Digital Transformation in Asset-Intensive Industries: Systemic Constraints and Synchronized Change

Shan Gao
Digital Transformation in Asset-Intensive Industries: Systemic Constraints and Synchronized Change

Shan Gao

A doctoral dissertation completed for the degree of Doctor of Science (Technology) to be defended, with the permission of the Aalto University School of Science, at a public examination held at the lecture hall AS1 of the school, and also via remote technology, on 21st August 2020 at 12:00.

Zoom link: https://aalto.zoom.us/j/67027932248

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Aalto University publication series
DOCTORAL DISSERTATIONS 106/2020

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ISBN 978-952-60-3959-6 (pdf)
ISSN 1799-4934 (printed)
ISSN 1799-4942 (pdf)

Unigrafia Oy
Helsinki 2020

Finland
Abstract

Digital transformation induces fundamental changes to a wide range of business operations. Prior research is abundant in cases from industries where digital transformation has emerged rapidly. This has led to the establishment of a shared notion of the promising future and impact of digital transformation. However, the slow progress of digital transformation in asset-intensive industries indicates that there are context-specific development patterns, and that the related challenges, opportunities, and capability requirements warrant a more comprehensive study.

To fill this knowledge gap, this doctoral research included empirical inquiry in the metals and mining industry. The four original research articles included in the dissertation adopt a qualitative case study approach with a focus on understanding the common new requirements, challenges, and development patterns of the organizational capabilities. Both inductive and abductive methods are utilized to derive findings from 53 interviews which were conducted during 2015-2018 - the global respondents represented 35 firms that either operate within or supply technologies to the metals and mining industry. The critical realist perspective is adopted in the study.

The findings show that firms operating in a stable business environment setting demonstrate limitations on their dynamic capabilities, and they consequently encounter market-specific digital transformation constraints. The outcome suggests the industrial firms shall develop and acquire new types of capabilities that organically connect the technological and social aspects of the transformation. For an individual firm, inter-organizational ambidexterity, which can be achieved by combining internal and network capabilities, is critical for unlocking the full potential of digital transformation. On the industry ecosystem level, this requires the connected firms to address the systemic constraints and to drive changes in a synchronized manner. Therefore, capability evolution calls for a balance between developing internal capabilities and exploring for complementary capabilities through networks.

This study adds understanding to the existing body of digital transformation and information system research, and contributes to the theoretical disciplines of dynamic capabilities and organizational ambidexterity. The study highlights the critical need for a synchronized transformation among the connected organizations, which in turn requires renewal of organizational capabilities. By introducing a novel terminology "boundary spanning dynamic capabilities", and by explicating organizational ambidexterity with network capabilities, this study attempts to shift the existing dynamic capabilities discussion towards a network perspective. The strong practical implications of this study reveal possibilities on how firms in the asset-intensive industries could overcome the recognized constraints and drive the digital transformation process.

Keywords dynamic capabilities, digital transformation, socio-technical model, organizational change, ambidexterity
Acknowledgements

The idea of this research was initiated by my confusion and curiosity towards the phenomena observed in the business environment, and the idea has been finally turned into this book through a few years of part-time research done mainly during weekends and evenings. This dissertation would not have been accomplished without the strong help from my brilliant academic fellows and the work colleagues, and the constant support from my family members and friends.

Given that my academic background was from Automation and Computer Science, and what I had was only a self-generated and somewhat immature idea that would be pursued on my free time, this dissertation would not have started without the trust from my supervisor Professor Jan Holmström. I would like to express my deep gratitude to Jan, and not solely for the academic support, but also for the guidance on the issues I encountered in my professional life.

I would like to thank the pre-examiners Professor Marko Kohtamäki from University of Vaasa and Professor Samuli Pekkola from Tampere University. In addition, I appreciate Professor Kohtamäki for agreeing to be the opponent.

It has been a definite privilege to have Professor Risto Rajala as my instructor throughout the whole journey. As a distinctive thought leader, Risto has been the one that pulls me out from self-doubts and confusion, clarifies the research direction, and drives for constant improvements on research quality.

I feel truly grateful to my instructor Dr. Esko Hakanen for the coaching and collaboration in all four research articles. Working with Esko is very enjoyable, inspiring, and efficient as he has extraordinary abilities in both research and coaching. Without his help this dissertation would have come years later.

Big thanks shall be given to my co-author Professor Pekka Töytäri for the support especially on the theory clarifications. I am always able to learn something new from the fruitful discussions with Pekka. In addition, I particularly want to thank Dr. Saara Brax for the valuable guidance on how to conduct proper research and the support on academic writing.

This research also has the honour to receive guidance from Professor Kalle Lytinen and Professor Blaize Reich. In addition, I enjoyed the inspiring and fruitful discussions with my fellows Juri Matinheikki, Jere Lehtinen, Mikael Öhman, An Chen, Eero Aalto, Tom Olsson and Hani Tarabichi from Aalto DI-EM. Thank you all for the precious support.
Among my professional circle, I have received tremendous help from my previous colleagues in Outotec for the data collection and idea generation. Dr. Kari Saloheimo has been the mentor for both my work and research. I really appreciate Kari’s constant help and guidance with his extensive knowledge and wide industry network. I want to further express the gratitude to my previous colleagues for the help during data collection and idea generation: Jari, Janne, Jussi, Jani, Eija, Mika, Claudia, Valentina, Susanna, John, Ari and many others. I thank Rui and Diana who are my former colleagues and long-time friends for the strong mental support.

I appreciate the support from my Reddal colleagues. In particular I thank Kun and Viivi for taking care of my project while I was away for one month to finalize this manuscript.

I thank the Bitter Lemon drink which serves as my writing companion during the past years. It is just fascinating that there is such a flavour that perfectly matches my occasional feelings towards academic research.

Finally, I appreciate the constant support from my parents, friends and relatives. Particularly, I acknowledge my husband Dr. Ville Paasikallio for the years of sarcastic academic jokes and all the proof-reading work.

Espoo, 03 June 2020
Shan GAO
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<th>Full Form</th>
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<tr>
<td>IoT</td>
<td>Internet of Things</td>
</tr>
<tr>
<td>IT</td>
<td>information technology</td>
</tr>
<tr>
<td>OEM</td>
<td>original equipment manufacturer</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>research and development</td>
</tr>
<tr>
<td>CxO</td>
<td>collectively refers to “corporate executives”</td>
</tr>
<tr>
<td>RBV</td>
<td>resource-based view</td>
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<tr>
<td>RFID</td>
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List of Publications

This doctoral dissertation consists of a summary and of the following publications which are referred to in the text by their numerals


Author’s Contribution

**Publication 1:** Technical capabilities are not enough: deploying Internet of Things in the metals and mining industry

This article project was initiated and led by the author of this dissertation. She was in charge of defining the research questions, planning the data collection process, and had the main responsibility of analysing the data, drawing the finding and contributions. The other author contributed to the data collection and development of the conceptual background. The authors had an equal contribution to writing the manuscript and managing the review process.

**Publication 2:** Digital transformation in asset-intensive businesses: lessons learned from the metals and mining industry

The article was initiated and led by the author of this dissertation, who had the main responsibility of formulating the research questions, conducting data collection, data analysis, drawing the finding and contributions, and writing the manuscript and managing the submission and review process. The other authors had a role in linking the findings with the theoretical perspectives, and they contributed to writing the manuscript and managing the review process.

**Publication 3:** Digital transformation calls for systemic and synchronized changes

The article was initiated by the author of this dissertation, who had the initiative of defining the research questions, data collection, data analysis, drawing findings and contributions, and writing the manuscript. E. Hakanen had a role in the data collection, data analysis, structuring and drawing findings, writing the manuscript and managing submission. R. Rajala and P. Töytäri took part in the discussions and provided guidance on theoretical perspectives, and reviewed and commented on the manuscript.

**Publication 4:** Digital transformation: the interplay of explorative and exploitative capability development

This article was initiated and led by the author of this dissertation, who had the main responsibility of the research questions, data collection, data analysis, identifying theoretical perspectives, drawing findings and contributions, writing the manuscript, managing submission, and review process. E. Hakanen contributed to the data analysis and writing of the manuscript. R. Rajala participated in planning of the research, as well as reviewed and finalized the manuscript.
1. Introduction

“It is not the strongest, nor the most intelligent that survives; it is the one most adaptable to change.” – Charles Darwin

1.1 Research motivation

Digital technologies are generating disruptive changes to the business environment. The change is ignited by the breakthroughs and early adoption of digital technologies and realized through interaction with people and existing structures. Changes as such are neutral, which can be an opportunity as well as a threat to firms. On the positive side, digital technologies enable fast evolution of innovations, drastic improvements on productivity and efficiency, and formation of new growth markets. The threat comes from the disruption to the existing business environment and the consequently diminishing industry boundaries and entry barriers.

The research motivation of this study was formed based on my practical experiences as well as confusion encountered during digital transformation related activities in asset-intensive industry sectors. The main objectives of this dissertation are to create an overall picture of digital transformation under a certain industry context setting, to investigate the underlying reasons for the slow rate of adoption, and to identify the needed organizational capabilities to effectuate the transformation. As the implications of digital transformation vary significantly depending on the industry, each industry needs to define its own digital vision and the path to reach it. Therefore, the scope of this dissertation is set as the industrial firms’ digital transformation process in an industry that is representative of the asset-intensive sectors: the metals and mining industry.

Prior research investigated the disruptive effects of digital technologies to the market environment (Porter & Heppelmann, 2014, 2015; Sebastian et al., 2017) and corporate strategy and business model (Hakanen & Rajala, 2018; Ross, Sebastian, Beath, Mocker, et al., 2016), the formation of platform economy (Karhu, Gustafsson, & Lyttinen, 2018), and the emergence of digital innovations (e.g. Lyttinen, Yoo, & Boland, 2016; Tumbas, Berente, & vom Brocke, 2018). However, considering digital transformation as a socio-technical change (Tilson, Lyttinen, & Sørensen, 2010), further research is needed to investigate digital transformation in a specific contextual setting. This study focuses on the asset-intensive sectors wherein the technological
changes have been limited during the past decades. Due to this kind of stability, organizations operating within this sector can be slower or more resistant towards digital transformation when compared to the organizations operating within the information technology or media sectors. Within the industrial context, organizational capabilities, and in particular dynamic capabilities are needed to drive the transformation within the firms. Recent studies (e.g. Teece, 2018b; Vial, 2019) highlight the need for future research on dynamic capabilities in the context of digital transformation. By combining the perspectives of both digital technologies and organizational capabilities, this dissertation responds to the aforementioned research needs.

From a practical perspective, the metals and mining industry has been facing emerging disruptions and growing challenges including aging workforce, declining ore grades and productivity, growing environmental and safety considerations, and new requirements imposed by circular economy (Ernst & Young, 2014; World Economic Forum, 2017). Industrial firms have gradually formed understanding and ideas about what digital technologies can do in their industrial context, and digital transformation has been recognized as an opportunity to mitigate the negative effects induced by the aforementioned disruptions and challenges (Ernst & Young, 2017, 2018; World Economic Forum, 2017).

The core goal of the metals and mining firms in adopting digital technologies is to improve the safety and efficiency of the mining operations (World Economic Forum, 2017). Therefore, the prominent implications of digital transformation are to bring automation, robotics and analytics into the operations, and to engage the workforce with digital platforms and applications. With collective efforts as such, the industrial firms attempt to reduce the involvement of humans in the physical mining operations which would lower the chances of safety incidents, and to replace manual work with automatic processes, machinery and remote operation.

1.2 Research objectives and questions

The main purpose of this dissertation is to ground the understanding of how digital transformation is realized in the targeted empirical context. In particular, we are curious about the firms’ capability requirements (Rajala, Hakanen, Seppälä, Mattila, & Westerlund, 2018; World Economic Forum, 2017; Xu, He, & Li, 2014) and the corresponding capability development (Adeniran & Johnston, 2016; Hakanen & Rajala, 2018; Teece, 2018b) for digital transformation. To answer this, it is important to understand what the practical forms of implementation for digital transformation in the industry context are, and what challenges the firms are likely to encounter during the process. Therefore, the overall research question (RQ), and the sub research questions (SRQ) are defined below:

RQ: How do companies in asset-intensive industries build up capabilities to drive digital transformation?
SRQ1: What are the practical applications of digital technologies in the industrial context?
SRQ2: Why did the industrial firms find digital transformation so challenging?
SRQ3: What capabilities are considered as essential for implementing digital technologies?
SRQ4: What capabilities shall the firms acquire to address the internal and external obstacles during the transformation?
SRQ5: How do firms evolve and expand their capabilities?

1.3 Dissertation outline

This dissertation includes four original research articles with each article responding to separate sub research question(s). Figure 1 provides an overview of the dissertation storyline and the relations of the included research articles. In particular, the real-life complications of the digital transformation process are uncovered in Articles 1 and 2. The capability requirements and acquisition actions which are expected to resolve the complications are explained by Articles 1 and 3. Article 1 focuses on discussing new applications and capability requirements induced by the external technology change force (digital technologies), whereas the emphasis of Articles 2 and 3 is on what are the internal challenges, obstacles and the capability acquisition needs among the industrial firms. Finally, the tensions and actions from both perspectives guide the firms to a development path towards reaching organizational ambidexterity throughout digital transformation. This perspective is discussed in Article 4. The highlights from each article are illustrated below.
**Article 1** – This article provides a consolidated view on the expectations of the IoT applications in the industrial context, and what are the digital technologies offered by the suppliers to fulfil these expectations. In order to facilitate and maximize the value of the implementation, the industrial firms should consider a novel portfolio of capabilities including analytic capability, IoT competency, business development, and the expertise on substance.

**Article 2** – This article focuses on industrial firms’ dynamic capabilities in responding to the disruptions brought by digital technologies. In particular, four categories of the challenges are identified: lack of capabilities to change, ambiguous goals, technological constraints and external constraints. The research highlights the interdependencies between the market rate of change and the firm’s dynamic capabilities, and proposes that transformations happen concurrently among the connecting firms.

---

1 Map of dissertation storyline against original research articles and adopted conceptual background can be found in Section 4.6 Synthesis of the findings.
Article 3 – Building on top of Article 2, this work deepens the understanding by interpreting the practical manifestation of the digital transformation process. The study extends the theoretical discussion from organizational capabilities towards the literature on socio-technical change. It argues that digital transformation requires systemic and concurrent efforts among the connected firms to acquire complementary capabilities and to develop boundary spanning dynamic capabilities in order to enable a synchronised transformation.

Article 4 – This research investigates the industrial firms’ capability evolvement path through digital transformation. The article identifies that industrial firms tend to start with exploitative activities and gradually add explorative activities. Empirical evidence shows that inter-organizational ambidexterity is seen as crucial to capture the full value potential of digital transformation. The research highlights the necessity and benefits of combining internal and external capabilities to achieve ambidexterity.

This dissertation consists of six sections. The introduction chapter provides an overview of the empirical context and adopted theoretical perspectives. Chapter 2 elaborates the theoretical foundation and the theoretical disciplines which have been the focus of this study, focusing on the impact of digital transformation in the industry context, and on the organizational capability development. Chapter 3 explains the research design, the evaluation of the research reliability and validity, and the corresponding ontological and epistemological considerations of this study. Chapter 4 presents the study findings on each sub research question, and then elaborates on their relevance and contributions to the main research question in a synthesized fashion. Chapter 5 consolidates the contributions to concept development, and discusses the need for synchronized change. Chapter 6 presents the practical and policy-related implications of the study, and discusses the limitations of the research and suggests future research directions. At the end, the original articles are included.
This chapter introduces the conceptual background of this dissertation. Figure 2 provides an overview on the empirical context and the applied conceptual background of this dissertation, as well as the main conceptual perspective each original research article (A1-A4) focuses on. The empirical context is set as the firm’s digital transformation in asset-intensive industries. This dissertation examines the empirical context of digital transformation as a socio-technical change (Leavitt, 1964; Lytyinen, Newman, & Al-Muhrifi, 2009) through which the changes happen in a set of fundamental, dependent and interacting social and technological components.

The conceptual background derives from the perspectives of organizational capabilities, and digitalization and digital technologies. As for the organizational capabilities, this dissertation particularly focuses on the discussions of dynamic capabilities and organizational ambidexterity. In turn, digital technologies enable and empower transformation (Porter & Heppelmann, 2015; Vial, 2019), and organizational capabilities drive the realization of the transformation (Helfat et al., 2007; Vial, 2019).

![Diagram](image)

**Figure 2.** Overview of the empirical context and conceptual background of this dissertation

### 2.1 Digital transformation reality in asset-intensive industries

During the last decades, the evolvement and adoption of digital technologies have become pressing development areas in the industrial environment. As general-purpose enablers, digital technologies are pervasive, capable of undergoing technical improvements, and they empower innovations on an applica-
tion level (Bresnahan & Trajtenberg, 1992; Jovanovic & Rousseau, 2005; Teece, 2018b). Notable innovations empowered by digital technologies have been observed in industries such as media, aviation, advanced manufacturing and logistics (Gandhi, Khanna, & Ramaswamy, 2016; Rigby & Tager, 2014; Wahi & Ahuja, 2017). In particular, the Internet of Things (IoT) is a representative enabling technology that builds a basis for digital transformation.

2.1.1 Digital transformation progresses slowly in asset-intensive industries

Digital transformation is gradually reshaping the business world. Defined as “a new development in the use of digital artifacts, systems, and symbols within and around organizations” (Bounfour, 2016, p. 20), digital transformation in this dissertation refers to a socio-technical process of applying digital technologies in social and institutional contexts (Tilson et al., 2010), and through which the changes are induced (Vial, 2019). Previous studies highlight the potential of digital transformation (e.g. Porter & Heppelmann, 2014, 2015; Yoo, Boland, Lyytinen, & Majchrzak, 2012) and how the established firms create and execute digital transformation strategies (e.g. Ross et al., 2016; Sebastian et al., 2017). Success cases which have arisen (e.g. Karhu et al., 2018; Ross et al., 2016) in certain industries have increased the overall expectations towards digital transformation – application of digital technologies is almost by default expected to generate business value.

The extent of success can, however, be highly industry dependent. The author of this dissertation has observed the slow progress and challenges encountered in the practical implementation of digital transformation in asset-intensive industries during 2015-2018. A similar pattern is also reflected in official statistics. Figure 3 illustrates the pace of digitalization for different industrial segments in the European Union as published by the European Commission. Asset-intensive industries such as base metals, construction, petroleum, chemicals and paper are still at a very early phase of digitalization. For example, the latest report from the European Commission illustrates that around 6% of enterprises in the base metal & fabricated metal products segment have high or very high digital intensity index (DII), whereas in the ICT sector the corresponding figure was well above 60% (European Commission, 2019). The difference is drastic, and a further noteworthy aspect is that the DII value of the metals sector declined from 10% in 2016 (European Commission, 2017) to 6% in 2018, which became the lowest among all the surveyed sectors.
2.1.2 Specific characteristics of the empirical context of this study

The empirical context of this study is set as digital transformation of the metals and mining industry based on three concerns: 1) metals and mining industry faces strong “headwinds” and these challenges are likely to stay and become the “new normal” market condition (World Economic Forum, 2017, p. 4); 2) actors in metals and mining industries were aware of the possibilities to apply digital technologies in transforming the industrial firms to fit for the new market condition and started taking action (Ernst & Young, 2018); 3) even among asset-intensive industries, the metals and mining sector is recognized as a representative context by statistics (European Commission, 2017, 2019) where low digital intensity was observed.

Mining and agriculture are the primary industries for the formation of early civilizations, and they continue to supply the basic resources for sustaining modern civilizations (Hartman & Mutmansky, 2002, p. 1). The metals and mining industry has been relatively stable for several decades, and consequently implementation of incremental operational improvements has been emphasized over disruptive innovations. However, in the past decade this sector has been suffering from a series of challenges such as declining ore grade and productivity (Ernst & Young, 2014), aging workforce and growing skill gaps (World Economic Forum, 2017) and weak demand on certain natural resources as China’s economy growth slows down (Deloitte, 2014; World Economic Forum, 2017). On the other hand, the increase in the demand for
battery materials has in the recent years given a certain degree of revitalization to the industry sector as well.

The disruption created by the pervasive digital technologies is interpreted by the industrial firms as an opportunity to help them transform and achieve competitive advantages under new market conditions (Ernst & Young, 2017, 2018; Jonsson, Mathiassen, & Holmström, 2018). However, existing literature (Bughin, Catlin, Hirt, & Willmott, 2018; Ernst & Young, 2017), available statistics (European Commission, 2019) and the author’s observations from practice indicate industry-wide deficiencies in driving digital transformation. There are a few hypothetical reasons associated with the industry characteristics which may hinder the transformation. First of all, the conservativeness of the metals and mining industry may not provide an environment that encourages trial-and-error and open innovations when compared to sectors such as information technology, media and e-commerce. This, in turn, makes the sector less appealing for the talents with digital skills. In addition, as an asset-intensive sector, the industrial firms are more likely to get stuck with legacy systems and machinery, whereas the disruptive business innovations with digital technologies tend to lean towards asset-light models as exhibited by e.g. Uber and Airbnb. Moreover, unlike in second or tertiary industries where firms have a certain degree of freedom in designing their offerings and pricing, the end-products from firms in a primary industry such as metals and mining are largely traded as commodity goods. In this context, the market prices are heavily influenced by overall global economic performance, as well as by periodic imbalances between supply and demand. To summarize, the industrial firms may lack the motivation, means and levers for discovering novel business models which would ultimately provide them with new ways of capturing value with digital technologies.

As the unique characteristics of the metals and mining industry impose specific challenges and opportunities to digital transformation, the experiences and learning from other sectors where the pace of digital transformation has been more rapid, are not directly applicable to this context. Therefore, the contextual setting of this dissertation is digital transformation of the metals and mining sector.

2.1.3 Internet of Things forms the basis for implementing digital applications in the industrial environment

Internet of Things is generally interpreted as a combination of various integrated and connected devices, machines, sensors and objects, among which the data is transferred through a network (Atzori, Iera, & Morabito, 2010; Xu et al., 2014). The Global Standards Initiative gives the following widely accepted definition for Internet of Things:

“The infrastructure of the information society enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies” (ITU-T, 2012, p. 1).
The term “Internet of Things” was initially brought up probably by Kevin Ashton in 1999 to describe the connected objects applying radio-frequency identification (RFID) (Ashton, 2009). IoT is not a radically new concept, but it has rather evolved and developed to describe the cyber-physical system (CPS) which links physical products to software agents in management and control applications, as elaborated in Figure 4. The key enabling technologies include RFID, communication technologies such as wireless sensor networks (WSN), networks and service-oriented architecture (Xu et al., 2014).

For instance, RFID is recognized as a crucial technology which enables the unique identification of individual objects (Holmström, Främling, & Alarisku, 2010; Lim, Bahr, & Leung, 2013). Communication technologies and networks further allow communication and information sharing among the objects. Combining the use of these technologies significantly increases the amount of collected information, achieves better control over the connected objects, and supports the integration of various new objects (Borgia, 2014; Holmström, Kajosaari, Främling, & Langius, 2009; Kärkkäinen, Holmström, Främling, & Artoo, 2003; Xu et al., 2014).

The adoption of IoT technologies forms a fundamental basis for incorporating intelligence on physical objects (Lin et al., 2017; Porter & Heppelmann, 2014). Meyer et al. provided a three-dimensional classification on intelligent objects based on the level of intelligence, the location of intelligence and the aggregation level of intelligence (Meyer, Främling, & Holmström, 2009). The level of intelligence varies from managing own information, sending notifications up to handling own decision making (Kärkkäinen et al., 2003; Meyer et al., 2009). The intelligence can be deployed to the edge (object level), or hosted through the platform (Iansiti & Lakhani, 2014; Lin et al., 2017; Meyer et al., 2009). In addition, depending on the aggregation level, the object can be an “intelligent item” which acts as the smallest unit for identification and management, or an “intelligent container” which can manage a group of items within the container, further serving as a proxy for the contained items (Meyer et al., 2009, p. 140).

<table>
<thead>
<tr>
<th>RFID 1980-</th>
<th>WSN 1990-</th>
<th>IoT 2000-</th>
</tr>
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<tbody>
<tr>
<td>• Automatic identification and tracking</td>
<td>• Intelligent sensor networks</td>
<td></td>
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<tr>
<td></td>
<td>• Industrial monitoring</td>
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<td>• Healthcare monitoring</td>
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<td>• Environmental monitoring</td>
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<td></td>
<td>• Interconnectedness of things</td>
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<td></td>
<td>• Ubiquitous computing</td>
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<td></td>
<td>• Multi-agent computing</td>
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<td></td>
<td>• Cyber-physical systems</td>
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</table>

Figure 4. Emergence and evolvement of IoT-related technologies - recreated based on Xu et al. (2014, p. 2234)

By taking the development of intelligent objects as a starting point and an essential prerequisite, IoT deployment often involves complex and systematic integration of intelligent objects, connectivity, data storage and software applications (Atzori, Iera, & Morabito, 2014; Porter & Heppelmann, 2014, 2015). When it comes to different industrial contexts, IoT applications are evolving fast while still exhibiting high potential (Atzori et al., 2010; Miorandi, Sicari,
De Pellegrini, & Chlamtac, 2012; Xu et al., 2014). For instance, development and spreading of IoT in the automotive, healthcare and media sectors have demonstrated early and convincing success (O’Halloran & Kvochko, 2015; World Economic Forum, 2016), whereas due to the varying industry nature and maturity, IoT-enabled applications are still at an early adoption phase in industries such as oil and gas, construction, and metals and mining (Ernst & Young, 2018; European Commission, 2019; Rigby & Tager, 2014).

Traditionally, mining operations require heavy human involvement in machinery control. The number of sensors is rather limited, and the precision is often negatively influenced by the tough operational environment that is often unavoidable in mining operations. In addition, these sensors are either disconnected or only visible at the site level e.g. at the Distributed Control System (DCS). The constraints on data availability, connectivity, visibility, as well as the semi-manual processes have generated silos in the operational processes, which has led to a situation where daily operational decisions are not sufficiently supported by data. However, the integration of IoT allows real-time data collection and information integration at the enterprise level, and potentially sharing the information with partners. The rich data and the connectivity create the fundamental basis for 1) creation of novel industrial applications such as autonomous logistics for surface mining and remote operation for underground mining, as well as 2) collaboration with partners on developing and deploying these industrial applications. Therefore, application of IoT, or digital technologies in general, is expected to generate radical changes to the industrial firm’s value creation process.

2.1.4 Digital technologies enable a new form of value creation

As mentioned in the previous section, by applying digital technologies in business and operational processes the physical objects are connected, tracked and controlled throughout, and at the same time, data and information are generated, stored and made available within and across organizations (Borgia, 2014; Keil et al., 2001; Wortmann & Flüchter, 2015). This does not just reshape the value creation process of the mining and metal processing firms, but it also has important implications for their equipment and technology suppliers. For instance, traditionally product related information has not been communicated efficiently between manufacturers and users. Digital technologies enable record tracking throughout the lifecycle of the product while at the same time enabling information sharing among the value chain players (Holmström, Holweg, Lawson, Pil, & Wagner, 2019). The complete information feedback loop allows the suppliers to adopt an open approach in continuous improvement on the product, and it also provides them new value streams such as offering information-empowered services to their customers (Hakanen & Rajala, 2018; Ranasinghe, Harrison, Främling, & McFarlane, 2011; Ross, Beath, & Mocker, 2019).

There are several representative information-empowered services that are particularly relevant to the metals and mining context. Straightforward services that suppliers can possibly start with are remote support and predictive
maintenance. As mining sites are often located in remote areas, unpredicted issues often lead to the shutdown of equipment. Operation is resumed after technology or maintenance specialists have travelled and solved in the issue in question on-site. Such on-site support can be replaced with long-term remote support services. With the predictive maintenance service, both the suppliers and the customers have better understanding and predictability regarding the operating conditions, which would allow them to make more informed decisions for pre-ordering spare parts, planning for the next maintenance actions, and for preventing unscheduled shutdowns.

In addition, the available product lifecycle information is an enabler as well as an accelerator of circular economy. For example, with sufficient data the mining equipment suppliers can better estimate the salvage value of their install-base, which may encourage them to purchase the legacy equipment from their customers and make full use of the old parts.

Furthermore, real-time visibility and traceability to the equipment also allows the suppliers to get deeper integration to their customer’s business in the long run. Services such as asset leasing, joint operation and performance-based services encourage value co-creation. The industrial firms can convert the operating model from asset-heavy to asset-light, and share risks with suppliers. At the same time, the suppliers can shift from product business which is often associated with one-time purchases, and instead enter into the world of long-term services where the revenue is more steady and predictable (Kamp & Parry, 2017).

Existing organizational boundaries tend to get blurred in conjunction with new forms of value creation. If the target is to create value via collaborative activities with customers, then the supplier also needs a more detailed understanding of the customers’ activities and goals to enhance their offerings to be more customer-oriented and innovative (Nylén & Holmström, 2015; Ross et al., 2019).

Firms are able to receive new ideas via such collaborative activities, but these ideas do not necessarily match the firms’ current capabilities, resources or offering portfolio. Thus, successful collaboration and value creation in environments comprising multiple actors with individual goals requires dynamic and fluent information exchange. Data is the cornerstone for value creation with digital technologies, and consequently, organizations need to adjust to a new way of working and acquire adequate capabilities in order to utilize and manage data (Durrant-Whyte, Geraghty, Pujol, & Sellschop, 2015; Ross, Sebastian, Beath, Scantlebury, et al., 2016; Tumbas et al., 2018). The benefits of sharing information among supply chain partners have been reported extensively (Yu, Yan, & Cheng, 2001). However, previous studies have not fully explained the challenges that are encountered during the formation of new value creation due to misalignment of stakeholder interests, or due to poor execution of the digital transformation process (e.g. Hakanen & Rajala, 2018; Porter & Heppelmann, 2014). Overall, it can be stated that a successful transformation process for an industry sector necessitates that both the mind-set and the capabilities of the involved firms are well aligned (Töytäri et al., 2018).
2.1.5 Digital transformation as a socio-technical change

This study focuses on the “transforming the firm to the digital era” aspect; this should be considered as a consolidated long-term effort instead of just a pilot or an ICT implementation project. Organizations find it easy to commit to and implement individual experiments, and therefore digital initiatives often start with experimenting with digital technologies in an agile manner to develop, test and demonstrate ideas. Transforming the whole organization in complex business environments, however, requires firms to be capable of organizing strong governance, cross-disciplinary engagements and clear objectives (Hakanen, Eloranta, Töytäri, Rajala, & Turunen, 2017; World Economic Forum, 2018b; Yoo et al., 2012). Experiments on technologies can provide quick wins, but the value impact often comes only after a successful shift of the social aspects such as new business model and way-of-working (Bresnahan & Trajtenberg, 1992; World Economic Forum, 2018a).

Therefore, digital transformation in this dissertation is considered as a socio-technical change (Nambisan, 2017; Tilson et al., 2010) which requires the organizations to respond to the disruptions and changes in the market and modify the value creation processes by taking in the new digital technologies (Vial, 2019). Leavitt (1964) proposes that a socio-technical change requires modifications on four interdependent and interacting variables including structure, task, people and technology.

On one hand, the firms operate within a social framework; they create and adopt beliefs, norms, values, structures and practices to conduct economic activities which fulfill the societal legitimacy (e.g. Oliver, 1997; Scott, 2013). In the context of digital transformation, the novel digital initiatives need to first gain legitimacy, and then spread within and across organizations (Hinings, Gegenhuber, & Greenwood, 2018). The newly formed legitimacy reshapes the beliefs, structures and practices at multiple levels which include society, organization and individuals (Scott, 2013). In other words, institutional factors such as beliefs and values influence a firm’s perceptions on whether to proceed with digital transformation, and as a result, the outcomes of the digital transformation process can be observed through updates on the institutional factors such as legitimacy, structures and practices.

On the other hand, digital transformation is led and driven by organizational capabilities. For asset-intensive sectors, such as the metals and mining industry, which have not been exposed to digital technologies extensively in the past, dynamic capabilities are required to empower the change. Shortage on dynamic capabilities results in slow progress and pitfalls during the change. Both existing literature (e.g. European Commission, 2019; World Economic Forum, 2017) as well as the author’s practical observations from the empirical environment highlight the slowness of the transformation progress and the lack of competences. Consequently, this dissertation selects organizational capabilities as the dominant theoretical perspective, with a particular focus on dynamic capabilities.

There are three reasons for the perspective choice. First, the nature of digital transformation is a purposeful change, which is aligned with the contextual
setting of dynamic capabilities perspective (Helfat et al., 2007). In addition, previous studies indicate relevance and linkages between capabilities and digital transformation, and call for research on elaborating the role of dynamic capabilities in digital transformation (e.g. Teece, 2018b; Vial, 2019). Last but not least, the empirical evidence highlighted the industrial firms’ constraints on dynamic capabilities. As an example, terms such as “ability”, “capacity” and “able/unable to” have recurred frequently when informants referred to their digital transformation efforts (Gao, Hakanen, Töytäri, & Rajala, 2019).

Previous studies have focused on the barriers and failures in the implementation of ICT projects (e.g. Arvidsson, Holmström, & Lyytinen, 2014; Töytäri et al., 2017). Furthermore, numerous studies can be found on the topic of business model transformation (e.g. Christensen, Bartman, & van Bever, 2016; Foss & Saebi, 2017). The digital transformation process is considered as a phenomenon that comprises several challenges, the interrelations of which are not fully understood. Studying this transformation process in a particular industrial context, where the technical prerequisites are far from ideal, should enable us to observe the associated challenges with less ambiguity.

2.2 Organizational capabilities drive the realization of digital transformation

2.2.1 New set of capabilities required for digital transformation

Disruptive changes require the firms to reassemble and update their resources and capabilities (Christensen & Overdorf, 2000; Hakanen & Rajala, 2018; Teece, 2018b). Companies supplying digital technologies face the challenges of diverse and constantly evolving base of information technology components, as well as the heterogeneous requirements on offering fit-for-purpose applications (Tilson et al., 2010). The different expectations of the users and other associated stakeholders make capturing of value with general purpose technologies very challenging (Teece, 2018b). In such an environment, technology suppliers need to develop new capabilities to be able to differentiate their offering from the competitors (Porter and Heppelmann, 2014; Adeniran and Johnston, 2016).

To start with, technological capabilities are apparently needed to design and develop new applications (Lin et al., 2017; McKinsey & Company, 2015; Svaht, Mathiassen, & Lindgren, 2017). As digital technologies are new to most of the traditional industries, the firms in these sectors are used to producing and selling tangible physical products instead of trying to create value through data (Ahmed et al., 2017; Porter & Heppelmann, 2014). Previous research has emphasised the essence of a series of capabilities in driving digital transformation – these include data collection and storage (e.g. Kärkkäinen et al., 2003; Meyer et al., 2009; Oriwoh, Sant, & Epiphaniou, 2013), digital platform management and application development (e.g. Atzori et al., 2010; Hakanen et al., 2017; Rajala et al., 2018), and data analytics (e.g. Ahmed et al., 2017; Gust, Flath, Brandt, Ströhle, & Neumann, 2017; Xu et al., 2014).
In addition, the firms shall have the capabilities to make sense of the digital technologies in business operations, i.e. they need to be able to change how value is created, delivered, and captured (Teece, 2010) - this perspective has been broadly discussed by scholars (e.g. Hakanen & Rajala, 2018; Hess, Benlian, Matt, & Wiesböck, 2016; Töytäri et al., 2017a). As the business world is becoming increasingly connected and networked, prior research has suggested the call for open business models and collaborative innovation among organizations (Fjeldstad & Snow, 2018; Hakanen et al., 2017; Töytäri et al., 2018). Such approaches allow for networked collaborative value creation (Gawer, 2011; Shipilov & Gawer, 2019), through which the individual firms could strengthen their own specialized competences and while gaining access to complementary expertise (Helfat & Raubitschek, 2018).

2.2.2 Dynamic capabilities form firm’s competitive advantage

Dynamic capabilities derive from the resource-based view (RBV), which fills the gap of explaining a firm’s competitive advantage in a turbulent/changing market. The main bulk of research concerning dynamic capabilities has been generated after publication of Teece et al. (1997), in which they extended the concept of resource-based view to include the dynamic capabilities approach.

RBV can be used for explaining what kinds of conditions are required in order for firms to achieve a sustained competitive advantage based on their resources and capabilities (Wernerfelt, 1995). The underlying assumption behind RBV is that resources and capabilities are distributed heterogeneously across firms, and that this kind of heterogeneity may be retained over extended time periods. A given firm’s resource and capability pool may provide a competitive advantage, but only under circumstances where the resources and capabilities in question are valuable and rare. In order for such an advantage to be sustainable for time, these capabilities must also be costly to imitate and non-substitutable. One shortcoming of the RBV is, however, its static nature, because of which it cannot be used for explaining how firms generate and maintain a competitive advantage under a changing environment (Barreto, 2010).

Dynamic capability is initially described by Teece et al. (1997, p. 516) as “the firm’s ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments.” Dynamic capabilities belong to the portfolio of organizational capabilities which are classified to two categories (Winter, 2003). Winter (2003) considers that the “zero-level” capabilities are the ordinary operational capabilities that firms adopt to manage routine tasks with roughly the same technologies to support existing products, services and customer basis. Dynamic capabilities serve at a layer above these basic capabilities. Teece (2007, 2018a) divides dynamic capabilities into two levels: the microfoundations and the higher-order capabilities. The microfoundations (also called “second-order dynamic capabilities”) allow firms to modify the current and to develop new ordinary capabilities such as refining products or expanding sales regions. The higher-order dynamic capabilities refer to the “the sensing, seizing, and transforming competencies that aggre-
gate and direct the various ordinary capabilities and the second-order dynamic capabilities" (Teece, 2018a, p. 41).

Teece et al. (1997) discuss that the formation of dynamic capabilities is associated with a rapidly changing environment. Later research (e.g. Eisenhardt & Martin, 2000; Zahra, Sapienza, & Davidsson, 2006) argues that a turbulent market is not a prerequisite for dynamic capabilities, but rather that the dynamic capabilities may be more value-adding in such markets (Zollo & Winter, 2002). While dynamic capabilities are generally considered as heterogeneous (Teece et al., 1997), commonalities can, however, emerge as a result of taking different dynamic capability driven development paths to achieve similar “best practices” for configuring resources and performing tasks across the firms (Eisenhardt & Martin, 2000). Although there may be common features, dynamic capabilities of different firms are still idiosyncratic on the detail level (Barreto, 2010).

Dynamic capabilities are necessary to generate and sustain a firm’s competitive advantage (Eisenhardt & Martin, 2000; Teece, 2007). However, there is no direct linkage between an individual firm’s dynamic capabilities and its performance, rather, the purpose of dynamic capabilities is to influence the resource configuration (Helfat et al., 2007). The reconfigured resources may impact the firm’s performance (Helfat & Peteraf, 2009), and the impact can be positive or negative. As an example, dynamic capability may create damages when used in a misinterpreted context (Zahra et al., 2006), or its benefits will not be realized when lacking long-term commitment of specific resources, or simply because of the various types of costs during its development and adoption (Winter, 2003).

In addition to quasi-automatic cumulation of experience from repeating practice, dynamic capabilities are developed through organizational learning (Eisenhardt & Martin, 2000; Zahra et al., 2006; Zollo & Winter, 2002). Zahra et al. (2006) further concluded that learning from experience is seen more relevant to the established firms, whereas learning via trial-and-error and improvisation processes are more relevant to the young firms. In the early work, Teece et al. (1997) assumed that dynamic capabilities were typically built inside organizations as opposed to being obtained from external sources. Consequently, the initial formation and further development of dynamic capabilities are dependent on organizational processes which are in turn influenced by asset positions and evolutionary paths the firms have taken in the past. However, in the very recent work Teece (2018a) acknowledged the potential benefits of involving external providers on handling operational capabilities-level activities. This in turn offers flexibility for the firms to allocate resources and attention for dynamic capabilities-level activities. The detailed discussion regarding dynamic capability development through learning can be found in the next subsections.

“Big ideas often take a long time to take on definition” (Williamson, 1999, p. 1094). A few researchers pointed out that the early studies have not formed a consolidated main construct for dynamic capabilities (Arend & Bromiley, 2009; Barreto, 2010), rather, the definition is considered as vague and confus-
ing (Winter, 2003). Through the evolvement of the theory other researchers have put significant efforts in bringing clarity and compatibility by redefining dynamic capabilities (e.g. Barreto, 2010; Helfat et al., 2007; Teece, 2007). In this dissertation, I adopt the definition of dynamic capabilities as an organization’s capacities

“(a) to sense and shape opportunities and threats, (b) to seize opportunities, and (c) to maintain competitiveness through enhancing, combining, protecting, and, when necessary, reconfiguring the business enterprise’s intangible and tangible assets” (Teece, 2007, p. 1319).

This definition emphasizes the need to respond to digital transformation and the pace of change in the industrial markets (Anunziata & Evans, 2012), and in this context asset-intensive sectors are no exception. Digital transformation falls clearly outside the traditional research and development (R&D) activities, and firms consequently have heterogeneous abilities for responding to disruption induced by digital technologies which the industry is so far inexperienced with. The deviations can appear in detection of opportunities, evaluation of these potential opportunities, or reconfiguration of the resources and capabilities. As the way dynamic capabilities are applied is shaped by the manager’s cognitive frame, change resistance may be formed inside organizations based on shared beliefs concerning organization roles and ways of doing business (Helfat & Peteraf, 2015). Therefore, based on interpretations to the empirical context, this dissertation focuses on investigating higher-order dynamic capabilities.

2.2.3 Firms develop dynamic capabilities through explorative and exploitative learning

A firm’s competitive advantage, as well as continuous survival, are determined by the extent of the firm’s dynamic capabilities (Eisenhardt & Martin, 2000; Henard & Szymanski, 2001; Teece et al., 1997). In turn, the development of dynamic capabilities lay’s in the firm’s flexibility in reconfiguring the resources to react on or to drive changes, or to be more specific, the ability to innovate and transform (Eisenhardt & Martin, 2000; Griffith & Harvey, 2001; Yalcinkaya, Calantone, & Griffith, 2007). Exploitation and exploration are the two fundamental learning activities applied by firms throughout the innovation and transformation processes (Lisboa, Skarmeas, & Lages, 2011; Yalcinkaya et al., 2007).

Exploitation

Exploitation represents activities as associated with “refinement, choice, production, efficiency, selection, implementation, execution” (March, 1991, p. 71). It emphasizes development and adoption of existing knowledge with certainties (Levinthal & March, 1993; March, 1991) and is often associated with characteristics such as stable markets and technologies, path dependencies, and routines and mechanistic structures (Ancona, Goodman, Lawrence, & Tushman, 2001; Yalcinkaya et al., 2007). The main purpose of exploitative
activities is to improve existing operational processes and products in an incremental manner in order to better meet current market demand, and to reach better customer satisfaction and increased revenues and profits. Exploitative activities tend to utilize the resources, partner networks and customers that are currently available for the firm (Li, Vanhaverbeke, & Schoenmakers, 2008). Knowledge searches are carried out within short distances, and the focus is on further cultivation of existing capabilities (Ahuja & Lampert, 2001; Argyres, 1996). Alliances are seen crucial for exploitative activities since the companies could learn from their partners (Rothaermel & Deeds, 2004).

**Exploration**

Exploration consists of activities related to “search, variation, risk taking, experimentation, play, flexibility, discovery, and innovation” (March, 1991, p. 71). As a risk-taking approach, it entails searching and pursuing knowledge that is currently unknown (Levinthal & March, 1993; March, 1991). Exploration is often associated with concepts such as emerging customer needs, untapped markets and technologies, and path-creation (Ahuja & Katila, 2004). Firms engage in explorative activities in order to provide novel products and services for the existing market situation, or alternatively to prepare for future market demand (Jayanthi & Sinha, 1998; Yalcinkaya et al., 2007). The novelty of a particular solution, i.e. product or service, can be categorized depending whether it is new to the firm, to the industry or to the world (Ahuja & Lampert, 2001). Generation of novel solutions is often done in exploration alliances wherein inter-organizational learning plays an important role. The partners in these kinds of alliances may come from different technology domains, and the alliance activities often include searching for knowledge from more distant domains as well as broadening of capability portfolios (Ahuja & Lampert, 2001; Argyres, 1996; Dittrich & Duysters, 2007; Rothaermel & Deeds, 2004).

**Ambiguity and clarity of exploration and exploitation – an integrated framework**

There are a number of definitions of exploration and exploitation in various empirical contexts, and this has led to inconsistency and ambiguity (Li et al., 2008). First of all, there are different interpretations of the terms “exploration” and “exploitation” (Gupta, Smith, & Shalley, 2006; Li et al., 2008). Exploration is often interpreted as searching for and creating knowledge which is currently unknown. There is, however, still confusion concerning whether exploration also entails utilization of pre-existing knowledge outside of the organization, or if only pursuit and acquisition of new knowledge should be counted as exploration. Some prior studies argue that both exploration and exploitation are highly relevant in learning and generating new knowledge (e.g. Benner & Tushman, 2003; Gupta et al., 2006; He & Wong, 2004). The main difference between these two concepts is related to the manner of learning: in exploitation, learning follows the same trajectory as the previous knowledge whereas in exploration there is a substantial deviation in the direction of learning. However, other studies (e.g. Perretti & Negro, 2007; Rosenkopf & Nerkar, 2001) classify all learning activities as exploration while
the term exploitation is reserved for activities where the central goal is the utilization of past knowledge.

The second source of confusion comes from the different units of analysis prior research has chosen when discussing exploration and exploitation. Li et al. (2008) provided examples of existing research wherein exploration and exploitation have been interpreted on the level of individuals (e.g. Audia & Goncalo, 2007), projects (e.g. Perretti & Negro, 2007), organizations (e.g. Benner & Tushman, 2002; Vanhaverbeke & Peeters, 2005), inter-organization networks (Hagedoorn & Duysters, 2002; Rothaermel & Deeds, 2004), and industries (Gilsing & Nootenboom, 2006).

Li et al. (2008) suggested a framework (See Figure 5) to account for the different aspects of exploration and exploitation in studying technology innovation – this framework includes two domains, i.e. function domain and knowledge distance domain. Substantive knowledge such as science, technology and market specific knowledge are incorporated into the function domain, whereas the knowledge distance domain differentiates between exploitation that involves local knowledge search and exploration which is focused on distant knowledge search. The knowledge distance can be further described via three component vectors: cognitive, temporal and spatial vectors.

![Figure 5. Framework of different perspectives in studying exploration and exploitation (Li et al., 2008, p. 119)](image)

As this dissertation focuses on the firm level digital transformation efforts induced and empowered by the disruptive digital technology innovations, the exploration and exploitation discussions are not limited to the product-market domain, but rather involve technological knowledge. I adopted the definition of exploitation and exploration by combining the function domain and knowledge distance domain, see Figure 6. Firms engage in exploitation activities by searching for knowledge that is located within their organizational boundary and the existing knowledge base. On the other hand, in exploration,
the knowledge is unfamiliar and more distant. The search for knowledge may be carried out along cognitive, temporal and spatial dimensions. Overall, the knowledge distance domain can be used as a basis for specifying whether a given activity should be classified as exploitation and exploration within each value chain function. Firms can conduct learning activities at multiple value chain functions. In such cases, upstream learning activities are considered to be more research oriented and therefore exploratory, whereas downstream learning activities are focused on profit seeking in commercial activities, i.e. exploitation.

![Figure 6. Typology of exploitation and exploration based on function and knowledge distance (Gao, Hakanen, & Rajala, 2020)](image)

### 2.2.4 Firms pursue ambidextrous performance

The previous subsection elaborates that a firm’s explorative and exploitative activities reflect its dynamic capabilities in driving and reacting to changes (Lisboa et al., 2011; Yalcinkaya et al., 2007). The roles of exploitation and exploration often coexist within the organizations (Rothaermel & Deeds, 2004). Positive exploitation performance builds the necessary foundation and provides the financial resources for conducting explorative activities, and explorative activities are needed to avoid inefficiency which may occur when firms focus solely on exploitation (Lee & Ryu, 2002; March, 1991; Yalcinkaya et al., 2007). Thus, a combination of exploitative and explorative capability development is argued as a key enabler for firms’ long-term survival, enhancement of financial performance and innovation improvement by a number of studies (e.g. Cottrell & Nault, 2004; Govindarajan & Trimble, 2005).

The aforementioned concept of combining exploitation and exploration is referred to as organizational ambidexterity (Raisch & Birkinshaw, 2008). Ambidexterity is a dynamic capability which can generate competitive advantages by facilitating efficient configuration of capabilities and resources (Eisenhardt & Martin, 2000). This capability is critical especially when firms are facing market and technology changes during which path dependency and organizational inertia may lead to stagnation. Choosing to pursue ambidexterity is often associated with operating in turbulent and competitive markets, as well as having diverse experience within the senior management team (Beckman, 2006; Jansen, Van den Bosch, & Volberda, 2006; Raisch & Birkinshaw, 2008).
Exploitation and exploration, however, usually compete for the same organizational resources (March, 1991), and therefore achieving a sustainable level of ambidexterity can be challenging. Realizing this requires that the organizational vision is clearly justified, the strategic intent well designed, and that the execution with the available resources is carried out according to the plan (March, 1991; Rotemberg & Saloner, 2006).

Gibson and Birkinshaw (2004) identify two types of organizational ambidexterity: structural ambidexterity and contextual ambidexterity. In this context, structural ambidexterity emphasizes handling the exploration-exploitation trade-offs by assigning the conflicting tasks to different groups or business units (Duncan, 1976). Contextual ambidexterity refers to “the behavioural capacity to simultaneously demonstrate alignment and adaptability across an entire business unit”. Therein, alignment refers to the explorative and exploitative activities working together in a coherent manner towards the same vision, and adaptability represents the capability of quickly reconfiguring and redirecting the activities when confronted with changing demands (Gibson & Birkinshaw, 2004, p. 209). Contextual ambidexterity emphasizes setting up processes and systems that allow and encourage the organization to have flexibility in dividing the resources among the explorative and exploitative tasks that seemingly conflict (Gibson & Birkinshaw, 2004; Tushman & O’Reilly, 1996).

Considering the exploration and exploitation typology illustrated in Figure 6, contextual ambidexterity can be reached by combining exploration and exploitation within and across value chain domains. A firm can achieve ambidexterity by searching for local and distant knowledge within the ‘knowledge distance domain’ of a single value chain function. Alternatively, firms can search for knowledge vertically from its upstream and downstream value chain functions. However, the bidirectional search across value chain functions can be very resource-intensive, and therefore different combinations which utilize targeted searches within and without a given value chain function may be used (Li et al., 2008).

Organizations tend to have limited means for managing conflicts arising between exploitation and exploration activities, and researchers therefore introduced the concept of partner perspective to supplement ambidexterity-related discussions (Kang, Morris, & Snell, 2007; Kauppila, 2010). Existing studies have highlighted the fact that alliances often serve as important complementary parties in exploitation and explorations activities of firms (Heimeriks, Duysters, & Vanhaverbeke, 2007; Kauppila, 2010).

2.2.5 Dependencies and integration among resources and capabilities from different sources

Dynamic capabilities of an individual firm can be limited and the firm can run into pitfalls during the sensing-seizing-transforming process (Teece, 2007). As digital transformation leads to broad aspects of changes on the processes and structures (Falkenreck & Wagner, 2017), this requires concurrent development and acquisition of complementary capabilities to different parts of the organi-
zation. Digitally enabled value creation requires integration of resources and capabilities from various units within an organization (cf. Chan & Reich, 2007) based on the new boundary-spanning processes and key dependencies. In particular, there are dependencies between resources and capabilities. The value creation via e.g. a new capability may require access to specific resources or capabilities. Such dependencies can be either unidirectional or bidirectional: in the former case the value of a certain capability is enhanced by another capacity whereas in the latter option concurrent availability of both capabilities is required for value creation (Jacobides, Cennamo, & Gawer, 2018; Teece, 1986). Dependencies as such are evident in the digital transformation process. Many of the relevant capabilities are valuable only under circumstances where the dependent specialized and co-specialized capabilities are available and accessible (Jacobides, Knudsen, & Augier, 2006; Teece, 1986).

However, when considering the organization-level change, developing and integrating the dependent resources and capabilities are likely to suffer from unoptimized organizational structures, strategic incentives and managers’ diversified cognitions (Helfat & Peteraf, 2015; Teece, 2007, 2018b). Most of the governance structures and management models that are in place have been designed to support existing operations, and they therefore do not necessarily provide adequate support for grasping the emerging business opportunities. Different functional units inside an organization also perceive things, such as development goals, differently, which may hinder the business transformations that are enabled by information technology innovations (Chan & Reich, 2007; Helfat & Peteraf, 2015).

On the other hand, the connected firms within an ecosystem should build shared cognitive models and integrate complementary capabilities beyond firm boundaries (Teece, 2018b; Töytäri et al., 2018). However, the digital resources and related specialized and co-specialized skills are often distributed across multiple organizations with different governance structures. Consequently, a truly integrative approach is often impeded and complicated by existing organization boundaries (Teece, 2018a). The situation gets further complicated when transformations proceed at varying speeds in the connected firms.
3. Research Design and Methodology

Research design and the associated choice of research methodology determines how the research will be conducted (Bell, Bryman, & Harley, 2018). This dissertation aims to generate an overall understanding about the realization of the changes enabled by digital technologies in the asset-intensive industries. This study focuses on the capability requirements and capability build up for driving digital transformation. The critical realism paradigm is adopted in this study to guide the observations of events in the target empirical context (Easton, 2010). All the original research articles applied qualitative case study as the research method.

This chapter starts with introducing the research paradigm of this dissertation, and it is followed by presenting the research design of this study. At last, research reliability and validity are discussed and evaluated.

3.1 Research paradigm of this dissertation

A paradigm is considered as a “basic belief system based on ontological, epistemological and methodological assumptions” (Guba & Lincoln, 1994, p. 107). Choosing a particular research approach is associated with making theoretical assumptions concerning the nature of reality. These ontological considerations define reality in a certain way, and this is reflected in the research aims, and in the way the research is carried out (Bell et al., 2018). The chosen ontological positioning has direct implications on how knowledge can be gained under a certain reality. This epistemological aspect is translated into more concrete terms when designing the research methodology – the practical implementation needs to match underlying epistemological and consequently ontological theory basis (Bell et al., 2018).

3.1.1 Ontological consideration

Guba and Lincoln (1994) define the ontological questions related to the belief of the world as: “what is the form and nature of reality and, therefore, what is there that can be known about it?” This dissertation adopts the critical realism perspective to interpret the world. Critical realism assumes that “there is a real world out there”, and that it is impossible to approve or disapprove this assumption (Easton, 2010, p. 119). Critical realists consider that the world exists regardless of our observations, and it will be “imperfectly apprehendable be-
cause of basically flawed human intellectual mechanisms and the fundamentally intractable nature of the phenomena” (Guba & Lincoln, 1994).

Connecting to this study, the target empirical context is set as the digital transformation process in a representative asset-intensive industry – the metals and mining industry. Digital transformation is considered as a socio-technical change (Nambisan, 2017; Tilson et al., 2010), which involves complex interrelations among the social and technological components including task, people, technology and structure (Leavitt, 1964).

The observations concerning technological changes are straightforward as disruptions generated by digital technologies have already resulted in a series of tangible applications that have been developed and presented by industrial firms (e.g. Kotze, 2018; Turner, 2018; World Economic Forum, 2017a). Technological change as a reality can be accessed through e.g. annual corporate reports, press releases, published whitepapers and cases, tangible digital artifacts and technology demonstrations.

The social change is more complicated to access: what is the reality about the social aspects of digital transformation? This dissertation focuses on the organization level digital transformation and investigates the associated organizational capabilities for the change. As an organization is formed by individuals, therefore the shared views, beliefs, and capabilities within the organization are critical (Crossan, Lane, & White, 1999). Individuals try to make sense of a change and create their own worldview. Worldview and the associated beliefs influence how people, and ultimately organizations, behave and rationalize their actions. In an organization, individuals become embedded in teams, organizations, industries and cultures, each of which has its influence on the individuals (Hughes, 1936; Lawrence, Suddaby, & Leca, 2011). These settings provide the platforms on which individuals interact with others and ultimately build shared understanding (Huotari & Chatman, 2001). Therefore, the reality for the social aspects of change studied in this dissertation is based on the maintenance and reproduction of stable human behaviour that is guided by the shared understanding. The ontological foundation of this dissertation is that the organizational capabilities are real as they are reflected in the organization’s routines and processes, which can be observed through activities, documents and measurable results.

3.1.2 Epistemological consideration

Guba and Lincoln (1994) identify key epistemological questions as “what is the relationship between the knower or would-be knower and what can be known?” The naïve realist epistemology assumes that the reality can be readily accessed and measured, whereas the socially constructed phenomena rarely fulfil such conditions (Easton, 2010). On the other hand, critical realists assume an “eclectic realist/interpretivist epistemology” (Easton, 2010) as the researchers “acknowledge that social phenomena are intrinsically meaningful, and hence that meaning is not only externally descriptive of them but constitutive of them (though of course there are usually material constituents too). Meaning has to be understood, it cannot be measured or counted, and hence
there is always an interpretative or hermeneutic element in social science” (Sayer, 2013, p. 17).

Critical realism fits for social science research that aims to understand and explain the social phenomena. The research relies on “recording and analysing the associated events that take place as a result of the actors acting, whether they are human or non-human (e.g. machines such as computers)” (Easton, 2010, p. 123). To understand and interpret the mechanism which affects the events which may be only observable through social phenomena, social scientist needs to stay critical on the object (Sayer, 2013).

Critical realism has a stratified ontology including the domain of the empirical, the actual and the real (Bhaskar, 2008). The observations are made in the empirical domain, the events occur in the actual domain, and the events are results of the mechanisms that operate in the real domain (Easton, 2010). Therefore, the observations are fallible since they are unlikely to generate a complete understanding of the targeted phenomena (Easton, 2010). With the same data, different researchers will generate varying interpretations and apply different theoretical perspectives. This epistemic fallacy means that as researchers we are not certain about the observations, and what can be done is to design a proper research methodology which would improve the comprehensiveness of the understanding.

Therefore, the planning of this study starts with a definition on what information from the empirical context is relevant to this research subject, what could be the sources for such information, what type of methodology would allow us to gain the information and to proceed with the analysis, and how we can mitigate the effect of fallible observations (e.g. through triangulation). The detailed reflections are covered in Section 3.2 and Section 3.3.

### 3.2 Research Design

This dissertation includes four empirical research articles which all adopt the empirical qualitative case study method. The goal is to create a holistic understanding on how the asset-intensive industries react to the pervasive digitalization. To achieve this, 35 firms operating in the metals and mining industry were interviewed during January 2015 - December 2018 to collect the primary interview data. Article A2 adopts the inductive approach to ground the understanding about the challenges and lessons learned in the digital transformation of the industry. Articles 1, 3 and 4 utilize the abductive approach to iteratively derive the key insights from the data with previously generated knowledge (Dubois & Gadde, 2002).

This section elaborates the study context, the unit of analysis, and the data collection and analysis processes. In the end, the chosen research method and the rationale are clarified.

#### 3.2.1 Case selection

To better understand the context dependent patterns and challenges behind the slow progress of digital transformation in asset-intensive industries, this
dissertation adopts the single-case study method (Easton, 2010; Eisenhardt, 1989; Ragin & Becker, 1992; Yin, 2009) for which the empirical context setting is the digital transformation in the metals and mining industry in 2015-2018. This context offers a unique but representative circumstance (Yin, 2009) for studying how a traditional, established industry, which has enjoyed long-term stability, reacts to changes. This study took place during a time period when the industrial firms have started to react to the widespread attention received by digital transformation. The sample firms were selected from different value chain blocks of the metals and mining business sector, and they consist of both mineral and metal producers, industry relevant original equipment manufacturers, consulting firms as well as technology providers. With this setting, the insights generated with one set of firms can be triangulated and cross-validated with the information inputs derived from another set of firms (Guba & Lincoln, 1994; Ketokivi & Choi, 2014).

The main reason why I treat the entire industry as a single case instead of considering a multiple-case design, i.e. classifying an individual industrial firm as a case, is the methodological fit to the research interest. One motivation for this dissertation was the desire to understand the underlying reasons for a number of commonly recurring challenges the author had observed from different industrial information sources. Taking the entire industry sector as the empirical scope of a single case study offers possibilities to holistically understand the inter-organizational and intra-organizational correlations and interactions occurring during digital transformation activities. Considering the boundaries among individual case firms, the multiple-case design will likely have limitations when the aim of the research is to achieve a holistic understanding for both within and across the industrial firms.

3.2.2 Unit of analysis

For case study research, the unit of analysis is tightly associated to the definition of the case, the primary research questions and the envisioned contributions to certain theoretical disciplines (Yin, 2009). Table 1 illustrates the unit of analysis and focal point of each included article. Article 1 focuses on mapping the IoT applications in the industrial context and the capabilities required for the practical implementation, and therefore the unit of analysis is set as the application of digital technologies. The digital transformation process of an industrial firm is the unit of analysis in Articles 2, 3 and 4; this is based on the overall focus of the study and the aimed contribution towards organizational capability discussions in the context of digital transformation. This unit of analysis is applied to the different layers of discussion within this case study: the industry (e.g. Article 2), the network (e.g. Article 3 and 4), and the organization (e.g. Article 2, 3 and 4).
Table 1. Unit of analysis and study focus of original research articles (A1-A4)

<table>
<thead>
<tr>
<th>Unit of analysis</th>
<th>Focus of study</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 Industrial application of digital technologies</td>
<td>The required capabilities for IoT applications</td>
</tr>
<tr>
<td>A2 Industrial firm’s digital transformation process</td>
<td>Barriers and lessons learned during the transform-</td>
</tr>
<tr>
<td></td>
<td>process</td>
</tr>
<tr>
<td>A3 Industrial firm’s digital transformation process</td>
<td>Capabilities acquisition to overcome internal and</td>
</tr>
<tr>
<td></td>
<td>external change obstacles</td>
</tr>
<tr>
<td>A4 Industrial firm’s digital transformation process</td>
<td>Firms’ knowledge search in explorative and</td>
</tr>
<tr>
<td></td>
<td>exploitative learning activities</td>
</tr>
</tbody>
</table>

3.2.3 Data collection

The primary empirical data includes 53 in-depth semi-structured interviews collected from 35 companies which operate in the metals and mining sector, see Table 2 for details. The interviews were conducted during 2015-2018 with respondents from 13 major countries having a strong presence in the industrial discipline, see the highlighted regions in Figure 7. Interview data was collected either via face-to-face meetings or through teleconferences anonymously to avoid bias. The interview length varies from 45 to 100 minutes. The interviews were audio recorded and transcribed for further data analysis. The majority of the interviews were conducted in English, while Finnish, Chinese, Russian and Spanish were used in country specific interviews to ensure smooth communication. Two interviews were handled jointly with an interpreter with subject matter expertise. The collection of interviews was a team effort with several researchers, but the author of this dissertation organized and handled 40 out of 53 interviews.

Table 2. Case firms and the adoption in different articles

<table>
<thead>
<tr>
<th>Firm</th>
<th>Details</th>
<th>Informant(s)</th>
<th>Interview date</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>Operates in multi-continent, produces multiple metals and minerals</td>
<td>Head of Automation</td>
<td>Feb 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M2</td>
<td>Operates in multi-continent, produces multiple natural resources</td>
<td>Operation Manager; Operation Manager (former); IT manager</td>
<td>Mar-May 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M3</td>
<td>Operates in multi-continent, metal producer</td>
<td>Superintendent; Principle Advisor; Global Director; Head of Innovation (2 interviews)</td>
<td>Apr-Jun 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M4</td>
<td>Operates in multi-continent, gold producer</td>
<td>Former employee with various management positions</td>
<td>May 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M5</td>
<td>Operates in multi-continent, precious metal producer</td>
<td>Senior Director</td>
<td>Jun 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M6</td>
<td>Operates in China, produces mineral concentrate</td>
<td>Head of Operations; Head of Technology</td>
<td>Mar 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M7</td>
<td>Operates in Russia</td>
<td>Head of Automation</td>
<td>Jun 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M8</td>
<td>Operates in multi-continent, gold producer</td>
<td>Chief Metallurgist</td>
<td>Apr 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M9</td>
<td>Operates in Mexico, produces multiple metals</td>
<td>Automation Manager; Process Engineer; Head of Technology</td>
<td>Apr 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M10</td>
<td>Operates in South America, copper producer</td>
<td>ICT Director</td>
<td>May 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M11</td>
<td>Operates in India, steel producer</td>
<td>Former CIO</td>
<td>Apr 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M12</td>
<td>Operates in North America, produces iron concentrate and pellets</td>
<td>Technical Service Manager</td>
<td>May 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M13</td>
<td>Operates in Russia, precious metal producer</td>
<td>Director of Development</td>
<td>Jun 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M14</td>
<td>Operates in multi-continents, produces industrial minerals</td>
<td>Head of Instrumentation</td>
<td>May 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M15</td>
<td>Operates in Americas, copper producer</td>
<td>General Manager; Metallurgist</td>
<td>Jun-Jul 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M16</td>
<td>Operates in Mexico, produces precious metal</td>
<td>Lead Metallurgist</td>
<td>Jun 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M17</td>
<td>Operates in China, steel producer</td>
<td>Operation Manager</td>
<td>Jun 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M18</td>
<td>Operates in China, produces multiple metals</td>
<td>Director of Technology; Vice General Manager</td>
<td>Mar 2016</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M19</td>
<td>Operates in multi-continent, mining and metal production</td>
<td>R&amp;D Director; Head of Technical Analysis; Managing Director</td>
<td>May 2018</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M20</td>
<td>Operates in multi-continent, produces multiple metals</td>
<td>R&amp;D Manager; Business Director</td>
<td>Jun 2018</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M21</td>
<td>Operates in Europe, mining and metal production</td>
<td>R&amp;D Manager; Business Development Manager</td>
<td>Jun 2018</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M22</td>
<td>Operates in Finland, mining and basic refining</td>
<td>Process Engineer</td>
<td>Aug 2018</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

**Technology, equipment and service providers to metals and mining industry**

**Original equipment manufacturers (E)**

| E1  | Global firm, supplies mining machinery | Former CIO | Mar 2016 | x | x | x | x |
| E2  | Global firm, supplies automation equipment and systems to metals and mining companies | Former General Manager | Apr 2016 | x | x | x | x |
| E3  | Global firm, supplies equipment and platform solutions to metals and mining companies | Chief Data Scientist; Marketing Director | Apr 2016 | x | x | x | x |
| E4  | Global firm, supplies mining and materials processing machinery | Mining Technology Director; Global Division President | Jan 2015 & Jun 2018 | x | x | x | x |
| E5  | European-based vehicle manufacturer and supplier of drivetrains | R&D Director | May 2015 | x | x | x | x |
| E6  | Technology provider for mining and metals processing companies | R&D Director | Jun 2018 | x | x | x | x |

**Consulting firms (C)**

| C1  | Small Australian technology consulting group, specializing in metal and mining technology | Technology Director | Apr 2016 | x | x | x | x |
| C2  | Global professional service provider, offers digitalization development and consulting service to metals and mining companies | Senior Manager; Senior Managing Director | Apr-May 2016 | x | x | x | x |
Since this dissertation adopts a single case study approach (Eisenhardt, 1989; Ragin & Becker, 1992) and the unit of analysis is the metals and mining industry firm’s digital transformation process, the primary goal for data collection is to capture a comprehensive picture about the digital transformation practices within an industry. Since the transformation effort involves multiple actors, the case companies were chosen with caution to reflect the relevant actors as well as for triangulating the findings (Yin, 2009). The case firms consist of metals and mineral producers (22), mining and mineral processing original equipment manufacturers (6), management and metallurgy consulting firms (5), and digital and industrial technology providers (2). The case companies have significant variation in terms of scale, operating locations, organization culture as well as the end products. In this study, the global firms and the mid-size companies were selected and reached via direct connections. The local firms were connected to using snowball sampling through academic and business networks.

All the chosen informants have or had been involved with, or they have had direct influence on the corporate digital transformation process. From the metal and mineral producers, the informants’ background mainly falls into three categories: Corporate Executives (CxOs), Middle Managers on Operation/Maintenance/Automation/R&D, and Heads of Corporate IT. On the sup-
pliers’ side, the informants were the experts with particularly extensive experience on digital transformation processes of customers from the metals and mining sector. Among the interviewees, one informant got interviewed twice because of the in-depth knowledge and experience on the subject matter.

Since the abductive approach was utilized in three out of four studies, the data collection process iteratively reflects the gained knowledge about the subject matter (Dubois & Gadde, 2002), and the gradually gathered data are used to develop and refine the existing understanding.

Additionally, the study has adopted all accessible materials as supporting inputs and for triangulation, including but not limited to observations, meeting notes, publicly available reports, and corporate press releases.

3.2.4 Data analysis and theory development

Mantere and Ketokivi (2013) elaborated on the three forms of reasoning for drawing conclusions: “deduction is an inference to a particular observation (or case), induction and inference to a generalization, and abduction an inference to an explanation”. This dissertation applies inductive reasoning in Article 2 and abductive reasoning in Articles 1, 3 and 4.

Inductive reasoning

For a qualitative case study, inductive reasoning is used to form generalized explanations to a phenomenon with contextual data and observations (Bell et al., 2018; Mantere & Ketokivi, 2013; Yin, 2009). When considering the chronological order of research processes for the articles included in this dissertation, Article 2 was the very first work for which the initial idea was formed at the end of 2016. At that point, the research team had neither found existing research that would directly address our research question nor did they have deep understanding formed on this particular context. Therefore, Article 2 adopts the inductive approach (Gioia, Corley, & Hamilton, 2013) through which the inference is derived.

To organize and demonstrate the linkage between collected data and the inference in a systematic and traceable manner, the authors adopted the data structure produced by Corley and Gioia (2004). Data was coded and primarily organized into 1st order categories. Then the authors jointly discovered the similarities and relationships among the 1st order categories and clustered them into 2nd order categories. In the end, the 2nd order categories lead to the emergence of the aggregated themes which serve as the overarching framework of the findings. Similar data structuring method was also utilized in Article 3.

Abductive reasoning

Abductive reasoning, or abduction, is an inference that “goes from data describing something to a hypothesis that best explains or accounts for the data” (Josefsson & Josefsson, 1996). It serves as one of the primary reasoning methods widely applied in scientific research (Mantere & Ketokivi, 2013). The abductive process typically proceeds in a manner where data and observations
(D) are first taken in, and then used for building a hypothesis (H) which could explain the data and observations. The original hypothesis (H) is then compared against alternative hypotheses, and if these alternatives cannot explain D as well as H can, then H is likely to be true (Josephson & Josephson, 1996). Compared with inductive reasoning which is often used for developing and generalizing knowledge, abductive reasoning is more geared towards elaborating and refining pre-existing theories (Josephson & Josephson, 1996; Ketokivi & Choi, 2014; Mantere & Ketokivi, 2013).

When it comes to utilizing abductive reasoning in case studies, Articles 1, 3, and 4 in this dissertation adopted the “systematic combining approach” described by Dubois and Gadde (2014, 2002). In this approach, the development of the findings evolves through iterative reflections of the empirical data and the existing knowledge on the phenomenon. Inspired by this, the researchers designed their own approach to implement abductive reasoning which is illustrated in Figure 8. The abductive research process includes simultaneously matching the case scoping, empirical data and theoretical perspectives. The matching leads to an integrative generation of a framework which illustrates the study outcome. This framework will be examined by the research team, and in combination with existing knowledge, it can then provide feedback and guidance for an iterative generation of new inputs. The new inputs will then be subsequently used for the verification of existing interpretations, and for revealing unknown aspects (Dubois & Gadde, 2002). Triangulation is therefore carried out by utilizing multiple data sources and shifting between analysis and interpretation (Dubois & Gadde, 2002; Yin, 2009).

**Figure 8. Adopted process for abductive case study**

**Data analysis environment**

For this dissertation, the generated interview data were aggregated, coded and analysed within ATLAS.ti (Version 7). This platform offers comprehensive toolsets for organizing and analysing qualitative unstructured data. It supported also the collaboration on the joint data analytics and cross-verification of interpretations among the researchers.
3.3 Reliability and validity

3.3.1 Triangulation

This study adopts the critical realism paradigm, and therefore the adopted triangulation exercises stayed consistent with the realist ontology and epistemology. Triangulation can be used in qualitative research to improve research validity and reliability by combining more than one approach in studying the same phenomenon to cross validate the outcome (Given, 2008; Kowalkowski, Kindström, & Witell, 2011). Denzin (1978) identified four categories where this triangulation exercise could take place: data, methodology, investigator and theory.

*Data triangulation* refers to collecting data from different respondents at different times and spaces (Carter, Bryant-Lukosius, Dicenso, Blythe, & Neville, 2014; Denzin, 1978). *Methodological triangulation* requires data collection and analysis with different techniques or procedures (Denzin, 1978). In this study, the large variety of interviews was collected globally throughout 4 years with informants from 35 case companies including both the industrial operators and the technology suppliers. Diversity was taken into account when choosing the case companies and informants. In addition, other data sources such as observations in workshops, meeting notes and publicly available reports are used to improve triangulation, and to eliminate the procedural bias which may be associated with the interviews.

*Investigator triangulation* suggests that more than one researcher should participate in the research process to avoid biased views brought by individuals. All the articles included in this dissertation have been a team effort where-in multiple researchers have taken part in data collection and analysis.

*Theory triangulation* involves using multiple theoretical perspectives in the study. This study mainly adopts organizational capability perspective while focusing on two streams that complemented each other: dynamic capabilities and organizational ambidexterity. In addition, triangulation is implemented by investigating and contributing to organizational capabilities in an empirical context explained by sociotechnical theory.

3.3.2 Evaluations on the reliability and validity

To evaluate the quality of an empirical qualitative case study in the field of social science, Guba and Lincoln introduced the term “research trustworthiness” which consists of four dimensions: credibility, transferability, dependability, and confirmability (Guba & Lincoln, 1982; Lincoln & Guba, 1985; Morse, Olson, & Spiers, 2002). This dissertation is evaluated based on these proposed criteria, see Table 3 for details.
<table>
<thead>
<tr>
<th>Criteria</th>
<th>Definition</th>
<th>Evaluation Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Credibility</td>
<td>Credibility measures to which extent the study represents the truth (Lincoln &amp; Guba, 1985). Credibility can be demonstrated by data and method triangulation, peer debriefing and checking with participants (Lincoln &amp; Guba, 1985; Moon, Brewer, Januchowski-Hartley, Adams, &amp; Blackman, 2016)</td>
<td>The researchers applied four types of triangulation methods (data, methodology, theory, investigator) throughout the research process, see previous section. The author of this dissertation was working in the industry on this subject during the time when the research was conducted, and therefore there has been direct contact and first-hand experience. The chosen informants are credible ones to comment since they were deeply involved in digital transformation projects.</td>
</tr>
<tr>
<td>Transferability</td>
<td>Transferability is a measure of how applicable the obtained results are, i.e. how widely do they apply in other contexts (Lincoln &amp; Guba, 1985; Moon et al., 2016)</td>
<td>A qualitative case study does not allow for statistical generalization, but a well conducted case study is analytically generalizable (Gibbert, Rutgros, &amp; Wicki, 2008). First of all, our case scope is broad since it is built on the industry level with global data sources. Under this setting, the findings of this study are rooted in asset-intensive industries, and specifically, in the metals and mining context. Since there are commonalities shared among different manufacturing industry sectors, we consider that the findings may be valid to the other asset-intensive industries to a certain extent.</td>
</tr>
<tr>
<td>Dependability</td>
<td>Dependability evaluates the consistency of the research findings. Presenting the results in a transparent manner also helps to make the research more repeatable by others (Moon et al., 2016)</td>
<td>The sample companies included in this study vary significantly in size, geographical location, culture, operational processes, ambition, and maturity level on digital transformation. The firms are not limited to metals and minerals producers, but also their suppliers were included to avoid sample bias and allow for triangulation. The shared explanations generated from this case setting can be argued as stable and consistent. To clarify the chain of evidence in drawing the findings, we adopted the data structure proposed by Gloia et al. (2013) to document the inference processes to enhance repeatability (e.g. Article 2 and 3).</td>
</tr>
<tr>
<td>Confirmability</td>
<td>Confirmability is also a measure reflecting repeatability of a given study. Fulfilling this measure requires the researchers to demonstrate the clear linkage between the results and conclusions which is independent from the researcher’s bias (Moon et al., 2016).</td>
<td>This study has been a joint effort wherein several researchers have reviewed and analysed the findings to mitigate individual researcher’s bias. Research outcomes from this study were compared and linked with existing studies in different empirical contexts in order to build a compelling logical reasoning. Additionally, the included articles have adopted different theoretical perspectives to investigate the same empirical phenomenon. Additionally, the results have been validated with practitioners and other researchers to confirm the findings.</td>
</tr>
</tbody>
</table>
4. Findings

This chapter starts by presenting the contributions of the original research articles against each sub research questions and ends by synthesizing the results against the main research question. All the original research articles contribute directly in answering the main research question. The linkage between the articles and the sub research questions can be found in Figure 1.

4.1 SRQ1: What are the practical applications of digital technologies in the industrial context?

IoT is a core technology that enables and drives digital transformation (Châlons & Dufft, 2017; Jankowski, Covello, Bellini, Ritchie, & Costa, 2014; Porter & Heppelmann, 2014, 2015). Article 1 provides an overview about the applications of IoT in the industrial context. In particular, the research uncovered that the users (e.g. the metal and mineral producers) tend to focus on very concrete and practical applications which address the challenges related to operational routines, whereas the solution providers (e.g. network providers and OEMs) focus more on the specific building blocks (e.g. telecom network) of the overall IoT application.

4.1.1 Potential IoT applications at the operational side

In Article 1 we generated a collective overview of the identified and expected IoT applications from the metals and mining firms. The findings reveal that the operational side has clear targets on addressing the practical challenges within the current operational processes via potential utilization of IoT technology, see Figure 9. We classified the primary targets into two categories: *device intelligence and operational control.*
On the machinery level, *device intelligence* represents the need to upgrade existing assets with digital means. This category is realized in the form of smart, connected components, intelligent control, and autonomous vehicles and logistics management. Smart connected components can typically be taken into use without substantial capability development, and intelligent control, the concept of which was introduced years ago (Holmström et al., 2009; Kärkkäinen et al., 2003; McFarlane, Sarma, Chirn, Wong, & Ashton, 2003), is still seen as an evolving IoT application field. The operational benefits and cost savings brought by autonomous vehicles and logistics management are mainly applicable for remote sites where minimization of human labour is attractive from both cost and safety perspective (Durrant-Whyte et al., 2015; Ernst & Young, 2018).

On the other hand, *operational control* takes in the human perspective which reflects the operational level demands. Safety management via IoT is expected to provide improved mitigation approaches for risks that are associated with the hazardous environment of mining operations. Smart connected components also serve as a basis for automatic reporting. The core of this concept lies within being able to obtain real-time data for critical assets and replacing more limited on-site reporting practices. Remote access via e.g. cloud applications is also of interest, but information security and specific development needs still need to be addressed (Ernst & Young, 2017; Weber, 2010; Yan, Zhang, & Vasilakos, 2014). More comprehensive reporting capabilities can also serve as a foundation for implementing predictive maintenance practices. Avoiding unscheduled shutdowns and keeping a more limited spare part inventory are both clearly defined goals, but the nature of the operational environment and the processes make real-life implementation challenging. Remote operation, which is still at an immature development stage, can be seen as the technological endgame. It also requires all other IoT building blocks to function in order to yield its multitude of expected benefits.

### 4.1.2 IoT elements provided by suppliers to fulfil strategic objectives

In response to the requests from the operational side, technology suppliers provide the technical elements that are seen as essential for deploying IoT. The identified IoT elements from the interviews are summarized in Figure 10, and
they include a) smart, connected components, b) telecommunication networks, c) digital platforms for business, d) information visualization and e) data analytics. The study reveals that for metals and mining firms, the decision on adopting IoT technologies for addressing a certain challenge is guided by internal visions, strategies or competences. On the other hand, the IoT solutions proposed by suppliers mainly reflect the technology disciplines and functions when deploying or implementing IoT. Therefore, the proposed solutions do not directly match with the identified “IoT applications” on the operational side.

![Figure 10. IoT elements and their integration from technology suppliers’ perspective](image)

The smart, connected components category was the one element where customer demands and supply were best aligned. These components, however, always require a telecommunication network to enable information exchange. Mines in particular are a demanding operational environment, and the standardized telecommunication solutions that were selected by the suppliers often did not reach the performance level expected by the customers. The data from the processes would be processed, managed and stored in a digital platform (Iansiti & Lakhani, 2014; Rajala et al., 2018), which would further comprise possibilities for asset and application management, as well as transparent information sharing in some cases even to technology suppliers. These platforms, which were seen as development priorities by several suppliers, would also be used for value added services of data analysis and information visualization (Ahmed et al., 2017; Durrant-Whyte et al., 2015). The former involves transforming data into structured information and further into understandable intelligence and knowledge for e.g. guiding the decision making processes. Information visualization, which can mean e.g. constructing digital twins of key equipment, was seen as an important element by the suppliers who seek to support their customers on this.
4.2 SRQ2: Why the industrial firms found digital transformation so challenging?

The aim of Article 2 is to understand the challenges and lessons learned throughout the digital transformation process of industrial firms. The findings, which are illustrated in Table 4, are further categorized into four aggregate themes: lack of capabilities to change, ambiguous goals, technological constraints and external constraints. To start with, the industrial firms have challenges in sensing the change opportunities. Once the opportunities are recognized, firms lack the capabilities at the organizational level to define goals, to clarify the transformation scope and to drive the required actions. During the transformation process, industrial firms run into the technological constraints which limit the implementation scope and the outcome. Additionally, external constraints brought by the operational environment, legislation and social responsibilities influence the industrial firms’ motivation, scope and content of the transformation.

Table 4. Discovered challenges and constraints in the digital transformation process (Gao et al., 2019)

<table>
<thead>
<tr>
<th>1st order</th>
<th>2nd order</th>
<th>Aggregate themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Current ways of working do not suit digital transformation</td>
<td>Not ready for radical change</td>
<td></td>
</tr>
<tr>
<td>• Firms in the industry are not used to change</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• The industry is not attractive to employees with IoT and data expertise</td>
<td>Unappealing brand among target professionals</td>
<td>Lack of capabilities to change</td>
</tr>
<tr>
<td>• Firms find it difficult to recruit highly skilled workers</td>
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<td></td>
</tr>
<tr>
<td>• Lack of support and commitment from top management</td>
<td>Lack of commitment and investments</td>
<td></td>
</tr>
<tr>
<td>• Investments to non-critical, advanced technologies seem unappealing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Smaller companies lack the resources (financial and/or expertise) for the change</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Workers are not used to digital tools or collaborative methods</td>
<td>Outdated skills</td>
<td></td>
</tr>
<tr>
<td>• Limited previous experience in transformation projects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Silos and different ways of working inside and between firms</td>
<td>Outdated governance model</td>
<td></td>
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<tr>
<td>• A need for extensive training and different processes to initiate the change</td>
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<tr>
<td>• Difficult to define scope of transformation projects ex-ante</td>
<td>Managing expectations and scope of change</td>
<td></td>
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<tr>
<td>• Unforeseen issues are inevitable, and they make projects with fixed scope and price unrealistic</td>
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<td></td>
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<tr>
<td>• Customers expect too much from the supplier</td>
<td></td>
<td></td>
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<tr>
<td>• Misalignment of expectations at different organizational levels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Transformation projects fail if firms cannot agree on what to focus on</td>
<td>Unfocused change initiatives</td>
<td></td>
</tr>
<tr>
<td>• Firms try to change or automatize too many aspects at once</td>
<td></td>
<td></td>
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<tr>
<td>• Managers fear that IT projects tend to over-promise and under-deliver, while exceeding the budget</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Difficult (or even prohibited) to get any kind of wireless signal underground</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Current interfaces demand human actions to transfer data</td>
<td>Connectivity issues</td>
<td></td>
</tr>
<tr>
<td>• Breaches in security can result in serious, even fatal, accidents</td>
<td>Cyber-security concerns</td>
<td></td>
</tr>
<tr>
<td>• Operational data is both business sensitive and critical to safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• The data from sensors are not in standardized form</td>
<td>Lack of IoT standards</td>
<td></td>
</tr>
<tr>
<td>• Non-standard data is challenging to integrate across platforms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Ambiguous stances on the ownership of or access to data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Even if accessible, the datasets may be too complex or scattered</td>
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</tr>
</tbody>
</table>
4.2.1 Lack of capabilities to change

The metals and mining industry has not undergone fundamental changes in its operations for a long time, and therefore the firms have focused on incremental improvements. The dynamic capabilities for implementing radical changes have been very scarce, which has been clearly reflected when trying to incorporate practices from more distant industries such as IT. The challenges caused by the lack of internal capabilities are further amplified by the fact that this industry has found it difficult to attract employees with the right expertise for driving digital transformation forward.

In addition, conflicting internal interests and lack of high-level commitment on the ultimate transformation targets can lead to unsuccessful implementation, as explained by a Senior Managing Director from C2: “if a project, that’s critical to a company, is not sponsored by the right level of executives in that organization it’s gonna fail”. Since the performance and cash flow of the metals and mining firms are strongly influenced by the global economy, the firms demonstrate a clear lack of interest in investing in digital technologies especially during economic downturns.

4.2.2 Ambiguous goals

After a firm has decided to pursue digital transformation, organizational constraints and unclear project goals often hamper practical progress. As the existing skills, governance and management models are formed to support the day-to-day operations, the capabilities and models required for digital transformation are often absent. As mentioned in the previous section, it is difficult
to attract talent with digital technology skills and experiences. Therefore, the industrial firms suffer from a lack of capabilities on expectation and scope management.

As explained by a Global Director from M3, “you can get seduced by the idea that—oh—if we automate everything, […] in fact that’s wrong”. Misguided by blurry and unrealistic targets, the organization may have trouble assessing which development projects are worth doing, and have difficulties in prioritizing the tasks. Overall, such challenges often lead to projects where investment is not in line with the delivered results, which can in turn result in tensions among the different stakeholders.

4.2.3 Technological constraints

Although digital technologies have evolved enormously during the past decades, several technical constraints that are associated with the challenging environments in which metal and mining companies operate in have been identified. To begin with, the challenging operational environment imposes large constraints on setting up the (wireless) network; this applies especially to the underground operations. Once the connectivity is established, cybersecurity management becomes crucial and challenging since a serious cybersecurity incident would risk the safety of the site personnel, and possibly cause substantial operational losses.

Due to lack of standardization for the new digital technologies and the use of various types of non-integrated legacy systems at mining sites, implementation and integration of digital technologies has become labour intensive and slow. In addition to the challenging integration process, the legacy systems are also seen as more reliable and robust compared to the new digital applications. The latter do not often reach their expected performance levels due to inaccurate sensors and connectivity issues, whereas the legacy systems are limited in terms of providing data to digital platforms. In some cases, even after the deployment of new digital applications, the firm still keeps the legacy systems as redundancy measures, which generates dual costs and maintenance efforts.

4.2.4 External constraints

The external constraints shall not be ignored. The considerations and restrictions of the operating environment, health and safety aspects, legislation and policies, and social responsibilities have imposed challenges to the industrial firms’ digital transformation. One common trait for these constraints is that the firms have very limited possibilities to influence them. As it has been stated multiple times, mines tend to be located in challenging environments, and smart connected devices often do not function as well as they should in such places. Safe operation at mining sites requires robust and reliable hardware. There are uncertainties related to the functionality of new digital technologies, and therefore health and safety concerns are sometimes used as a reason for not implementing changes.
Legislation and policies often revolve around the effect of digital transformation on the employees. Loss of jobs, which may occur due to digitalization, is opposed by both labour unions as well as political bodies. Furthermore, the social responsibilities also at times block changes. This applies especially when the mining sites have received government incentives or direct investments which would be linked to local employment commitments and ecosystem formation. If implementing digital technologies leads to eliminating local employment and ecosystems, the industrial firms will encounter high pressure from the society.

4.3 SRQ3: What capabilities are considered as essential for implementing digital technologies?

Article 1 concluded that driving the implementation of digital technologies, or from a more holistic perspective, the digital transformation throughout organizations, requires the metals and mining firms to reconsider and reconfigure the capabilities that are accessible to them. Based on the reflections from the informants, and consistently with existing research, we suggest a capability portfolio that is required for IoT implementation in the industrial context, see Figure 11.

Overall, four different capability areas are seen as essential for IoT implementation. Analytic capability is needed for converting data into tangible knowledge which can be used to support decision making (Iansiti & Lakhani, 2014; Turunen, Eloranta, & Hakanen, 2018). IoT competency, on the other hand, is necessary for providing, integrating, and managing intelligent devices which supply the data used in analysis (e.g. Ahmed et al., 2017; Holmström et al., 2009; Ness et al., 2015). While technology suppliers have focused on IoT competency, substantive knowledge, which the metals and mining companies are naturally considered to excel at, is required to incorporate IoT with its maximum potential in a certain context. Differences in the substantive backgrounds of the technology suppliers and the customers may lead to misalignment – the offerings of the suppliers are often perceived to lack the social, economic and technical value that the customers are expecting, which is also reflected in Section 4.1 of this dissertation. Last but not least, business development capabilities are needed in order to generate value for both technology suppliers as well as end-users (Baden-Fuller & Haefliger, 2013; Hess et al., 2016).
4.4 SRQ4: What capabilities shall the firms acquire to address the internal and external obstacles during the transformation?

Through identifying organization-level and system-level obstacles of dynamic capability reconfiguration in relation to digital transformation, Article 3 discusses the demand for new organization-level capabilities with a clear highlight on the demand for capabilities that enable synchronized systemic change across the industry. As changes do not occur only inside a single organization, dynamic capabilities are required for addressing the internal and external obstacles. Overall, this process of change entails various obstacles and associated capability requirements, which are summarized in Table 5.
Table 5. Capabilities renewal required to address obstacles at organization level and system level

<table>
<thead>
<tr>
<th>Aggregate theme</th>
<th>2nd order theme</th>
<th>1st order items</th>
<th>Interrelation (Leavitt, 1964)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand for new capabilities at the organization level</td>
<td>Obstacles to renewing current tasks</td>
<td>Simple manual tasks are implemented in absence of better alternatives</td>
<td>Task-People</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Current industry structure neither attracts people with desired competences nor does it support the integration of new capabilities and resources</td>
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<td></td>
<td></td>
<td>The capability portfolio needs fundamental renewal</td>
<td>Structure-Technology</td>
</tr>
<tr>
<td></td>
<td>Tension between new technologies and market demands</td>
<td>Current structures and existing solutions do not support technology development efforts</td>
<td>Structure-People</td>
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<tr>
<td></td>
<td></td>
<td>Firms rely on accustomed criteria, such as energy efficiency, when they market new technologies</td>
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<tr>
<td></td>
<td></td>
<td>Mining-specific adaptations needed when implementing new technologies</td>
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<tr>
<td></td>
<td>Boundary conditions for technology implementation</td>
<td>Technologies are unable to match the demands for securing business-sensitive information and operational integrity</td>
<td>Technology-People</td>
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<tr>
<td></td>
<td></td>
<td>Critical mass of data sources needed to gain full benefits of new technologies</td>
<td></td>
</tr>
<tr>
<td>Demand for capabilities towards systemic and synchronized change</td>
<td>Multiple, competing and conflicting views about the future direction</td>
<td>Powerful external stakeholders who can impose competing goals</td>
<td>Structure-Task</td>
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<tr>
<td></td>
<td></td>
<td>Multiple hierarchical goals across different stakeholders</td>
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<td></td>
<td></td>
<td>Conflicting goals among stakeholders</td>
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<td></td>
<td></td>
<td>Concerns that the public image of the industry deters talented future employees</td>
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<td></td>
<td>Humans as a part of digital operation</td>
<td>How to integrate people and technology?</td>
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<td></td>
<td></td>
<td>Unclear management vision of the change</td>
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<td></td>
<td></td>
<td>Conflicting opportunity seizing among stakeholders</td>
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<td></td>
<td></td>
<td>Personal interactions and face-to-face communication are seen crucial</td>
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<td></td>
<td></td>
<td>Feelings of distrust lead to upholding old, redundant systems</td>
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<td></td>
<td></td>
<td>Unforeseen integration issues to existing human-centric systems</td>
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<td></td>
<td></td>
<td>Long-term commitments limit the flexibility for making changes</td>
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<td></td>
<td></td>
<td>Need for sharing risks</td>
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<td></td>
<td></td>
<td>Customers need to support the vision</td>
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<td></td>
<td></td>
<td>No joint innovation mindset between companies</td>
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<td></td>
<td></td>
<td>Multiple concurrent goals</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Market structure discourages explorative development tasks</td>
<td></td>
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<tr>
<td></td>
<td>Idiosyncratic, firm-specific pace of change</td>
<td>Deficiencies in information availability</td>
<td>Task-Technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Standard technologies not applicable</td>
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<td></td>
<td></td>
<td>Wireless technologies not allowed in mining environment</td>
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<td></td>
<td></td>
<td>Mandatory tasks regarding security and sustainability</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Shared information and data needed for optimizing current tasks</td>
<td></td>
</tr>
</tbody>
</table>
4.4.1 Demand for new capabilities at organization level

Three particular themes of organizational level obstacles are identified in Article 3: obstacles to renewing current tasks, tension between new technologies and market demands, and boundary conditions for technological development.

Obstacles to renewing current tasks
We were able to discover clear obstacles between people and tasks in digital transformation at organization level. A noteworthy aspect was that reliance on manual processes was still surprisingly high. Furthermore, finding and attracting suitable new talent for supporting the digital transformation process, and for renewing the existing capability portfolio, was considered challenging.

Tension between new technologies and market demands
Incorporating new technologies into existing structures may cause two types of tensions. First, the current structures existing in the metals and mining industry have not been supportive for technology development, and therefore introduction of new technologies results in tension with regard to market demand. Acceptance of new solutions has been reliant on using accustomed criteria such as energy efficiency, even though the main benefit of the new technology might relate to e.g. improved environmental friendliness. Furthermore, implementing new technologies is in general challenging in a mining environment wherein context-specific adaptation is common. This has caused issues when trying to adopt solutions which have been previously proven in less demanding industrial contexts. Such solutions need to be further adjusted by e.g. improving robustness and reliability in order to apply them in the mining environment.

Boundary conditions for technological development
Prominent challenges were observed related to the interrelation between structure and technologies as a result of boundary conditions for technological development. One reason is that digital transformation means fundamental and radical changes on top of the existing legacy technology systems. On one hand, the metals and mining firms (who generate data) raise heavy concerns on cyber security and protection of business-sensitive information. However, as value creation through digital technologies relies on collection and utilization of data from various components, service providers, who are looking to utilize data, can only prove the value of new solutions when data are made available.

4.4.2 Demand for capabilities towards systemic and synchronized change

Multiple, competing and conflicting views about future direction
Although capability development is certainly required at organizational level, there is also a clear need and potential to improve system level alignment via cultivation of the right capabilities. This could alleviate the discord that would
otherwise arise due to the existence of competing and conflicting views for future development. Such interaction between the system structure and the people operating in it also reflects the presence of several powerful external stakeholder groups.

**Human as a part of digital operations**

A collection of challenges was found related to the integration between people and technology, which indicates the need to drive systemic and synchronized change. In particular, the standard operating procedures currently applied in mines have been largely designed for human employees, and therefore unexpected issues may arise when trying to replace humans with digital applications, as an example:

“Because the [autonomous] trucks travelled exactly on the same path [...] the road got huge ruts [...] where the truck travelled. The road was not being worn down evenly, and so the maintenance on the road actually had to increase because of that (M3).”

To avoid fundamental changes on the physical infrastructure at the mine, the digital solutions would need to be human-like:

“So what they actually did to repair that was to put in a very small random error [in the algorithm]. (M3).”

Up until now, the overall vision for change has been unclear, and incorporation of digital technologies has not been managed in a transparent and systematic way. Different stakeholders attempted to push through their own views and preferences in seizing opportunities of adopting digital technologies. However, the people working in the metals and mining industry still appreciate traditional face-to-face communication, and currently the digital solutions cannot offer fully matching experiences. Overall, there have been some feelings of mistrust against new technologies, which has in turn lead to upholding of redundant legacy systems in parallel.

**Idiosyncratic, firm-specific pace of change**

We noted several instances where tensions originated from the idiosyncratic rate of change among connected firms in relation to the current system structure and performed tasks. The fundamental nature of the change caused by the digital transformation process dictates that sponsorship from high-level executives is required both inside and across firms. However, implementation of such changes has been inhibited by the slow change-averse environment of the industry, as well as by the constraints imposed by the preference for long-term agreements:

“Our production capacity is [X tons of metal] annually and, basically, have already sold our whole capacity. That means that if we want to find new business, we have to do investments. For that, we want to create long-term partnerships ... to get long contract, which will secure our payback. (M2o)”

In contrast to existing operating models, the willingness and necessity to share investment risks were brought up by several informants. Formal support from the customer side was considered highly desirable, but the firms in question did not yet equip a supportive mindset and processes for engaging in such joint innovation. The heavily regulated nature of the metals and mining indus-
try sets limitations for the firms operating within it. Environmental, health and safety concerns are usually emphasized in different development activities, but actual targets for improvement can, nevertheless, be defined in very broad terms. Having multiple concurrent and overlapping goals also means that practical prioritization can be very difficult. Finally, as the financial results of most firms are heavily dependent on fluctuating commodity prices, securing of the annual cash flow takes usually precedence over explorative development tasks.

**Technical obstacles to incorporating digital technologies to current tasks**

Our empirical evidence shows that digital transformation processes can be hindered by a few obstacles related to technology and tasks. One key shortcoming is the limited number of data-generating sensors in the existing physical assets – this has a direct implication on the implementation of data-driven digital operations. In addition, the employment of standard technologies to the specific mining operational environment can face unexpected limitations. For instance, wireless technology, which may e.g. interfere with blasting charge detonators, is in many cases not allowed in mines. In the absence of solutions which fit the operational tasks better, digital solutions in the metals and mining industry may often rely on unsophisticated manual processes.

Furthermore, the existing regulatory environment has directed technology development and investments heavily towards monitoring of safety, security and environmental factors. Digital transformation could bring benefits to these areas as well, but this aspect has not yet been explored extensively. Since this area is nevertheless a key concern on the customer side, it is clear that more thorough understanding and integration between technology and the current operational tasks would help facilitate future development tasks.

**4.4.3 Summary of required capabilities to overcome systemic constraints**

Overall, these findings illustrate the tensions that are induced by the digital transformation process, which in itself can be considered as a complex socio-technical change. In Article 3, the conventional perspective of socio-technical change is complemented by dividing the demand for capabilities into two distinct categories to overcome discovered obstacles: individual firms need new capabilities, but these need to be further supplemented by capabilities which enable synchronization of change among different firms. The emergence of this latter category is a novelty in the current industrial context, as previously there has been little need to consider cross-firm interactions when implementing changes. This notion is also reflected in the overall value chain of this industry which has been characterized by long bi-lateral agreements with limited flexibility – such arrangements do not normally include an explicit need to broaden your perspectives outside of your own immediate focal areas.
4.5 SRQ5: How do firms evolve and expand their capabilities?

Article 4 discusses the industrial firms’ evolvement patterns of explorative and exploitative capability development throughout the digital transformation process. Specifically, we investigate the firms’ knowledge search activities, whether the activities are explorative or exploitative, and whether the activities are organized via internal or network capabilities.

4.5.1 Knowledge search activities in digital transformation and the source of capabilities

Article 4 reveals the capability development path of the firms in the metals and mining industry through perspective of the interplay between exploration and exploitation. When a firm is conducting certain activities which involve the adoption or deployment of digital technologies, this firm must have access to the capabilities needed for the activity. Therefore, this research starts with investigating the domain (exploration or exploitation) of knowledge in the search process of each firm, and whether the required capabilities for this search process are acquired internally or through networks. Figure 12 summarizes the findings concerning the digital transformation activities of the interviewed firms, and it in particular differentiates between exploration and exploitation through internal or network capabilities.

![Figure 12. Digital transformation activities of the interviewed firms (Gao et al., 2020)](image)

According to our findings, the metals and mining firms are mostly undertaking explorative activities with network capabilities. Purchase-ready solutions and full dependence on the technology suppliers’ capabilities have been the preferred approaches for starting the digital transformation process. Small and medium size firms have resource and capability constraints, and therefore they may expect the technology suppliers to prepare “fit-for-purpose solutions” (M6) which could directly address the challenges in operations. On the other hand, most of the giant global metals and mining firms (M1-M5) from the interviewed firms are seeking to combine the development of internal capabilities with acquisition of network capabilities to jointly develop solutions to improve business operations with digital technologies. Through partnerships with technology suppliers (e.g. M5), the firm gains access to external complementary capabilities which allows them to develop and leverage their internal capabilities in exploitative activities.
A part of the interviewed firms has not been satisfied with exploitation only, and they have instead started to explore potential applications empowered by digital technologies which have not appeared in the metals and mining domain. Traditionally, this industry does not have extensive capabilities for “working with data” (M3), but the initial ideas on data utilization may be formed internally. Nevertheless, external capabilities are heavily depended on in this cross-domain exploration, and especially for the deployment and integration parts. Among all the interviewed firms, M3 is seen as having accomplished a complete integration of exploration and exploitation with both network and internal capabilities. This particular firm has a massive business scale and network with a tradition of bringing new technologies and innovative applications to the industry context already during the recent decades.

In contrast, the interviewed technology and equipment suppliers demonstrated a different pattern. The suppliers attempted to balance the exploration and exploitation activities in digital transformation. In particular, firms invest on both internal and network capabilities in exploring novel digital technologies and innovative business models. This can mean e.g. acquiring start-ups, building data centers and initiating digital services. When it comes to their existing products and services, the firms seem to have a clear roadmap and internal capabilities for gradually adding digital elements such as smart sensors and data collection tools. Through our interview data we have not found suppliers adopting network capabilities in exploitative activities. We interpret this to mean that conventional integrated supply chain partners might have taken part in such processes, but the informants have not explicitly considered them as being “externals”.

4.5.2 Metals and mining firms’ capability development path

After consolidating and investigating the development patterns of 22 interviewed firms operating within the metals and mining industry, in which traditionally information technology and digital solutions have not been part of the core business, we mapped the evolvement path for the metals and mining firms. Although the firms vary significantly in scale, commitment level, and maturity and endgame vision of digital transformation, they still demonstrate the characteristics that match the different steps of this same evolvement path, which is illustrated in Figure 13.

The process often starts with product-market exploitation via network capabilities e.g. by purchasing ready-made solutions to improve existing operations (Step 1). Some firms may first initiate the ideas for incremental improvements and then outsource the development and implementation completely to the technology suppliers. Along with time, the firms seek to develop internal capabilities and to leverage them throughout the exploitation process. Most of the metals and mining firms are comfortable staying at this knowledge search domain. This is understandable if the return is considered as adequate already, and because exploration typically means “a huge learning curve” (M3) and a time-consuming exercise because “it’s almost hit-and-miss” (M3).
However, some players were willing to take more innovative approaches and started to extend their search in the domain of digital technologies to find opportunities for creating novel applications under this industrial context (Step 2). Exploration as such often relies on the network capabilities. The front runners that formed adequate investment commitments and driving forces were able to take in, develop and utilize new internal capabilities on digital technologies. In the end, the firms applied the novel outcomes to existing operations to enable improvements, which can be considered as an example of cross-function exploitation (Step 3).

![Diagram](image)

**Figure 13.** Evolvement path of metals and mining firms (Gao et al., 2020)

### 4.5.3 Technology suppliers’ capability development path

Compared with the metals and mining firms, the technology suppliers demonstrated a different pattern concerning the evolvement path. As illustrated in Figure 14, the firms initiate the transformation process by incrementally developing and updating the firm’s existing product and service portfolio with digital elements utilizing internal capabilities (Step 1). Moving forward, the firms explore within the metals and mining product-market domain with the help of network capabilities to create novel solutions which have not been in the existing portfolio (Step 2). Often concurrently, technology suppliers explore cross-functionally for the developments and applications of digital technologies in other contexts (Step 3). As a result, firms would be able to create innovative digital technologies together with their partners (Step 4). Through the process, the firms will be able to build up new internal capacities such as digital application development and deployment. Interviewed firms have highlighted the importance of partnerships and combined effort in Step 3 and 4, and this may in practice involve efforts to e.g. “bring talents from universities and start-ups together” (E1).
As an outcome of the explorative and exploitative activities, a new solution for the metals and mining market could be developed either through within-functional exploration (Step 2), or via cross-functional exploitation of the novel digital technologies to this market domain (Step 5).

4.6 Synthesis of the findings

This dissertation used four original research articles (listed in Figure 1) to uncover the different aspects of the overall research question “How do companies in asset-intensive industries build up capabilities to drive digital transformation?”. Consolidated in Figure 15, the findings from the individual research articles reflect the “sense-seize-transform” stages of dynamic capabilities (Teece, 2007). The industrial firms start with sensing both the external disruptions brought by digital technologies, as well as the readiness and constraints to change. Next, the industrial firms seize the digital transformation opportunities by identifying the demand for the novel capabilities for implementing digital applications, and by acquiring the needed organizational capabilities to overcome the change constraints. Finally, the two perspectives lead the industrial firms to a transformation path towards achieving organizational ambidexterity.
In industrial sectors where experience with digital technologies is limited, the industrial firms' digital transformation starts by sensing external opportunities and change forces (SRQ1), which, in this context, means the potential applications of digital technologies. As digital technologies are considered to be general-purpose, their applications need to fulfil the industry specific expectations and demands. As the integration of digital technology develops and becomes more mature in this industrial context, there are also new capability requirements that extend beyond conventional technical capabilities. Article 1 provides an overview on the expected IoT applications from the metals and mining firms’ perspective, and it introduces the technical elements provided by suppliers as the basis for fulfilling these expectations. Such changes require new capabilities as driving forces. In this article we suggested a portfolio of four capabilities that are required for IoT adoption - these include data analytics, the competence on IoT technologies, industrial and process specific knowledge, as well as competence on business model development (SRQ3).

In the context of organizational aspects, firms perceive change opportunities differently depending on their institutional logics (Hinings et al., 2018) and level of dynamic capabilities (Helfat et al., 2007). The informants have identified and recognized a series of challenges and constraints in driving digital transformation that are imposed by industrial firms’ business and operational environments (SRQ2). Article 2 uncovers four categories of challenges that are related to industrial firms’ dynamic capabilities for facing digital disruptions. First of all, firms in general demonstrate a lack of capabilities to change partially due to the long-time stability of the market environment. When responding to the changes, firms found it challenging to address the ambiguous goals.

\(^2\) Map of dissertation storyline against original research articles can be found in Section 1.2 Research objectives and questions.
and the technological as well as external constraints. This research reveals that digital transformation is not an isolated exercise within an organization, but it rather develops concurrently among the organizations in the network.

In order to seize the business potential empowered by digital technologies, the industrial firms need to acquire the needed capabilities to overcome the internal and external obstacles (SRQ4). By taking the findings from Article 2 as the basis, Article 3 further identifies that digital transformation is a socio-technical change which contains a series of interrelated components (Leavitt, 1964), and investigates the obstacles residing in the interrelations between the components. The findings suggest that two categories of capabilities should be acquired to overcome the identified obstacles. On the organization level, Article 3 highlighted that firms should acquire new capabilities to address the tensions in the interrelations of Task-People and Structure-Technology categories. Empirical evidence shows that digital transformation is not an exercise of an individual organization; the associated changes in fact involve multiple connected organizations and other stakeholders. Therefore, to address the obstacles at the system level which involves multiple external participants, firms should develop novel capabilities which enable synchronized systemic change across the industry.

Firms evolve through the digital transformation. In particular, the dynamic capabilities of an organization develop and strengthen throughout the change (SRQ5). Article 4 focuses on the capability development paths of industrial firms. The outcome shows that metals and mining firms prefer exploitative activities with network capabilities, while gradually expanding to explorative activities and development of internal capabilities. On the other hand, the technology suppliers tend to proceed with exploration and exploitation simultaneously, and with less dependence on network capabilities. The empirical evidence suggests that inter-organizational ambidexterity is critical in order to maximize the potential return of digital transformation, and that it can be better achieved via a combination of internal and network capabilities.
5. Contribution to Concept Development

Digital transformation is a socio-technical change (Nambisan, 2017; Tilson et al., 2010), which requires organizations to respond to disruptions and to alter their value creation mechanisms to incorporate digital technologies (Ross, Sebastian, Beath, Mocker, et al., 2016; Salovaara, Lyytinen, & Penttinen, 2019; Sebastian et al., 2017). Dynamic capabilities play a crucial role in this response (e.g. Daniel & Wilson, 2003; Vial, 2019). Firms operating in a stable market have limited exposure to disruptions, and as a result, development of dynamic capabilities has not been prioritized. This in turn has led to a series of market-specific challenges and pitfalls when attempting to drive changes via digital transformation. In addition, the realization and implementation of digital initiatives require firms to have capabilities to connect and configure technical and organizational aspects throughout the process (Teece, 2018b; Töytäri et al., 2017).

Combining the perspectives of digital technologies and organizational capabilities, this dissertation aims to provide an overview of the digital transformation in asset-intensive industries, to uncover the obstacles and pitfalls in this specific empirical context, and to reveal the acquisition and evolvement of the needed organizational capabilities throughout the transformation. This study offers distinctive terminologies to describe the collective, systemic and concurrent actions that are associated with the socio-technical components of digital transformation, and it expands the dynamic capabilities discussion beyond organizational boundaries.

As illustrated in Chapter 2. Conceptual Background, this dissertation studies the requirements, development, acquisition and integration of organizational capabilities in the context of digital transformation of an asset-intensive industry sector. Therefore, this study contributes to 1) digital transformation and information system literature as well as to 2) dynamic capability and organizational ambidexterity literature. First of all, when one considers digital transformation as a socio-technical change, this study proposes that digital transformation requires synchronized change that addresses the systemic constraints on both technical and social aspects, and that the change should occur in a concurrent manner among the connected organizations. Such changes call for strategic renewal of the organizational capabilities. This study pinpoints the critical implications and the necessity of dynamic capabilities for digital transformation, and further suggests expanding the dynamic capabilities discussion towards a network perspective. In particular, the conceptual develop-
ment for the network perspective of dynamic capabilities focuses on two aspects: boundary spanning dynamic capabilities, and organizational ambidexterity with network capabilities. The conceptual development outcomes of this dissertation are summarized in Figure 16, wherein the development of dynamic capabilities is represented with grey arrows. The following subsections provide detailed reflections on the conceptual development.

![Concept development highlights](image)

**Figure 16.** Summary of the conceptual development of this dissertation

### 5.1 Lessons learned from the slow transformation

This dissertation answered a key concern associated with this specific empirical context: why have the industrial firms’ early attempts on digital transformation progressed slowly, and what notable pitfalls have been observed in the metals and mining sector? This study identifies four categories of challenges that are associated with the industrial firms’ ability to drive digital transformation, and they are listed as *Findings 4.2.1-4* (the findings illustrated in Sections 4.2.1, 4.2.2, 4.2.3 and 4.2.4): lack of capabilities to change, ambiguous goals, technological constraints as well as external constraints. The empirical findings are in line with the sense-seize-transform framework of dynamic capabilities. The provided empirical evidence further highlights the different challenges that are encountered during different stages of the process (Teece, 2007). These collective challenges further reveal the dependencies between the market rate of change and the firm’s level of dynamic capabilities (Teece et al., 1997). If the market’s historical rate of change is low, the firms operating within this particular market lack both opportunities and motivation to develop dynamic capabilities, which in turn leads to constraints on dynamic capabilities when a disruption occurs.

Meanwhile, digital technologies empower new applications in the industrial context (*Finding 4.1.1*), inducing the need to create or to gain access to a portfolio of essential capabilities such as analytics capability, business development, IoT competency and substantive experience. The firms that are supplying the solutions based on digital technologies need to incorporate the techno-
logical competences with properly designed customer specific use scenarios. Designing the use scenarios requires the firms to have in-depth understanding about the customer’s operational processes and business model. Likewise, the customers should develop the capabilities which would allow them to evaluate the feasibility and potential benefits of the proposed solutions based on social, economic and technical criteria relevant to their own operational environment (Berman, 2012; Nicolescu, Huth, Radanliev, & De Roure, 2018). As the industrial firms could not fulfil the need for new capabilities to drive digital transformation (Finding 4.3) and because the industrial brand is unappealing to the talents with high digital competences (Finding 4.2.1), the necessity of being more networked and engaged in inter-organizational collaboration is further emphasized (e.g. Adner, 2017; Jacobides et al., 2018; Rajala et al., 2018; Töytäri et al., 2018). A more open approach to capability acquisition allows firms to focus on their own specific strengths and competences, while ideally leveraging complementary capabilities from the networked partners.

On the organization level, the interdependencies among these emerging applications suggest that during the transformation stage of the dynamic capabilities, there may be a need to generate a microstructure to manage the sequence of tasks (Finding 4.1 and Finding 4.2). The specialized and co-specialized capabilities and resources (Teece, 1986) influence what kind of sequence needs to be followed in the development and integration activities, whereas the overall scope of change is limited by boundaries originating from internally induced constraints (Findings 4.2.1-2, 4.3).

On the system level, Findings 4.2.3-4 indicate that firm’s digital transformation is not an independent exercise isolated from the market environment. The ability to successfully leverage digital technologies requires concurrent changes among the connected firms as well other external stakeholders such as labour unions and public policy makers. True value cannot be derived from digital transformation if e.g. legislation regarding data ownership, access, and use lags severely behind. In addition, Finding 4.1 uncovers a notable deviation between the needs, desires, and visions for the potential applications between the operational side (i.e. customers) and technology providers (i.e. suppliers). This further highlights the need and criticality of staying aligned and concurrent on changes among multiple participants.

5.2 Synchronized transformation among organizations

5.2.1 System level interrelations explain systemic constraints

Finding 4.4 empirically demonstrates that the misalignment of technical change and organizational change at both organization level and system level impedes the progress of digital transformation. Leavitt (1964) provides a socio-technical model incorporating the core components (task, people, technology, structure) associated with the change. The digital transformation process can be analysed and discussed in more detail by increasing the clarity and distinction between the different components and the associated interrelations
(Lyytinen et al., 2009). Building on top of these previous studies, Figure 17 visualizes the outcome against different interrelations. The interrelations at the organization level are drawn in green lines and the system level interrelations are depicted as orange lines. As the change constraints and capability demands at the organization level are more self-evident and have been therefore discussed extensively by the existing literature (e.g. Colin & Hodges, 2010; Herterich, Uebernickel, & Brenner, 2016; Töytäri et al., 2017), this dissertation decides to place the focus on the system level interrelations and the associated constraints (Finding 4.4.2). As illustrated in Figure 17, our empirical findings (Finding 4.4) show that four out of six interrelations are at the system level and that they involve multiple participants. This highlights the significance of system level interrelations, and the criticality of addressing systemic constraints to enable and effectuate digital transformation. The systemic constraints which reside in each system level interrelation are further discussed below.

![Systemic constraints induced by system level interrelations against Leavitt’s (1964) socio-technical model](image)

1. **Structure-People: Multiple, competing and conflicting views about the future direction.** Our empirical findings illustrated that conflicting goals and priorities may stand in the way of notable changes. For example, improving operational safety is often considered as a top priority in this industry. Good initiatives that seek to improve this by utilizing of e.g. autonomous vehicles in mining sites have been blocked since the change conflicts with the employment targets from the labour union and the local government.

2. **Technology-People: Humans as a part of digital operations.** Incorporating digital solutions into an industry where most systems and processes have been designed for human operations can lead to pit-
falls which are difficult to predict and prevent in advance. To minimize the probability of such issues, new technologies and organization structures should be collaboratively aligned between the related stakeholders. In the context of the metals and mining industry, such agreement would be necessary for e.g. shifting the operational culture away from the utilization of tacit experience-based knowledge towards data-driven operations. This kind of change reflects the overall need to create a shared understanding or even an industry-level consensus on the proper level of integrity and integration between human and machines at current and future development stages.

3. **Structure-Task: Idiosyncratic, firm-specific pace of change.** One defining characteristic of mining operations is that the initial ore deposit determines the expected lifetime of the mine. This aspect influences the mine operator’s mindset and motivation for investing in digital technologies. In practice, mines which are already at a late stage in their operational lifetime are less likely to prompt investments into new technologies. Public discourse on the digitalization of mining operations can be saturated by promising visions of the future, but actual investments need to be rationalized by improvements which extend over a long time period.

4. **Technology-Task: Technical obstacles to incorporating digital technologies to operational tasks.** Our interviews also revealed that regulatory issues influence the adoption of digital technologies. Existing regulation is based on conventional operational conditions which do not take into account fundamental changes brought on by implementation of digital technologies. Consequently, regulators need to be more proactive on interpretation work to assess the changes induced by new technologies. This includes defining new regulations that encourage the transformation happens in a systemic and synchronized manner. Due to the pronounced role of regulation, firms could stand to benefit from having capabilities that enable them to provide proactive inputs to the future regulation.

As systemic constraints tend to be rather complicated with the involvement of multiple participants, the initiatives and change actions of one organization alone are unlikely to address the challenges that reside on the system level. This in turn restricts the change progress and the associated value creation. Thus, there is a call for concurrent actions from multiple participants, which will be discussed further in the following section.

### 5.2.2 Systemic constraints call for synchronized change

One main implication of this dissertation is identification of the demand for synchronized change among multiple connected organizations in driving digital transformation. Value creation via digital transformation involves increased connectivity (Hakanen et al., 2017; Nicolescu et al., 2018; Rajala et al., 2018), and therefore the relevant new development needs are often spread across several organizations. Overall, these development efforts should be con-
current and aligned, but there is nevertheless difference on whether these systemic changes are synchronized in terms of temporal, situational or contextual aspects. These aspects can come successfully together e.g. in the form of a joint-value proposition — a perspective that often appears in ecosystem-related discussions (e.g. Adner, 2017; Jacobides et al., 2018; Kapoor, 2018). We, however, seek to complement these views by discussing dynamic capabilities as a component that helps facilitate and align the needed socio-technical change.

Combining Findings 4.2 and 4.3, we highlighted that digital transformation in asset-intensive industries often faces systemic constraints such as a misaligned pace of change as well as conflicting goals among organizations. The organizations were found to lack the needed capabilities to enact synchronized change which may span existing firm boundaries. In practice, achieving such synchronization requires that the involved organizations have a shared overall understanding along with mutually agreed technology standards and transformation goals, while staying concurrent on the pace of change. One helpful way is to form joint change targets, and to develop resources and capabilities collaboratively across organizations - this can also help overcome conflicts concerning goals and interests. As illustrated in Figure 18, we argue that obtaining optimal results requires bi-lateral ways of working for the connected firms. Synchronized change for a single firm can be associated with e.g. collaborations targets, or domains such as product, market or technology. Synchronized change would ideally take place in a multilateral manner so that the value of one organization’s output depends on the outputs of other connected organizations (Shipilov & Gawer, 2019).

Synchronized change does not, however, mean that there is not a sequential order of activities. Instead, it strengthens the rationale in facilitating the activities by taking the complementary activities into the overall plan. However, we observed very little empirical evidence that would suggest that firms in the metals and mining industry have employed complementary and synchronized approaches to facilitate digital transformation. Therefore, we suggest that the firms shall develop and acquire dynamic capabilities to enable synchronized change that also takes into consideration the context specific institutional environment and cultural aspects.
5.3 Dynamic capabilities for synchronized transformation

5.3.1 Boundary spanning dynamic capabilities

Digital transformation requires a comprehensive integration of the social and technological changes, and a synchronized renewal of existing business operations, partner networks and the associated legislation. Such updates require a broad scope of new capabilities which are unlikely to be found within an individual organization. This dissertation proposes an expansion of the existing mainstream dynamic capabilities discussion to capture the perspective of networked collaborative development.

On one hand, the mainstream literature on dynamic capabilities considers that dynamic capabilities are created within an organization (Helfat et al., 2007; Teece, 2007; Teece et al., 1997). Only very recent discussions are starting to recognize the possibility and benefits of involving external partners in activities associated with dynamic capabilities (Teece, 2018a; Töytäri et al., 2018; Zhu & Iansiti, 2019). On the other hand, previous discussions on boundary spanning have largely focused on the individual roles or members (e.g. Aldrich and Herker, 1977; Levina and Vaast, 2005; Tushman and Scanlan, 1981), or activities (e.g. Dollinger, 1984; Rosenkopf and Nerkar, 2001). Building up on these two streams of discussion, this dissertation frames boundary spanning dynamic capability as an organizational capacity to:

a) sense opportunities and threats of own and external organizations
b) seize opportunities for own and external organizations
c) transform and co-specialize own and external assets.
Boundary spanning dynamic capabilities are highly relevant for digital transformation. With boundary spanning dynamic capabilities, an individual organization in an emerging network will be able to capture the current and potential demands of the connected organizations, define its own position in the network, and expedite the alignment and synchronization of the connected firms towards a purposeful change.

Note that boundary spanning dynamic capabilities may not directly bring additional value to the organization especially in a short time span. Boundary spanning activities are difficult to routinize (Aldrich & Herker, 1977). Boundary spanning dynamic capabilities also require a broad learning scope (Rosenkopf & Nerkar, 2001), and it can therefore be costly to develop, maintain and update them. However, when confronting market disruptions, organizations with boundary spanning dynamic capabilities would be able to influence and facilitate the formation of new networks, and recognize opportunities for developing and providing complementary capabilities to address the constraints of connected organizations.

5.3.2 Complementary capabilities across boundaries

Previous studies on dynamic capabilities consider that complementary capabilities have important and direct implications on a firm’s ability to create and capture value (e.g. Jacobides et al., 2018; Morgan, Vorhies, & Mason., 2010), and especially when market conditions are changing (Morgan et al., 2010; Teece, 2007; Töytäri et al., 2018). Existing literature discusses value enhancing dependencies between complementary assets (Teece, 1986, 2018a) within the organization boundaries. However, Finding 4.4.2 highlights the existence of critical dependencies of resources and capabilities among connected organizations, and the challenges in adopting an identical governance structure to the complementary capabilities that reside in different organizations.

My study suggests that in order to leverage and capture the full potential of digital transformation, the connected firms should develop and apply boundary spanning dynamic capabilities for concurrent development of specialized and complementary resources and capabilities (Jacobides et al., 2006; Teece, 2018b) to overcome the systemic constraints and empower synchronized change.

5.3.3 Organizational ambidexterity with network capabilities

Finding 4.5 focuses on exploring how firms evolve and expand their capabilities in order to support the new forms of value creation enabled by digital transformation. There is a growing demand for new capabilities to implement digital technologies (Finding 4.3) as well as to transform the business via modifying the connected technological and social components (Finding 4.4). This further reinforces the firms’ motivation and momentum on developing and updating their capabilities through explorative and exploitative learning. Finding 4.5.2 illustrates that the metals and mining firms tend to start with the development of exploitative capabilities within the product-market function.
Some firms decide to go further to explore digital technologies with a heavy reliance on network capabilities. In the end, these capability developments lead to an update of the firm’s existing operational processes. Among the interviewed metals and mining firms, only a few front runners on digital transformation have managed to achieve ambidextrous learning via a combination of internal and network capabilities. On the other hand, the technology suppliers’ capability evolvement seems more multipronged with more cross-functional learning, and as a result, new complementary capabilities and solutions are generated to better serve the diverging market demand brought by digital disruption (Finding 4.5.3).

The findings suggest that organizational ambidexterity is vital for an individual firm to unleash the full value potential brought by digital transformation, and that it can be achieved by combining explorative and exploitative learning in a series of activities that balance internal capabilities with the complementary capabilities from the network. In connection with the industry ecosystem level discussion in Section 5.2, acquiring complementary capabilities through the network to achieve ambidextrous performance urges the connected firms to equip boundary spanning dynamic capabilities to enable and drive a synchronized transformation.

Therefore, this dissertation also contributes to the literature of organizational ambidexterity (March, 1991; Raisch & Birkinshaw, 2008; Tushman & O’Reilly, 1996) in terms of elaborating theory (Ketokivi & Choi, 2014) through analysis of different types of knowledge search activities within and across functions (Li et al., 2008), and the associated capability evolvements in the context of digital transformation. Our research outcome acknowledges the networked view of ambidexterity (Kauppila, 2010; Simsek, 2009) through an empirical explication of different types of within-functional and cross-functional knowledge searches (Li et al., 2008) associated with digital transformation. In addition, this study reflects that the cross-functional knowledge search combining internal and network capabilities may be less dependent on the formal structures than following traditional alliance portfolios (Hoffmann, 2007), which leaves more room for dynamic capability development (O’Reilly & Tushman, 2008; Teece, 2007).
6. Conclusion

The findings of this dissertation indicate that firms in the metals and mining industry have experienced challenges in driving digital transformation and generating value through the transformation. This dissertation concludes that the industrial firms have been lacking the motivation to develop the relevant capabilities due to multiple reasons. First of all, the firms need to identify goals for the purposeful change which in turn requires investments on both resources and capabilities. However, at the same time, the investments are unlikely to generate short-term profits because digital transformation requires synchronized change among multiple organizations in order for the value to be fully realized. Without synchronized change, firms lack confidence for gaining significant benefits through being the first movers.

This chapter discusses the implications to managers and regulators, explains the limitations of the research, and pinpoints possible future research directions.

6.1 Managerial implications

Simply put, this dissertation is built around one subject: change. The results suggest that in a market that has experienced a long time of stability without heavy exposure to digital technologies, a synchronized change is needed to help the firms operating within to succeed in digital transformation. Boundary spanning dynamic capabilities are the prerequisites for the synchronization. Developing boundary spanning capabilities does not mean that boundaries will not exist or that they are not needed anymore. Instead, the boundaries among the firms are likely to be reformed in alignment with new business models, and they are likely to become more dynamic and flexible. The main roadblock for implementing synchronized change might be the different interpretations on value, and in particular, the amount of the value created and the fair share of value capture among the connected organizations.

Complementary capabilities from the participants further address the change constraints residing at the system level. Complementary capabilities are seen vital for both the suppliers and the customers. On the level of individual firms, the extent of developing complementary capabilities towards a certain connected firm or subject needs to be evaluated case-by-case. “Overfitting” may create two challenges: a) the knowledge and solution lack reusability and the economy of scale is not achieved; b) a risk that talents associated
with the complementary capabilities move to the other side of the table which leads to the firm losing the complementary capabilities.

To conclude, we suggest the managers who are involved or even actively driving the digital transformation in asset-intensive businesses to:

1. *Stay constructive towards emerging partnerships and collaboration.* On the system level, the managers shall not consider synchronized transformation as a zero-sum game, but rather as an opportunity to diminish the old ways of value creation and generating new ones. On the organization level, acquiring network capabilities in combination with internal capabilities will accelerate the firm’s capability evolvement towards organizational ambidexterity. Industrial firms should put aside the traditional understanding of products and services, customers and suppliers, but rather collaboratively enable an environment that encourages experimentation on the digital initiatives, and the development of boundary spanning dynamic capabilities and complementary capabilities through joint explorative and exploitative learning.

2. *Evaluate the essence of participating in a synchronized transformation.* Our findings indicate that the potential value of digital transformation remains uncertain, and we believe that value generation varies case-by-case. As an example, it is challenging to justify the benefits of the synchronized transformation for industrial firms whose end-products are commodity goods and whose overall profitability therefore heavily correlates with macro-economic performance. Therefore, managers should carefully evaluate the essence of participating in the change, and if the ultimate decision is positive, then the industrial firms should be prepared to take risks on uncertain returns on investment especially for the short-term.

3. *Clarify and balance the visions for capability development.* Digital transformation often requires long-term continuous driving forces, which calls for a long-term strategic directive to balance between exploration and exploitation, and between quick wins and long-term achievements. In addition, as ambidexterity can be time-consuming and costly to achieve, the firms should try to optimize the development and combined use of in-house capabilities and network capabilities, and stay focused on the value-adding targets.

### 6.2 Policy Implications

This study highlights that regulators should play a notable role in empowering digital transformation. By defining new rules and norms for operations, regulators determine the conditions for the involvement of digital tools. As an example, development and adoption of digital applications at organization level would require the regulators to define technology standards, information security regulations, and the updated health and safety guidelines which fit for the new human-machine interactions.
Legislation can either encourage or impede changes. Empirical evidence from this study identifies that labor unions and local governments may stand against digital transformation efforts as they often lead to reduction of recruitments (Durrant-Whyte et al., 2015; World Economic Forum, 2017). We suggest the regulators and relevant stakeholders to keep a constructive mindset towards the change, and to work together to help the influenced workforce members through e.g. financial support and retraining.

Finally, regulators are in a critical position to setup incentives and directions for the desired type of change. For instance, digital applications allow the real-time tracing of environmental and sustainability impacts (e.g. Bell & Morse, 2012; Bennett, James, & Klinkers, 2017). However, monitoring and publishing real-time environmental measures may land outside of the individual firm’s area of interests. Regulators, on the other hand, would be able to setup incentives to make sure that the firms find it appealing or necessary to develop towards the direction of bringing more transparency on emissions and sustainability.

6.3 Limitations and recommendations for future research

This study is not without limitations. First of all, single-case study as a research method contains limitations on generalizability. Different industries have varying market dynamics and change patterns, and the findings from the metals and mining industry will not fully explain the digital transformation related phenomena observed in asset-intensive industries in general. Therefore, further research in other industrial contexts is likely needed. Second, the empirical data provides a snapshot of the metals and mining firms as well as their suppliers which are at different stages and maturity levels of digital transformation. Therefore, the research on capability evolvement and expansion (Findings 4.5.2 and 4.5.3) are interpretations built through our abductive analysis of the snapshot findings from firms at varying stages of digital transformation. Further empirical studies could be designed to continuously follow-up on the firm’s capability evolvement.

Digital technologies support the emergence of new business models and ecosystems, and they also empower more efficient collaboration among connected firms. Digital transformation induces changes to several interrelated socio-technical aspects as well as to multiple participating organizations, which requires changes to happen systemically and synchronously. This study proposes that organizations would benefit from boundary spanning dynamic capabilities which bridge the gaps among different partners, facilitate the complementary capabilities to address each other’s challenges, and drive the partner network towards a synchronized transformation. Future research would be needed to investigate the boundary spanning dynamic capabilities in the context of partner interactions and formation of new ecosystems. In addition, empirical studies can be generated on how firms develop boundary spanning dynamic capabilities, and what is the associated influence on value creation and capturing. Moreover, research is needed to investigate what socio-technical mechanism
would allow and encourage the formation of boundary spanning dynamic capabilities.

As the empirical evidence from this study suggests that regulators have strong influence on digital transformation in asset-intensive industries, we suggest that future empirical studies would investigate the role of regulators in enabling and accelerating a systemic and synchronized transformation.

Finally, in the context of capability evolvement within industrial firms, our findings indicate that the asset-intensive industries are more favouring development of internal capabilities through exploitative learning. However, more studies are needed to investigate explorative learning in the context of asset-intensive industries. As this study emphasizes the criticality of boundary spanning dynamic capabilities and network perspective, future research could investigate the ambidexterity on the network/system level involving multiple organizations.
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