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Technical capabilities are not enough: Deploying Internet of Things in the metals and mining industry

Abstract:

Technologies enabling the Internet of Things (IoT) have emerged in business operations across industries. Our research investigates the related changes in the metals and mining industry. Based on 53 qualitative interviews among experts and managers within this industry, we identified considerable misalignment between the user expectations and the supplied technologies. Hence, we suggest a more collaborative approach across the industry participants. Openness helps in acquiring the broad set of capabilities (analytic capability, IoT competency, business development, and substantive expertise) that are needed for the implementation of the IoT technologies in the industry-specific context.

Keywords:

Internet of Things; implementation; application; metals; mining; capabilities; case study; business models; intelligent products; product intelligence; open innovation; open approach

Reference

Biographical notes:

1 Introduction

People from the headquarters have not spent that much time at the mining site. They have visions, are well-read, and get excited of new, abstract ideas. But once you go to the mine, you'll look around and realise that here we are, in the middle of nowhere, with no infrastructure, where everything has been built from scratch. […] There are strong prejudices against anything too sophisticated because people expect that those systems do not work […] The reality is that new solutions are dismissed. (Mining Technology Director, OEM4)

Having all objects and things communicating with each other is the fundamentals of the Internet of Things (IoT) (Atzori et al., 2010; ITU-T, 2012). Such an approach underscores the role of information exchange and collaboration between the objects and the entities that control them (Atzori et al., 2014). Thus, the approach is more open than when designing traditional production planning control systems (Arica and Powell, 2014). The new technologies enable efficient control of resources and processes throughout the supply chain (McFarlane et al., 2013; Ranasinghe et al., 2011). Such possibilities are destined to transform whole industries (Porter and Heppelmann, 2014).

The metals and mining industry provides a vivid example of an industry facing transformation that is characterised by the possibilities and challenges of the new technologies. As an asset-intensive industry, the distinguishing contextual features have been long-term investments, reliance and trust on legacy systems, and preference on robust, simple solutions over cutting-edge gadgets. Despite some exceptions showcasing how a mine can be totally digital and operate fully autonomously (Kotze, 2018; Turner, 2018), the overall adoption of the new technologies has been slow across the industry (European Commission, 2017). Moreover, as the quote above illustrates, the industry participants can have very different approaches to the situation, making it difficult to align the operational needs and demands with the strategic visions and desires. Thus, despite the technological promise that the IoT can bring to the industry, the advancements have been slow.

Our research focuses on the *practical implementation of the IoT technologies in the mining industry context*. We highlight the broad *set of skills and capabilities* that are required from the firms, many of which are new to the industry participants. More specifically, we answer three interrelated questions: 1) how the IoT technologies can be applied to metals and mining operations, 2) how the technology suppliers have responded to these emerging needs, and 3) why new capabilities are relevant for driving the change. Our findings are based on 53 qualitative interviews from informants from metals and mining industry firms. In addition, the findings build on our previously published work.

The article continues in four parts. First, we detail the theoretical background of our study; this consists of an overview of the IoT technologies, how they facilitate value creation, and highlight the demand for new capabilities. Next, we outline our methodology, which builds on case study research with abductive data analysis. In the next section, we present our findings regarding the identified practical needs and provided technology solutions regarding the IoT application, and connect these findings to existing literature. We continue by discussing the broad set of capabilities that is required for implementing the IoT technologies. Last, we conclude by summarising our main findings and restate our focal argument in favour of more open approaches for acquiring the needed capabilities beyond the existing firm boundaries.

2 Background

New technologies, such as the IoT, enable new possibilities and induce notable changes (Wahi and Ahuja, 2017). One key possibility is the opportunity for more detailed resource control and orchestration across the product life cycle. In addition, various technological innovations change the way companies operate and create value. Thus, new capabilities are needed both for understanding the technological features and for seizing these opportunities in a complex, dynamic setting. Next, we will discuss these three aspects in detail.

IoT technologies for resource control and orchestration

The Internet of Things (IoT) can induce drastic changes to industrial operations and existing production systems (Borgia, 2014). The IoT connects a variety of things and objects around with each other through unique schemes of interaction (Atzori et al., 2010). According to these views, objects can now be designed for adaptive connectivity (Borgia, 2014) and unknown future use cases (Atzori et al., 2014; Yoo et al., 2012). Such emphasis differs from the traditional production planning and control systems, which have aimed toward uniformity and reduced variation among all produced items (Arica and Powell, 2014). The complexity and adaptability of the production control systems have increased considerably, inspiring overarching descriptions such as "digital transformation" (Berman, 2012; European Commission, 2017).

Thus, digital transformation is revolutionising the essence of products. Physical products with mechanical and electrical components have been transformed into complex systems consisting of hardware and software, with embedded sensors, microprocessors, data storage, and connectivity capabilities (Porter and Heppelmann, 2014). These new kinds of products have granted the suppliers a direct access to data, and have enabled the manufacturing firms an avenue beyond the explicitly stated user requirements for the development of new functionalities, insights, and offerings (Berman, 2012; Rajala et al., 2018).

The discussion on intelligent products (McFarlane et al., 2013; Ranasinghe et al., 2011) forms the core for defining the prerequisites for the practical implementation of the IoT technologies. Using the new technologies, the physical items and product orders can now be linked to the process that governs how the product is made, stored, or delivered (McFarlane et al., 2013). To support these functions, the products need to be capable of storing and delivering information about themselves and about the changing, case-specific requirements, either locally or through a network. Perhaps the most apparent motivator for increasing the intelligence of products is the current mismatch between the generation and demand of resource-related information during manufacturing and supply chains (Hakanen et al., 2017; McFarlane et al., 2013). Put differently, the design choices and specifications from the manufacturing phase are not conveyed to the user, whereas the feedback from the usage phase does not reach the manufacturer. Thus, the so-called product intelligence (McFarlane et al., 2013), or material intelligence (Hakanen et al., 2017), is a crucial enabler for more advanced product life-cycle management. When all the life-cycle participants gain detailed information about the properties and history of an item, the products can be used more efficiently (Rajala et al., 2018; Ranasinghe et al., 2011). Recurrent feedback loops enable a more open approach to product development and dynamic production management, in which the individual objects can participate in the decision-making during their life-cycle (McFarlane et al., 2013). In summary, the IoT technologies have brought new tools for resource control and orchestration, and have begun to transform how value is created using the products.

Creating value with the IoT technologies

The new forms of value creation–that the IoT enables–tend to blur the existing organisational boundaries. When value creation takes place as a result of collaboration in the customer´s operations (Baines et al., 2009; Berman, 2012), suppliers need a more profound understanding of the customers' goals and activities. By learning from their customers' activities, the supplier can better find and link activities that fulfil its customers' needs (Amit and Zott, 2015). However, while such openness feeds the focal firm with new ideas, these suggestions are rarely aligned for the current capabilities, resources, and offering portfolio of the focal firm. Thus, value creation needs to be facilitated with the right resources and competencies across all the participating firms. Thus, the business models are becoming more open, with a higher emphasis on open innovation (Chesbrough, 2010; Fjeldstad and Snow, 2018; Foss and Saebi, 2017).

Since the resulting systems involve entities with individual goals, they rely on dynamic constellations between various actors. Such systems require fluent information exchange between companies that aim for collaborative value creation. Although the role of data management and utilisation for value creation with the IoT are often highlighted (Ahmed et al., 2017), the various benefits of collaborative information sharing have not been emphasised in the previous IoT discourse. In turn, previous works that have focused on such possibilities (Hakanen et al., 2017; Hakanen and Rajala, 2018), rarely consider the challenges that result from the misalignment of interests and execution of digital transformation processes. The successful transformation of an industry requires the alignment of both the mindset and the capabilities of all the involved firms (Töytäri et al., 2018). In addition, the new technological solutions call for new business models from the firms (Baden-Fuller and Haefliger, 2013; Rajala et al., 2018). In the process, new capabilities are needed to support this transformation across multiple firms.

Capabilities for deploying the IoT

The IoT enables new opportunities for value creation and, thus, call for new capabilities. Firms need to develop and utilize their resources and capabilities in a new way to capture the emerging opportunities (Hakanen and Rajala, 2018; Teece, 2018a). Existing studies emphasis that firms seeking for implementing IoT in their business need to acquire new capabilities such as data collection and storage (Atzori et al., 2010; Xu et al., 2014), information technology system and application development (Atzori et al., 2010; Xu et al., 2014), data analytics (Gust et al., 2017; O'Halloran and Kvochko, 2015) as well as incorporation to the business operations (Burmeister et al., 2016; Porter and Heppelmann, 2015; Rajala et al., 2018).

The new digital infrastructures–such as the IoT–impose new challenges for the firms. The growing installed base consists of heterogenous, unbounded, and evolving system of information technology components, in addition to diverse base of users and stakeholders (Tilson et al., 2010). This diversity makes it difficult to capture profits from the enabling infrastructure of general purpose technologies (Teece, 2018a). Firms need to develop new capabilities to differentiate from their competitors and to succeed in the competition (Porter and Heppelmann, 2014; Adeniran and Johnston, 2016). Data analytics, collection, and management across the value chain demand capabilities that are new to most firms, who have focused to handle physical goods (Ahmed et al., 2017; Porter and Heppelmann, 2014; Rajala et al., 2018).

Put differently, there is a need for a complex and dynamic portfolio of capabilities that are new to the industry incumbents. Not only do the supplier firms need the technological competence for developing new solutions (Teece, 2018b) but they also need to understand the customer's operational activities deeply enough to formulate enticing offerings that target their specific needs (Berman, 2012). In addition, customers should evaluate the value of these offerings holistically, as the proposed benefits may relate to a broad set of social, economic or technical aspects (Nicolescu et al., 2018).

3 Method

This research builds on case study methodology (Easton, 2010; Eisenhardt, 1989; Ragin and Becker, 1992). The study findings are based on 53 qualitative interviews among representatives of metals and mining industry firms. Our abductive data analysis (Dubois and Gadde, 2014) aims to elaborate on the existing knowledge and theoretical perspectives (Ketokivi and Choi, 2014) on the implementation of IoT technologies in the mining industry. Our analysis and conclusions are also supported by our previously published work.

This study aims at offering a consolidated discussion of applications and required capability synchronisations for implementing IoT solutions. These requirements are studied within the context of the metals and mining industry value chains, both from the customer and the supplier perspective. The metals and mining industry serves as an example of an industry facing transformation that is driven by the new technologies. In our study, we focused on the wide range of perspectives that the industry participants have. Our purpose was to understand the background from which these differing perspectives originate. In our study, we had three lines of enquiry that focused on 1) the expected operational benefits of the IoT solutions, 2) the identified opportunities for the technology suppliers, and 3) the required capabilities for achieving a workable solution for the industry.

Case

We conducted a single case study that includes a number of firms within the same industry. The firms in our sample share the contextual setting, and this shared context is what defines our case (Ragin and Becker, 1992). We studied the application of the IoT at the firm level, yet continuously evaluated these firm-level actions against the activities happening concurrently across other firms. This approach provided us with detailed insights from the operational activities of individual firms while simultaneously allowing us to triangulate (Denzin and Lincoln, 1994) these findings against the views of the other firms. Thus, we consider that all the firms in our sample belong to the same case, defined by the contextual setting enclosing the firms (Ketokivi and Choi, 2014).

Our specific research interest is to look into the practical application of the IoT within the case context. We entered the field with the expectation that the firms in the industry had sensed the opportunity for improving their business practices with the new digital tools, yet may have had challenges that have prevented a wide-scale implementation. The shared contextual setting across the firms allows us to analyse implications from an industry-wide perspective. Our case focuses on the potential IoT applications in this field and the responses among the technology suppliers to these emerging needs (Denzin and Lincoln, 1994; Ragin and Becker, 1992).

Data collection

Our empirical material is based primarily on qualitative, semi-structured interviews. The data consists of 53 interviews conducted between 2015-2018, and it covers 12 major mining countries in the world. Our informants originate from 35 companies, varying from global leaders to local SMEs. The firms differ in their focus areas and offerings. The company set includes 22 metals and mining firms, and 13 technology and equipment providers (5 OEMs, 5 consulting firms and 3 technology suppliers). The large and midsize companies were chosen and contacted by the researchers. The local firms were reached by snowball sampling through both academic and professional business networks.

The profile of the informants varied, which is why the main themes of each interview were adjusted to suit the background of each informant. The informants from the metals and mining firms represent three categories: top management (CxOs), middle management (head of operation/maintenance/automation) and technology leaders (IT, lead metallurgist). The informants from the technology providers are IoT experts on technical and business perspectives. The main themes during the interviews varied from firms' implementation of digital technologies to date, to barriers and/or potential of using new digital technologies in the industry. We also asked what have been the main drivers for wanting or developing new technical solutions for each firm. Interviews were voice recorded and transcribed verbatim. The list of conducted interviews, company profiles, and our informants is provided in Table 1.

Insert Table 1 about here.

Data analysis

Our findings are based on abductive data analysis, which involves continuous reflection between the collected data and the previous knowledge of the phenomenon (Dubois and Gadde, 2014, 2002). We focus on the application of IoT in the metals and mining industry context, covering both the day-to-day demands that arise from the operational side and the long-term visions that guide the solution development from the supplier side. In the process, we aim to elaborate on the existing theoretical perspectives (Ketokivi and Choi, 2014) on the implementation of technological solutions in a specific context (Jonsson et al., 2018; Nicolescu et al., 2018; Töytäri et al., 2018). In addition, our analysis is supported by our previously published work on the topic, as we have triangulated the results against those papers.

The abductive data analysis involves simultaneous of collection and compilation of data, in which the data is continuously matched against prior understanding (Dubois and Gadde, 2002). This process allows the researcher to evaluate how the interpretation of the data evolves, as multiple sources of information are combined, similar to triangulation (Denzin and Lincoln, 1994; Dubois and Gadde, 2002). The purpose of our thematic analysis (Fereday and Muir-Cochrane, 2006) was to identify patterns and emerging categories in the data (Easton, 2010).

Through this iterative analysis process, we ultimately defined the essence of our case (Ragin and Becker, 1992). Our case revealed a considerable division between the practical needs of the mining operators and the strategic visions of the technology suppliers. In result, we formulated a consolidated capability portfolio that highlights the importance of open and synchronised development across the entire value chain.

4 Results and discussion

Our study provided three key observations that address the implementation of the IoT for the metals and mining industry. The first two are directly derived from our empirical material, whereas the last observation relies more on abductive reasoning. First, we noted that the operational side (i.e. the customers) expect very practical benefits and applications. The demands can arise out of mundane, day-to-day problems in the current operations, or from proven ideas and reference cases that derive from different industries. Second, the offered solutions (i.e. the suppliers) are geared toward visions and opportunities that are identified with a broader, strategic perspective. The suppliers may have targeted a specific aspect of the overall solution (e.g. providing the communication network) or a trending management focus (e.g. developing digital platforms). Last, we end by discussing the broad set of capabilities that the firms need for harnessing the value potential of the IoT. We present these capabilities through four, intersecting themes: analytic capability, IoT competency, business development, and substantive expertise.

Operational-side expectations call for technical competences

Our study provides an overview of the metals and mining operators' expectations on how to apply the IoT technologies in their business context. Specifically, the first set of findings focused on the potential applications that the operational side had identified or hoped for. Our findings highlight a strong emphasis on resolving practical issues and needs currently at the site. The identified IoT applications relate to two primary targets: device intelligence and operational control. In more detail, *device intelligence* refers to needs that aim for upgrading equipment to a more intelligent level, labelled as smart, connected components, intelligent control, and autonomous vehicles and logistics management. In turn, *operational control* includes demands that relate to facilitating safety management, automatic reporting, predictive maintenance, and remote operation. An overview of these findings is presented in Figure 1. Next, we will explicate these results.

Insert Figure 1 about here.

Smart, connected components were considered as the "low-hanging fruits" of the IoT implementation. The capability requirements for the industrial firms pursuing these improvements were seen as lower compared to other applications. Although the concept of **intelligent control** was initiated decades ago (McFarlane et al., 2003), it is still considered as a fast evolving IoT application with promising value.

Autonomous vehicles and logistics management have been recognised as highly potential applications of the IoT (Borgia, 2014). These solutions can result in considerable cost savings, especially in countries with remote sites and high labour wages, and therefore this area has been an active area for developing IoT applications. By optimising the logistic paths, timetables, loading, and speed, firms expected to reduce their maintenance costs. In addition, by an implementation of a fully autonomous, integrated logistics network at a mining site, the firms hoped to achieve improvements on operational safety, as a result of minimising the presence of humans at the active mining site.

Moreover, **safety management** was seen as a critical feature for future IoT applications. Different initiatives arose from the hazardous environment, with large machinery, dirty conditions, and harmful substances, to name a few. For instance, the operational side hoped for attachable sensors that will automatically trigger a protection mechanism if personnel get too close to the machine in question. Yet, such improvements have been difficult to implement using previous tools and technologies, which is why the IoT-enabled systems had sparked the interest of the firms.

The IoT technology enables integrated and **automatic reporting**. Majority of the operational side of the case companies were developing a reporting system that will provide real-time information of all their (critical) assets. The users will be able to access their authorised reports from anywhere, at any time, and for any need or purpose. Such development can, for instance, replace old habits, where experienced operators place screwdrivers on top of the machinery to sense vibrations and evaluate machine condition, with measurements and readings from digital sensors (Jonsson et al., 2018). In this front, we found rising interest in putting reports to the cloud and facilitating mobile access to the machinery. However, information security concerns and limited capabilities for development have limited progress on this front.

Predictive maintenance was brought up as a popular field where the informants expected a contribution from the IoT applications. However, proven success stories are still limited within the industry, due to the complex nature of the operational environment and production processes. In general, IoT applications related to predictive maintenance were expected to prevent unscheduled maintenance shutdowns and bring better prediction for spare part inventories.

As expressed by the majority of the informants, the IoT technology is driving the industry towards **remote operation**. The remote operation offers significant contributions towards centralised decision making, productivity optimisation, operational cost reduction, better safety management, and knowledge storage and sharing. However, fully remote operation was still seen as immature, with most concerns directed towards technology constraints, capability limitations, as well as operational culture resistance.

Supplier side aims to fulfil strategic objectives

The second key theme that arose from our interviews was that most of the technology suppliers had chosen their own focus area regarding the IoT deployment. Figure 2 summarises these views as the main elements that emerged from the analysis. In the figure, the five functional elements, i) data analytics, ii) information visualisation, iii) digital platforms for business, iv) telecommunication networks, and v) smart, connected components delineate the categories of functions in which the IoT technologies are deployed in the industry. Our interpretation is that the decisions to adopt IoT technologies were mostly driven by the internal visions, strategies, or competences of each firm. The technology suppliers were guided by the integration and implementation of different IoT elements, including smart, connected components; telecommunication networks; digital platforms; data analysis; and information visualisation. However, these functional needs, and the proposed solutions that they had led to, were different from the "IoT applications" that the customer side had identified.

Insert Figure 2 about here.

In alignment with customer needs, the suppliers had proactively begun to offer **smart, connected components** to the metals and mining machinery. These solutions were aimed to embed intelligence to different stages of the process and to enable better operational control (McFarlane et al., 2013). Thus, these development initiatives indicated the highest compatibility between the customers and the suppliers in our interviews. Yet, the individual components form only the other half of the solution since they need to be complemented with a supporting communication network.

Therefore, on top of the devices, the suppliers were offering a **telecommunication network** for enabling information exchange between connected things, databases and systems. However, the supplied solutions were not fully compatible with the needs of the customers. The suppliers had encountered issues in providing connectivity solutions that fulfil all the demands regarding security, sufficient bandwidth, and affordable cost, especially in the demanding operational environment of a mine. By focusing their efforts on choosing the "right" telecommunication network standard for the IoT (Teece, 2018a), the suppliers had not foreseen all the operational demands of the systems in the metals and mining context.

In turn, **digital platforms for business** were identified as a common development target for the supplying firms. The aim of the platforms was to facilitate the integration of elements such as asset management, data storage, data management and application management, in order to ultimately enable deployment of new applications using a single digital tool. Furthermore, the platforms were designed to allow flexible and transparent information sharing while at the same time reducing the overall IT costs. By connecting the machinery to a digital platform, the operating firm could conduct systematic, condition-based monitoring and maintenance of their assets. This opportunity was seen particularly important for critical production assets. If the information was made visible also to the technology suppliers, they could offer tailored value-adding services that could increase the overall efficiency of the value chain.

Data analysis was considered as the prime example of such value-adding service. A number of informants indicated how their firm excels in transforming the gathered data into structured information, and further into usable knowledge and intelligence. Thus, it was considered essential that the information is perceivable and understandable to the decision makers. Machine learning was expected to strengthen these offerings in the future, by guiding the decision-makers to well-informed choices with continuous updates.

Last, **information visualisation** has been gradually becoming an indispensable part of the IoT applications. For example, a combination of 3D modelling and the IoT data enabled creating a digital twin for any piece of equipment that could be used for simulating the physical processes. These possibilities were highly-regarded among technology suppliers, and they were looking to support their clients in this front. In turn, our interviews among the operational side revealed a demand for such competence, as few of the metals and mining companies had so far acquired such capabilities in-house.

Research implications

Our findings led us to conclude that the metals and mining industry firms need to reconsider the capabilities that are accessible to them. Based on our findings, we elaborate on these capabilities that are needed to support the IoT implementation. Our findings are congruent with previous perspectives, which highlight how businesses have become more networked and have led to increased collaboration between multiple participants (Adner, 2017; Jacobides et al., 2018; Rajala et al., 2018). In addition, we found support to the views on why collaboration is needed to facilitate the value creation with the IoT technologies (Atzori et al., 2014; Hakanen and Rajala, 2018; Nicolescu et al., 2018). Based on our findings, we suggest a capability portfolio (see Figure 3) that is required for successful IoT implementation in an industrial context. We present these capabilities through four categories: analytic capability, IoT competency, business development, and substantive expertise.

Insert Figure 3 about here.

In our view, all four capability areas are essential for the IoT implementation. **Analytic capability** forms the base for extracting knowledge from data provided by the sensors and machinery. During our interviews, the capabilities for data analytics were argued as the essential core of the IoT implementation by metals and mining technology suppliers, while similar views have been argued in the existing literature (e.g. Ahmed et al., 2017; Turunen et al., 2018). In turn, **IoT competency** refers to the comprehensive set of capabilities for providing, integrating, and managing intelligent devices (Ahmed et al., 2017; Borgia, 2014; Ranasinghe et al., 2011). The technology suppliers had heavily focused on this area when developing the foundation for future offerings to the metals and mining industry firms. However, in order to fully utilise the IoT technology and data analytics in a particular business context, considerable **substantive expertise** is required. Naturally, the metals and mining industry firms excelled in this front, while the suppliers had encountered some issues in conveying the value of their offering to the customers, as the social, economic, and technical aspects of the solutions were perceived differently (Nicolescu et al., 2018). Last, the capability for **business development** is necessary for realising the economic potential of any technical innovation (Baden-Fuller and Haefliger, 2013). These capabilities are needed for both the technology suppliers to capture a share of the value from a customer solution, and for the operational side to transform the IoT applications as a value-adding element of their existing business models (Foss and Saebi, 2017; Teece, 2018b).

We did not find a single firm which could fulfil the whole capability portfolio purely with in-house resources in our case study. This conclusion further strengthens the calls for more open business models and a higher emphasis on open innovation (Chesbrough, 2010; Fjeldstad and Snow, 2018; Ruggles III, 2004). With a more open approach, the firm can focus on their own specific competence and combine this expertise with the in-depth capabilities of other firms. Especially, when technology development is allowing products and objects with adaptive connectivity (Borgia, 2014) and unknown future use cases (Atzori et al., 2014; Yoo et al., 2012), such openness can prove vital for succeeding in a turbulent industry.

When the scope of IoT adoption expands, the capability requirements will further increase. The needed capabilities go beyond the elementary technological solutions and become more complex, with the continuous advancements in data analytics (Ahmed et al., 2017; Turunen et al., 2018), technological competence (Borgia, 2014; Teece, 2018a; Keesookpun and Mitomo, 2014), business model development (Foss and Saebi, 2017; Teece, 2018b), and the context-specific expertise and knowledge (Durrant-Whyte et al., 2015; Jonsson et al., 2018). Moreover, the firms need not only to manage their own expertise but also to understand what are the specific needs that originate from their customers' capability development (Berman, 2012). The diverging competences can lead to mismatched expectations and increase the misalignment between the customers and suppliers, as the companies develop their capabilities guided by their background, mindset, and visions. Such division was already evident in our findings, as we identified a significant division across the industry on how to implement the IoT solutions. Metals and mining companies tended to perceive IoT through lenses that are heavily tinted with substantive expertise (i.e. mining operations), whereas the technology suppliers view the field from a perspective of data analytics and the IoT technology elements.

Managerial implications

Based on our findings, we argued how the firms could benefit from being more open in their mindset and operations. Successful IoT implementation requires a broad set of specific capabilities. The firms can either try to possess all these needed capabilities in-house or rely on their network for acquiring the needed competencies. We argue in favour of more open approaches because we found no companies that possessed all these elements in-house in our case study data.

Thus, industrial firms who are planning or undergoing IoT adoption processes should maintain an open attitude when acquiring and managing their capability portfolio. In the process, activities that span the existing firm boundaries gain a more focal role. Furthermore, while the IoT is evolving fast on both technical and application levels, it is essentially a general purpose technology that, as an intermediate tool or product, can be challenging to monetise (Teece, 2018a). The fast developments lead to a constant revision of the capability requirements. Therefore, we argue that firms also need to continuously synchronise their capability development to maintain efficient collaboration and implementation practices. Since the IoT applications involve multiple entities with different goals, fluent information exchange and dynamic constellations linking various actors are needed. Altogether, many of the value creation possibilities of the IoT rely on collaboration with different network participants, both human and machines (Nicolescu et al., 2018).

5 Conclusion

In this paper, we outlined the avenues for applicating the IoT technologies in the metals and mining industry context. During our case interviews, we found 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). We argued that such deviation could be explained by the differences in the processes both sides have used for identifying these potentials. The operational side and the supplier side had focused on very different aspects of the same phenomenon when outlining the potential solutions. Last, we discussed the importance of a more open approach for finding common themes between the two sides and emphasised how a more open mindset may be required to acquire the broad set of capabilities that is needed for successful IoT implementation.

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Table 1. Interview data

Firm	**Introduction**	**Informant(s)**	**Date of interview**
Firms that operate within the metals and mining industry (M)			

M1	Operates in multi-continent, produces multiple metals and minerals	Head of Automation	Feb-16
M2	Operates in multi-continent, produces multiple natural resources	Operation Manager; Operation Manager (former); IT manager	Mar-May 2016
M3	Operates in multi-continent, metal producer	Superintendent; Principle Advisor; Global Director; Head of Innovation (2 interviews)	April-Jun 2016
M4	Operates in multi-continent, gold producer	Former employee with various management positions	May-16
M5	Operates in multi-continent, precious metal producer	Senior Director	Jun-16
M6	Operates in China, produces mineral concentrate	Head of Operation; Head of Technology	Mar-16
M7	Operates in Russia	Head of Automation	Jun-16
M8	Operates in multi-continent, gold producer	Chief Metallurgist	Apr-16
M9	Operates in Mexico, produces multiple metals	Automation Manager; Process Engineer; Head of Technology	Apr-16
M10	Operates in South America, copper producer	ICT Director	May-16
M11	Operates in India, steel producer	Former CIO	Apr-16
M12	Operates in North America, produces iron concentrate and pellets	Technical Service Manager	May-16
M13	Operates in Russia, precious metal producer	Director of Development	Jun-16
M14	Operates in multi-continents, produces industrial minerals	Head of Instrumentation	May-16
M15	Operates in Americas, copper producer	General Manager; Metallurgist	Jun-Jul 2016
M16	Operates in Mexico, produces precious metal	Lead Metallurgist	Jun-16
M17	Operates in China, steel producer	Operation Manager	Jun-16
M18	Operates in China, produces multiple metals	Director of Technology; Vice General Manager	Mar-16
M19	Operates in multi-continent, mining and metal production	R&D Director; Head of Technical Analysis; Managing Director	May-18
M20	Operates in multi-continent, produces multiple metals	R&D Manager; Business Director	Jun-18
M21	Operates in Europe, mining and metal production	R&D Manager; Business Development Manager	Jun-18
M22	Operates in Finland, mining and primary refining	Process Engineer	Aug-18
Technology, equipment and service providers to metals and mining industry			
Original equipment providers (E)			
E1	Global firm, supplies mining machinery	Former CIO	Mar-16
E2	Global firm, supplies automation equipment and systems to metals and mining companies	Former General Manager	Apr-16
E3	Global firm, supplies equipment and platform solutions to metals and mining companies	Chief Data Scientist; Marketing Director	Apr-16

E4	Global firm, supplies mining and materials processing machinery	Mining Technology Director; Global Division President	Jan-2015 & Jun-2018
E5	European-based vehicle manufacturer and supplier of drivetrains	R&D Director	May-15
Consulting firms (C)			
C1	Small Australian technology consulting group, specialising in metal and mining technology	Technology Director	Apr-16
C2	Global professional service provider, offers digitalisation development and consulting service to metals and mining companies	Senior Manager; Senior Managing Director	Apr-May 2016
C3	Small Canadian mining technology consulting group	Consultant	May-16
C4	Small metallurgical technology consulting group	Technology Adviser	May-16
C5	Mining focused consultancy, development, and holdings company	R&D Manager	Jun-18
Technology suppliers (T)			
T1	Global firm, offers comprehensive ICT solutions including telecom networks and devices	Data Architect	Mar-16
T2	Technology provider for metals and mining companies	Former Vice President of Marketing and Technology	May-16
T3	Technology provider for mining and metals processing companies	R&D Director	Jun-18

Figure 1. IoT applications in the metals and mining industry

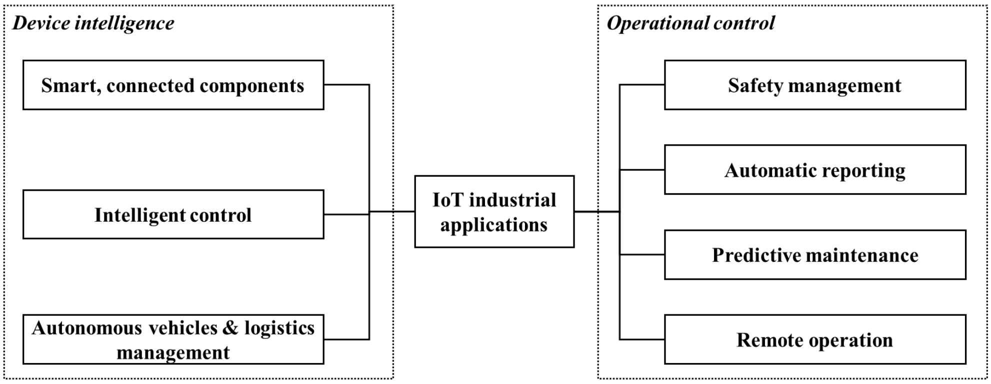

Figure 2. IoT elements and their integration from technology suppliers' view

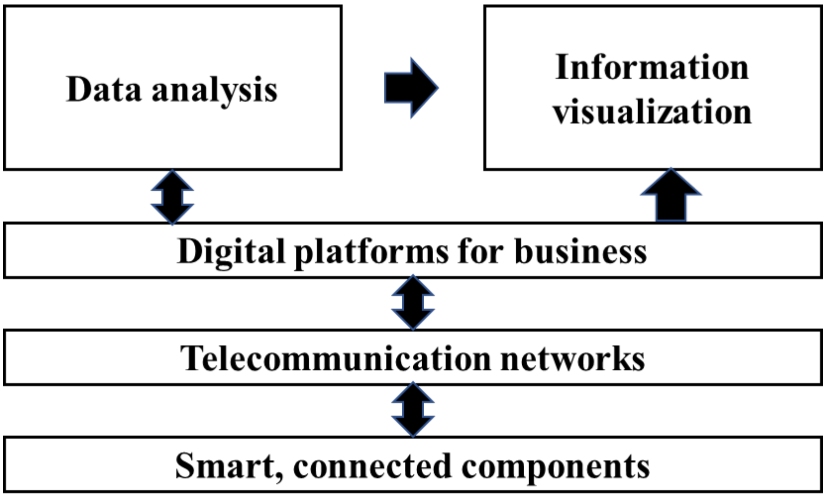

Figure 3. Capability portfolio for successful IoT implementation