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Research Article

Representation and mediation in digitalized work: evidence from maintenance of mining machinery

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Abstract

The increased digitalization of work results in practices that are increasingly networked and knowledge-based. As such, we need to continuously inquire *how* digital technology leads to changes in work and not be content knowing *that* it leads to change. This paper contributes to advancing such knowledge through an analysis of digitalized condition-based maintenance of machinery in a Swedish iron ore mine. Drawing on the distinction between digital representation and digital meditation figurations of human and material agency, we analyze how the distributed network of workers used a diverse portfolio of digital technologies to make complex knowledge-based decisions on when and how to maintain the mining machinery. We combine these empirical insights with extant literature to advance a new theoretical perspective on how key characteristics of digital technologies are implicated in networked, knowledge-based work practices.
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Introduction

The role of technology in the changing nature of work has been on the agenda for IS scholars for decades, examining issues of work content, coordination, control, organization, competencies and skills (Kling, 1996; Shaiken, 1986; Zuboff, 1988). However, work content, processes and organizing are now different from what they were in the 1960s and 1970s when computerization took off (Barley and Kunda, 2001; Forman *et al.*, 2014). As modern organizations digitalize work, people increasingly access and share information and work remotely with others mediated by technology. Work is also moving out from the office into a multiplicity of new locations (Felstead and Jewson, 2000; Felstead *et al.*, 2005). As the nature of work continues to change, we need to understand digitalization based upon contemporary practices and not on ideas developed in a different era with collocated, locally controlled manufacturing (Forman *et al.*, 2014). Against this backdrop, it becomes important to study the sociotechnical configurations that make up today's emerging work practices. Yet, our understanding of *how* key digital technology characteristics are implicated in shaping today's work practices is limited.

To afford such theorizing, we rely on an iron and ore mining company as an interesting context of digital technology usage (Bamberger, 2008; Johns, 2006). As the mining company implemented condition-based maintenance of its machinery, it captured machine vibrations digitally and engaged a remote diagnostics service provider to help monitor its machines and alert the mine to imminent failures. This networked configuration of maintenance work allowed remote analysts and onsite workers to jointly make preventive maintenance decisions based on sensory data and information about the mining machinery's physical condition, such as their temperature and vibrations. The complexity of digitalized work in this particular context is illustrative of important gaps in our understanding of how digital technologies are implicated in contemporary work practices (Leonardi, 2010; Mutch, 2013). To reveal new insights, we rely on the notion of figurations to conceptualize how the mine used a portfolio of digital technologies to create a work space and a distributed work arrangement for maintenance of its machinery. Figurations are observable traces of how human and material agency, as common building blocks, come together in the constitution of a work practice (Latour, 2005). As such, they allowed us to build on the foundational entanglement of material and human agency to conceptualize how key digital technology characteristics materialized in the mining context. Hence, rather than seeing the social and material as inherently inseparable (Cecez-Kecmanovic *et al.*, 2014; Orlikowski and Scott, 2008), we develop the notions of digital representation and digital mediation figurations to investigate: *How can we empirically and theoretically account for digital technologies in the constitution of condition-based maintenance of mining machinery*? As a result, we reveal how digital representation and mediation figurations entangle to produce a networked, knowledge-based work practice, with the former designating use of IT to monitor and produce a work space, and the latter designating use of IT to share and enact a distributed work arrangement.

Our argument proceeds as follows. We begin with a discussion of the context under study. Next, we draw on extant research on digitalized work to develop the distinction between digital representation and digital mediation figurations. After presentation of our research method, we then offer a detailed account of how condition-based maintenance of machinery constituted in the iron ore mine through entanglement of representation and mediation figurations. As a final step, we draw on insights from the field study and extant literature to advance new theoretical perspectives on digitalized work that gives particular attention to the characteristics of digital technologies.

Condition-based maintenance of mining machinery

Organization researchers have increasingly focused on specific contexts to drive theory development (Bamberger, 2008). Contexts illuminate those "situational opportunities and constraints that *affect* the occurrence and meaning of organizational behavior as well as functional relationships between variables" (Johns, 2006, p. 386). As such, they are critical drivers of cognition, attitudes and behaviors and researchers can use them as sensitizing devices to gain insights into how particular opportunities and constraints govern and shape observed phenomena (Cappelli and Sherer, 1991).

Maintenance of mining machinery offers an interesting context for understanding how the particular characteristics of digital technologies are implicated in shaping contemporary work practices. In these contexts, each individual machine is very expensive and unplanned breakdowns can lead to loss of valuable production time. Accordingly, mining companies are seeking to improve the machinery uptime through efficient maintenance planning. Condition-based maintenance is one type of preventive maintenance where the equipment's condition is monitored (Tsang, 2002). The aim of monitoring the equipment is to minimize the total cost of maintenance by collecting and interpreting continuous data of the operating condition for critical components (Knapp and Wang, 1992). Performance-parameter analysis, vibration monitoring, thermography, oil analysis are some condition-monitoring techniques that enable preventive maintenance. With these technologies, the condition of the equipment can be monitored while it is in operation and decisions about when to repair can be based upon knowledge of the components condition (Yam *et al.*, 2001). Mining companies have therefore strong incentives to invest in digital technologies to detect signals of breakdowns based on detailed condition data about each machine and its performance, including its configuration of components, its performance history and current operation. Moreover, maintenance technicians, planners and managers operate in a highly distributed setting, with individual machines distributed underground with difficult and time-consuming accessibility, and with mines and plants distributed over considerable geographical areas. For these reasons, there are also strong incentives to invest in digital technologies to connect maintenance technicians, planners and managers, so they can easily communicate, share information and jointly make decisions without necessarily being present at the same location at the same time. Finally, there is a long history of digital technologies use in this context. During the 1970s and 1980s, digitalization took off as work began to be automated. Early sociotechnical studies focused on the consequential changes in the steel, coal and dock industries (Mumford and Banks, 1967; Scott *et al.*, 1963), and these changes raised interest from IS researchers to study related labor and workplace democracy issues (Nygaard and Bergo, 1975).

This paper focuses on a mining company that invested in sensor technology to monitor its machinery including transportation belts, gearboxes, mills, elevators and shaking tables based on data about vibrations, temperature, pressure, speed and more of relevant components (Jardine *et al.*, 2006). Monitoring and analyzing such data afforded assessment of a machine's condition to anticipate breakdowns. At the same time, this condition-based approach enabled a new maintenance organization where a remote center with specialized analytic capability monitored and diagnosed machinery from across multiple organizations. This new, distributed organization integrated onsite and remote work and applied diagnostic software to continuously produce a digital version of each machine based on sensor data. In this arrangement, remotely located analysts with skills in interpreting sensor data analyzed and compared information about machines operating in different organizations and industries and they utilized mediating technologies to collaborate closely with onsite workers.

Representation and mediation in digitalized work

The move from the industrial to the postindustrial society has been enabled by various technologies (Bell, 1973; Beninger, 1986; Yates, 1989) in which new forms of IT continue to play particularly important roles in automating and informating (Zuboff, 1988) as well as complementing work (Brynjolfsson and McAfee, 2014; Nicolini, 2007). In this process, organizations must embrace the changing nature of digitalization (Stieglitz and Brockmann, 2012) and negotiate both positive and negative effects, such as creativity and innovation (Vlaar *et al.*, 2008), high levels of stress (Ayyagari *et al.*, 2011; Barley *et al.*, 2011) and simultaneously increased and decreased sense of autonomy (Mazmanian *et al.*, 2013). To understand these complex issues, the IS discipline has adopted different theoretical perspectives.

Early authors focused on how the physical structure and operation of a digital technology constrain or enable practices, beliefs or social configurations (Mumford, 1964; Winner, 1980). Markus and Robey (1988) explained how IT usage can enrich and routinize jobs, centralize and decentralize authority, and often produce unexpected outcomes (Boudreau and Robey, 2005). To further advance our understanding of digitalized work, recent research has found conceptual inspiration in social construction of technology (Bijker, 1995), social shaping of technology (Williams and Edge, 1996) and actor-network theory (Latour, 1987). A more recent stream of IS research has focused specifically on the distinct characteristics of digital technology (Kallinikos *et al.*, 2013) and the implications of digital technology in work practices (Yoo, 2013). This stream of research has shown how the layered modular architecture of digital artifacts enables any content to be encoded into a digital form and consumed via a wide array of services, distributed to numerous devices through diverse networks (Yoo, 2010). The loose coupling of these layers fosters distribution of the locus of control of digital artifacts, introducing high levels of complexity in digital innovation processes (Svahn *et al.*, 2017). Since digital artifacts are programmable and editable to a much larger degree than analog artifacts, they are highly malleable (Kallinikos *et al.*, 2013; Yoo, 2010) making digital innovation processes evolve in unbounded ways (Nylén *et al.*, 2014; Yoo, 2012).

Despite these efforts, IS researchers have recognized that the role of the IT artifact is undertheorized (Leonardi and Barley, 2008; Orlikowski and Iacono, 2001; Zammuto *et al.*, 2007) and have called for more sophisticated conceptualizations that focus explicitly on how digital technologies are implicated in shaping contemporary work practices (Leonardi, 2010; Leonardi and Barley, 2008; Volkoff *et al.*, 2007). In response, we propose to distinguish between digital representation and digital mediation figurations as two complementary ways in which digital technologies are implicated in work practices. Digital representation focuses on the content, i.e., how IT is used to monitor and produce digital content, whereas digital mediation focuses on the medium, i.e., how IT can be used for digitally mediated cooperative work. In the same way as Zuboff (1988) focused on automate and informate as fundamental characteristics of information systems to understand key features of work organization such as power (Burton-Jones, 2014), we zoom in on digital representation and mediation as key characteristics of information systems that shape contemporary work arrangements.

Although digital representation and digital mediation figurations may exist independently of each other, many contemporary work practices are produced through their coexistence, as illustrated well within healthcare. Robotic surgery is an example of a purely digital representation figuration that can improve precision and reduce errors if applied appropriately. The robot becomes an instrument that allows the doctor to use a knife (or other instruments) based on digital imaging of the physical target of surgery. The doctor can manipulate the knife, see how it applies to the patient's body, and zoom in and out as needed, while simultaneously receiving useful information about progress of the surgery. The digital representation (the doctor's work space) is thus co-created through the features of the technology and the manipulations and knowledge of the doctor.

Similarly, tele-based psychiatry is an example of a purely digitally mediated figuration. With the doctor and patient located in separate locations, a videoconference system affords verbal and visual connectivity that enables diagnosis and therapy over distance. Such a work arrangement is also co-created by the features of the technology (coding sounds and pictures into bits, transfer, and decoding into sounds and pictures), possible support staff (connecting sites, steering cameras, adjusting microphones, and possibly recording and storing sessions) and, not least, the experience and knowledge of the patient and psychiatrist.

Tele-based surgery is then an example of how digital representation and digital mediation figurations may entangle to produce a work practice. In this case, the doctor and the patient are located separately as surgical practices constitute through robotic surgery as well as tele-medicine. There is typically IT usage specific to robotic arrangements (movement of the instrument), tele-medicine arrangements (mediated communication between local and remote staff), and both (ongoing production of surgical images). As illustrated by these examples, digital representation and digital mediation figurations are both produced through human agencies (such as skills, power, norms, resistance and routines) and material agencies (such as sensors, codes, algorithms, passwords, inscriptions, and workspaces). Nevertheless, they draw on specific characteristics of digital technologies and represent two quite different forms of digitalized work.

Digital representation focuses on the use of IT to monitor and produce a work space. Digital representation draws attention to how human and material agency afford opportunities to leverage representations of real-world phenomena (e.g., a patient or a machine) in particular tasks (e.g., medicine or maintenance) (Mingers and Willcocks, 2004). According to Zuboff (1988), the representational capacity is one of the fundamental characteristic of information systems in which "activities, events and objects are translated into and made visible by information" (pp. 10–11). In their work on affordances and the changing fabric of organization, Zammuto *et al.* (2007) identify three affordances related to digital representation: visualizing entire work processes, real-time flexible product and service creation and simulation-synthetic representation. Through digital representation activities, people can access and make sense of requisite information (Zammuto *et al.*, 2007). Simulation work (Leonardi, 2012) is an example of a work practice where the digital represents a physical object or process as closely as possible to its physical form and enables its manipulation in digital format (Bailey *et al.*, 2012). Most contemporary work practices are constituted through digital representations in which various types of text, image and sound are made available and processed in digital form. The digital representation perspective deals with the ways in which representations are created and interpreted to arrive at perceived meanings (Ramaprasad and Rai, 1996). Studies show that representations can help people communicate to achieve shared understandings (Bechky, 2003b; Carlile, 2002) and enlist support (Bechky, 2003a).

Digital mediation refers to the use of IT to share and enact a work arrangement (Andersen, 1990; Persson *et al*., 2009), rooted in the CSCW perspective on IT (Schmidt and Simone, 1996) as well as the semiotic perspective on IT (Mingers and Willcocks, 2004). Different forms of IT have enabled collaboration in distributed teams that span time and space boundaries. Contemporary organizations interact with the environment, increasingly mediated by digital technology (Kallinikos, 2009) and bringing changes to the geographic distribution of work (Hinds and Kiesler, 2002) as new forms of digital mediation emerge (Aguinis and Lawal, 2013), such as globally outsourced work (Levina and Vaast, 2008) and virtual teams (Chudoba *et al*., 2005). Enabled by various forms of communication and collaboration technologies, these digital mediations constitute through the entanglement of work performed in remote and onsite settings. As such, these arrangements are often associated with discontinuities that threaten the cohesion of work (Chudoba *et al*., 2005), including physical location, time zones, national or professional culture, and organizational affiliation. Researchers have investigated Procter & Gamble's use of IT to collaborate with distributed actors in scientific networks in order to develop new products (Huston and Sakkab, 2006), challenges to building trust that are not present among co-located teams (Newell and Donald, 2007), virtually collocated teams from the perspectives of identity formation (Wiesenfeld *et al*., 1999) and effects of cultural diversity (DeSanctis and Poole, 1997) and trust (Jarvenpaa *et al*., 1998). The digital mediation perspective thus focuses on use of IT to share and enact a work arrangement.

As summarized in Table 1, we adopt specific theoretical concepts to analyze condition-based maintenance of machinery in the mining industry and to advance new theory that emphasizes how digital technology characteristics are implicated in shaping contemporary work practices. We consider practices as locally defined and emergent ways of doing work that are produced through entanglement of specific figurations of human and material agency. Moreover, we draw on the broader literature on digitalized work to zoom in on representations and mediations as two types of digital figurations with particular relevance for understanding how digital technologies are implicated in shaping networked, knowledge-based practices such as condition-based maintenance of mining machinery.

Research methodology

Our theorizing is grounded in a qualitative field study of condition-based maintenance at Luossavaara-Kiirunavaara AB (LKAB) and the remote diagnostics company Monitoring Control Center (MCC). We chose LKAB and MCC because condition-based maintenance is exemplary of how IT and work are fused in intrinsic ways as people make use of IT to monitor and produce a work space and to establish a medium for sharing and enacting a distributed work arrangement. We followed the basic principle of case studies to get an in-depth understanding of the phenomenon (Cavaye, 1996; Yin, 2003), which in our case meant investigating the daily work in condition-based maintenance and the effects and implications it had for the involved people and organizations. In our research, we observed strong evidence of two strands of IS research related to digital representation and mediation and we came to understand that they manifested as entangled figurations in the observed condition-based maintenance between LKAB and MCC.

We conducted a total of 33 interviews with key stakeholders (10 from MCC and 23 from LKAB), see Table 2. Figure 1 presents the time line of the development of condition-based maintenance in the case and our related data collection. We collected data at different occasions with access to different respondents that could help us develop our understanding of condition-based maintenance. This recurring data collection gave us detailed insights into the observed work practice from different perspectives. In addition to the interviews, we collected publications from LKAB and MCC. The sampling of interviews was purposeful (Strauss and Corbin, 1990) focusing on LKAB employees in top and middle management, group managers, maintenance planners and technicians with important relations to condition-based maintenance. At MCC, we talked to all categories of involved employees including management, technical developer and analysts. The interviews were semi-structured and open-ended to reveal the everyday work practice and the respondent's use of different technologies at work. Each interview lasted between 1 and 2 h, and all interviews, except three, were conducted face-to-face at the respondents' workplace, which provided us with contextual understanding and insights into the work processes within each company. Although key informants helped us identify relevant interviewees, participation in the research was strictly voluntary.

Table 1 Theoretical concepts

Concept	*Definition*	*Sources*
Work practice	A work practice is a locally defined and emergent way of doing work that is produced through entanglement of specific figurations	Leonardi (2011, 2013)
Figuration	A figuration is an empirically observable trace of how human and material agency, as common building blocks, come together in the constitution of a work practice	Latour (2005) and Leonardi (2011, 2013)
Digital representation	A digital representation is a figuration in which IT is used to monitor and produce a particular work space	Zuboff (1988), Ramaprasad and Rai (1996), Carlile (2002) and Mingers and Willcocks (2004)
Digital mediation	A digital mediation is a figuration in which IT is used to share and enact a particular work arrangement	Andersen (1990), Chudoba *et al*. (2005), Levina and Vaast (2008) and Persson *et al*. (2009)

Table 2 Interviews

MCC	*Date*	*LKAB*	*Date*
Business consultant	2003-11-19	Technician	2003-10-09
Manager	2004-04-27	Production manager	2003-10-10
Manager	2006-01-31	Maintenance technician A	2003-10-10
Team leader	2006-01-31	Maintenance technician B	2003-10-10
Technician A	2006-01-31	Maintenance technology manager	2004-04-28
Technician B	2006-02-01	Maintenance team manager A & B	2004-04-27
Technician C	2006-02-01	Production manager	2006-01-31
Developer	2006-02-01	Maintenance team managers B-J	2006-03-21
Technician C	2010-08-23	Maintenance team manager K-N	2006-03-22
Team leader	2010-08-25	Maintenance team manager A	2006-04-28
		Maintenance team manager A	2006-04-28
Total of 10 MCC interviews		Total of 23 LKAB interviews	

The first author conducted the interviews together with a fellow researcher. We ended the data collection when we had achieved saturation, i.e., when additional interviews did not reveal new insights. The three data collection engagements during 2003–2006 (Figure 1) with purposeful sampling were complemented with two follow-up interviews in 2008 and 2010 where we talked to the manager and an analyst to complement our data and get knowledge of how condition-based maintenance had been consolidated.

Our project's research archive consists of all transcribed interviews and twenty documents, including public yearly reports, history descriptions of LKAB, news coverage and internal documents of MCC's business plans and machinery assessment routines. The first author and fellow researcher produced a full case write-up for all respondents, and the results were also orally presented for MCC management. The different data sources, the case write-up and the feedback from respondents helped us triangulate and validate our interpretation of the case (Miles and Huberman, 1994).

To analyze the data, we followed recommended procedures for qualitative research (Eisenhardt, 1989; Miles and Huberman, 1994), using related literature to guide the process through three steps of coding. The first round of coding involved the first author (who had collected the data) re-reading all data material to become immersed in the data and look for central themes. During this work, the researcher took notes and highlighted key phrases that were representative for the respondents. This round of coding was open-ended (Strauss and Corbin, 1990) and helped the researcher recall the details of the case, which was important as a number of years had passed since the data was collected. The second round of coding involved all authors. The first author

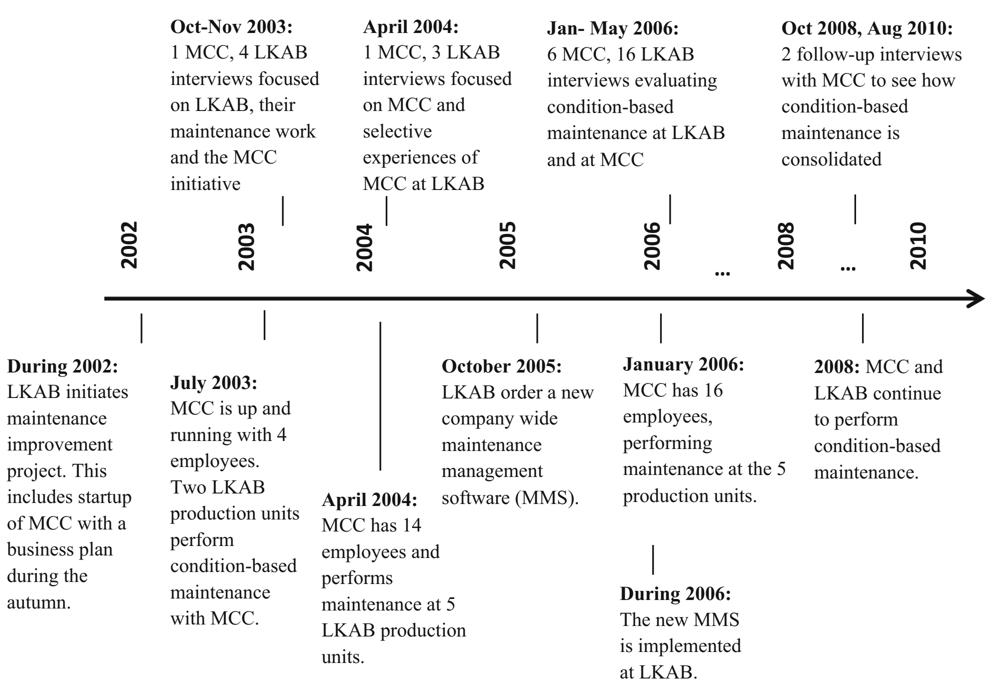

Figure 1 Data collection strategy.

looked for examples of digitalization and mediation and wrote up a three-page document with examples of empirical accounts categorized as digital representation or digital mediation figurations. This document served as a basis for discussion between all three authors to refine our understating of the concepts and agree upon a common understanding of the case. During these activities, we identified four figurations (digital representation figuration 1: *collecting machine data*, digital mediation figuration 1: *connecting maintenance workers*, digital representation figuration 2: *data-driven maintenance planning, and* digital mediation figuration 2: *cross-firm analyst team*) and we looked *at condition-based maintenance* as a whole to understand how digital representation and mediation entangled to produce condition-based maintenance. Specifically, regarding digital representation we focused on how people used IT to monitor and produce a work space, and regarding digital mediation we focused on how people used IT to share and enact a work arrangement. We define a work space as the tasks and the context in which the tasks are performed supported by the IT artifact and a work arrangement as the way in which actors are distributed to execute the tasks. Hence, in this activity we generalized from theory (the conceptualization of digital representation and digital mediation figurations) toward description (of condition-based maintenance practice) (Lee and Baskerville, 2003). In this second step, we were attentive to the figurations and the overall work practice. For example, we considered how the collection of machinery information was associated with norms among machine suppliers for providing access to such information. In the third step, we used the codes from the second round (marked above in italics) to re-code the data. In doing so, we iterated between analysis of empirical evidence of digital representation, digital mediation and their entanglement to understand the observed practice of condition-based maintenance (Eisenhardt, 1989). We focused on capturing the unique characteristics of condition-based maintenance as an instance of a digitalized work practice. Although our data analysis progressed primarily from empirical toward conceptual analyses, there were constant interactions, with empirical material leading to specific conceptual characteristics and conceptual reflections triggering further analysis of the data.

Empirical analyses

LKAB is one of the world's leading producers of upgraded iron ore products for the steel industry, as well as a supplier of industrial mineral products to other sectors. Historically, each production unit at LKAB (five plants, two mines and one logistics unit) had its own separate maintenance organization. Each of these worked almost in isolation as expressed by the production manager: *We did not collaborate between the maintenance organizations at each production unit. It was like separate worlds, we rather went to Stockholm to collaborate with an external partner than collaborating within the company. For example, we never had meetings.* Another example of this separation of the maintenance organization was the IT infrastructure. There were eight different types of maintenance management software at LKAB as each production unit had chosen the system they found most appropriate for their work. Each unit also had technicians that were skilled in repairing its specific machinery and planners who ordered spare parts and scheduled work for those machines.

Maintenance was to a large extent reactive, although lubrication and oil changes were done preventively. Also, technicians who had worked in the same unit for a long time inspected machinery with a preventive mindset. Based on extensive experience, they knew individual machines well and they could assess the condition of these specific machines based on their embodied senses (sight, smell, sound and touch). As an example, experienced technicians would place a screwdriver on the machine to sense vibrations in order to detect imminent breakdowns of machinery components. Although some machinery could potentially be inspected while in operation (which is not the case in settings such as maintenance of jet engines), safety reasons restricted this option, limiting such revelations to scheduled maintenance windows about once every quarter. In addition to being dependent on highly experienced technicians, this form of preventive maintenance was very subjective and variable. The production manager explained: *Often when you walk around in the plant you might see or hear something, but … we need to get rid of the person-dependency. If one guy walks around today and another tomorrow, their data should be the same.* In addition to being highly person dependent, this embodied form of preventive maintenance produced non-sharable data in the mind of individual technicians. Far from producing objective and sharable data that could be assessed and valued by others, the inspections gave the technician a sense that the machine "*does not sound as usual,*" which he could then share with others as a basis for making repair decisions.

In 2002, LKAB initiated a productivity improvement project to reduce downtime and unplanned work stoppages in its operations. The goal was to have their four pellet plants up and running 340 days per year, yielding a yearly production of 1360 pellet days. Increasing production by three days per year would augment revenues by eight million Euro. In addition, decreasing the number of unplanned machine stops of less than 1 h duration would increase the quality of the iron pellet. As part of the improvement project, LKAB decided to implement condition monitoring of machinery and execute maintenance proactively to avoid breakdowns, effectively moving from reactive to preventive maintenance. This would help them address the shortcomings of embodied diagnostics and realize its goals. To implement the new condition-based approach to maintenance, LKAB turned to Svenska Kullager Fabriken (SKF), a

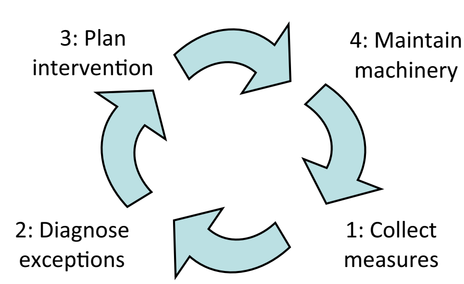

Figure 2 Work space of condition-based maintenance.

large supplier of bearings used in industrial machinery, and Sandvik, a larger supplier of industrial machines. In 2003, the three companies established MCC as an independent joint venture dedicated to performing remote diagnostics in different industries.

Condition-based maintenance

Figure 2 depicts condition-based maintenance of mining machinery from a work space perspective. The work space constitutes through four cyclical tasks:

1. Collect measures—for machinery with installed sensors, information is automatically and continuously collected; for machines not equipped with sensors (due to lack of network connectivity, for example), an MCC analyst periodically visits the mine to collect data manually with a micrologger. As precondition for this task, machines were selected to decide which to monitor online or off-line and the selected machinery components were connected via sensors.
2. Diagnose exceptions—the remote analyst examines all measures and collects additional information from onsite workers if necessary. As precondition for this task, the new distributed maintenance organization was established and people both within LKAB and MCC were equipped with mediating technologies as mobile phones and e-mail.
3. Plan interventions—the remote analyst reports the status of the monitored components to onsite maintenance managers; the maintenance manager talks to maintenance technicians who regularly observe the physical machinery in the mine to make final decisions about maintenance interventions, taking both the MCC analyst's interpretations of the sensor data, as well as other information into account, e.g., criticality of the machine, availability of spare parts, and time to the next scheduled maintenance window. The maintenance planner then prepares the maintenance by ordering spare parts, scheduling work and creating work orders.
4. Perform maintenance—the planned interventions are executed by maintenance technicians.

The distributed work arrangement between LKAB and MCC includes distributed technicians, planners and managers across different production units and experts analyze collected data at MCC's remote office. As summarized in Table 3, the work space and work arrangement relies on diverse digital technologies including: sensors to collect data; a centralized database; mobile phones to enable direct communication between distributed people; e-mail to enable transfer of documents; and, diagnostic software for analyzing and visualizing data to make recommendations, generate alarms or initiate responses. This portfolio of technologies is highly dynamic as the status of machines constantly changes, depending on where and how they are used, their components (replacement parts are often different from the originals) and wear of the components. To keep pace with this evolving composition of machinery, the digital representations are continuously updated and software simulations are adapted. Moreover, LKAB and MCC constantly upgrade infrastructure with the latest sensor, networking and monitoring technologies. For example, new broadband

Table 3 Portfolio of technologies in condition-based maintenance

Technology	*Description*	*Users*	*Usage*
Sensors	Device that converts a real-word property into data	Remote analysts	Collect measurements from machinery above ground (Figure 2, task 1)
Logging computer	Stationary computer that collects data from the sensors		
Micrologger	Handheld device with sensor for manual data collection		Collect measurements from machinery underground (Figure 2, task 1)
Diagnostic software	Software for analysis of data		Creating a digital representation of the machinery and for analysis of collected measures (Figure 2, task 2)
Laptop	PC with software and Internet access that is utilized during manual, off-line monitoring		Used for creating digital representations, analysis, e-mail and writing diagnostics reports (Figure 2, task 1–3)
E-mail	Outlook Express, standard e-mail software	Remote analysts and maintenance managers	Communication and sharing of information between the distributed actors
Mobile phone	Sony-Ericsson, regular mobile phone		Communication and sharing of information between distributed actors
Maintenance management software	Maintenance software with technical information on machinery and work orders	Maintenance managers, planners and technicians	Contains relevant information for creating digital representations of the machines and used for creating work orders and scheduling maintenance (Figure 2, task 3, 4)
Stationary PC	Traditional stationary PC with required software		Used for searching relevant information in the maintenance management software and for creating and scheduling work orders (Figure 2, task 3, 4)

technology promises to improve connectivity within the mine, thus decreasing the need to collect diagnostic data manually with a micrologger.

In the following, we analyze four figurations that are empirically observable in condition-based maintenance practices: *collecting machine data (representation figuration), connecting maintenance workers (mediation figuration), data-driven maintenance planning (representation figuration),* and *cross-firm analyst teams (mediation figuration)*. Based on these insights, we synthesize how condition-based maintenance practices are produced through entanglement of these figurations.

Collecting machine data (digital representation figuration)

One of the fundamental aims of condition-based maintenance is to create and maintain an accurate digital representation of each machine and component that needs monitoring. The collection of measures involves both collecting machinery information to build a digital representation of the machine in the diagnostic software and the continuous collection of sensor measures (Figure 2, task 1). Building the digital representation of the machinery in the diagnostic software entails combining manufacturer-supplied technical information about each machine with preinstalled information in the diagnostic software, e.g., on types of bearings and the number of teeth on bearings in a gearbox. Analyst C at MCC described this as follows: We build a digital representation of a machine that is identical to its physical counterpart. For example, we build a [representation of a] transporter with all of its components, such as the electrical engine and gearbox, and we add measurement points to the digital machine. Then we add all available technical data on the electrical engine and the gearbox. The manufacturer has information about the bearing type, the kind of motor and its bearings.

Producing an accurate digital representation of a machine is important because it provides a basis for defining measurement points and planning manual collection of sensor data from the physical machine. In other words, the digital representation of the machine—rather than the machine itself—serves as the referent in the processing of diagnostic data. While producing an exact digital copy of any piece of machinery is the ideal, achieving this goal poses numerous challenges, partly because of missing documentation. Analyst C at MCC explained: *Sometimes when I need certain information I go to the customer and we search for a drawing, but we can't find it. Then I call the machinery supplier, but they don't want to share the drawing with me. Then I contact the customer and ask them to push the supplier to get access to the drawing. It would be much easier if the information was delivered with the purchase of the machine, but that's not the case today.*

Thus, gathering the information needed to produce the digital representation of a given machine is inherently conditioned by social institutions, particularly norms associated with supplier-customer relationships. Machine suppliers are reluctant to work with third parties like MCC, but are obliged to provide customers like LKAB detailed design information about their machines. Thus, while the encoding of analog information into digital format is a technical process (e.g., a sensor encoding vibrations into bits) it is intrinsically dependent on human actions (technicians finding construction information to insert into the diagnostic software). This is indicative of the entanglement of the social and material in producing a digital representation of each machine. Another indication is that LKAB had not kept exact historical records of all parts that had been replaced in a given machine over the years. Even the continued maintenance of machines was not adequately documented, making it difficult to update the diagnostic software with new technical specifications in a reliable and timely manner. In light of these challenges, analysts sometimes inserted information about standard components into their digital representations. While these pragmatic workarounds made the digital representation complete, the differences between the physical and the digital machines remained and had to be considered in the interpretation of sensor data and simulated status for a given machine.

While the rendering of a given machine's components in the diagnostic software digitizes machinery in relatively static terms, the sensor data provides a dynamic digital representation of the machine's behavior. Generally, sensors are permanently installed on the physical machine to collect and communicate data on, for example, the vibrations of bearings. These online sensors are connected to a central monitoring unit, which in turn is connected to a logging computer that transfers the sensor data to a central database for storage. However, installing online sensors on some machines was not feasible, for instance at locations down in the mines that are too remote for network connectivity. In these cases, analysts visit the mine to collect data with a micrologger, a portable handheld device that can be affixed by means of a magnet to a machine's bearing house in order to collect and store vibration data. After collecting data from a number of machines on a given route, the analyst connects the micrologger to a laptop and downloads the sensor data, which are then transferred to the central database for storage and to the diagnostic software for processing. Vibration data collected through the micrologger were considered inferior to data collected online, because of variations in factors such as the placement of the magnetic sensor on the machine and the periodicity of the data collection (in contrast to the continuity of the automatic online data collection). MCC analyst A also highlighted the inconvenience of collecting data manually: *I think the online monitoring should be further developed; it is the best. If you're uncertain about a machine, you can get the vibration data immediately. You don't have to change clothes, drive to the customer's facilities, take measurements, drive back, shower, and then begin the analysis. With online monitoring you get better quality, you can sit calmly and just look at the [digital representation of the] machinery.* Hence, manually collecting digital representations of machinery status requires that people change clothes, go into the mine, touch the physical machine and shower, when they would prefer to "sit calmly and just look at the digital representation of the machinery." This further highlights how this figuration is continuously produced through entanglement of digital materiality (i.e., the sensor data and the diagnostic software that represents the machine so that the analyst can "just look" at it) and social actions (i.e., driving to the mine, placing the sensor on the machine, starting the micrologger).

Collecting machine measures (Figure 2, task 1) is a representation figuration that involves two main activities, building a digital representation of a machine in the diagnostic software and representing the vibrations of the components through sensor data. While the representation of a machine is relatively static (the components are the same for longer period of times), the representations of vibrations are highly dynamic with updates every second (online monitoring). As this section has revealed, representational activities are inherently sociotechnical involving entangled technologies, social norms, knowledge, routines and actions.

Connecting maintenance workers (digital mediation figuration)

As part of their move toward preventive maintenance, LKAB decided to reorganize the maintenance organization to get workers collaborate and to share knowledge across units within the company. The goal was to create *one* maintenance organization across all production units, as expressed by the production manager: *We broke up the [maintenance] units, they had been like their own kingdoms within the company […] The aim was to create a new culture of collaboration […] The goal for the new maintenance organization was to drop centennial dogmas and principles.* As the production units are disseminated geographically, digital technologies became important in mediating the collaborations between the distributed actors. Different technologies like shared maintenance management software, e-mail and mobile phones were used to achieve this. Besides shared and mediating technologies, the change involved social issues as well, for example new routines regarding maintenance work were developed to be used throughout the company. The managers at each production site also started to have regular face-to-face meetings. With shared technologies and routines in place, new work arrangements could be made where one worker could change work place and still know how to perform the work. The information transfer between maintenance workers at the different production units did mainly take place through phone calls, e-mail and face-to-face meetings, while information regarding planned stops and work orders was shared through the new maintenance management system. The internal mediation was hence still low-tech meaning in the sense that LKAB did not make use of complex or advanced computer-supported collaboration systems to facilitate information sharing and coordination among its workers, but compared to the historical situation the change has created higher connectivity within the company. This did, however, require changes and replacements of social as well as material conditions.

Changing the maintenance organization to allow people to collaborate across teams and production units was of course challenging, but it was an important antecedent for the new preventive maintenance approach. Software that had been used and adapted under many years should be replaced, and people were asked to collaborate across traditionally rigid organizational boundaries. It was necessary to push the organization toward new goals while preserving the employees' trust and ensuring their willingness to go there. The production manager expressed how the main challenge was to make people understand and accept the changes and follow the new routines. The increased emphasis on preventive maintenance through better routines was seen as particularly challenging. Maintenance manager A explained: *If we have a breakdown and everything stops, the production or maintenance manager runs down to the machine. It's of course fun for the maintenance technician to work then. You become important. Everyone ask you, "can you fix this?" But, we can't continue to work that way. We must develop a new culture where you get feedback and work preventively. The managers shouldn't show up when there is a breakdown; they should come and meet the groups and ask about the continuous preventive work. That's very difficult.* Despite these challenges, the shared technologies and collaboration across maintenance units was in place after only 3 years. The production manager was pleased with the new maintenance organization even though the change toward preventive maintenance still required a lot of work. In parallel to connecting the workers across production units, LKAB decided to invest in monitoring and diagnostics technology that improved condition monitoring of machines as part of preventive maintenance.

Data-driven maintenance planning (digital representation figuration)

The collected machine data are used for a variety of analyses to gain knowledge of the status of the monitored components and decide if intervention is necessary to avoid machinery breakdown (Figure 2, task 2). To analyze the collected data and diagnose the exceptions, remote analysts create an overall vibration spectrum as well as detailed charts of specified frequencies for each physical component with the help of the diagnostic software. By examining frequencies of vibrations, the analyst simulates when and where types of damage are likely to occur. When used for monitoring bearings, the diagnostic software provides detailed information on whether damage is likely to occur on the bearing's bullets, outer ring or inner ring. Based on their experience and knowledge, the analysts then search for likely causes of detected problems, e.g., mechanical looseness, an imbalance or a lubrication issue. To make sense of the information from the diagnostic software, analysts consider overall spectra as well as specific frequencies. The technical developer at MCC explained: *There are filtered monitoring modes, called envelope measurements, where we can see bearing damage very early. But if we can spot damage in the speed monitoring [in the overall spectrum], we know from experience that the damage is greater.*

The status of the machinery, digitally represented through data processing, is thus produced through an entanglement of the social and material, in this case the built-in data-driven capacity of the software and the analyst's personal expertise. By monitoring physical vibrations at different frequencies, the diagnostic software develops profiles of a machine's behavior. For example, in the digital speed monitoring mode, vibration values are measured over a wide spectrum covering many frequencies. Different frequencies cover vibrations from different physical parts of the bearing. To enable a specific part to be monitored, analysts tend to focus on a narrow frequency range. Analyst C described the procedure as follows: *A specific rotation speed may be at 24 Hertz frequency. Then we can build a trend at that frequency and the software filters out everything else [signals at other frequencies]. For example, you adjust the frequency to cover a range from 23.89 to 24.02 Hertz and just analyse [signals in] that frequency range.* This type of filtered analysis enables analysts to trace the vibration patterns of a given physical component over time. Measuring trends at specified frequencies helps them set alarms and track the wear and tear of specific physical components. The analytical process is thus iteratively zooming in and zooming out, through decisions on what to look at based on values presented on a screen as well as the analyst's experience. While focusing on narrow frequency bands is efficient, the quote above also provides clues about the kinds of digital machines that the diagnostic software creates. Interestingly, the digital representations focus on the internal operations of machines, which are frequently invisible to those interacting with the physical machine. The following example, recounted by maintenance technician B at LKAB, highlights the added insight gained through the digital representation of the machine status: *A year ago, we had a serious issue with a lantern gear in one of the plants. The MCC analysts told us it didn't look good. We went there but couldn't see anything. A few days later he called again […] He told me that the vibrations were increasingly dramatic. I decided we should stop the process the next morning to check. When we stopped, we could see the machine was close to a total breakdown; it had coarse sand in the gear. When we looked at it running, we could see nothing wrong. But when we stopped it, we could see imminent damage.* Accordingly, conditions invisible during a physical inspection of the running machine were digitally visible thanks to the digital representation of machine status. Once a month, the MCC analysts summarize the status of all machinery in a report. Analyst C recalled his first reports: *The first reports I wrote, wrote and wrote. When I sent the report, I was waiting for a response, but no. Now, I have made them simpler so you don't need to be an engineer to understand them. Now, when I send the report my onsite contact person always calls and asks for clarifications.* At LKAB the information gained from the reports and from direct contact with the remote analysts is important in maintenance planning (Figure 2, task 3). In the regular maintenance meetings between planners and managers, the information is interpreted and additional onsite information is added to give an overall view of the status of the machinery and the appropriate time for intervention. When interventions are decided, a work order is placed in the maintenance management software and the maintenance planner order new parts accordingly. Maintenance technicians perform the maintenance (Figure 2, task 4) based on the work orders with specification of which component to repair or replace.

Initially, many onsite workers questioned data-driven recommendations to preventatively maintain machinery. The skepticism and how it was overcome through experience was recounted by maintenance manager D: *We had [a data-driven] indication of imminent damage to a bearing in one of the refiner engines. When our technicians replaced the bearing, there were a lot of discussions [among the LKAB maintenance staff] about whether it had been necessary or not. When they opened the engine in our workshop they could not find any damage on the bearing, so the discussions increased. We decided to send the bearing to our supplier for further analysis and they could detect damage.* Similarly, maintenance technician I recalled: *Data-driven analyses indicated a problem in the motor. It was replaced. But then the measurements indicated problems in the new motor as well. That motor was also replaced and sent for inspection, which revealed that there actually were problems in the new motor as well. So, the measurements were correct. Then I started to believe that data-driven analyses actually work.*

This figuration zoomed in on data-driven maintenance which involves the dynamic creation of a digital representation of the machinery status. This representation is the result of analysts' process collected data with the diagnostic software to detect upcoming issues. In this processing, built-in capabilities of the software afford zooming in on specific frequencies as the analysts' knowledge and experience entangles with the digital representation of the current status of the machine component.

Cross-firm analyst team (digital mediation figuration)

A key part of realizing preventive maintenance at LKAB was to include the complementary skills of remote analysts that on a full-time basis focused on monitoring and analyzing data about a variety of machinery across many different firms and locations. To enable this, remote analysts had direct access to the digital representations of machinery through PCs and laptops and they could use the data in full or selectively to support their particular role in the new distributed work arrangements. In the beginning, onsite workers at LKAB had hesitations about this work arrangement as expressed by maintenance planner A: *I had some thoughts and hesitations when they [MCC] got access from their office and could see the results there. How would it be then, do we lose a lot? But it has worked better than I thought […]* With the new distributed work arrangement, onsite workers did not get immediate information about work being performed by remote analysts. Collaborations and information sharing is now mediated through different technologies. So, in addition to collecting data about the inner workings of individual machine components directly via network connections, the onsite workers and remote analysts used phone, e-mail and face-to-face meetings to jointly produce shared knowledge of the status of the machinery. However, as the representations of machinery conditions were limited by what sensors could measure, these mediated work arrangements were critical for the work. The manager at MCC emphasized the importance of these mediated collaborations: *Actually, it is a new way of working. Earlier they [the onsite workers] did this in their own plants, but now they have to release it and trust the remote analyst group. You have to understand the borders, what are the remote group and the onsite group doing? It should not become two different camps; the groups should complement each other.* Maintenance could only become preventive rather than reactive by treating onsite and remote work as complementary and by drawing on the full scale of different sensing capabilities and data collection technologies. In fact, appropriate decisions to take preventive action could only be made by combining remote analyses of sensor data with insights from onsite workers who had both historical and situated knowledge of the machines and the current conditions in the mine. The remote analysts therefore needed requisite social competencies as expressed by analyst C: *You need a large, large portion of social competence. If not, it's pointless […] The worst thing you can do is to step on someone's toe, you might get the job, but if they set against you, you might not get that additional help you need. That extra help about the equipment is valuable to get. Then, I* *can talk to the onsite workers and ask if the machinery always has behaved like this?* Hence, although collaboration between onsite workers and remote analysts was supported through technologies as phone and e-mail, social skills were equally important to actually gain the necessary information.

Beyond LKAB, the technology afforded remote analysts the opportunity to collaborate with onsite workers located at other locations within different firms. Besides LKAB, MCC also had other customers in the region. This helped them develop deeper knowledge of the status of machinery components in different settings. However, MCC envisioned growing and having customers outside the region, analyst A said: *We could monitor a machine in Africa. It is just to plug in the cable if you have a network and access to Internet. But then we need good contact with someone onsite. We could not go there regularly. You would need a personal relation* via *phone and email and a lot of information sharing for example though photos or video link. In a way, it does not matter if this rotating shaft is located in this basement or in Africa.* Again, we see how social competence to create personal relations was viewed as important in digital mediation, no matter where machinery is located. When technologies are used for mediating information between people, social skills become important to get accurate information. Accordingly, it is the entanglement of the social (skills) and the material (phone, e-mail) that produces the digital mediation in condition-based maintenance. Also, different technologies can be utilized in these mediations to support information sharing. Photographs or video links were not used in the present arrangement with LKAB, but these technologies were envisioned to become more important, in particular where onsite visits are impossible or difficult to arrange.

Condition-based maintenance practices

Insights into the role of digital representation and mediation figurations in producing networked diagnostics are helpful in considering the maintenance practices as a whole. The transition from corrective to preventive maintenance at LKAB and MCC was not the result of a simple aggregation of digital representations and mediations. Instead, it was the ongoing, day-to-day constitutive entanglement of four different figurations that produced the ability to make appropriate decisions about when to repair machinery before a breakdown occurred. The technical developer at MCC articulated this entanglement: *When we get an alarm [from the digital representations], we always consider additional information sources [through digital mediation] to be able to refine the data so we can tell what has caused the alarm.*

Condition-based maintenance produced an environment in which onsite workers and remote analysts—using a portfolio of digital technologies—co-created relevant and meaningful information to support crucial decisions about when and how to prevent breakdowns of machinery. This constitutive entanglement of digital representation and digital mediation figurations was directly observable in the frequent discussions between onsite workers and remote analysts in which digital representations were compared to onsite knowledge and experience about conditions in the mine to adjust diagnostic insights. It was also evident every time maintenance managers at LKAB combined and balanced information from several sources to decide when and how to engage in preventive repairs. Moreover, the entanglement of representations and mediations served as a concrete demonstration of the vision that MCC could serve as a hub in a web-of-machinery in which it leveraged its portfolio of technologies and analysts to collaborate with maintenance workers across different companies and industries.

As a first important characteristic, condition-based maintenance at LKAB and MCC was produced through digital representation and digital mediation figurations that were mutually complementary. Simply put, the digital representations provided up-to-date, specific information about the condition of each machine, while the digital mediations produced additional information and knowledge sharing across organizational boundaries. This complementarity was important because the condition of the physical machinery was more nuanced and situated than could be sensed separately by the digital representations and mediations. On the one hand, digital representations afforded detailed changes in vibration signals and the remote analysts used software to continuously produce diagnostic insights regarding the operational performance of each machine. On the other hand, digital mediation made additional information available based on remote analysts' knowledge of similar machinery at other locations, and onsite workers' knowledge of the history of each machine and their observations of the physical conditions in and around machines, like dirt in the oil.

As a second characteristic, the representation and mediation figurations were highly interdependent in the sense that they could hardly exist without each other. On the one hand, the digital mediations were directly reliant on digital representations to afford inclusion of remote analysts in the distributed work arrangement. Without representation of the configuration and condition of each machine, there would be little need for remote analysts and diagnostic software. On the other hand, although representations without mediations would have been possible (by recruiting or training onsite analysts), such an arrangement would not have held the promise of growth and learning offered by extending the collaboration between onsite workers and remote analysts to other firms and industries.

As a third characteristic, although the complementarity of information sources provided a rich basis for making appropriate decisions on when and how to repair machinery, it required a shared sense of urgency to constantly drive the dispersed actors to effectively and continuously co-produce requisite information and appropriate decisions. Indeed, despite heterogeneity in terms of the many actors and technologies involved, the actors shared a common mission that encouraged them to constantly collaborate and coordinate. Maintenance manager G explained: *Knowledge of the status of bearings earns money in this conjuncture. If we avoid unplanned breakdowns we earn money, because everything we can produce can be sold.* Maintenance manager D acknowledged the shared sense of urgency between LKAB and MCC: *He [the remote analyst] also knows the importance; he knows the consequence if a machine with a red line [indicating imminent problems] stops.*

To summarize, condition-based maintenance at LKAB and MCC continuously addressed an essentially simple question: when is it appropriate to intervene and perform maintenance on a given machine? However, making this decision remained challenging because of the situated, complex and constantly changing condition of mining machinery. In response to this challenge, the mutual complementarity and high interdependence between the digital representations and mediations produced condition-based maintenance practices that allowed remote analysts and onsite workers to co-create requisite diagnostic insights to support condition-based maintenance at LKAB. The ability to produce these new practices out of considerable social and material heterogeneity was to a large extent driven by economic pressures to prevent unplanned breakdowns and shared social commitments to keep the expensive machinery running through preventive maintenance.

Discussion and theory development

As increasingly sophisticated digital technologies proliferate across a wide variety of contexts, they become entangled in new ways with human activities and the material underpinnings of practice. It is therefore important to understand the implication of this emergent fusion of IT and work and the ways in which it affects today's organizations. Against that backdrop, our research focuses on empirically and theoretically accounting for how digital technology characteristics are implicated in the constitution of contemporary work practices. In the previous sections, we introduced digital representation figurations and digital mediation figurations to understand the fusion of IT and work in the particular context of condition-based maintenance of mining machinery in the Swedish iron ore mining business, LKAB. Consistent with the idea that figurations are empirically observable traces of how human and material agencies come together in the constitution of a work practice (Latour, 2005), we built on the foundational entanglement of material and human agency (Leonardi, 2011, 2013) to analyze how representations and mediations materialized in the mining context. Based on the empirical findings and the idea that digital technologies are embedded in wider ecosystems such that they become increasingly editable, interactive, reprogrammable, and distributable (Kallinikos *et al*., 2013; Yoo, 2013), this distinction between digital representation and digital meditation figurations of human and material agency helps us to advance a new theoretical perspective on how key characteristics of digital technologies are implicated in work practices.

Digital representation and mediation figurations

Our findings revealed how LKAB used a range of digital technologies such as sensors, microloggers, networks and laptops to produce measures of their mining machinery (Table 3), how they collaborated with suppliers to establish and maintain information about the configuration of mining machinery and how they collaborated with remote analysts that used software to analyze the measures to gain knowledge of the status of individual machines. Hence, as a fundamental characteristic of how digital technologies were used at LKAB, we described how digital representations were used to monitor and produce a work space for condition-based maintenance of mining machinery (Ramaprasad and Rai, 1996; Zuboff, 1988). One digital representation constituted through systematic collection of data from the physical machines within the mine, relying on a combination of sensor or logging technology (Representation figuration: collecting machine data). Although each measure represents a particular attribute (e.g., vibration) of the state of a physical machine at a certain moment in time, frequent and continuous sampling of several measures at uniform intervals afforded valuable insights into when a specific machine would likely need preventive maintenance. A related representation figuration relied on additional data about the historical configuration of each machine to assess its current condition and make decisions about when it should be serviced next (Representation figuration: data-driven maintenance planning).

At the same time, we described how condition-based maintenance at LKAB was highly distributed because individual machines are located underground with difficult and time-consuming accessibility and because different mines and plants are located across a considerable geographical area. There are therefore multiple distributed technicians and managers dedicated to the maintenance of different machines. Hence, as another important characteristic of the use of digital technologies at LKAB, the organization used digital mediation figurations to produce and enact maintenance work arrangements (Andersen, 1990; Persson *et al*., 2009) across geographical (Hägerstrand, 1975; Olson and Olson, 2000) and temporal boundaries (Chudoba *et al*., 2005). The onsite workers used digital technologies to mediate their internal collaboration across different locations (Mediation figuration: connecting maintenance workers), and they collaborated with analysts at remote sites that used advanced analytic software to support preventive maintenance of industrial machinery across multiple firms (Mediation figuration: cross-firm analyst teams). These digital mediation figurations constituted through entanglement of a variety of skills and work routines with digital technologies such as e-mail and mobile phones to help the distributed actors jointly make preventive maintenance decisions about individual machines. These digitally enabled work arrangements provided the remote analysts with information about individual machines beyond what was immediately available through digital representations, and they provided them access to up-to-date information about machines even when workers could not inspect them for safety reasons as the machines were operating.

Accordingly, digital representations produced a work space for assessing the condition of individual machines and digital mediations bridged geographical and temporal boundaries in a highly distributed work arrangement that allowed the involved actors to share information from the work space for joint problem solving and decision making.

Inherent attention and coordination uncertainties

Having understood the opportunities afforded by representation and mediation figurations at LKAB, we consider related challenges consistent with previous research on the fusion of IT and work. For example, Bailey *et al*. (2012) show how digital tools to simulate, visualize and test new complex products, and their "crashability" made it challenging to separate physical objects and people from the digital representations of design objects; Mazmanian *et al*. (2013) demonstrate how IT simultaneously increased and decreased workers' sense of autonomy. Similarly, we revealed inherent challenges in condition-based maintenance of mining machinery that may be understood in terms of the notion of uncertainty (Daft and Lengel, 1986; Galbraith, 1973). Galbraith (1973) defines uncertainty as "the difference between the amount of information required to perform the task and the amount of information already possessed by the organization" (p. 4). Drawing on this concept, we conceptualize the inherent uncertainties evoked in the digital representation and mediation figurations in condition-based maintenance of mining machinery through the notions of *attention uncertainty* and *coordination uncertainty*.

Attention uncertainty captures how the digital representation figurations at LKAB afforded access to a work space with selective (i.e., representing only some aspects of each machine's condition) and disembodied (i.e., relying on data about rather than experiences with each machine's condition) information about each machine's condition. The digital representation is detailed, giving the remote analyst information about what is measured—e.g., vibrations, speed and temperature—and not the broad spectra of information that can be captured by onsite workers. Hence, both observed digital representation figurations (collecting machine data and data-driven maintenance planning) involved an inherent level of attention uncertainty: the difference between the information needed to make preventive maintenance decisions about a machine and the information that is available about that machine in the digital representation figuration.

Similarly, coordination uncertainty captures how the digital mediation figurations at LKAB afforded access to a work arrangement with episodic (i.e., mediating periodic interactions) and non-situated (i.e., relying on mediated rather than embodied presence) collaboration. Hence, the onsite workers raised concerns whether machines were monitored appropriately as they could not see the remote analyst doing the work and they had limited understanding of how they performed this task. At the same time, remote analysts experienced that onsite workers did not appropriately read the reports they e-mailed them and they also experienced problems keeping information about individual machines up-to-date as they did not receive information when components were replaced onsite. Accordingly, both observed digital mediation figurations (connecting maintenance workers and cross-firm analyst teams) involved an inherent level of coordination uncertainty, i.e., a difference between the information needed to support coordination between the distributed actors involved in preventive maintenance and the information available in the digital mediation figurations that supported their coordination.

Configuration principles of cohesion and coupling

Following the logic of organization design, theorizing can provide complementary insights into the organizational principles underpinning the observed digital figurations in condition-based maintenance of mining machinery. To that end, we draw on Simon's architectural principles (1962, 1996) as they are espoused in the product design (Baldwin and Clark, 2000; Murmann and Frenken, 2006; Wilson, 1969) and software development literature (Bansiya and Davis, 2002; Mathiassen *et al*., 2000; Yoo *et al*., 2010). Across a variety of complex arrangements, this literature emphasizes modular architectures with high cohesion to support consistency within modules and loose coupling to enable flexibility between modules. Adapting this principle to the fusion of IT and work suggests the involved actors should strive for *high cohesion* in digital representation figurations to ensure consistent representations of work spaces and *loose coupling* in digital mediation figurations to ensure flexibility of work arrangements.

High cohesion in digital representation figurations affords continuous evaluation and revision of a representation in relation to the physical world to ensure its utility as a shared reference point for joint problem solving and decision making. Hence, although digital representations may be enabled by a portfolio of digital technologies the involved actors must engage to make the information about the physical world as up-to-date, valid and useful as possible. In our analysis, we saw how onsite workers at LKAB and remote analysts continuously interacted to establish, collect and maintain appropriate digital representations of each machine. Remote analysts collected machine supplier information to make sure sensor data were analyzed according to the specification of the installed components (e.g., bearings); they decided on which interval to collect data and whether to use microloggers or sensors; they communicated with onsite workers to check the validity of measure and to collect complementary information about the condition of each machine (Representation figuration: collecting machine data); and they analyzed the collected data to produce knowledge of the machine status (Representation figuration: data-driven maintenance planning). As such, digital representations in the fusion of IT and work afford new opportunities for evidence-based management of work spaces. However, to achieve up-to-date, valid and useful insights into a real-world work space, the involved actors must heedfully interrelate (Weick and Roberts, 1993) to ensure each representation is highly cohesive.

Loose coupling in digital mediation figurations affords continuous adaptation of a work arrangement in relation to local conditions while at the same time enabling production of intended outcomes. Many scholars have suggested organizations will increasingly adopt distributed work arrangements as digital technologies provide new sophisticated opportunities for mediation across space and time (Leonardi and Bailey, 2008). Consistent with this claim, our findings suggest digital mediations play important roles in the fusion of IT and work by affording new opportunities for organizing and enacting highly distributed work arrangements. To afford appropriate flexibility while at the same time enabling participants to contribute to intended outcomes, the digital mediations must rely on loose coupling between the local tasks of the work arrangement. In our analysis, we saw how distributed onsite workers at LKAB coordinated their work following local schedules and routines (Mediation figuration: connecting maintenance workers). Similarly, the remote analysts independently monitored and analyzed several machines across LKAB and within other firms as new data became available (Mediation figuration: cross-firm analyst teams). These loosely coupled work arrangements provided a powerful combination of idiosyncratic sensing capability close to the physical conditions of each individual machine combined with systematic sensing capability based on detailed and up-to-date digital representation of key machine conditions. When this distributed and complementary sensing suggested a breakdown was imminent, or information was missing, the actors had to come together to exchange additional information, discuss interpretations and make preventive maintenance decisions.

Entanglement of representations and mediations

While extant research has portrayed digital representation and digital mediation practices independently, we considered the two together in the same work practice to gain new insights into the fusion of IT and work. Building on the notions of digital representation (Carlile, 2002; Mingers and Willcocks, 2004; Ramaprasad and Rai, 1996; Zuboff, 1988) and digital mediation (Andersen, 1990; Chudoba *et al*., 2005; Persson *et al*., 2009), our analysis revealed how condition-based maintenance at LKAB was produced through entangling of the two types of figurations. We argue that this fundamental characteristic of condition-based maintenance was essential for reducing the inherent uncertainties in the digital representation and mediation figurations, allowing the involved actors to jointly produce appropriate preventive maintenance decisions about each individual piece of mining machinery.

While digital representation introduced attention uncertainty due to its selective and disembodied nature, our empirical analysis showed how the distributed actors reduced this uncertainty through digitally mediated and asynchronous contributions. For example, when remote analysts received sensor data indicating fluctuating temperature in a machine they did not always know what had caused these fluctuations (Representation figuration, data-driven maintenance planning). To reduce this uncertainty, analysts used a mobile phone to text or call a worker onsite to get additional information that helped them identify what caused the issue (Mediation figuration, cross-firm analyst teams). This demonstrates how attention uncertainty introduced by digital representation figurations may be reduced by complementary digital mediation figurations as the two types of figurations entangle.

Similarly, while digital mediation figurations introduced coordination uncertainty due to their episodic and non-situated nature our analyses showed how the distributed actors reduced this uncertainty by relying on the shared work space that constituted through digital representations. For example, when onsite workers and remote analysts coordinated to support preventive maintenance decisions for specific machines, the onsite workers had little or no understanding of the highly technological context in which the remote analysts worked. At the same time, the remote analysts did not have the onsite worker's embodied sense of the particularities of each machine and the conditions under which it operated. To reduce these coordination uncertainties, the distributed actors shared the same digital representations, continuously collaborating to make this work space an appropriate foundation for joint problem solving and decision making. This demonstrates how coordination uncertainty introduced by digital mediation figurations may be reduced by complementary digital representation figurations as the two types of figurations entangle.

In 1988, Zuboff presented her seminal study of IT in the work place and introduced the concepts of automate and informate. With the concept of informate, she distinguished computer-mediated work from other forms of purely automated jobs. The concepts of automate and informate are still valid to understand computer-supported work, but during the 30 years that have passed since Zuboff's study, IT has moved out from the office and control room to every corner of the work place. Although automate is still a very important perspective on the fusion of IT and work, this paper therefore recognizes that informate has taken on increasingly complex forms by extending Zuboff's focus on informate with a complementary focus on collaborate. As such, the distinction and intrinsic relation between digital representation and digital mediation offers a nuanced and elaborate explanation of how technology is applied to create and share information in today's increasingly networked and knowledge-based work arrangements.

The literature on processing information in organizational context has for long emphasized how actors need to produce quality information to cope with environmental uncertainty and support decision making (Galbraith, 1973; Premkumar *et al*., 2005). Moreover, this line of research suggests two strategies for coping with uncertainty, by reducing the adverse effects of these uncertainties through various forms of buffers, or by implementing combinations of information processing capabilities and structural mechanisms that improve information production and consumption (Premkumar *et al*., 2005). Extending these insights, our study has demonstrated how the intrinsic entangling of digital representation figurations (affording new information processing capabilities) and digital mediation figurations (affording new structural mechanisms) may help us better understand how the specific characteristics of digital technologies are implicated in the fusion of IT and work. In particular, our study revealed how heedful interrelation (Weick and Roberts, 1993) across multiple, distributed actors produced the entangling of digital representation and mediation figurations that allowed them to reduce the inherent attention and coordination uncertainties and arrive at appropriate preventive maintenance decisions for each individual machine.

Concluding remarks

As noteworthy limitations, we grounded this research in empirical material describing a specific case of condition-based maintenance of mining machinery to advance digital representation and digital mediation as two distinctive figurations in the fusion of IT and work. Hence, our research offers analytical, case-based generalizations rather than statistically rigorous, sample-based generalizations (Lee and Baskerville, 2003). Further, we have not theorized how figurations unfold over time. While this study was carried out some years ago, the condition-based maintenance is still carried out with the same organization. The concepts of digital representation and digital mediation can thus still be used to describe how IT affords new forms of work practices in the studied case. Further research needs to extend and apply digital representations and mediations in other types of settings and involving other types of IT-based practices. In addition, while digital representations and mediations are contemporary characteristics of the use of IT artifacts, the fusion of IT and work is not always constituted through entanglement of these figurations. Some practices are mainly produced through digital representations and others are mainly produced through digital mediations. As such, we suggest that digital representation and digital mediation figurations afford researchers a strong conceptual foundation to theoretically and empirically investigate the fusion of IT and work.

Considering implications for management, although figurations as observed in condition-based maintenance are quite different from the norm, they remind us that IT and work settings are far from homogeneous. Contemporary practices rely on distributed work arrangements and complex portfolios of technologies, often involving digital representation as well as digital mediations. In such practices, the managerial challenge is not so much to ensure the use of specific technologies in distinct situations as to learn how they may entangle to support business goals. This involves helping diverse, distributed actors make use of a variety of technologies to coherently perform a work space and a shared work arrangement.

References

Aguinis, H. and Lawal, S.O. (2013). eLancing: A Review and Research Agenda for Bridging the Science-Practice Gap, *Human Resource Management Review* **23**(1): 6–17.

Andersen, P.B. (1990). *A Theory of Computer Semiotics: Semiotic Approaches to Construction and Assessment of Computer Systems (No. 3)*, Cambridge: Cambridge University Press.

Ayyagari, R., Grover, V. and Purvis, R. (2011). Technostress: Technological Antecedents and Implications, *MIS Quarterly* **35**(4): 831–858.

Bailey, D.E., Leonardi, P.M. and Barley, S.R. (2012). The Lure of the Virtual, *Organization Science* **23**(5): 1485–1504.

Baldwin, C.Y. and Clark, K.B. (2000). *Design Rules: The Power of Modularity*, Cambridge, MA: MIT Press.

Bamberger, P. (2008). Beyond Contextualization: Using Context Theories to Narrow the Micro-Macro Gap in Management Research, *Academy of Management Journal* **51**(5): 839–846.

Bansiya, J. and Davis, C.G. (2002). A Hierarchical Model for Object-Oriented Design Quality Assessment, *IEEE Transactions on Software Engineering* **28**(1): 4–17.

Barley, S.R. and Kunda, G. (2001). Bringing Work Back In. *Organization Science* **12**(1): 76–95.

Barley, S.R., Meyerson, D.E. and Grodal, S. (2011). E-mail as a Source and Symbol of Stress, *Organization Science* **22**(4): 887–906.

Bechky, B. (2003a). Object Lessons: Workplace Artifacts as Representations of Occupational Jurisdiction, *American Journal of Sociology* **109**(3): 720–752.

Bechky, B. (2003b). Sharing Meaning Across Occupational Communities: The Transformation of Understanding on the Production Floor. *Organization Science* **14**(3): 312–330.

Bell, D. (1973). *The Coming of Post-Industrial Society: A Venture in Social Forecasting*, New York, NY: Basic Books.

Beninger, J.R. (1986). *The Control Revolution: Technological and Economic Origins of the Infromation Society*, Cambridge, MA: Harvard University Press.

Bijker, W. (1995). *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical shange*, Cambridge, MA: The MIT Press.

Boudreau, M.-C. and Robey, D. (2005). Enacting Integrated Information Technology: A Human Agency Perspective, *Organization Science* **16**(1): 3–18.

Brynjolfsson, E. and McAfee, A. (2014). *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*, New York, NY: W. W. Norton & Company.

Burton-Jones, A. (2014). What have we Learned from the Smart Machine? *Information and Organization* **24**(2): 71–105.

Cappelli, P. and Sherer, P.D. (1991). The Missing Role of Context in OB: The Need for a Meso-Level Approach, in L.L. Cummings and B.M. Staw (eds.) *Research in Organizational Behvior* (Vol. 13, pp. 55–110), Greenwich, CT: JAI Press.

Carlile, P.R. (2002). A Pragmatic View of Knowledge and Boundaries: Boundary Objects in new Product Development, *Organization Science* **13**(4): 442–455.

Cavaye, A.L.M. (1996). Case Study Research: A Multi-faceted Research Approach for IS, *Information Systems Journal* **6**(3): 227–242.

Cecez-Kecmanovic, D., Galliers, R., Henfridsson, O., Newell, S. and Vidgen, R. (2014). The Sociomateriality of Information Systems: Current status, future directions, *MIS Quarterly* **38**(3): 809–830.

Chudoba, K.M., Wynn, E., Lu, M. and Watson-Mannheim, M.B. (2005). How Virtual are We? Measuring Virtuality and Understanding its Impact in a Global Organization, *Information Systems Journal* **15**: 279–306.

Daft, R.L. and Lengel, R.H. (1986). Organizational Information Requirements, Media Richness and Structural Design, *Management Science* **32**(5): 554–570.

DeSanctis, G. and Poole, M.S. (1997). Transitions in Teamwork in New Organizational Forms, *Advances in Group Processes* **14**(1): 57–176.

Eisenhardt, K.M. (1989). Building Theories from Case Study Research, *Academy of Management Review* **14**(4): 532–550.

Felstead, A. and Jewson, N. (2000). *In Work, At Home: Towards an Understanding of Homeworking*, London: Routledge.

Felstead, A., Jewson, N. and Walters, S. (2005). *Changing Places of Work*, London: Palgrave Macmillan.

Forman, C., King, J.L. and Lyytinen, K. (2014). Special Section Introduction—Information, Technology, and the Changing Nature of Work, *Information Systems Research* **25**(4): 789–795.

Galbraith, J.R. (1973). *Designing Complex Organizations*, Boston: Addison-Wesley Longman.

Hägerstrand, T. (Ed.). (1975). *Space, Time and Human Conditions*, Westmead: Saxon House.

Hinds, P.J. and Kiesler, S. (2002). *Distributed Work*, Cambridge, MA: MIT Press.

Huston, L. and Sakkab, N. (2006). Connect and Develop: Inside Procter & Gamble's New Model for Innovation, *Harvard Business Review* **84**(3): 58–66.

Jardine, A.K.S., Line, D. and Banjevic, D. (2006). A Review on Machinery Diagnostics and Prognostics Implementing Condition-Based Maintenance, *Mechanical Systems and Signal Processing* **20**: 1483–1510.

Jarvenpaa, S.L., Knoll, K. and Leidner, D.E. (1998). Is Anybody Out There? Antecedents of Trust in Global Virtual Teams, *Journal of Management Information Systems* **14**(4), 29–64.

Johns, G. (2006). The Essential Impact of Context on Organizational Behavior, *Academy of Management* **31**(2), 386–408.

Kallinikos, J. (2009). On the Computational Rendition of Reality: Artefacts and Human Agency, *Organization* **16**(2), 183–202.

Kallinikos, J., Aaltonen, A. and Marton, A. (2013). The Ambivalent Ontology of Digital Artifacts, *MIS Quarterly* **37**(2): 357–370.

Kling, R. (1996). *Computerization and Controversy*, London: Academic Press.

Knapp, G.M. and Wang, H.P. (1992). Machine Fault Classification: A Neural Network Approach, *International Journal of Production Research* **30**(4): 811–823.

Latour, B. (1987). *Science in Action*, Cambridge, MA: Harvard University Press.

Latour, B. (2005). *Reassembling the Social: An Introduction to Actor-Network Theory*, Oxford: Oxford University Press.

Lee, A.S. and Baskerville, R. (2003). Generalizing Generalizability in Information Systems Research, *Information Systems Research* **14**(3): 221–243.

Leonardi, P.M. (2010). Digital Materiality? How Artifacts without Matter, Matter, *First Monday* **15**(6–7). ISSN 13960466.

Leonardi, P.M. (2011). When Flexible Routines meet Flexible Technologies: Affordance, Constraint, and the Imbrication of Human and Material Agencies, *MIS Quarterly* **35**(1): 147–167.

Leonardi, P.M. (2012). *Car Crashes without Cars: Lessons about Simulation Technology and Organizational Change from Automotive Design*, Cambridge, MA: MIT Press.

Leonardi, P.M. (2013). Theoretical Foundations for the Study of Sociomateriality, *Information and Organization* **23**(2), 59–76.

Leonardi, P.M. and Bailey, D.E. (2008). Transformational Technologies and the Creation of New Work Practices: Making Implicit Knowledge Explicit in Task-Based Offshoring, *MIS Quarterly* **32**(2): 411–436.

Leonardi, P.M. and Barley, S.R. (2008). Materiality and Change: Challenges to Building Better Theory about Technology and Organizing, *Information and Organization* **18**(4): 159–176.

Levina, N. and Vaast, E. (2008). Innovating or Doing as Told? Status Differences and Overlapping Boundaries in Offshore Collaboration, *MIS Quarterly* **32**(2): 307–332.

Markus, M.L. and Robey, D. (1988). Information Technology and Organizational Change: Casual Structure in Theory and Research, *Management Science* **34**(5): 583–598.
Mathiassen, L., Munk-Madsen, A., Nielsen, P.A. and Stage, J. (2000). *Object-Oriented Analysis & Design* (Vol. 25), Aalborg: MArko.
Mazmanian, M., Orlikowski, W.J. and Yates, J. (2013). The Autonomy Paradox: The Implications of Mobile Email Devices for Knowledge Professionals, *Organization Science* **24**(5): 1337–1357.
Miles, M.B. and Huberman, A.M. (1994). *Qualitative Data Analysis: An Expanded Sourcebook*, London: Sage.
Mingers, J. and Willcocks, L. (2004). *Socioal Theory and Philosophy for Information Systems*, Chichester: Wiley.
Mumford, L. (1964). Authoritarian and Democratic Technics, *Technology and Culture,* **5**: 1–8.
Mumford, E. and Banks, O. (1967). *The Computer and the Clerk*, London: Routledge and Kegan Paul.
Murmann, J.P. and Frenken, K. (2006). Toward a Systematic Framework for Research on Dominant Designs, Technological Innovations, and Industrial Change, *Research Policy* **35**(7): 925–952.
Mutch, A. (2013). Sociomateriality—Taking the Wrong Turning? *Information and Organization* **23**(1): 28–40.
Newell, S. and Donald, G.D. (2007). An Analysis of Trust Among Globally Distributed Work Teams in an Organizational Setting, *Knowledge and Process Management* **14**(3): 158–168.
Nicolini, D. (2007). Stretching out and Expanding work Practices in Time and Space: The case of Telemedicine, *Human Relations* **60**(6): 889–920.
Nygaard, K. and Bergo, O.T. (1975). The Trade Unions. New Users of Research, *Personnel Review* **4**(2): 5–10.
Nylén, D., Holmström, J. and Lyytinen, K. (2014). Oscillating Between Four Orders of Design: The Case of Digital Magazines, *Design Issues* **30**(3): 53–68.
Olson, G.M. and Olson, J.S. (2000). Distance Matters, *Human-Computer Interaction* **15**: 139–178.
Orlikowski, W.J. and Iacono, S. (2001). Desperately Seeking the "IT" in IT Research: A Call to Theorizing the IT Artifact, *Information Systems Research* **12**(2): 121–134.
Orlikowski, W.J. and Scott, S.V. (2008). Sociomateriality: Challenging the Separation of Technology, Work and Organization, *Annals of the Academy of Management* **2**(1): 433–474.
Persson, J.S., Mathiassen, L., Boeg, J., Madsen, T.S. and Steinson, F. (2009). Managing Risks in Distributed Software Projects: An Integrative Framework, *IEEE Transactions on Engineering Management* **56**(3): 508–532.
Premkumar, G., Ramamurthy, K. and Saunders, C.S. (2005). Information Processing View of Organizations: An Exploratory Examination of Fit in the Context of Interorganizational Relationships, *Journal of Management Information Systems* **22**(1): 257–294.
Ramaprasad, A. and Rai, A. (1996). Envisioning Management of Information, *Omega, International Journal of Management Science* **24**(2): 179–193.
Schmidt, K. and Simone, C. (1996). Coordination Mechanisms: Towards a Conceptual Foundation of CSCW Systems Design, *Computer Supported Cooperative Work: The Journal of Collaborative Computing* **5**: 155–200.
Scott, W.H., Mumford, E., McGivering, I. and Kirkby, J. (1963). *Coal and Conflict*, Liverpool: Liverpool University Press.
Shaiken, H. (1986). *Work Transformed: Automation and Labor in the Computer Age*, Lexington, MA: Lexington Books.
Simon, H.A. (1962). The Architecture of Complexity, *Proceedings of the American Philosophical Society* **106**(6): 467–482.
Simon, H.A. (1996). *The Sciences of the Artificial* (3rd ed.), Cambridge, MA: The MIT Press.
Stieglitz, S. and Brockmann, T. (2012). Increasing Organizational Performance by Transforming into a Mobile Enterprise, *MIS Quarterly Executive* **11**: 189–204.
Strauss, A.L. and Corbin, J. (1990). *Basics of Qualitative Reserach: Grounded Theory Procedures and Techniques*, Newbury Park, CA: Sage.
Svahn, F., Mathiassen, L. and Lindgren, R. (2017). Embracing Digital Innovation in Incumbent Firms: How Volvo Cars Managed Competing Concerns, *MIS Quarterly* **41**(1): 239–254.
Tsang, A.H.C. (2002). Strategic Dimensions of Maintenance Management, *Journal of Quality in Maintenance Engineering* **8**(1): 7–39.
Vlaar, P.W., van Fenema, P.C. and Tiwari, V. (2008). Cocreating Understanding and Value in Distributed Work: How Members of Onsite and Offshore Vendor Teams Give, Make, Demand, and Break Sense, *MIS Quarterly Executive,* **32**(2): 227–255.
Volkoff, O., Strong, D.M. and Elmes, M.B. (2007). Technological Embeddedness and Organizational Change, *Organization Science* **18**(5): 832–848.
Weick, K.E. and Roberts, K.H. (1993). Collective Mind in Organizations: Heedful Interrelating on Flight Decks, *Administrative Science Quarterly* **38**: 357–381.
Wiesenfeld, B.M., Raghuram, S. and Garud, R. (1999). Communication Patterns as Determinants of Organizational Identification in a Virtual Organization, *Organization Science* **10**: 777–790.
Williams, R. and Edge, D. (1996). The Social Shaping of Technology, *Research Policy* **25**(6): 865–899.
Wilson, D. (1969). Forms of Hierarchy: A Selected Bibliography, in L.L. Whyte, A.G. Wilson, and D. Wilson (eds.) *Hierarchical Structures* (pp. 287–314), New York, NY: American Elsevier.
Winner, L. (1980). Do Artifacts Have Politics? *Daedalus* **109**(1): 121–136.
Yam, R.C.M., Tse, P.W., Li, L. and Tu, P. (2001). Intelligent Predictive Decision Support System for Condition-Based Maintenance, *The International Journal of Advanced Manufacturing Technology* **17**(5): 383–391.
Yates, J. (1989). *Control Through Communication: The Rise of System in American Management*, Baltimore: Johns Hopkins University Press.
Yin, R.K. (2003). *Case Study Research: Design and Methods*, London: Sage Publications.
Yoo, Y. (2010). Computing in Everyday Life: A Call for Research on Experiential Computing, *MIS Quarterly* **34**(2): 213–231.
Yoo, Y. (2012). Digital Materiality and the Emergence of an Evolutionary Science of the Artificial, in P.M. Leonardi, B.A. Nardi, and J. Kallinikos (eds.) *Materiality and Organizing: Social Interaction in a Technological World* (pp. 134–154), Oxford: Oxford University Press.
Yoo, Y. (2013). The Tables Have Turned: How Can the Information Systems Field Contribute to Technology and Innovation Management Research? *Journal of the Association for Information Systems* **14**(5): 227–236.
Yoo, Y., Henfridsson, O. and Lyytinen, K. (2010). Research Commentary: The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research, *Information Systems Research* **21**(4): 724–735.
Zammuto, R.F., Griffith, T.L., Majchrzak, A., Dougherty, D.J. and Faraj, S. (2007). Information Technology and the Changing Fabric of Organization, *Organization Science* **18**(5): 749–762.
Zuboff, S. (1988). *In the Age of the Smart Machine: The Future of Work and Power*, New York: Basic Books.

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