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Connect Your Smart Manufacturing via Smart Work: A Single-Case Study from the Renewable Energy Industry

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Abstract. The evolvement of new-generation information technologies, such as the Industrial Internet of Things (IIoT), is bringing today's production systems nearer the Industry 4.0 (I4.0) agenda, to why manufacturers have invested heavily in new equipment to become smarter in the way of working. While the development of organizational capabilities to support these investments is showing slow progress, practitioners are having difficulty getting their manufacturing connected using I4.0 technologies as they provide a limited understanding of how to balance the interrelation of the variables within their sociotechnical system configurations. To close this gap, this study presents a single-case study from the Renewable Energy Industry demonstrating how Smart Work principles (human-centric solutions) prove beneficial in balancing the social and technical variables for implementing IIoT technology in a production environment with a moderate number of I4.0 technologies implemented. By studying the company's organizational capabilities through the lens of sociotechnical theory, our findings demonstrate that the complexity of implementing new technology is related to the difficulty of handling transdisciplinarity within the sociotechnical system.

Keywords. Industry 4.0, Smart Work, Sociotechnical systems, Single-case study.

Introduction

The Industrial Internet of Things (IIoT) is labeled as the fundamental pillar of smart manufacturing [1, 2] being the computing concept describing the pervasive connection between various industrial devices with the information systems and business processes [3]. For several years, manufacturers have explored the opportunities of "going smart," where the onus is to make the manufacturing more automated to obtain a large volume of data throughout the product lifecycle to why industrial automation systems and connected factory concepts enabled by IIoT solutions are of particular interest to both academia and practitioners [4, 5], as these offer effective solutions for shop floor monitoring and control [3].

To harvest the related outcomes of going smart, manufacturers have invested heavily in various technologies to enable data-driven approaches to make their manufacturing process less cumbersome. However, although the applicability of IIoT technologies has been rapidly tested [4], several operations management (OM)- and technology

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management (TM) researchers have labeled "optimal interactions" between humans and technology as an area of underdeveloped competencies due to an imbalance in equally dealing with the social and technological variables [2, 6, 7]. This unfolds as a problem as manufacturers tend to handle technology implementations from an isolated viewpoint as they lack an understanding of what it takes [2, 8, 9] Following Mathiasen & Clausen [8], the problem is not that manufacturers do not work in collaborative teams ranging across disciplines when dealing with technology implementations; the problem is that transdisciplinary collaborations necessitate the team members to possess knowledge and skills ranging across disciplines to become successful (see Wognum et al. [10]).

Given this, manufacturers are showing slow progress in capitalizing on their IIoT-oriented investments as they lack the necessary capabilities to support it [7, 11, 12, 13]. To contribute to closing this gap, this study aims to provide transparency on handling technology implementations that require transdisciplinary collaborations with parties inside and outside a company. With this, the study strives to demonstrate the importance of practitioners' ability to enhance transdisciplinarity by acquiring knowledge and skills across disciplines when implementing "new" technology successfully.

To do so, the study presents a single-case study from the Renewable Energy industry demonstrating the experiences of introducing industrial edge notifier technology (IENT) to enable the immediate use of data for improved monitoring and control of an automated production setup on the shop floor. The case study dictates a transdisciplinary approach [10] outlining a collaborative method requiring knowledge transfers across various disciplines. Given that the research topic is sociotechnical in nature (e.g., [14, 15]), we take a sociotechnical theory lens [16] when studying the requirement outlining the necessary capabilities for implementing IENT. With this, the study considers the company as a system defined by social and technical variables. The research question, "What problems do practitioners face when implementing IIoT technologies, and how can they be addressed?" guided the study.

The paper is structured as follows. First, the background is presented, then the method is described in detail, followed by the case description presenting the empirical material. Finally, the results are discussed, and conclusions are formulated.

1. Background

The IIoT, an Industry 4.0 (I4.0) and a smart manufacturing concept [17], presents a complex technology architecture of the manufacturing systems as to why implementing such technologies is a primary concern in today's manufacturing and a focal research subject [2]. With I4.0, technological advancement is changing manufacturing processes rapidly. However, currently, there is a paucity of practical cases demonstrating successful implementations [14, 15]. With most theoretical studies and contributions rather than empirical studies proving practical evidence of successful I4.0 implementations [2, 14], practitioners possess limited support to handle the implementation effectively.

Prior research on implementing I4.0 technologies has mainly focused on maturity frameworks and adoption levels, to why we have learned that no universal solution for implementing I4.0 technologies exists as it is conditioned by the sociotechnical variables of an environment and the maturity levels of these [15]. However, OM researchers with stands towards the TM domain, such as Cagliano et al. [14], Marcon et al. [15], and Meindl et al. [18] argue that the implementation of I4.0 technologies in companies with robust sociotechnical systems is most likely to become more successful with the implementation as they understand or possesses experience with the complexity of sociotechnical interactions.

With this, more studies on balancing the interrelation of the social and technological variables when implementing I4.0 technologies are needed [15]. Given that I4.0 results from technological advancement, it is unsurprising that the social factors have often been overlooked [2]. With this, TM-oriented OM researchers such as Frank et al. [2] and Meindl et al. [18] have called attention to the fact that I4.0 must acknowledge the human workforce as a crucial factor for improving productivity through I4.0 technologies. Similarly, the European Commission has labeled human-centric manufacturing highly relevant to why the conceptualization of Industry 5.0 should be considered a complementary view to I4.0 [19, 20].

Frank et al. [2] brand this human-centric solution phenomenon as Smart Working (SW) when introducing their very acknowledged "Theoretical framework of I4.0 technologies", to which SW should be considered an expansion of the Operator 4.0/Smart Operator concepts [19, 21]. While the Operator 4.0/Smart Operator concepts debate how the human role, primarily on the shop floor, should evolve in the I4.0 context by suggesting new worker profiles [18], SW considers both the operational activities performed by shop floor workers (i.e., the micro-level) and the remote-operational activities taking a broader outlook on the work processes, including the cognitive managerial activities performed by managers, engineers, and supervisors of the manufacturing (i.e., the macro-level) [18, 21]. Cagliano et al. [14]. demonstrate an SW-alike approach in their work exploring how I4.0 technologies interplay at the micro- and macro levels by adopting a socio-technical systems approach. Within their study involving 19 manufacturing companies, Cagliano et al. [14] identified four sociotechnical configurations ranging from a Process-automated Factory label to an I4.0 Smart Factory label. Although their study shows that the interplay between technological and social variables cannot be considered in a deterministic way, the companies within or close to the Smart Factory configuration are most likely to become successful when introducing new technology, as their socio-technical configuration appears more mature if considering the dimensions on the micro level. Although the macro-level in this context is an understudied topic, Cagliano et al. [14] were able to present a few linkages. However, in conclusion, they highlight that the macro-dimensions are of utmost relevance for successfully implementing I4.0 technologies, to why it deserves research attention.

2. Method

To investigate the above-presented research question, this study adopted a single-case study approach [22]. The case study follows an inductive methodology [23, 24] intending to generate theoretical implications by describing the explored phenomenon thoroughly to create explanations [25]. Furthermore, case study approaches are appropriate to study situations where new phenomena are inquired, such as studying I4.0-related topics (see [14]), as it allows the researcher to understand the complexity of the investigated phenomenon in its real-life context [26].

The data collection procedures included face-to-face interviews with key informants, online interviews with other key informants, onsite observations, and project documents from the case company. Due to the diversity of information sources, a protocol to guide the data collection was developed [23]. The protocol was inspired by principles presented by Rashid et al. [27]. The protocol took an outset in the framework describing the environment configuration in terms of the technical and social system variables for studying the conditions of implementing IENT (see section 3.2).

The protocol (see Figure 1) listed the data collection's purpose and the types of informants to involve. Snowball sampling [28] was applied to select what informants to involve. The internal project manager provided the first contact information for the sampling technique. The protocol proved helpful in ensuring that all data collection processes were well-planned and aligned [27]. Notes were taken simultaneously during the observations and interviews. Moreover, the internal project manager approved the protocol to increase the study's credibility, and all notes were discussed with the informants being interviewed. Data source triangulation [22] was conducted by ensuring all data sources converged on similar facts to ascertain data validity.

The data analysis follows Stake's [22] interpretation strategy, from where the authors analyzed data simultaneously while collecting data. To avoid misrepresentation and misunderstandings, a framework to clarify the sociotechnical system of the environment configuration guided the analysis. The framework was inspired by Cagliano et al.'s [14] classification of sociotechnical system configurations.

Data collection protocol
What problems do practitioners face when implementing IIoT technologies, and how can they be addressed?

Purpose and data source	**Informants involved**
1. Understanding the macro-level conditions At the early stage of involvement in the IENT project, the authors needed to understand the project characteristics, to why *unstructured interviews* seemed appropriate as a natural extension of observing the project environment through participating in project meetings.	One onsite meeting of **two hours** at the external collaboration partner involved unstructured interviews with two *automation engineers*. Three onsite meetings of **one hour** at the case company with a *senior manufacturing & technology engineer* (project manager) and an *automation specialist*. The informants represent the **macro-level activities.** Informal meetings were held with the informants during the project.
2. Understanding the micro-level conditions After understanding the technical system characteristics of the environment and being introduced to the IENT, the authors were ready to clarify the social system characteristics. *Semi-structured interviews* were conducted to explain these and to identify whether the current conditions determining the environment configuration seemed sufficient for implementing IENT.	Three online meetings of **30 minutes** (via Microsoft Teams) involving a *process engineer*, a *tooling & maintenance engineer*, and two *production workers*. The informants represent the **micro-level activities.**
3. Towards a transdisciplinary understanding & testing After mapping the sociotechnical system of the environment, *a pilot test* was run on-site at the external collaboration partner. *Observations* clarified whether the sociotechnical system was mature to implement IENT. After identifying the required capabilities for implementing IENT, changes were made to the technical system, followed by a final IENT test. *Observations* documented the test results and were applied to develop guidelines for how the project team implements the IENT.	**Pilot test – 3 hours.** Onsite: An *automation engineer* (external collaboration partner), an *automation specialist*, a *business specialist*, and *one of the authors*. Online: A *senior manufacturing & technology engineer*, a *digital solutions product owner*, an *industrial solutions architect*, a *quality engineer*, and a *digital manufacturing engineer*. **Final test – 2 hours.** Onsite: An *automation specialist* and *one of the authors*.
Secondary data to support the authors' understanding • An *external report* (documentation of the development process of IENT). • An *internal user manual* of the production equipment/environment to implement IENT.	

Figure 1. The data collection protocol.

3. Case description

Siemens Gamesa Renewable Energy (hereafter referred to as *the company*) is a global wind turbine manufacturer with around 27000 employees. The case presented in this paper occurs in one of the company's Danish production facilities producing wind turbine blades. Following the current industrial trends enabled by I4.0, the company wants to unfold as a more modern/smart manufacturer, to why many resources are spent on implementing various new types of information technologies to enhance efficiency at the operational level on the shop floor. Generally, producing wind turbine blades is characterized by a high level of manual labor, which is why few I4.0-related technologies are implemented at the plant's production phase and process levels.

3.1 The environment for implementing IENT

This case investigates the production phase consisting of an advanced automated machine, milling and drilling holes into the wind turbine blade's root end. Approximately 10-15 shop floor practitioners are involved in the activities concerning the milling/drilling machine (MD machine) daily. Figure 2 illustrates the environment of the MD machine.

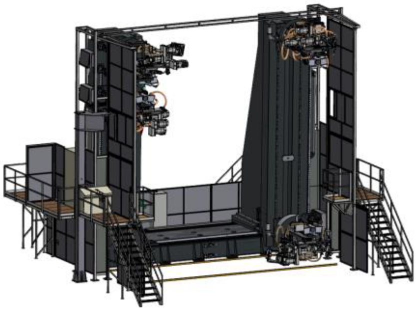

Figure 2. The MD machine environment.

Figure 3. HMI/ user panel of the MD machine.

When the MD machine is active in milling or drilling, a production worker (PW) is assigned to observe the machine's HMI being the machine's user panel, see Figure 3. The HMI is placed on the stair bridge on the machine's right side. The PW cannot leave the HMI unobserved when the machine is operational, as actions must be taken immediately if error messages appear on the HMI. The PW's main task is to avoid machine breakdown, which often comes with many costs.

To operate, control and monitor the HMI, the PW must have acquired a certain skill set. The PWs are undergoing an internal training program, and the instructors must verify their skills before they are assigned to work at the MD machine. No formal training program exists. It is up to the instructors when a PW is ready to monitor and operate the HMI. Currently, three different skill levels exist.

The MD machine was implemented in the plant in 2021. It was crafted by a Danish automation company and the machine is built with many different sensors that make it possible for the company to monitor and control the machine following data-driven approaches. Another Danish company, an all-around industrial automation competency provider (designated *Gamma* in the remainder) has developed the software to make the machine operational. However, the machine data is currently not utilized fully due to several problems and a lack of capabilities as to why data is mainly collected manually. Given this, the operational activities of monitoring and controlling the MD machine do not follow data-driven approaches. For that reason, the PWs often must contact several different support functions when error notifications appear on the HMI, as these notifications are not connected to other devices. Figure 3 illustrates the escalation plan if error notifications appear on the HMI.

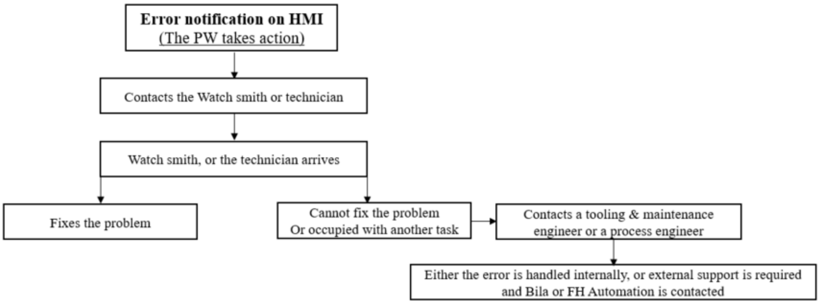

Figure 4. Escalation plan if error notification on HMI appears.

According to the PWs and engineers involved in the process visualized in Figure 4, the escalation plan contains too many steps, often resulting in long reaction times. The involved support functions must cover a broad area in the plant, to why much time is spent figuring out what persons is able to deal with the error notification.

3.2 Describing the sociotechnical system of the MD machine environment

To become more reliant on data-driven approaches for monitoring and controlling the production environment, the company is seeking an approach to implementing new technologies as seamlessly as possible. The company considers implementing IENT for the MD machine environment as a research study, to why the authors support and document the process. While one of the authors is an internal automation specialist within the company, the others are external researchers supporting the project with objective opinions.

Based on the interview material (derived from steps 1 and 2 in Figure 1), the authors have described the sociotechnical system of the MD machine environment considering the current macro- and micro-level conditions, see Figure 5. The framework is inspired by the work of Cagliano et al. [14]. The authors have added *Transdisciplinarity* as a social system variable to the framework, as supporting the MD machine environment ranges across different departments within and outside the company.

MD machine environment	**Technical system**	**Social system**					
Partially integrated production environment	A medium number of I4.0 related technologies implemented (mainly at production phases level).	Job control and autonomy (SHOP FLOOR)	Cognitive demand (SHOP FLOOR)	Hierarchy (ORGANIZATION)	Centralization of decision-making (ORGANIZATION)	Social interaction (ORGANIZATION)	Transdisciplinarity (ORGANIZATION)
		Prescription of work procedures; autonomy in work procedures related to controlling	Both manual and cognitive tasks	Vertical organization, with bottom-up flows of information	Plant management level/departmental level	Primarily Intra-team interactions	Limited inter-team interaction. No standard communication guidelines

Figure 5. Sociotechnical system configuration of MD machine environment.

While the definition of the technical system is static, the social system evaluates both the micro-related and macro-related dimensions, to why the evaluation includes a focused shop floor- and a holistic organization perspective. The overview presented in Figure 5 made it possible for the authors to clarify the current situation and suggest some of the barriers to implementing new technology, such as IENT, in the MD machine environment. The authors suggest that the company's lack of capabilities to work cross-sectoral at the managerial levels (e.g., the collaboration between the IT department and Business development department), and lack of capabilities to work cross-organizational boundaries (e.g., low involvement of shop floor practitioners in technology projects on the shop floor) might prove problematic, given that the social interactions are characterized by intra-team interaction, and no collaboration/communication standards exist to bridge inter-team interaction.

3.3 Exploring IENT for the MD machine environment

At the outset, the implementation of IENT aims to provide shop floor practitioners with easily accessible real-time error notifications on notifier devices from the MD machine to eliminate the current inefficient escalation plan (Figure 4). The project team consisted of two automation engineers from Gamma, the project manager (a senior manufacturing & technology engineer), an automation specialist (one of the authors), and an external researcher (one of the authors). Given the learnings from Figure 5, the authors recommended that the project team pay attention to the project's transdisciplinarity before moving on, as no practitioners from the MD machine environment were enrolled. The interviews conducted in step 2, Figure 1, supported the project and were applied to identify the user requirement of implementing IENT.

In November 2022, a pilot test was conducted at Gamma. The pilot test aimed to identify whether the IENT was ready to be implemented in the MD machine environment (clarify whether the company possessed the technical capabilities to support the implementation). Simulated data was applied to run the pilot test. Figure 6 visualizes the technical setup for the pilot test in the setting at Gamma. Although the equipment visualized in Figure 6 only applies for testing purposes, the lineup with all components reflects how the setup would appear in the real setting in the MD machine environment.

To share this learning experience within the company, five people outside the project team relevant to this subject (see Figure 1) observed the test online and were allowed to engage with questions.

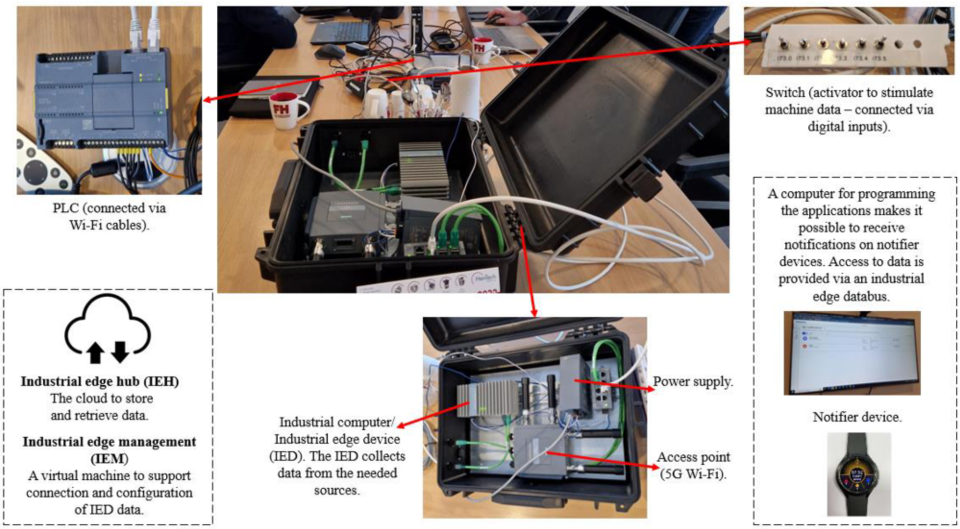

Figure 6. Overview of the technical setup of the IENT pilot test at Gamma.

The pilot test demonstrated that IENT proves to be a promising solution for improving connectivity between people and machines via real-time notification on smart-devices such as watches or tablets. When the machine reported an error (simulated), a notification appeared on the notifier device within five seconds. Although the technology seemed beneficial to handle the practical problem, the pilot test revealed several technical issues. More issues were identified when preparing the equipment to carry out tests in the MD machine environment. Figure 7 reports the technical issues identified from the pilot test and how these were handled.

Technical issues	Handling status
• Problems with PLC and setting up accounts (difficult to get access).	• Prolonged communication with Gamma and their sub-suppliers to solve the issues.
• Black spots in Wi-Fi connection (notifier devices will not work if users are too far from the access point).	• **Not dealt with at this point.**
• The notifier application turns off when the device is not active	• The smartwatch does not turn off when the pulse monitor is activated (GDPR issue)
• Notifier device is only able to receive information.	• Through a simple configuration, it was possible to program a solution allowing the notifier device to respond to error notifications.
• The HMI on the smartwatch notifier device is difficult to operate (too small dashboard).	• The smartwatch notifier devices should only be applied by practitioners with limited need to send responses (people who just need to be informed, such as the production managers). Other devices, such as tablets or machine HMIs, can be applied.

Figure 7. The identified issues after the pilot test and how these are handled.

After the pilot test, Gamma handed over the equipment to the company, and the project team had to implement the IENT on their own. Dealing with the technical issues from Figure 6, required transdisciplinary approaches, as external support outside the project team was needed, to why the project team extended the communication with Gamma and had to get in contact with one of Gamma's sub-suppliers to receive the necessary support. The technical issues related to the notifier application and smartwatch device were handled internally by the automation specialist. Approximately, 28 hours were spent on setting up the equipment/system and programming. Besides the 28 hours, several meetings were conducted with Gamma and their sub-supplier. The final test within the MD machine environment was delayed by 1,5 months due to the technical issues. The final test proved that IENT, from a technical system perspective, is ready to be implemented. The final test was conducted in February 2023 and included the automation specialist and one of the authors. Figure 8 visualizes how the MD machine notifications appear on the smartwatch device and how responses can be sent via the MD machine HMI and the smartwatch device. The system setup mirrors the pilot test (Figure 7), with hardware and software solutions meeting the technical requirements to support the MD machine environment (e.g., a larger PLC, a more powerful industrial computer, etc.). The authors recommend involving the shop floor stakeholders in the MD machine environment, before implementing IENT, as their involvement and collaboration are crucial for successful implementation (cf. Figure 4).

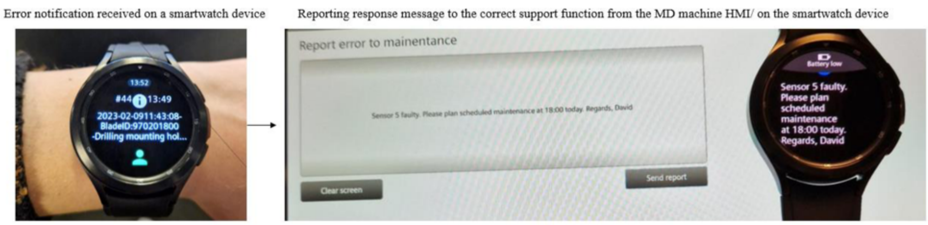

Figure 8. Notification on smartwatch device and MD machine HMI.

4. Discussion and conclusions

Guided by the following research question, "What problems do practitioners face when implementing IIoT technologies, and how can they be addressed?" this single-case study aimed to demonstrate how a human-centric solution approach, inspired by the SW principle [2], proves beneficial in balancing the social and technical variables when implementing an IIoT solution. Assuming a sociotechnical perspective, our findings exemplify a case identified with the *partially integrated factory* sociotechnical system configuration described by Cagliano et al. [14].

By understanding the configuration of the sociotechnical system, we were able to interpret the company's current organizational capabilities in terms of introducing an I4.0-related technology in a specific production phase. In our study, intra- team interactions penetrated the structure for social interaction across the organization. To comply with this, we added *Transdisciplinarity* as an additional variable when evaluating the social system, as we identified intra-team interaction as a barrier, as we saw that the project team was highly dependent on following a transdisciplinary approach [10]. To this end, we suggest that handling new technology implementation necessitates access to relevant knowledge across disciplines during the whole process. In this specific case, across-interactions were required all the time, both internally and externally in the company. While the *Social interaction* variable is considered from the micro-perspective in Cagliano et al. [14], this study evaluated it from the macro-perspective, as the implementation required cross-collaboration both inside and outside the company, to why we experienced a need to include evaluation ranging across work-team constellations (i.e., the shop floor, the project team, and external collaboration partners).

As the purpose of this study is to demonstrate the learnings of implementing new technology relying on an SW approach, we learned, the variables within the sociotechnical configuration framework, had to adapt to the conditions of the investigated environment, which confirm that every single technology implementation is unique [14]. Furthermore, the SW strategy, should not be based on an overall evaluation of the organization, as one company does not represent one sociotechnical figuration. The environment for the technology implementation has to be specified and evaluated accordingly.

In line with the studies performed by Frank et al. [2] and Cagliano et al. [14], our study contributes to clarifying the understanding of what it takes to implement I4.0-related technologies. To conclude, we believe that SW approaches are valuable to practitioners when implementing new technology, as it initiates a strategy to balance the social and technical variables. However, relying on such an approach requires the company to engage with the environment of the technology implementation, to why we recommend assuming a sociotechnical system perspective, as it allows the company to reflect and gain transparency on the relevant variables to include before getting started with the implementation. Moreover, ensuring a balance between the socio- and technical variables is dependent on how well the company understands the level of transdisciplinarity within the sociotechnical system and learns that this is the prerequisite to connect the manufacturing on the inter-team level. If not accommodating the requirements and needs of the sociotechnical system, the company will not be able to do a proper assessment of the capabilities required to fulfill the implementation successfully.

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