy consumption for heating, while office buildings with OHH use the main part for electric appliances (including space cooling). (3) The annual share of modelled heat consumption in buildings with OHH (supplied by DH) is higher than modelled space heating component for buildings with DEH, which can be explained by heat losses in the hydronic heating system (including main heat exchanger) and by heat consumption for domestic hot water (DHW) generation, which is included in DH consumption. (4) The results of the study show that smart meter data combined with cross-sectional information can be used for developing models for hourly consumption of DH and EL, but that the samples available in this study might be too small to achieve reliable results. |
| Rismanchi (2017) *Renewable and Sustainable Energy Reviews* | "This paper focuses on different district energy network (DEN) technologies, their applications, configuration, and has extensive information about the existing systems around the world." | literature review; case studies | (1) As district energy systems are designed to last for decades, one the important aspects of system design are the prediction of future heating and cooling demand. (2) DEN is a new concept with the aim to facilitate the management of energy by utilising intelligent decision-making algorithm that can bring balance between energy inputs and demand. |
| Sovacool, Kivimaa, Hielscher, & Jenkins (2017) *Energy Policy* | "Intended to reduce household energy consumption by 5–15%, the SMIP represents the world's largest and most expensive smart meter rollout. However, a series of obstacles and delays has restricted implementation. To explore why, this study investigates the socio-technical challenges facing the SMIP, with a strong emphasis on the 'social' side of the equation." | literature review | (1) The Smart Meter Implementation Program (SMIP) reveals a compelling obstacle to the vision of decentralised, prosumer-based energy provision. (2) Issues of timing, learning and alternatives are important. (3) The SMIP can do better. Although one can question the efficacy of a government mandated rollout passed to energy providers and suppliers at this stage, it remains likely that little can be altered at this point. (4) The SMIP reflects the contested politics of the smart economy. |
| Bridge, Özkaynak, & Turhan (2018) *Energy Research & Social Science* | "The papers in this Special Issue collection present compelling empirical evidence of how claims for energy infrastructure's national significance and/or necessity intersect with the (re)production of political and economic power." | literature review; composition of empirical evidence from other articles. | (1) Papers in this Special Issue confirm why it is important for social science research on energy to better understand claims about the national significance or necessity of energy infrastructure and their intersection with political power, particularly at a time of increasingly authoritarian populism globally. (2) Identification of five distinctive strands of enquiry within the existing literature, helping to differentiate the 'political work' of energy infrastructure. |

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| Kim (2018)<br>*Energy Policy* | "This study explores the effect of foreign aid as a channel of technology transfer on the recipients' technological capacity in the renewable energy sector." | empirical analysis | Foreign aid for technical cooperation in non-hydro renewable energy (NHRE) projects catalyses investments in NHRE capacity in low-income countries with a long incubation period. The findings confirm that hands-on cooperation, as emphasised by developing countries, contributes to their capacity building, although only in countries with low capacity to begin with. |
| Pereira, Specht, Silva, & Madlener (2018)<br>*Energy Policy* | "This paper, based on the large technical systems conceptual framework, investigates the complex evolution and company and market design adaptation needs." | case study; workshops | (1) Uncertainty regarding the value of full-scale rollouts of smart meters by distribution system operators. (2) Adapting operations for the provision or facilitation of these new value-added services, such as flexibility management, is considered a promising opportunity. |
| Tyner & Herath (2018)<br>*Applied Economic Perspectives and Policy* | "This paper picks up some important topics in the domain of energy economics and briefly describe the problems and issues that are addressed, how they are analysed and the current and future roles of agricultural economists working in this space." | literature review; policy analysis | In the future, issues relating to energy, climate change, environment and water will grow in importance, and we can expect agricultural economists to continue to make significant contributions. |
| Xu & Lin (2018)<br>*Energy Economics* | "Most of the existing studies use traditional linear models to investigate the relationships between new energy industry and its driving forces, ignoring the objective reality that there are many nonlinear relationships in economic variables. To overcome the shortcomings of existing research, this paper uses a data-driven nonparametric additive regression model to study the new energy industry." | empirical analysis | (1) Agricultural development has an inverted 'U–shape' nonlinear effect on the new energy industry. (2) Technological progress follows a positive 'U–shaped' pattern in relation to the new energy industry. (3) The nonlinear impact of foreign energy dependence on the new energy industry shows an inverted 'U–shaped' pattern. (4) The relationship between energy consumption structure and the new energy industry shows a positive 'U–shaped' pattern in the tail of the curve. (5) The nonlinear impact of economic growth shows a positive 'U–shaped' pattern. |
| Sovacool, Kivimaa, Hielscher, & Jenkins (2019)<br>*Energy Policy* | "In this Correspondence, we take the opportunity to reflect further on the Smart Meter Implementation Program (SMIP) and clarify elements of our research methodology and approach." | literature review | Smart meters have the potential to bring benefits to consumers in terms of reduced energy bills through a more efficient (and hence cheaper to run) energy system. |
| Yang, Hong, & Li (2019)<br>*Energy* | "An end-to-end deep ensemble learning model is proposed for probabilistic load forecasting which does not require additional feature extractions and selections on the input data. This technique is shown to be well suited to distributed computing, making it practical for large-scale industry applications. A LASSO-based quantile forecast combination strategy is formulated for deep ensemble learning model, which can further elevate the performance by refining the individual forecasts." | case studies; deep ensemble learning based probabilistic load forecasting model | Case studies conducted on residential and small & medium enterprise customers with two forecasting horizons demonstrate the superiority and effectiveness compared with state-of-the-art benchmark methods. This framework is particularly useful in practical applications such as residential demand response and home energy management in smart grids. |
| Batalla-Bejerano, Trujillo-Baute, & Villa-Arrieta (2020)<br>*Energy Policy* | "This paper summarises the insights to be gained from a literature review of empirical research devoted to behavioural considerations associated with the use of smart meters and energy information feedback." | literature review | (1) There is a sizeable potential market for smart Time-of-Use tariffs amongst consumers following the rollout of the smart meter. (2) Households with central aircon are more price-responsive and produce greater absolute percentage reductions in peak-period energy use than households without air conditioning. |

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| Belton & Lunn (2020) *Energy Policy* | "This paper presents an exploratory study that used experimental behavioural science to investigate consumer choice in electricity markets with time-of-use (TOU) tariffs." | experiments | (1) The findings suggest that consumers struggle to match tariffs to usage accurately, with a general aversion to TOU tariffs that may lead to sub-optimal choices between tariff types. (2) We identified a gap in the literature regarding how effectively individuals could decide between TOU tariffs, given that the benefits are dependent on usage patterns. |
| Chamaret, Steyer, & Mayer (2020) *Energy Policy* | "How do intermediary actors express resistance to smart meters? What is the relationship between intermediaries' expression of the arguments underlying their resistance, and the degree of resistance?" | quantitative clustering analysis; 444 reports | (1) A high degree of resistance (i.e. rejection) is closely linked with arguments of local electricity meter ownership or the lack of any benefit. (2) Lower degrees of resistance (i.e. postponement or leaving the choice to citizens) are related to arguments concerning the actual installation of Linky smart meters and municipalities' roles. |
| Chawla, Kowalska-Pyzalska, & Skowrońska-Szmer (2020) *Energy Policy* | "This study focuses on the consumers' preferences regarding smart meters." | survey | Results show that tech-savviness of India's consumers, common access to the internet for citizens, possession of smart phones by most of the population and ambitious goals of the Indian government, are a very productive mix for a nationwide roll-out of SM in India in the coming years. |
| Dutta, Bouri, Saeed, & Vo (2020) *Energy* | "This paper studies the effect of uncertainty in energy sector firms, as reflected in the information in the energy sector implied volatility index (VXXLE), on clean energy exchange traded funds (ETFs)." | Markov regime switching approach | (1) Relationship between the VXXLE and clean energy ETFs is asymmetric. (2) Clean energy assets are sensitive to changes in technology stock prices, while oil price volatility does not much matter for these ETFs. |
| Le Ray & Pinson (2020) *Energy Policy* | "In this paper a transversal literature review on smart metering is conducted, supported by practical examples through legal (i.e. right to privacy), technical (i.e. setups), social (i.e. how much data users accept to share) sciences, which then aims at giving a status overview about smart meters and eventually to define the range of utilities' possible practices." | literature review | (1) Mandatory installation of smart meters appears to be the best solution to fulfil the task on time. (2) The misalignment between expectations and delivered products (also related services), bad practices during the roll-out period, as well as the imbalance of risks and benefits for customers, are generating a negative image of smart grid technologies to customers. (3) In the current situation, the technological developments and investments are just used to have a more detailed picture of the demand side and not implementing an inclusive solution where customers would be stakeholders contributing to balance generation and consumption. (4) The insights from social sciences are necessary for the process of digitisation of the energy sector, as the technical–economical of smart grids technologies assume that the customers are rational. |
| Papadis & Tsatsaronis (2020) *Energy* | "This paper aims to contribute to the decarbonisation efforts by providing a basis for a better understanding of the challenges associated with it." | literature review | (1) Energy must become more expensive without causing political instability. (2) Complete global decarbonisation cannot be realistically achieved in the 21st century. |

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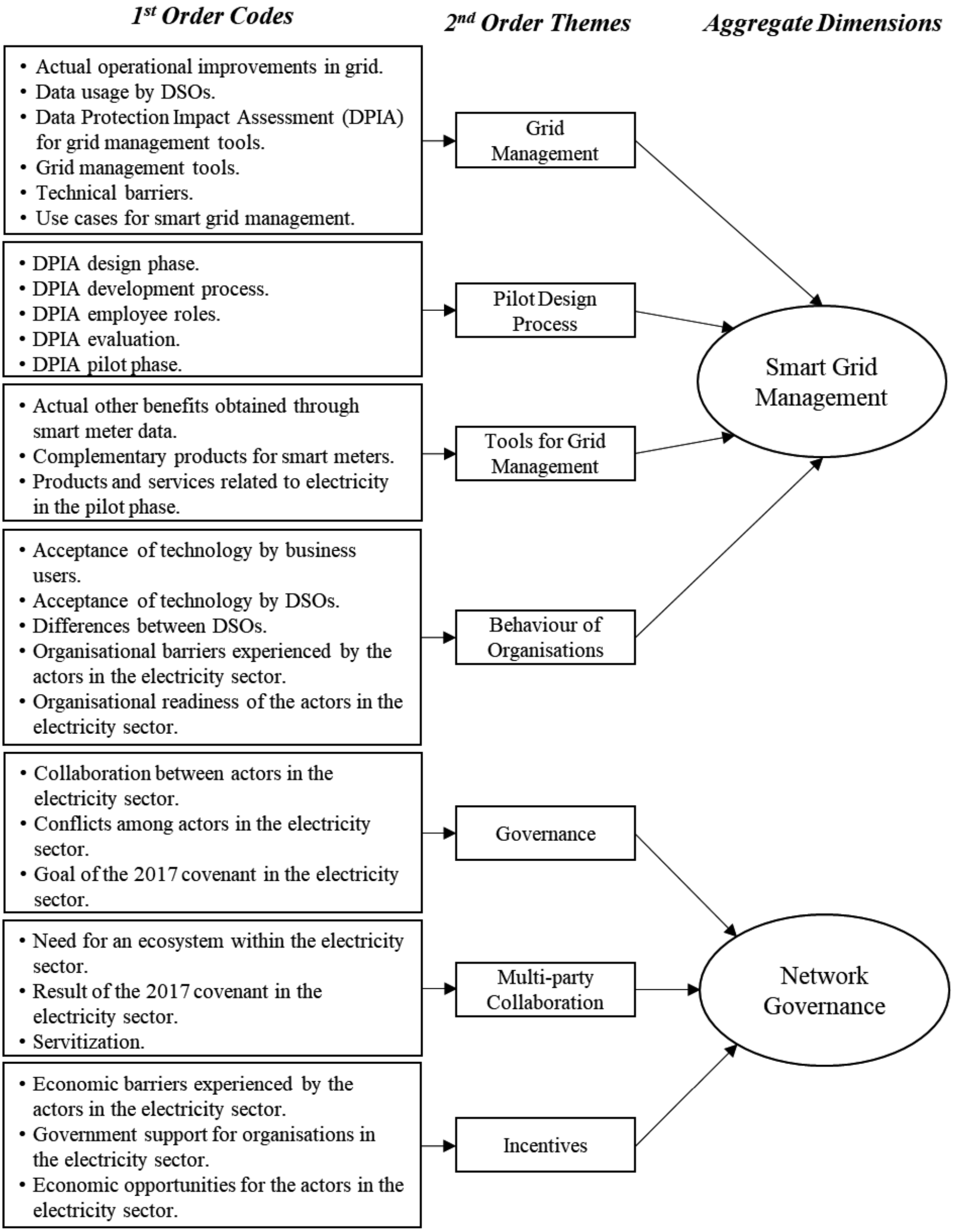
| Ahir & Chakraborty (2021) | "This study aims to identify the factors decisive for realising energy conservation through data analytics." | literature review; meta-analysis of 40 empirical studies | (1) The comparison with neighbour performance on energy conservation is more effective than goal-based comparison. (2) The combination of energy data analysis with goal setting may increase the effectiveness of energy conservation. (3) The appropriate sample size considered for the analysis would lead towards a deeper understanding of the usage and allows customers to get better insights of their consumption details. (4) As energy is invisible, the crucial factor considered for effective energy conservation is frequency. (5) The findings suggest that granular analysis of the energy data positively impacts effectiveness by allowing customers to be attentive about particular action needed. (6) In the case of household characteristic factors, income was not found to be a significant variable for energy conservation. |

# Appendix H


1st Order Codes
2nd Order Themes
Aggregate Dimensions
• Actual operational improvements in grid.
• Data usage by DSOs.
• Data Protection Impact Assessment (DPIA) for grid management tools.
• Grid management tools.
• Technical barriers.
• Use cases for smart grid management.
Grid Management
• DPIA design phase.
• DPIA development process.
• DPIA employee roles.
• DPIA evaluation.
• DPIA pilot phase.
Pilot Design Process
• Actual other benefits obtained through smart meter data.
• Complementary products for smart meters.
• Products and services related to electricity in the pilot phase.
Tools for Grid Management
• Acceptance of technology by business users.
• Acceptance of technology by DSOs.
• Differences between DSOs.
• Organisational barriers experienced by the actors in the electricity sector.
• Organisational readiness of the actors in the electricity sector.
Behaviour of Organisations
Smart Grid Management
• Collaboration between actors in the electricity sector.
• Conflicts among actors in the electricity sector.
• Goal of the 2017 covenant in the electricity sector.
Governance
• Need for an ecosystem within the electricity sector.
• Result of the 2017 covenant in the electricity sector.
• Servitization.
Multi-party Collaboration
• Economic barriers experienced by the actors in the electricity sector.
• Government support for organisations in the electricity sector.
• Economic opportunities for the actors in the electricity sector.
Incentives
Network Governance

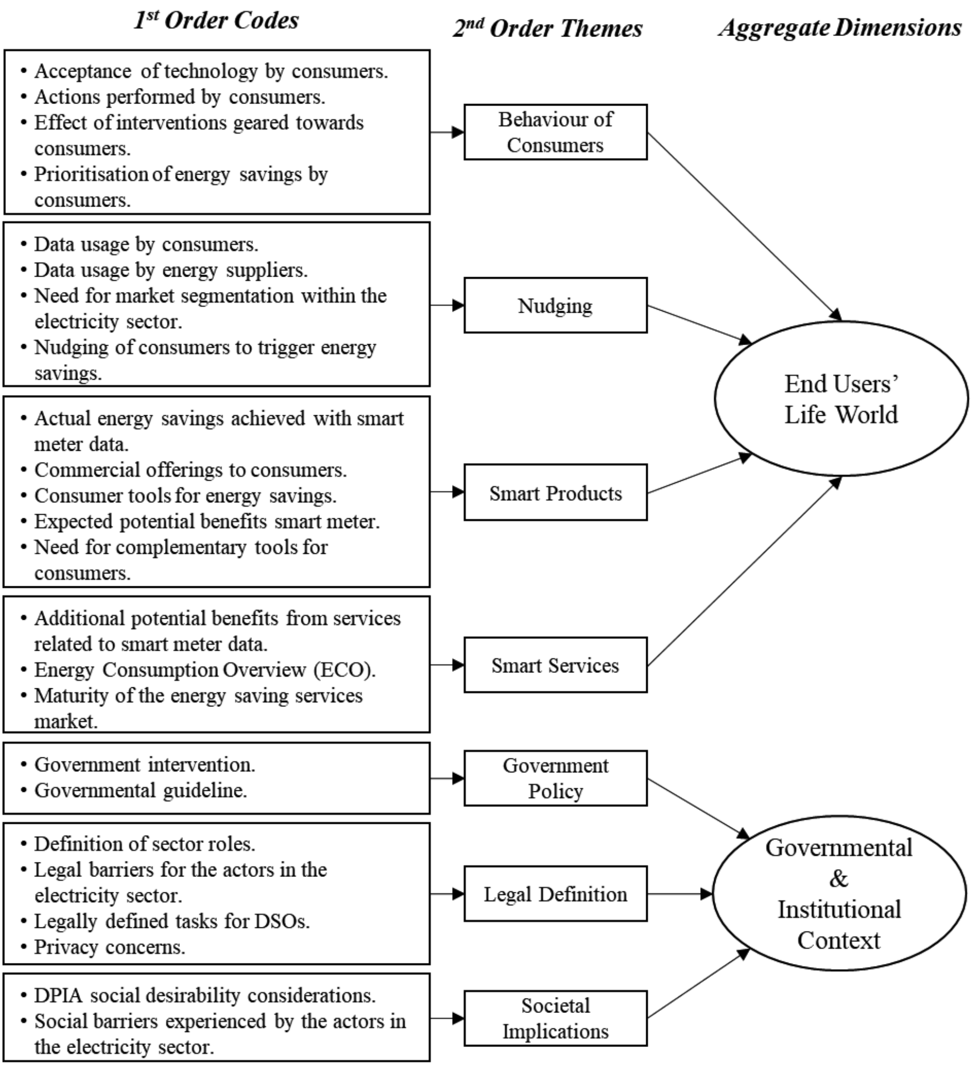



**Figure H1** Final coding scheme

# Chapter 5

## Discussion

The digitalisation of operations is in full swing, and it has an impact on both the internal operations of organisations and their inter-organisational operations with the various actors in their networks (Holmström et al., 2019; Søgaard et al., 2019). Triggered by digital technologies such as big data analytics, (smart) sensors, smart meters, RFID tags and IoT devices (Aryal et al., 2018; Ferretti & Schiavone, 2016; Kache & Seuring, 2017; Wunderlich et al., 2019), digitalisation provides (infrastructure) organisations with substantial amounts of (high quality) data that can be used to make better informed decisions (Waller & Fawcett, 2013). More concretely, the digitalisation of their operations provides infrastructure managers with opportunities to implement smart maintenance (Bokrantz et al., 2020) and smart grid management (Parker et al., 2019). Making smarter decisions regarding the management and maintenance of (infrastructure) assets is not simply a case of implementing digital technologies that produce data. Organisations must first have their internal data processing activities in place and must subsequently carefully consider the relationships with suppliers and other actors in their sector in order to able to leverage their partners' data and expertise (Birkel & Hartmann, 2019). This latter part is especially important for data regarding maintenance activities, as many organisations outsourced maintenance to specialised contractors (Caldwell & Howard, 2014). The question thus arises how these data processing activities can effectively be governed in both dyadic relationships and larger networks of actors. Additionally, digital technologies also trigger reconfigurations of supply chains and bring along uncertainty about potential future applications of these technologies that need to be addressed by (collaborating) organisations undergoing a digitalisation (Aryal et al., 2018; Birkel & Hartmann, 2019).

For the managers of critical infrastructures in the Netherlands many digital technologies are already mature enough to provide them with the right data to enable concepts such as smart maintenance and smart grid management. However, although digital technologies and data are widely available, recent reports showed that the Dutch infrastructure managers are slow with adopting and implementing digital technologies in their processes and that data is not yet being used to its full potential (Netbeheer Nederland, 2020; Van de Kerkhof et al., 2018). Therefore, the aim of the research that was conducted in this doctoral thesis was to investigate how infrastructure managers can, together with their direct partners (such as suppliers) or the larger network of actors in their sector (such as governmental institutions and end consumer), effectively share and leverage data coming from digital technologies to enable smarter management and maintenance of infrastructure assets. In this doctoral thesis, we specifically focused on data coming from 'new' technologies, such as (smart) sensors and smart meters, as well as data coming from the case organisations' existing databases.

In **Chapter 2**, the different data processing activities that organisations need to perform to obtain relevant information for their decision-making processes, and how these activities can best organised and governed in dyadic relationships, were investigated. By applying the lens of information processing theory (IPT), we identified two main data processing activities that organisations need to perform: data gathering and data transformation. Digital technologies enable the collection of more data (and thus enhance data gathering), as well as enable improved transformation capabilities (and thus enhance the quality of data transformation processes). Since the two main data processing activities require performing fundamentally different activities and the use of different types of capabilities, it also influences how these activities can be best organised in an inter-organisational setting. The results of the empirical investigation show that data gathering activities, needed to lower information uncertainty, include straightforward activities such as collecting data, obtaining access to data and sharing the data with other parties. To govern these activities, it is best to rely on clear contractual governance mechanisms. Here, relational governance mechanisms only play a supporting role and at most complement the contractual governance mechanisms. Data transformation activities, on the other hand, include less straightforward activities and typically require more cognitive skills, expertise from partners and joint sense-making. To govern these activities effectively, organisations need to rely mainly on relational governance mechanisms with a supporting role for contractual governance mechanisms.

In **Chapter 3** we built further on the findings of the previous chapter and investigated how these governance mechanisms are designed and adapted while the contracting parties are undergoing a digital transformation. Digital transformations influence the way contracts and the related relationships are organised, and at the same time pose additional challenges for the design of a contract and the relational governance mechanisms. This increases the possibility of post-formation adjustments being necessary. Along the way, organisations gain knowledge and gradually learn about the possibilities provided by new technologies. As such, intra-contract learning is important for buyer–supplier relationships dealing with (elaborate) inter-organisational data management processes, as this provides the contracting parties the ability to learn about new possibilities of data applications and incorporate these possibilities immediately in their contracts. The results show that, in order to keep flexibility during the contract period (to incorporate intra-contract learnings in the contract), good relationships between the individual employees at both sides of the dyad are crucial. Additionally, the initial design of the data clauses in the investigated cases were fairly 'generic' as their development was postponed to the last moment and their design turned out to be more difficult to draft than anticipated. As such, adjustments needed to be made during the contract period. This shows that the development of data clauses should be an integral part of the overall design process.

In **Chapter 4** we looked beyond the dyadic relationship and investigated how in a network of multiple actors in a specific sector (active on various levels) the individual actors can be motivated to jointly foster the sharing and leveraging of data for the purpose of making smarter decisions. When investigating a whole sector, the focus needs to go beyond the 'core supply chain' (i.e. the focal organisation with its first-tier customers and suppliers) towards a more extended notion of a network of actors, to include other actors such as end consumers and governmental institutions. As such, we have to look at three levels on which actors are present: the micro level (end consumers), the meso level (the core supply chain) and the macro level (government institutions). Although these actors operate on different levels, together they form an extended service network in which they need to collaborate to ensure that a joint goal is achieved (in our case the joint goal of ensuring smart meter data is used to make smarter decisions). This requires effective governance of the (extended) network of actors. The results show that it is vital to align the interests of the actors involved in the network and apply proper outcome-based incentives to motivate the individual actors to not only share data, but also use it. Moreover, it is imperative to actively involve (representatives of) all end consumers of data in the design of services or tools that enable leveraging data. Lastly, before (smart meter) data can be effectively accessed and used by the actors on the different levels, current (well-intended) privacy laws regulating the usage of (smart meter) data that are deemed personal data, need to be reconsidered. Here the government and other institutions need to better align the societal needs for privacy with the societal needs for improved smart grid management. The key findings of each of the studies that were described above are summarised in **Table 5.1**.

**Table 5.1** Overview of the key findings and theoretical implications of each study

| | **Key findings** | **Theoretical implications** |
|---|---|---|
| *Chapter 2* | Two main data processing activities were identified 1) collection of data to lower uncertainty and 2) transformation of data to lower equivocality.<br>To govern these two activities in public–private relationships requires: 1) strict control through contracts to collect data with a supporting role for relational governance and 2) joint goals and trust are needed to transform data with a supporting role for contractual governance. | Better understanding of how the introduction of digital technologies (producing data) affect data uncertainty and data equivocality.<br>Governance of data processing activities in inter-organisational situations. |
| *Chapter 3* | Drafting clauses related to data and data management is difficult as it is does not suffice to have a 'generic' design of these clauses.<br>Post-formation adjustments are common in relationships undergoing a digital transformation. This requires proper management of intra-contract learning and ensuring flexibility within the relationship. | Better understanding of the use of intra-contract learning processes in digitalising buyer–supplier relationships to enable post-formation adjustments.<br>In-depth insights in the dynamics of buyer–supplier relationships, thereby providing evidence that these relationships are not static. |
| *Chapter 4* | Some transitions require the cooperation of a whole sector and multiple actors.<br>Effective governance of extended networks should be focused on goal alignment and requires outcome-based incentives.<br>Better alignment between different societal needs when developing policies is needed. | OM scholars should extent their view from the meso-level to the micro- and macro-level as well.<br>Better understanding of how extended networks can be effectively governed.<br>OM scholars are well-placed to help address the 'wickedness' of public policy challenges. |

Looking at the doctoral thesis as a whole, the most surprising finding is that smart management and maintenance processes have not been implemented on a large scale yet, even though all infrastructure managers are claiming that 'becoming smarter' is essential to remain a thriving society with well-functioning infrastructure networks. So, it is not the lack of interesting in becoming smarter that is an issue here. Rather, it seems that the infrastructure managers are struggling to get the foundations in place before they are able to take the next step towards smart management and maintenance. This foundation entails employing appropriate digital technologies and leveraging the data coming from these technologies. In order to leverage data from digital technologies, infrastructure managers and their organisations need to access or collect the right data and be able to transform this data into valuable information. If not, it will be difficult to smarten the management and maintenance of assets. So, first the internal data processing activities need to be up and running. For this, infrastructure managers and their organisations need to invest in IT-systems and databases that can support the collection and transformation of data. Moreover, expertise among employees regarding data analysis needs to be fostered or new employees need to be hire (such as data scientists). Both implementing the right IT-systems/databases as well as ensuring your employees have the right expertise take quite some time. A difficulty here is that infrastructure managers do not have a 'paradigmatic example' (yet) that shows them how to effectively implement and use digital technologies such as managers of many (car) manufacturers had, for example, in the form of Toyota and their production plants (the Toyota Production System; Ohno, 1988), which was a great example showing organisations how to implement lean manufacturing principles with the aim to improve/protect their competitive advantage and profitability (Spear & Bowen, 1999).

Another main finding of this doctoral thesis it that data, digital technologies and (close) collaborations with not only suppliers, but at times also other actors in a sector, all play an important role in an infrastructure manager's (long) road towards the realisation of smart management and maintenance of the infrastructures he or she is responsible for. Infrastructure organisations cannot operate in solitude while dealing with the implications of digitalisation, especially in outsourcing situations. Since other actors in their networks often possess important data or the expertise to transform data, infrastructure managers are required to orchestrate data processing activities beyond their organisational boundaries in addition to getting their internal data processing activities up to speed. This adds to the length of the road infrastructure managers need to follow. Looking specifically into dyadic relationships, this doctoral thesis showed that contractual mechanisms are especially effective in getting the access to the right data and sharing it, while the relational mechanisms are especially needed to organise the transformation of data into valuable information.

In some situations, organisations must consider other actors in their networks as well in addition to their first-tier suppliers or customers, especially when the (digital) transformation of a whole sector is needed. Here, effective incentive schemes need to be developed with and for not only the organisations in the 'core' supply chain but also end consumers and governmental institutions to build an extended network. Collaborating with other actors in their networks does not only entail orchestrating the relationship. To be able to orchestrate it, effective contractual and relational governance mechanisms must be developed. The exact design of these governance mechanisms (which includes the design of formal contract, the establishment of common goals and the building of trust among other things) is subject to uncertainty created by rapid development of digital technologies. As it is difficult to foresee all new developments and their implications (e.g. new opportunities to further smarten maintenance), it is vital that contracting organisations create enough flexibility in their contracts and relationships to allow for intra-contract learning to make post-formation adjustments during their ongoing relationships to incorporate the latest developments or knowledge. In other words, the (long) road for infrastructure managers continues even after contracts with partners are signed.

## 5.1 Theoretical implications

The theoretical implications of the three studies conducted for this doctoral thesis are described in detail in the respective chapters and summarised in **Table 5.1**. Here, we shortly recap the main implications of each study and subsequently present the overall theoretical implications of this doctoral thesis.

**Chapter 2** has two main theoretical implications. First, it added to our understanding of how digital technologies affect the two types of information asymmetry that are identified by IPT (information uncertainty and information equivocality). In line with previous research (e.g. Sternberg et al., 2021), which states that digital technologies may reduce information uncertainty through enhancing both the quantity and quality of data, the findings in this chapter show that smart sensors enable real time data collection. The results also show that advanced data analytical tools, which are expected to produce useful information for better informed decisions (Frank et al., 2019), indeed enable organisations to combine data from different sources with relevant expertise of specialists to transform data into valuable insights, thereby reducing equivocality. Merely having these technologies in place does not automatically lead to the enhancement of data processing activities. These need to be properly managed in inter-organisational relationships. The second main theoretical implication of Chapter 2 is its contribution to existing theory about inter-organisational governance literature by investigating the roles of contractual and relational governance mechanisms in governing data processing activities (to lower information asymmetries) in relationships that are undergoing a digitalisation. The results show that an organisation needs to impose contractual control and coordination clauses to access data, and these reaffirm the need to set up incentive schemes that are proportional (Selviaridis & Van der Valk, 2019). To effectively transform data, the results show that organisations need to rely primarily on relational governance mechanisms, thereby highlighting that relational norms are needed to create bilateral expectations (Cannon et al., 2000) and trust is needed to allow for intensive collaborations.

**Chapter 3** built upon the results of Chapter 2 and added some nuance to these results. While the results in Chapter 2 show the 'ideal situation' with respect to the usage of the different governance mechanisms in digitalising inter-organisational relationships, Chapter 3 acknowledges that the digital technologies causing this digitalisation are still fairly new and create uncertainties regarding their use in the future. Moreover, new digital technologies can emerge and rapidly complement or even substitute existing digital technologies. As such, the main theoretical implication of this chapter is its contribution to the learning-to-contract literature as it examines how intra-contract learning processes are vital in digitalising buyer–supplier relationships to enable contracting parties to make post-formation adjustments to their contractual and relational governance mechanisms. These adjustments are needed to deal with uncertainties stemming from digitalisation in an effective way. Moreover, by applying a longitudinal research approach, this chapter also adds to a limited (but much needed) number of papers that provide in-depth insights into the dynamics of buyer–supplier relationships (Keller et al., 2021), thereby showing that these relationships should no longer be regarded as static once contracts are signed.

The main theoretical implication of **Chapter 4** is the contribution made to the small, yet emerging, literature regarding network governance by showing how a larger network of actors can effectively be orchestrated. More specifically, we investigated the effective orchestration of an energy service network, a topic that has received limited empirical attention to date but is becoming increasingly prevalent due the massive changes that are expected in energy networks around the world. Additionally, it shows how actors, operating on different levels, add to the creation of value with digital technologies by applying the multi-level framework that was recently introduced by Trischler and Westman Trischler (2022). Another important theoretical implication of this chapter is highlighting the importance of adding an operational perspective in the design of policies that are intended to support the digital transformation of a whole sector, as OM scholars are well-placed to help address the wickedness of public policy challenges (Helper et al., 2021). People and organisations are not fully rational as often assumed and require effective (network) governance, which is extensively being researched in the OM literature, to reach (more) optimal outcomes.

Looking at the overall theoretical implications of this doctoral thesis, the main message it conveys from a theoretical point of view is the fact that operations are (heavily) influenced by the digitalisation of their (inter-organisational) operations. This does not only influence the daily lives of practitioners working at digitalisation organisations, but also forces (OM) scholars to revisit their existing knowledge and theories. Since this doctoral thesis is focused on understanding the implications of the digitalisation of operations), it is no surprise that the results of all three studies in this thesis add to our understanding about how digital technologies trigger the digitalisation of (inter-organisational) operations and change these. Moreover, we took upon ourselves the challenge posited by Holmström et al. (2019) and set out to investigate whether and how established theories need to be revisited to better understand the implications of digitalising operations. We specifically focused on the challenges faced by organisations to share and leverage data coming from digital technologies more effectively (with the help of their partners), thereby extending the current governance and purchasing literatures to help scholars and practitioners better understand how data processing activities should be organised in both dyadic relationships and in larger networks of actors (Søgaard et al., 2019).

Another overall theoretical implication of this thesis stems from the fact that it focused on collaborations involving both public and private organisations. These organisations typically have diverging goals that need to be aligned, a feature that has not been highlighted a lot in OM literature as it is mainly focused on private–private collaborations (Mishra & Browning, 2020). In all three studies, we highlight how inter-organisational data processing activities can be governed in public–private collaborations and we explicitly address the challenges related to the alignment of divergent goals. Moreover, public–private collaborations are typically subjected to policies devised by governments. The (public) case organisations in all three studies are all heavily influenced by the policies designed by the Dutch government and need to follow these while managing their daily operations. As such, this thesis (and especially the fourth chapter) underscores the importance for OM scholars to investigate the OM–policy interface (Helper et al., 2021), while at the same time adding to this research stream by showing how public policies need to incorporate an operational perspective as well to ensure effective governance is achieved among actors targeted by policies.

## 5.2 Limitations and future research

No research is without limitations. Luckily, the limitations of the studies conducted for this doctoral thesis also provide interesting and useful avenues for future research. Below, the limitations of this thesis as a whole are discussed. Based on these limitations, future research opportunities are identified and presented.

A first limitation of this thesis is the focus on public–private collaborations (i.e. collaborations in which there is at least one (semi-)public organisation and at least one private organisation). The organisations in this type of relationship typically have inherently diverging and often opposites goals as public organisations often aim to achieve the (broader) goal of maximising societal value, while private organisations aim to achieve the opposite (and narrower) goal of maximising their own economic value (Caldwell et al., 2009; Klein et al., 2010). These divergent and opposite goals have an impact on the information asymmetries between the collaborating organisation, making it crucial to have optimal governance mechanisms (Cabral et al., 2019). In collaborations with similar types of organisations (e.g. public–public or private–private relationships), goals can still diverge and partially clash, but these are not opposing. Instead, the goals in these relationships are more aligned. For example, in a private–private relationship, both parties are typically interested in creating economic value (which is often enhanced when created jointly) and appropriating it. Therefore, an interesting avenue for future research is investigating how information asymmetry is addressed in other types of relationships and compare the results to the findings in this thesis that exclusively focuses on public–private relationships. It could very well be that the mix of governance mechanisms or the way these mechanisms are applied in collaborations between similar firms differ from those collaborations that include a mix of public and private organisations.

Another limitation of this thesis that it only focuses on a few specific types of digital technologies. However, there are many other types of technologies that are becoming available to organisations in our rapidly digitalising world. The focus in this thesis was specifically on (smart) sensors (the studies in Chapter 2 and 3) and smart meters (the study in Chapter 4) that produce substantial amounts of data for the infrastructure organisations involved, and on analytical tools that data scientists can use to analyse data (all three studies). These three technologies have their own specific influence on the asymmetries in collaborations and the governance of these collaborations. Other technologies, such as blockchain and artificial intelligence (AI), have their own specific influence on collaborations as well (Aryal et al., 2018). An interesting opportunity for future research is thus to investigate the specific influence of blockchain technology or AI on information asymmetries and governance mechanisms in collaborations between two or more organisations. Blockchain technology, for example, can be used to secure information transfers between entities, providing a more secure way to share data. This can foster more data sharing among organisations and thus potentially lower information asymmetries. AI, on the other hand, can radically change the way decisions are made. Instead of having human beings making decisions, AI enables computers to take decisions by themselves. This influences the transparency in collaborations (decisions are now made independently by AI programmes that are a black box for humans), as well as trust (organisations need to shift away from trusting human beings and start trusting technology).

A third limitation of this thesis is the fact that it involves (semi-)public organisations that operate, and are subjected to, the specific legal and regulatory context in the Netherlands. This context determines, among other things, the specific legal tasks that are given to (semi-)public organisations active in the Netherlands. For example, in the electricity sector, the Dutch government decided that the semi-public distribution system operators (DSOs) were not allowed to carry out commercial activities, and instead opted to rely fully on private companies to develop commercially interesting tools and services for end consumers of electricity. Moreover, the Dutch context also determines the degree to which organisations responsible for the management and maintenance of critical infrastructures are allowed to be privatised. While the Dutch government gave their executive agency Rijkswaterstaat the exclusive right to manage and maintain all major highways in the Netherlands, in some other countries, such as Italy and the U.S., the management and maintenance of highways are outsourced to private parties. A country's legislative and political frameworks thus have a significant impact on how organisations collaborate with each other, and which governance mechanisms are most effective. Therefore, an interesting future research opportunity is teasing out how big the effect of the specific legal and regulatory context of a country exactly is on how collaborations are shaped between public and private organisations, as well as on how effectively this context can trigger the digital transformation of public–private relationships. An interesting design would be to focus not only on the Dutch context but compare it with the contexts of different countries with diverging regulatory systems such as the U.S. (generally less governmental interference) or China (generally more interference by the government).

Finally, all three studies in this thesis were explorative studies into new and interesting phenomena (for both academia and society). Due to the explorative nature of the studies, a qualitative research strategy with different types of case studies were employed (Barratt et al., 2011; Ketokivi & Choi, 2014). While the case study approaches employed provided particularly good opportunities to gain a deep insight into the new phenomena, it also brought along limitations. For example, although the theoretically interesting cases in Chapter 2 and 3 enable theory building in the area of the governance of data processing activities in public–private relationships and of intra-contract learning in digitalising relationships respectively, there were no opportunities to test these newly built theories (Voss et al., 2002). Moreover, the case in Chapter 4 is not used to build theory per se, but rather is a very interesting case from a theoretical point of view that is used to showcase an important area of investigation (governance of extended networks), which has only been limitedly study in academia and for which further research is required (Hambrick, 2007). Put differently, the cases in this thesis highlight important areas for theoretical development and they can, at most, only build theory but not test them. As such, the results of this thesis require validation from other researchers and thus call for theory testing in future research. A related limitation here is the fact that the specific research project (LONGA VIA) had a significant impact on the selection of cases and the setting within which data was collected. The fact that five case organisations were already connected with LONGA VIA made it easier to access data, but at the same time it also limited the case selection as the cases needed to be found (preferably) within or around these organisations. This had the unintended side effect that the case studies (and the collected data) were all based on the Dutch situation, while it would also have been interesting to incorporate findings from other countries and the addition of more similar organisations.

## 5.3 Managerial implications

By taking the engaged scholarship as the central approach, the aim was not only to have a significant academic impact, but also to have a significant societal impact. In this section, the managerial implications of this doctoral thesis are discussed, thereby highlighting both the potential and the realised societal impact of the studies performed.

Before diving deeper into the managerial implications, first, a short reflection on the starting point of the research as described in Chapter 1. During preliminary interviews with representatives of the five case organisations, as well as the collection of the empirical data for the three studies later on, it became clear that there are indeed, from a technological point of view, various digital technologies already widely available that can be used to collect data and/or transform data into valuable information. Moreover, this information can indeed help them to make smarter decisions regarding the management and maintenance of infrastructure assets. For example, the introduction of smart meters in the Netherlands provided DSOs (such as Alliander) with additional data from the electricity grids they operate, providing opportunities for the introduction of smart grid management. Before the smart meters were introduced, the DSOs employed more reactive (only repairing assets after they broke down and end consumers called in a power failure) or preventive measures (preventively maintaining assets on fixed intervals before they fail) when maintaining their grids. Due to the smart meters, DSOs obtain data with which it is possible to more accurately and quickly pinpoint failures in their grids (e.g. a sudden power drop in a specific area can indicate a failure and a DSO can then already react before end consumers start calling). Moreover, the large pools of smart meter data can be used to identify trends with which DSOs can even start to predict pending failures and maintain their assets just-in-time. Moreover, the smart meter data can be used to provide end consumers with real-time information about their electricity consumption and help them to curb their consumption.

Another example of using data from a digital technology to enable smart maintenance for infrastructure networks is ProRail that equipped several trains with (smart) sensors. With these sensors, ProRail can monitor, in real-time, the condition of their railroad tracks. Before the sensors were placed, ProRail needed to send inspectors to each railway section to check the actual condition, which is a costly and labour-intensive process that at most enables the use of preventive maintenance techniques. Through equipping trains with sensors, ProRail now has 'eyes' on their railway tracks at all times without having to send inspectors to the tracks. This does not only save a lot of money, but it also enables the collection of far more amounts of data which ProRail can use to look for trends with which accurate predictions can be made regarding the remaining lifecycle of their tracks. A last example is the usage of analytical tools enabling data scientists to analyse large pools of data more easily (typically coming from different sources) providing the asset managers of their infrastructure organisations with opportunities to investigate the exact effect of the usage by end users on the health of their infrastructure assets and recalculate the remaining lifecycle of an asset or even individual components in that asset among other things. This helps infrastructure managers to smarten the management of their assets as they not only consider degradation models provided by manufacturers of the assets, but also the wear and tear caused by the actual usage of the assets.

### *5.3.1 Managerial recommendations to overcome internal organisational impediments regarding digitalisation*

A first recommendation is that organisations should develop a thorough understanding of their exact information requirements and of the data they already possess with which they can potentially address their information needs (or at least partially). To obtain a better understanding of their own needs, an organisation should first determine who needs information (who is the 'customer'?) and what that person or department needs to know (what information, insights or knowledge is needed?). Based on the customer (which can be both internal and external) and their information needs, the next step is to determine what data is required to satisfy their needs. Only when it is known what data is needed, it can be investigated whether this data is already possessed by the organisation or whether a specific digital technology is required to collect the missing data (i.e. equipping a critical component with a sensor that collects data about the health of that asset). To develop this better understanding, organisations are advised to set up internal programmes that promote and support pilots in which the employees that will eventually use the information work closely together with colleagues that can build the tools to deliver the information, as showcased by Rijkswaterstaat (and their Vital Assets programme) and ProRail (and their data lab) for example. Parallel to this, it is key that organisations develop an organisation-wide strategy regarding digitalisation and data management. This does not only force organisations to actively think about information needs and the implications of new technologies, it also (if finished) can be used as a tool to actively promote the use of data in daily operations and integrate data processing activities in the daily tasks of employees (rather than seeing it as a non-essential add-on).

Simply adopting digital technologies or building large data pools after an organisation determined their information needs is not enough to provide them and their end users immediately with the right information to make smarter decisions. Rather, it also requires the right data processing capacities and capabilities. As such, a second recommendation would be that an organisation should also evaluate to what extent they possess the required capabilities to obtain the information needed to satisfy the information needs of their internal and/or external customer. The research in this doctoral thesis has shown that there are different data processing activities that need to be performed before information is actually obtained. First data needs to be gathered after which it needs to be transformed into information. For both processes, experts are needed that can guide the organisation. These experts should be able to help the organisation to determine their exact information needs. Based on this the experts should be able to identify the different types of data that need to be linked with each other during the transformation phase to obtain the required information. This requires not only expertise related to data science (i.e. how to perform the data transformations), but also expertise related to the technical knowledge of the operation and maintenance of the specific assets in question. Fostering these experts can be done by either training asset managers in organisations (i.e. those employees that are experienced with operating and/or maintaining assets) to become data managers as well, or by hiring data scientists and place them directly in asset management departments.

### *5.3.2 Managerial recommendations regarding the governance of (dyadic) inter-organisational relationships undergoing a digitalisation*

Since many public infrastructure organisations outsourced the majority (or even all) of their maintenance activities to private contractor(s), they typically do not possess the required expertise to determine their exact information needs, let alone transform data into the required information. As such, infrastructure organisations need to collaborate with their contractor(s) and orchestrate these collaborations effectively. Below several recommendations in this area.

The first recommendation is that organisations should invest in a broader collaboration that not only focuses on the actual maintenance activities, but also on the organisation of data processing activities that cross organisational boundaries. Through collaborating, organisations can pool the data they collected individually, while also leverage each other's expertise during the transformation of data into valuable information. Additionally, a broader collaboration can also provide opportunities for joint exploration of the actual information needs, the location of required data to satisfy information needs and identifying the required expertise to transform the data into information. This requires a closer collaboration with the other party than in a situation where only specific products or services are being procured. Setting up these broader collaborations is challenging for many infrastructure organisations as they are used to having transaction-based contracts that focus primarily on strict contractual governance. Infrastructure organisations in the Netherlands are advised to refrain from entering into transaction-based relationships and, instead, invest in building strong relationships based on trust and clear relational norms that enables the pursuit of a joint goal. During the research, the case organisations showed progress in this area and took their first steps towards more collaborative relationships. For example, in the two cases from Port of Rotterdam the buying organisation and their two contractors consciously decided to focus on the relationship, be transparent to each other and do not let the contract dictate the relationship. Another example is Rijkswaterstaat that implemented an organisation-wide strategy in which their employees were motivated to work 'with the market' instead of pushing all tasks towards their contractors and strictly enforce the contracts. However, you still notice that collaborative relationship feels unnatural at times for infrastructure managers and contractors, especially when difficulties arise, prompting them to return to their old (and more protective) nature.

A second recommendation is ensuring that proper governance mechanisms for each type of data processing activity that needs to be performed are put in place. This is especially challenging in public–private partnerships as the involved partners often have divergent goals that need to be aligned before joint data processing activities can be established. Looking specifically at data gathering, the findings indicated that organisations should primarily focus on developing contractual governance mechanisms. By designing contracts with effective incentive schemes, the contracting parties will be able to control access to data and to coordinate the sharing of data among them. Designing effective incentive schemes entails, among other things, the creation agreements with proportional bonusses and/or penalties. If penalties are too high or too many risks are involved for the supplier which leads to a high chance it will cost them dearly, the supplier might refuse to sign the contract in the first place (this happened, for example, Port's case during Period 0). On the other hand, if penalties are too low, it makes it easy (and sometimes even profitable) for the contractor to not meet the agreements (which happened in one of the ProRail cases: the contractor preferred to pay the penalty since actually performing the task would have cost them more money). For data transformation, organisations are recommended to rely primarily on relational governance mechanisms. To transform data effectively into information, joint problem-solving is needed, which require a joint goal. It also entails sharing expertise and knowledge between the contracting parties for which trust and openness need to be fostered. This openness can be achieved by planning regular meetings and ensuring each other that the data or information shared will not be used against one another but will only be used for the (joint) goal of smarter management and maintenance of assets. This in turn helps contracting parties understand each other's intentions and makes it easier to discuss diverging intentions with the aim to align these for the benefit of the overall relationship.

Unfortunately, information requirements of the contracting parties are not always sufficiently clear *ex ante* as contracting organisations often do not have all the knowledge at hand to clearly determine these. Therefore, a third recommendation is to ensure that there is enough flexibility during a contracting relationship to allow for learnings, gained by the contracting parties when executing the contract, to be incorporated into the contract documents during the ongoing contract period (i.e. intra-contract learning). For this, it is important to evaluate the relationships between, and the behaviours of, the individuals at both sides of the dyad to see whether it is possible to have the required flexibility to incorporate intra-contract learnings during ongoing contract periods. Establishing a joint goal that benefits both partners (e.g. jointly learning how to perform data processing activities and adjust data clauses in contracts accordingly) is an important aspect here in which the employees from the contracting parties involved need to believe in. In case the behaviours of the individual employees are not aligned with the overall joint goal of the collaboration, frustrations can grow that may ultimately hamper intra-contract learning processes and prevent the further development of inter-organisational data processing activities and the related data clauses to govern these. Although it might seem contradictory to aim for both strict control and flexibility in contract documents during the relationship, these are not necessarily substitutes of each other. Rather, strictness and flexibility can be complementary. For example, before a relationship starts, the contracting parties can agree on a contract with specific KPIs regarding the sharing of data, which the buying organisations strictly controls and enforces. But by also formally agreeing to re-evaluate these KPIs together on a yearly basis, flexibility is built into the relationship (and the strict contracts), which provides enough space for all parties involved to improve the agreements and to keep benefitting from the contract at all times.

### *5.3.3 Recommendations regarding the governance of an extended network of actors undergoing a digitalisation*

In some situations, it is not enough to solely focus on your direct suppliers and/or customers. To achieve the full potential of digital technologies such as the smart meter, organisations are forced to collaborate with a wider network of actors in a sector, also known as an extended network. Below, several recommendations in this area.

A first recommendation is to govern the (extended) network of actors in such a way that all actors are incentivised to collaborate to attain a joint goal. Looking specifically at the Dutch electricity case, the use of outcome-based incentives is recommended for the governance of the energy service network. An important design feature here is the need to develop individual outcome goals for each actor involved that, if all achieved and added up, are equal to the intended overall outcome of ensuring that smart meter data can be leveraged effectively (e.g. to curb electricity consumption or enable smart management of the electricity grids). The individual goals should contain incentives for the involved actors to either make smart meter data available to the other actors in the sector (e.g. governmental institutions, DSOs and energy suppliers) or to actively start using this data (e.g. DSOs and end consumers). If not, you run the risk of having the same issue as the covenant that was signed in 2017 within the electricity sector (see Chapter 4) where the involved partners did achieve their individual goals, but the aggregated outcomes of these individual goals were not enough to achieve the overall goal. A related managerial recommendation with respect to the governance of extended networks is that it is pivotal to include end consumers as well. In the Dutch case in Chapter 4, the end consumers were not included, making it difficult to reach them and to incentivise them.

Not all data can be used freely by the actors in a network. For example, smart meter data are typically deemed ‘personal’ data and are protected by privacy laws, making it difficult for both public and private organisations to access the smart meter data and actually use it for either smart grid management or the development of tools and services providing consumers with information regarding their electricity consumption. Here you see a clash between the societal need for improved smart grid management and the development of tools and services based on personal data on the one hand, and the societal needs for privacy and protection of personal data on the other hand. To resolve this clash, the second recommendation here is that the policymakers should step up and find a good compromise between two pressing societal needs. Here, it is important to note that policymakers should not solely focus on legal considerations (in the smart meter case, the privacy regulations), but should also have an eye for the operational considerations (in the smart meter case, the development of effective smart grid management and tools and services for end consumers). Moreover, the governmental institutions are recommended to play a guiding role in the networks of actors to achieve the overall goal. In the smart meter case, for example, the Dutch government can actively promote increased energy awareness among Dutch citizens and businesses by providing financial incentives that rewards energy saving behaviours. With respect to smart maintenance, the Dutch government can, in consultation with the Dutch DSOs, promote smart grid management by providing clearer guidance with respect to which data can be used for smartening the management of grids and which data cannot be used at all.

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The digital transformation of organisations, triggered by various digital technologies such as smart sensors, smart meters and IoT devices, produces large amounts of data that make it possible to make smarter decisions. For infrastructure organisations this provides opportunities to smarten the management and maintenance of their assets. But why are these technologies not used on a large scale yet? Two important hurdles for infrastructure managers are 1) accessing relevant data and expertise needed to transform data into information and 2) the need to collaborate closely with partners in their respective supply networks. By investigating these hurdles, this doctoral thesis adds to the emerging literature regarding the impact of digital transformation on collaborating organisations. Moreover, this doctoral thesis provides infrastructure managers with practical ways to overcome these hurdles.

The three empirical studies in this doctoral thesis each investigate a specific aspect of the impact of digital transformations on collaborating supply network partners. Specifically, chapter two focuses on how the two main data processing activities (i.e. gathering data and transforming data) can be managed in dyadic relationships through contractual and relational governance mechanisms. Chapter three focuses on how post-formation adjustments to contractual and relational governance mechanisms in dyadic relationships are made to cope with uncertainty caused by the digitalisation of collaborative processes. Finally, chapter four focuses on the governance of supply networks (i.e. networks with three or more partners) and how the network partners can be motivated to share and use data from digital technologies.

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