Industry 4.0 Implementation: Novel Issues and Directions

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Abstract

Industry 4.0 (I4.0) is an emerging industrial paradigm yet to achieve its full potential. One research gap is understanding its unique implementation challenges. We highlight unattended issues in implementing I4.0 technologies by drawing on information systems implementation research. I4.0 is a weakly structured system, which requires users to discover then share affordances and later negotiate shared rules through joint regulation. This calls for different ways of implementing I4.0 when compared with earlier highly structured technologies such as MRP, which demanded user compliance. We develop a 2x2 framework of I4.0 implementation issues defined by (1) vertical or horizontal integration and (2) the capacity for the components of I4.0 systems to learn autonomously. We posit that these issues form a new frontier of implementation research in the next decade.

1. Introduction

There has been much discussion within academia, government, and industry about future industrial systems that leverage the internet of things (IoT) and cyber-physical systems (CPS) due to a predicted fourth industrial revolution [1, 2, 3, 4]. We will use the moniker Industry 4.0 (I4.0) to label this phenomenon because it is the most prominent term [5]. BCC Market Research Reports projected that I4.0 investments will grow from $5.1 billion to $21.7 billion from 2017 to 2023 with a compound annual growth rate of 23.1% [6]. Additionally, governments around the world have launched research initiatives to support the development of I4.0 [5] resulting in a surge in I4.0 research that began with four articles in 2012 and grew to 1,069 articles in 2018 [4].

Although there has been much discussion about features and solutions of I4.0 within academia, several challenges remain. The implementation of I4.0 has been identified as a significant gap in systematic reviews [2, 4, 9, 10]. Yet, the majority of I4.0 research has assessed the capabilities of the technologies with a technical focus rather than analyzing how to implement them effectively with intended outcomes. Generally, the field lacks research on implementation [11] though it is deemed highly relevant for practice [7, 8]. The dominant technical focus makes sense given that I4.0 is a nascent field.

However, the issues of implementation cannot be circumvented because these technologies are likely to pose new implementation challenges as learned from 40 years of information systems (IS) research on implementing multiple technologies such as MRP, ERP, and CAD/CAM systems in organizations. For the economic gains of I4.0 to be realized, organizational changes are necessary. Many of them are likely to be unexpected. This calls for research related to I4.0 implementation [12, 13]. We pose two research questions: (1) What are salient issues surrounding I4.0 implementation? (2) How can the recent IS implementation literature inform I4.0 implementation research? To address these questions, the remainder of the paper is organized as follows: (1) a review of I4.0 and IS implementation research, (2) an initial analysis of the capabilities and affordances of I4.0, (3) the formulation of a 2x2 framework to identify key issues that can spur future research on implementing I4.0, and (4) a discussion of the implications for research and practice.

2. Industry 4.0

The first industrial revolution was based on the mechanization of manufacturing using water and steam power, the second was based on mass production via electrically powered machines and transportation systems, and the third was based on automated manufacturing. The predicted fourth industrial revolution is based on interconnected information technologies (IT) for automating and enabling data exchange between machines that allows the extensive control of the machines and production and consumption processes [2]. The revolution will create intelligent manufacturing processes where interconnected machines gather and analyze data to enable faster, more flexible, and more efficient manufacturing [1]. Many terms have been proposed to label this future: Smart Manufacturing (general term), Industry 4.0 (Germany), Advanced Manufacturing Partnership (US), Smart Factory (South Korea), Made

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in China 2025 (China), Fabbrica Intelligente (Italy), and more [5]. Since Industry 4.0 (I4.0) was by far the most prominent term in Trotta & Garengo's [5] bibliometric analysis, we will use I4.0 to denote the future of industrial systems.

I4.0 has become an important concept for the academic, policymaking, and industry communities. The German government created I4.0 in 2011 [14]. The idea gained international attention at the World Economic Forum in 2016 and was called "Mastering the Fourth Industrial Revolution" [15]. Since the start of academic research in 2012, I4.0 research has experienced a high growth rate [1, 2, 3, 4]. This is but one demonstration of the relevance of I4.0 to the scientific and policymaking communities. A recent report demonstrated the relevance of I4.0 to industry by projecting that I4.0 investments will grow at a compound annual growth rate of 23.1% [6]. Numerous government-funded initiatives have emerged in the last decade, such as Advanced Manufacturing Partnership (US), Made in China 2025 (China), and Industry 4.0 (Germany) [5].

Despite its recognized importance, there is currently no consensus on how to define I4.0 [4, 16]. We will use Nazarov and Klarin's [4] I4.0 definition based on their recent scientometric analysis: "the integration of networking capabilities to machines and devices that allows seamless collaboration between the digital and the physical ecosystems for increased efficiencies in the organizational value chains that transforms industries and the society for an increased level of productivity and efficiency" [4:550]. The enabling technologies of I4.0 can be divided into nine groups: big data and analytics, autonomous robots, simulation, horizontal and vertical system integration, the industrial internet of things, cyber security, the cloud, additive manufacturing, and augmented reality [17]. The most common keywords in the I4.0 literature are (1) cyber-physical system, (2) internet of things, and (3) big data [1, 2]. The key underlying technologies for I4.0 are cyber-physical systems (CPS) and internet of things (IoT), which generate copious amounts of data requiring use of big data technologies (e.g., storage and cloud processing). Within the I4.0 literature, cyber-physical systems were initially the most used keyword (from 2011 to 2016), then internet of things (2017), and recently big data (2018) showing the evolving focus of the field [2].

Generally, I4.0 is viewed as a manufacturing paradigm shift that merges the physical and virtual worlds into CPSs that connect people, machines, and objects through IoT capabilities. Sensors 'represent' the physical world in the digital world, algorithms allow model-based data processing and analysis of such data, and communication and interaction technologies allow effectuation of results to the environment [14, 18]. These technologies drive three systemic characteristics of I4.0: (1) *horizontal integration* digitally mediates integration across the supply chain, (2) v*ertical integration* digitally mediates integration within the organization hierarchy, and (3) *end-to-end engineering* digitally mediates physical interconnections between products throughout their lifecycle [14].

2.1 Implementation gap in the I4.0 literature

I4.0 is expected to transform manufacturing work, related organizing, and ultimately the industrial economy. Extant research has been largely speculative and touted the positive benefits of I4.0. Initial studies have found that adopting facets of I4.0 have led to a 15-20% increase in efficiency [19] and increases in sales and cost savings [18]. The real-time processing of production data allows faster decision-making and improves knowledge management [20, 21, 22].

These positive impacts point to the potential of I4.0 to transform manufacturing, but the challenge to move these technologies to shopfloors should not be ignored. The complexity of I4.0 solutions create novel obstacles that organizations need to address before they can reap the benefits [10]. Not surprisingly, several literature reviews have identified implementation and process change as key issues in I4.0 research [2, 4, 9, 10]. Kipper et al. [2:16] note that implementation and process management have the greatest number of challenges to address in I4.0 research.

So far, the focus of I4.0 research has been technical with the aim to develop and assess the emerging I4.0 technologies. The majority of I4.0 research has been on system engineering (64.85%) and computer science solutions (45.28%), while business, management, and accounting research has a smaller share (15.87%) [3]. Management research, where implementation and organizational change belong, is in a nascent phase and focused on technical implementation topics and economic effects [16]. There is a lack of adopting socio-technical perspectives [23], which informed much of the research on industrial systems during the third industrial revolution (for an exception see [24]). To conclude, there is currently a significant lack of research into implementing I4.0 systems [11].

Most implementation research about I4.0 has focused on factors predicting *adoption* of I4.0 technology [10], not how it is *assimilated*. Past research on transformations induced by digital technologies suggest that organizational changes are necessary to realize the gains of technology [12, 13]. A significant driver of the business value of IT is the assimilating organization's ability to endow complementary investments involving business process changes, changes in work practices, and workforce training. These complementary investments have a multiplier effect on productivity gains by reducing costs, increasing flexibility, and enabling increases in output quality or improvements in intangible aspects of products (e.g., convenience, timeliness, quality, and variety) [12, 13]. These studies also suggest that implementation involves constant mutual adaptation between organizations' practices and technological adjustments and tinkering [25, 26, 27, 28]. Initial research into the implementation of I4.0 confirms that its implementation is like previous system implementations: there is a need for mutual technological and organizational change [29]. Such technology-induced changes are yet to be extensively studied for I4.0, forming a significant research gap. We need to focus not just on adoption drivers, but on implementation processes related to long-term assimilation of I4.0 technologies for I4.0 technologies to be successful. One way to move forward is to draw on past research on IS implementation related to different but somewhat analogous technologies.

3. IS implementation

IS implementation research investigates the purposeful effort and action to deploy IT in organizational contexts and the mutual adaptation of both social and technical systems during such effort [30, 31]. The question of how to effectively implement IS goes back to the roots of the IS discipline [30]. Similar issues continue to be investigated today [32]. Much has been learned through this research that can inform I4.0 implementation research and practice.

So far in IS implementation research, there has been few analyses of the nature of the implemented technology and the consequences of its character on the implementation effort and outcomes [33, 34, 35]. Likewise, research into the adoption and implementation of I4.0 has not carefully considered the impact of unique characteristics of I4.0 technologies. Most studies treat I4.0 like previously implemented IT systems such as ERP systems or CAD/CAM systems. However, some scholars have recently theorized that technological developments and changes in IT will generate contextual affordances, not just those conceived by the designers [36]. In this paper, we posit that I4.0 technologies differ in their nature because they provide generic cognitive functions to support daily tasks in manufacturing settings thus enabling novel affordances. I4.0 technologies rarely come with detailed embedded rules that govern their use such as with MRP and ERP systems. I4.0 technologies are hence weakly structured systems unlike previous operational manufacturing IT systems which were highly structured. This distinction between highly and weakly structured systems is important for future implementation studies because the processes for implementing differ for each type of system.

3.1 Highly and weakly structured systems

One dimension that characterizes IT artifacts is the embeddedness of organizational rules in the IT. The two ends of this continuum are highly structured and weakly structured systems. *Highly structured systems* convey organizational rules that govern the structure of and activities within organizations, thereby increasing an organizations' control and coordination capability [33]. Examples of such systems are ERP systems (e.g., [32, 37]) and process management systems (e.g., [38]). These systems convey organizational rules of how core functions of the organization are to be enacted by employees. They also commonly record the results of employees' actions for organizational control and coordination. IS implementation research has mostly focused on implementing such highly structured information systems. This is also the perspective taken by current I4.0 adoption and implementation research. Implementing highly structured information systems requires compliance because centrally agreed-upon rules are designed into the system and local practices are required to comply with those rules through the implementation process. Implementation clarifies the meaning of the rules and attempts to overcome discrepancies in practices from the rules by addressing associated user resistance. The goal is for the users to understand and comply with the rules after the implementation. This implies a top-down approach to implementation.

Weakly structured systems are systems in which use is not defined initially by organizational rules embedded in the IT. Examples of weakly structured information systems are e-mail [40, 41], e-learning systems [33], and knowledge management systems [42]. The systems' functions are initially unknown for the users [33] in that they provide generic cognitive functions, such as search, retrieve, store, manipulate, and display digital information. These functions can support daily organizational tasks such as sense-making, design, and decision-making. For example, these systems allow employees in manufacturing settings to communicate and share product or operational knowledge. Weakly structured system functions need to be contextually treated as affordances that allow users to utilize these functions to achieve their local task goals [39]. The affordances are discovered through use, embedded into practices, and then shared through common rules to expand the system use between the users. The implementation of such weakly structured systems has received less attention than highly structured systems [33]. This lack of research matters because most advanced technologies being adopted are weakly structured [33:3], such as IoT, big data, and machine learning.

The use of weakly structured systems is optional and open-ended, unlike highly structured systems. Previous research on implementing weakly structured systems has focused on individuals and their relationships to the technology. These studies have observed the gradual growth in individuals' system use as the users slowly discover original affordances of the system [43]. One recent study of group affordances focused on organizational-level effects of shared affordances [44]. These studies have mainly described how weakly structured systems change information flows and the social structure of organizing [28, 44]. Recently, Lyytinen et al. [33] used a regulation lens to analyze at a system level the implementation of a weakly structured system. They found that implementing weakly structured systems forms joint regulation that combines bottom-up movement of the discovery of affordances in practices to rules with the top-down coordination of how these rules are shared and enforced. Joint regulation entailed that users and other stakeholders introduced, negotiated, and enforced rules locally for the meaningful use of these technologies [45, 46]. The researchers contrast this with the implementation of highly structured systems which involves movement from rules to practices.

A weakly structured technology is generally implemented cumulatively while new affordances are discovered, shared, and institutionalized through joint regulation. This lens suggests that just adopting a weakly structured system does not mean that it will be used. The process of joint regulation needs to support its assimilation to the organization. Since much I4.0 implementation research so far has focused on adoption, it is not likely to provide a germane understanding of how to effectively implement I4.0. Implementation will likely involve forms of joint regulation where users and other stakeholders locally discover affordances and share those to become jointly regulated rules of use. If I4.0 technologies have weakly structured system components, then implementation needs to be studied in greater detail and with new frameworks.

3.2 Capabilities and affordances of I4.0

We assume that I4.0 technologies form mostly weakly structured systems defined by their cognitive functions. We include the nature of the technology in our theorizing by distinguishing between IT capability and IT affordance because previous research has shown this to be important [33, 39, 43]. *IT capability* is defined as "the possibility and/or right of the user or a user community to perform a set of actions on a computation object or process" [47:2]. The technical focus of I4.0 research has meant that most of the conversation has been about such new capabilities. However, weakly structured system research has recognized affordances as key to understanding the actual use of such systems. *IT affordance* related to a specific capability is defined as "the possibilities for goal-oriented action recognized by a specified user group" [48:622]. Affordances define potentials for action that develop from the contextual interactions between the IT capabilities and goal-oriented users or groups of users [48]. Therefore, IT capabilities generate multiple and different affordances for different users and groups. Previous research has also shown that IT capabilities themselves are mutable and negotiable, which makes the setting highly dynamic [49]. Generally, technological developments in IT will generate novel affordances, e.g., I4.0 technologies [36].

Unlike previous first-generation weakly structured systems (e.g., e-learning systems), I4.0 is not a single-purpose technology. Rather it is an assemblage of interconnected technologies that can be repurposed across settings. The application of I4.0 technologies to a specific organization will be unique based on the choice of technologies and the needs of the organization. I4.0 technologies also include artificial intelligence (AI) capabilities that allow CPSs to learn autonomously. AI capabilities are increasingly being used [50] and some claim that there will be an I5.0 based on AI [51]. For this paper, we will treat the application of AI as a part of I4.0.

The addition of AI to I4.0 is important because the systems have the capacity to learn independently. The AI-enabled technologies never precisely repeat their operations because they constantly learn and adapt to new inputs. As AI is incorporated into I4.0 technologies, the input-output relationships of AI-enabled technologies render the behavior of I4.0 systems fundamentally unknowable to humans, neither ex ante nor ex post [52]. Zhang et al. [52] showed that the use of AI-enabled autonomous design tools led chip designers to completely change their design practices. The designers were never able to develop full knowledge of their tools due to the tools' outcomes being unknowable. In manufacturing contexts, it is likely that practices need to change to accommodate the unknowable behavior of the AI-enabled technology. We do not know how the transfer of practices to rules occurs when machines also independently learn and change their behavior (e.g., [28]).

Learning machines have been recognized as a threshold event for disciplines that deal with organizing [53]. Lyytinen et al. [53] label systems including joint human and machine learning as *metahuman systems*, defined as "emergent, sociotechnical systems where machines that learn join human learning and create original systemic capabilities" [53:1]. Adding AI to I4.0 technologies makes them metahuman systems. Current implementation research cannot necessarily be generalized to this novel context, as witnessed with the unexpected shift in designers' practices while implementing AI-enabled design technology [52]. Implementing weakly structured systems that learn will become increasingly important as AI and weakly structured systems continue to proliferate [33, 50].

The capabilities of I4.0 will depend on the specific I4.0 technologies employed by the organization. The affordances of I4.0 will depend on the capacities of these technologies and the way humans interact with those technologies in concrete settings. Each study assuming a suite of capabilities and affordances will need to specify the technologies that are being implemented, define the capabilities, and study how and which affordances are discovered and shared. However, there are some capabilities that will be consistent across I4.0 technologies based on the I4.0 definition [4:550].

The following core capabilities of I4.0 are hypothesized and need to be empirically verified through future research (see Carlo et al. [54] for one way of identifying capabilities and affordances): (1) interconnected communicating machines within an organization, (2) interconnected communicating machines between organizations in the supply chain, (3) digital representations of the physical world and related digital models using embedded sensors, (4) machines autonomously acting on digital data, and (5) analysis and simulation based on digital models and data. One additional capability to be included in I4.0 is (6) the ability for the system to learn through the application of AI. Together, the I4.0 definition and capabilities show that I4.0 is a weakly structured system due to I4.0 technologies providing generic cognitive functions that support daily organizational tasks without organizational rules embedded in them.

3.3 Agenda for future research

I4.0 has the capacity to penetrate all levels of hierarchy within an organization (vertical integration), connect organizations on the supply chain downstream and upstream (horizontal integration), and have the potential to learn, when AI is incorporated (metahuman systems). In this section we posit that to study I4.0 implementation, researchers need to distinguish between implementing along a vertical and horizontal integration axis, and whether the implemented system can learn (dynamic) or not (static). We organize the research issues in implementing I4.0 technologies into a 2x2 framework (see Figure 1). The framework contains key questions that manifest the specific aspects of implementing I4.0 within each quadrant. The static I4.0 technology assemblages and vertical integration quadrant is highlighted with a white background instead of a light gray because we treat this quadrant as the foundational one that needs to be studied first. It lays the groundwork for progressing I4.0 functions and related implementation issues to the other quadrants. Therefore, the three remaining quadrants currently have higher levels of uncertainty and complexity in implementing I4.0. We assume that research will start in the static technology and vertical integration quadrant because: (1) vertical integration is required to be able to achieve horizontal integration; (2) horizontal integration is hard to realize due to social, regulatory (e.g., hesitancy in sharing data), and technical issues (e.g., interoperability problems; [55]); and (3) dynamic AI technology is currently an additional feature of I4.0. Most organizations are likely to start with static assemblages of I4.0 technology, which published case studies of I4.0 implementation confirm (e.g., [10, 56]).

Vertical and horizontal integration are two of the three systemic attributes of I4.0 (we do not include end-to-end engineering, the third attribute, because it is not an organizational topic, but an industry and production concern [14]). *Vertical integration* allows manufacturing information to be accessible at hierarchical levels of the organization. The technologies used previously in implementing weakly structured systems did not (with some exceptions, e.g., e-mail) penetrate all hierarchical levels. But they did connect multiple levels and provide a good reference for what I4.0 vertical integration may look like [28, 33, 43, 44]. The common process is that users and other stakeholders discover affordances, share those affordances, and create rules through joint regulation. We hypothesize that the vertical integration of I4.0 will result in a similar process taking place. One study found that the implementation resulted in the informal advice network of the users changing from hierarchical to democratic to meritocratic due to the movement of information through the new network [28]. The change did not transform the whole organizational structure. However, this result hints at the importance of studying power through the lenses of authority and decision rights, because vertically integrating will change how information flows and related power bases [57]. The change may result in a movement from centralized to decentralized decision making and decreases in hierarchical authority.

One important challenge in the vertical quadrants is how to deal with power related to the needs of joint regulation. The importance of power during I4.0 implementation emerged through the literature review. We use Jasperson et al.'s [57] analysis of power to inform our discussion. Assumptions of strict hierarchy and formal power have been dominant within manufacturing research. Such views are likely to influence the implementation of I4.0 in the future [58, 59]. The strict hierarchies within manufacturing are

	Vertical integration	Horizontal integration
Static technology assemblages (non-learning)	How does power influence the way affordances are shared and become rules through joint regulation in a vertically integrated organization? How does implementation change the hierarchical structure of organizations? Power: authority and centralization, decision rights, participation in decision making.	How are group affordances between organizations discovered and shared? How are the affordances discovered within one organization shared with other organizations in the supply chain? How are rules around system use created across the organizations and what are the forms of power mediation? How will horizontal integration change the relationships between organizations on the supply chain as more I4.0 technologies are adopted? Power: authority; centralization, decision rights, participation in decision making; influence.
Dynamic technology assemblages (learning)	What effect will this learning technology have on the implementation of weakly structured systems? How will practices and rules change due to the features of the learning technology and its outcomes? When machines can also learn, does the discovery and adjustment of technology stop after five to six months [67] [28], or do they continue for longer as episodic adaptations due to the unknowability and continual learning of the technology?	How do humans and machines communicate and learn across organizations? How do humans and machines discover affordances and share them? This quadrant is the most tentative and will rely on the findings from the other three quadrants to form appropriate questions.

Figure 1. Framework for the study of implementing I4.0 as a weakly structured system

different from the contexts of past research on weakly structured systems (e.g., engineering teams and higher education [28, 33]). In those settings, authority and power are decentralized, giving employees significant autonomy. Studying hierarchical authority and how it needs to change while implementing I4.0 forms an important topic because weakly structured systems implementation requires autonomous discovery and sharing of affordances contingent upon employees' autonomy.

So far, the research into implementing weakly structured systems has not investigated the role of power. Therefore, it is unknown how different forms of power mediate the implementation process during joint regulation. Lyytinen et al.'s [33] article describes the need to create shared rules as joint regulation. But the study does not investigate the influence and mechanism of power in how the shared rules are decided upon and enforced. Leonardi [28] showed the potential of weakly structured systems to change an organization's power structures latently and over time. Multiple concepts of power per Jasperson et al.'s [57] review are salient in analyzing the potential for vertical (and horizontal) integration during I4.0 implementation.

Horizontal integration is the digital integration across the supply chain. Horizontal integration is an interorganizational information system (IOIS) because it automates links that connect business processes between two or more organizations [60]. IOIS research began in 1982 [60] and later connected IOIS to supply chain management [61]. However, I4.0 is distinct from previous supply chain management IOIS because they were mostly highly structured systems using electronic data interchange protocols to manage order-fulfillment cycles. Despite the differences, this line of research can improve our understanding of I4.0 implementation since horizontal integration of I4.0 is a new special type of IOIS build on top of existing IOIS.

Previous IOIS research has found several characteristic technical, organizational, and network implementation barriers [62]. Of particular interest to I4.0's horizontal integration are the network barriers related to power: control over information and the degree of dependency and related power structures. Organizations remain unsure of how much data to share because they fear a loss of power and control [63], which leads to a reluctance to share [64]. Trust within the supply chain has been found to be important for abating the fears [65]. Previous research has also documented changes in bargaining power, perceived power, coordination, and network structures during IOIS implementation and use [60] while other studies have shown that IOIS may reinforce existing power structures [63]. One study found that the use of remote diagnostics systems shape where and when organizational boundaries are drawn and crossed [66]. The study points to the potential for I4.0 technologies to connect organizations thereby changing the way these organizations will draw boundaries. This may be due to affordances being discovered between the organizations and a negotiating process that is necessary to share the affordances.

The power analyses that are likely to be salient in horizontal integration I4.0 implementation are authority (organizations may influence each other to implement I4.0); centralization, decision rights, and participation (I4.0 may reinforce the power of the strong organizations within the supply chain); and influence (more powerful organizations could require their supply chain to adopt I4.0 technology despite low need for it) [57]. This leads to the following research questions: How are group affordances between organizations discovered and shared? How are the affordances discovered within one organization shared with other organizations in the supply chain? How are rules around system use created and negotiated across the organizations and what are the forms of power mediation? How will horizontal integration change the relationships between organizations on the supply chain as more I4.0 technologies are adopted?

Due to these differences in the types of implementation problems for vertical and horizontal integration, we believe that it would be more productive to treat the implementation of vertical integration and horizontal integration of I4.0 as separate but connected phenomena. The differentiation allows researchers and practitioners to clearly understand how to implement I4.0 depending on their setting, goals, and needs. We suggest that implementation research first focuses on vertical integration since research and implementation outcomes in these quadrants will lay the foundation for horizontal integration. There are also significant social, regulatory, and technical barriers that need to be overcome before horizontal integration can widely occur in practice [55].

The research on *static technology assemblages* will study human social learning and how community-level learning grows into practices and rules [33]. So far, the research on implementing weakly structured systems has assumed that the technology is static and cannot learn though new features are added as integration advances. In these studies, humans learn how to use an extensive set of ‘non-learning’ technologies (e.g., [33, 43]). However, users’ practices are predicted to significantly change when machines that learn are integrated into weakly structured CPS, making them metahuman systems [52].

Dynamic technology assemblages will include machines that learn in addition to human learning. Implementing weakly structured systems that learn remains an unexplored area that will become increasingly important as AI and weakly structured systems continue to proliferate [33, 50]. The research will need to investigate mixed learning of metahuman systems and the related challenges of delegation, cultivation of skills, and control [53]. Research on dynamic technology assemblages in I4.0 will learn from and contribute to the initial research into metahuman systems. Since this is a nascent area, many questions emerge that have major implications for the IS discipline generally: What effect will this learning technology have on the implementation of weakly structured systems? How will practices and rules change due to the features of the learning technology and its outcomes? When machines can also learn, does the discovery and adjustment of technology stop after five to six months [67] [28], or do they continue for longer as episodic adaptations due to the unknowability and continual learning of the technology?

4. Discussion

4.1 Implications for research

Academic research on I4.0 has experienced a high growth rate [1, 2, 3, 4] and numerous government initiatives have been created throughout the world to support future research [5]. An important gap in I4.0 research is how to contextually implement such systems [2, 4, 9, 10]. I4.0 implementation studies have mainly focused on adoption and have not investigated the implementation process and outcomes, so they cannot effectively support organizations in implementing I4.0. From an IS perspective, previous implementation research has focused on highly structured systems and primarily neglected weakly structured systems [33]. By studying I4.0 implementation as a weakly structured system, future research on I4.0 can also shed more light on how to generally implement weakly structure systems. This is important because advanced technology increasingly has weakly structured features [33:3].

This is the first paper, to the authors’ knowledge, that attempts to identify the capabilities of I4.0 technologies to later investigate the affordances of these technologies in use. Previous I4.0 research has mentioned the importance of the materiality and related capabilities of I4.0 [29] and made initial calls for the use of affordances in studying I4.0 [68]. Based on the authors’ reading of the I4.0 literature, this paper hypothesizes the capabilities of I4.0 to be (1) interconnected communicating machines within an organization, (2) interconnected communicating machines between organizations in the supply chain, (3) digital representations of the physical world based on embedded sensors, (4) machines autonomously acting on digital data, (5) analysis and simulation, and (6) the ability for the system to learn through the application of AI. The identification of these capabilities is a novel contribution to study I4.0 as weakly structured systems. Future research needs to investigate how these capabilities are put together and orchestrated in specific settings and how the capabilities are enacted as affordances in local practice.

Through conducting a comprehensive literature review and analyzing the features and capabilities of I4.0, we created a 2x2 framework defined by vertical or horizontal integration and technology features where the I4.0 system does not learn or can learn. The analysis of the framework revealed that I4.0 vertical and horizontal integration need to be studied as separate but interconnected implementation problems; the importance of studying power for I4.0 in both vertical and horizontal settings, but in different ways; and the unique challenges that weakly structured systems that learn autonomously pose to implementation research. Overall, the paper emphasizes the need for I4.0 implementation research to closely study practices and improve holistic, socio-technical understanding of implementing weakly structured I4.0 systems.

4.2 Implications for practice

This paper contributes to practice by identifying I4.0 as a weakly structured system. Identifying I4.0 as weakly structured entails certain ways of implementing the technology to unlock the full benefits for organizations. Whereas the implementation of highly structured systems requires user compliance to predetermined rules, weakly structured systems provide generic cognitive functions that lead to the discovery of affordances which are formed in practices, shared with others, and then jointly regulated through shared rules [33]. The identification of I4.0 as a weakly structured system implies that organizations implementing I4.0 should support users in finding ways to make the technology useful to their work, as opposed to trying to get users to use the technology in a certain way [44]. Therefore, supporting the discovery and sharing of affordances should lead to positive organizational transformation. Additionally, manufacturing employees will need to be given more training and autonomy so that they know how to use the technology and can innovate by discovering novel affordances.

5. Conclusion

A major barrier to realizing the potential of I4.0 is a lack of understanding in implementing these systems. This paper draws on the IS implementation literature to expose unexpected issues in implementing I4.0 technologies. Generally, I4.0 is identified as a weakly structured system. Previous research has found that implementing weakly structured systems requires users' discovery of affordances, sharing the affordances with others, and creating and negotiating shared rules through joint regulation. But extant research has studied uses of such systems in the context of knowledge work and not manufacturing. Manufacturing has traditionally followed a strict hierarchy and control, which is at odds with the idea of implementing weakly structured systems. To spur future research, we created a 2x2 framework with the dimensions of (1) vertical or horizontal integration and (2) autonomous technology learning. The framework identified key implementation issues in each quadrant and revealed the importance of varying forms of power for I4.0 implementation and more generally for weakly structured system implementation. Additionally, we recognized that weakly structured systems that learn autonomously form a new frontier of implementation research.

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