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Published in:
Computers and Industrial Engineering

DOI:
10.1016/j.cie.2021.107910

Computers & Industrial Engineering 165 (2022) 107910

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

The redesign of blue- and white-collar work triggered by digitalization: collar matters

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ARTICLE INFO

Keywords:
Digitalization
Work design
Socio-technical design
White-collar work

ABSTRACT

The implementation of digital technologies in the context of Industry 4.0 radically changes methods of production and thereby the jobs of blue-collar workers. Although the work design effects of digitalization on the operator 4.0 have been explored in the existing literature, less is known about the simultaneous effects on white-collar work and the underlying (re)design process of human work including the factors that shape this process. To address this gap, we performed an in-depth industrial case study of an organization in the process of digitalization. Our findings confirm the concurrent impact of digitalization on blue- and white-collar work and suggest that its human implications highly depend on the extent to which, and at what moment, human factors are considered during the design and implementation process. Where work design knowledge lacked, the motivation of system designers turned out to be an important individual factor to realize favorable work design outcomes. At the organizational level, results show the importance of early involvement of system users and incorporating social performance indicators in addition to operational performance indicators in the statement of project goals. Our findings provide important empirical input for the further development of human-centric models and theories that integrate the challenges and opportunities for blue- and white-collar workers that are emerging when adopting digital technologies.

1. Introduction

Manufacturing organizations worldwide are currently undergoing pervasive social and technological changes as a result of Industry 4.0 technological developments. Industry 4.0 refers to the confluence of new innovative technologies in manufacturing, with the potential to create ‘smart factories’ with an increasing machine and algorithmic intelligence (Da Xu, Xu, & Li, 2018). At its center lies the concept of digitalization, referring to the adoption of information technologies in manufacturing organizations (Stolterman & Fors, 2004). The continuing proliferation of digitalization is shaping the nature and organization of human work in manufacturing, yet there is limited empirical evidence to support the growing number of predictions of how the digital transformation affects workers (Kadir, Broberg, & Conceição, 2019).

While digitalization may make certain tasks obsolete, it can also change existing tasks and/or create new tasks and interaction requirements of humans with technological systems that may ask for other skills and may ultimately put new demands on the workers (Waschull, Bokhorst, Molleman, & Wortmann, 2020). Current predictions found in the literature mainly focus on the potential enrichment of the work of humans who perform manual tasks on the shop-floor (i.e., blue-collar work) (e.g., Romero, Stahre, et al., 2016). Since digitalization enables the integration of smart resources (machines, workers), products, and processes within and across organizational boundaries (Alcácer & Cruz-Machado, 2019), the unit of analysis needs to be expanded to include the work of humans who perform supporting tasks such as work preparation, control or decision-making (i.e., white-collar work) (Pacaux-Lemoine, Trentesaux, Rey, & Millot, 2017). In fact, in factories, blue- and white-collar work is often deeply intertwined on the process level, creating important interdependencies relevant for understanding predicted changes. However, to the best of our knowledge, there is limited research that addresses digitalization from the perspective of a manufacturing process with interacting blue- and white-collar work.

Moreover, for creating a holistic understanding of how digitalization changes human work, it is not enough to only consider the technical changes resulting from digitalization. Since manufacturing systems are socio-technical systems, both technical and social choices need to be made during the design and/or deployment process of digitalization

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https://doi.org/10.1016/j.cie.2021.107910

Available online 6 January 2022

(Neumann, Winkelhaus, Grosse, & Glock, 2021). These choices made during the design process will have implications for human factors by affecting the task, knowledge and social characteristics of human work (Humphrey, Nahrgang, & Morgeson, 2007). This topic lies in the realm of work design, which refers to the processes and the outcomes of how work is structured, organized, experienced, and enacted (Morgeson & Humphrey, 2008). Yet, the majority of work design research till now has focused on how the work design, which is characterized by certain job characteristics, leads to individual and organizational outcomes (Humphrey et al., 2007). Systematic empirical research on what actually happens during the design process of human work during digitalization, let alone why certain technical and social choices are made or neglected by system designers, is sparse. This is despite the several calls for more attention to factors that influence the design process of work, including individual factors relating to the system designer, and organizational factors relating to the context the digital transformation occurs in (Clegg & Spencer, 2007; Grant & Parker, 2009; Oldham & Hackman, 2010). For example, for many practitioners, the digital transformation and its implications on operations processes and related human work remain a big black box (Neumann et al., 2021).

As the design process in the context of digitalization may impact important outcomes including motivation, job satisfaction and productivity for multiple types of jobs, the design process of human work certainly deserves further attention. Therefore, detailed industrial case studies must be conducted to create a better holistic understanding of the relevant factors, interactions and influences when introducing new digital technologies in manufacturing (Kadir et al., 2019). These empirical studies are also needed to provide important input for the development of models and theories that integrate the challenges and opportunities emerging from the adoption of digital technology.

In response to these gaps, the current study formulated two aims focusing on changes of blue- and white-collar work triggered by digitalization. We first explore how the design process of the work of white- and blue-collar workers unfolds. This includes exploring what socio-technical changes and interactions take place, and what the resulting work design effects are in terms of changes in relevant job characteristics. We consider the work of operators, who have to cope with the adopted digitalization solutions but also include white-collar work, represented by the work of manufacturing engineers, who enable the proper functioning of these digitalization solutions for operators. Our second aim is to better understand why the design process of human work unfolds in the way it does.

To achieve these two aims, an in-depth qualitative study was conducted at an aerospace industry supplier who designs, develops, and pilots digital technology for shop-floor digitalization addressing the work of operators and manufacturing engineers. Multiple sources of data were collected over four years, providing a rich and detailed exploration of the forces at play. We found that digitalization involves interconnected design processes of blue- and white-collar work to standardize manufacturing execution, resulting in job simplification and job enrichment respectively in our case. Second, we show that the redesign process is strongly influenced by the motivation of the individuals in charge of the design (i.e., system designers), which is in turn shaped by several organizational factors.

2. Theory

In this section, we present relevant background information on digitalization within Industry 4.0 in Section 2.1, followed by an overview of the impact of digital technologies on blue- and white-collar work in Section 2.2. In Section 2.3, we pay attention to the design process of human work and in Section 2.4, we focus on the factors that shape this design process. Finally, in Section 2.5, we present the research questions and the research framework.

2.1. Digitalization within Industry 4.0

Digitalization refers to the process of adopting information technologies in various contexts, including manufacturing (Legner et al., 2017; Stolterman & Fors, 2004). Digitalization in industry already started decades ago with automation through the use of computers. The rise of the internet provided a further boost to the adoption of digital technologies. The latest wave of digitalization is associated with Industry 4.0 (e.g., Buer, Semini, Strandhagen, & Sgarbossa, 2021; Li, Dai, & Cui, 2020; Richter, Heinrich, Stocker, & Schwabe, 2018) and includes fundamental networked information technologies such as the Internet of Things (IoT), Cloud computing, Big Data, and advanced analytics that provide connectivity and intelligence (Frank, Dalenogare, & Ayala, 2019).

The digital transformation in the context of Industry 4.0 is expected to increasingly automate information processing functions at increasing scopes of operations in industrial production (Waschull et al., 2020). Whereas traditionally digitalization focused on data collection and data distribution, its aim in the context of Industry 4.0 is to first achieve vertical integration of the hierarchical levels of the factory, providing a new and unprecedented level of information transparency and interconnection of processes (Hermann, Pentek, & Otto, 2016). In practice, organizations are indeed found to first focus on the implementation of front-end digital technologies that enable vertical integration, such as sensors/PLCs, Supervisory Control and Data Acquisition (SCADA), Manufacturing Execution System (MES) and Enterprise Resource Planning (ERP) systems (Frank et al., 2019).

As a key enabler of digitalization and vertical integration in specific, MES focuses on the digitalization of shop-floor activities by monitoring, documenting and reporting information on the transformation of raw materials into finished goods, enabling the control and optimization of production activities as they occur (Saenz De Ugarte, Artiba, & Pellerin, 2009). It exchanges up to date shop-floor information (e.g., feedback, process data) across the different hierarchical layers (e.g., shop-floor actuators, manufacturing execution level, production management level and corporate planning level) (Liao, Deschamps, Loures, & Ramos, 2017; Saenz De Ugarte et al., 2009). More advanced implementation stages of Industry 4.0 include digital technologies to realize advanced automation, virtualization and flexibilization, such as industrial robots, Artificial Intelligence (AI), and Additive manufacturing (Frank et al., 2019). In this research, we will mainly focus on the first stage of the adoption of Industry 4.0 digital technologies, related to realizing vertical integration.

While it is inherent that digitalization within Industry 4.0 changes the design of the technical system, it is likely to also interact with the design of the social system. When redesigning existing methods of production and related human work, decisions on the overall task structure, the organization of tasks, the interaction with technology, and the required skills and competencies of humans need to be included (Hirsch-Kreinsen, 2016; Kadir et al., 2019). The expected risks and opportunities that emerge for human work apply not only to the work of blue-collar workers in the factory (operators) but also increasingly to work in the cognitive and higher-skills domains of white-collar workers (Frey & Osborne, 2017), such as manufacturing engineers, team-leads or quality controllers and managers (Autor & Dorn, 2013; Frey & Osborne, 2017;

Parker & Grote, 2020). Put differently, digital technologies do not only apply to a local machine or workstation and do not mainly change how people do things, but also impact how that work is controlled, how decisions are made, and how work is organized by others, spreading into domains that are commonly characterized as non-routine and cognitive (Cascio & Montealegre, 2016; Waschull, Bokhorst, Molleman, & Wortmann, 2020). The following two subsections provide further background on the impact of digital technologies on human work, and on designing work.

2.2. Impact of digital technologies on human work

The literature states both positive and negative predicted effects of digital technologies on human work (Hirsch-Kreinsen, 2016; Parker & Grote, 2020; Sgarbossa, Grosse, Neumann, Battini, & Glock, 2020). We will review the impact on blue-collar work first and then continue with the impact on white-collar work.

On the one hand, a large share of the literature describes a general enrichment scenario for blue-collar workers. In this scenario, blue-collar workers remain an integral part of the system, are in full control of the decisions, and are augmented by technologies to perform an increasing number of complex jobs in higher skill domains with higher cognitive demands (Gorecky, Schmitt, Loskyll, & Zühlke, 2014; Kagermann, 2013). For example, Gorecky et al. (2014) demonstrate solutions for assisting blue-collar workers to realize their full potential in a wide range of jobs, thereby assuming the role of strategic decision-maker and flexible problem-solver. Similarly, the operator 4.0 concept refers to the vision to empower 'smart operators' with new skills and gadgets to fully capitalize on the opportunities being created by Industry 4.0 technologies (Romero, Stahre, et al., 2016). On the other hand, a quite different scenario is sketched assuming a general job degradation of blue-collar workers. In this scenario, workers become subservient to the directives and control of machines and advanced AI technologies (Frey & Osborne, 2017). The majority of workers' tasks are reduced to solely monitoring the automated system, and a few complex jobs remain that are related to the design, implementation, and training of the system, or aspects of innovation (Waschull et al., 2020).

In contrast, relatively little research has focused on the effects of digitalization on white-collar factory workers, who deal with decision-making, control and scheduling (Kadir et al., 2019; Pacaux-Lemoine et al., 2017). Extant literature implicitly seems to assume that blue-collar workers will slowly transform into white-collar workers due to job enrichment and the augmentation capabilities of advanced digital technologies. For example, operators will take over tasks that were originally considered to be engineering tasks such as process control or continuous improvement (Spath et al., 2013).

Although the extent of these developments remains to be seen, digitalization influences the interaction between blue- and white-collar work in factories through the encapsulation of product design and production process information into unique digital artifacts (Holmström, Holweg, Lawson, Pil, & Wagner, 2019). This leads to possibilities to redistribute activities within and across organizations. In case digital technologies are used at the interface of white- and blue-collar work, it may potentially impact the work of both and their collaboration.

To characterize and evaluate changes in human work triggered by digitalization, work design theory is applied as a theoretical lens in this research. This theory primarily deals with the question how work ideally should be designed by exhibiting several job characteristics with the goal to improve individual outcomes (e.g., motivation, well-being, satisfaction) (Hackman & Oldham, 1975; Morgeson & Humphrey, 2008). The job characteristics are grouped into three major categories (Morgeson & Humphrey, 2006):

- Task characteristics: how the work itself is accomplished including the range and nature of tasks e.g., job autonomy, task variety, feedback from the job;
- Knowledge characteristics: reflecting the type of knowledge, skill and ability placed on the individual, e.g., job complexity or skill variety; and
- Social characteristics: the broader social environment of the job, e.g., social support and interdependence.

Jobs that embody many of these characteristics are usually referred to as enriched jobs, while their absence leads to degraded, or simplified jobs. For example, task simplification, skill simplification, and repetition are typical design interventions that lead to simplified jobs.

While work design can be regarded as an outcome, specifying a job's characteristics, it can also be seen as a process to create or modify jobs in order to realize certain desired characteristics. Relevant background on this design process of human work is presented in the next Section 2.3.

2.3. Designing human work

The integration of digital technologies into manufacturing systems creates engineered systems consisting of humans and technological components which reflect socio-technical systems (STS) (Wang, Törngren, & Onori, 2015). STS theory is a key theory of work design, centering on the idea that when the social and technical systems are jointly optimized, the design and performance of systems can be improved and/or a system works more satisfactorily (Cherns, 1987; Clegg, 2000). Examples of improvements include improved productivity and competitiveness, but also employee-related performance (van Eijnatten, Shani, & Leary, 2008). The technical system refers to the related infrastructures and functionalities of the technologies that are exploited, whereas the social system is related to the people and their tasks, their relationships, and their organization (Trist, Higgin, Murray, & Pollock, 2013).

STS theory offers a set of principles to guide the design process, yet the application in practice has been found to be disappointing (Clegg, 2000). For example, the principle of joint design and optimization of the social and technical system remains rare, meaning that IT projects have been found to often emphasize the technical over the social system (Davis, Challenger, Jayewardene, & Clegg, 2014). In such techno-centric designs (i.e., design processes that primarily pay attention to the technology), human work is designed around, or needs to adapt to the new technology rather than influencing the design of the technology (Challenger, Clegg, & Shepherd, 2013; Clegg & Shepherd, 2007).

To overcome these challenges and to facilitate a socio-technical design, existing research in the context of Industry 4.0 till now has primarily focused on the development and application of so-called human-centric design methods and how these lead to the better accommodation of human workers in the design phase. Human-centric design methods are in essence socio-technical design approaches, accounting for the workers' physical, cognitive and sensorial capabilities during the design and operation of systems. For example:

- Pinzone et al. (2020) developed a framework that guides decision-makers in analyzing how the functionalities of a Cyber-Physical

System relate to operational and human-factor related performance impacts;

- Romero, Bernus, Noran, and Stahre (2016) promote a human-centric design approach in the context of Industry 4.0, aiming to enhance humans' physical, sensorial and cognitive capabilities and to ultimately improve their overall well-being, motivation, and productivity; and
- Kadir and Broberg (2021) propose a framework integrating human factors, work system modeling, and strategy design to promote a human-centric design of work systems.

The design and/or adoption of digital technology involves making design choices by individuals in the local context (e.g., engineers, managers), both in terms of the technical system and social system and considering their interdependency. Key choices refer to the functionalities of the technology, and how the work will be distributed, managed and organized (Clegg, 2000). These choices will affect the characteristics of jobs in terms of the tasks, knowledge and social requirements of jobs. For example, the decision to automate a data collection task through digitalization may reduce an operator's task variety.

Despite the large bulk of knowledge of STS theory, and the positive effects of enriched work (Humphrey et al., 2007), poorly designed work continues to exist at many organizations (Lorenz & Valeyre, 2005). This provokes questions as to why work is designed in a certain way. To understand this, we address the individual and organizational factors that shape the redesign process in the next section.

2.4. Factors shaping the redesign process

To better understand the design process of human work triggered by digitalization, e.g., why certain choices are made or neglected, we need to consider the influence of several individual and organizational factors on the design process of human work (Findlay, Warhurst, Keep, & Lloyd, 2017). The limited number of empirical studies that focus on the design process of work suggest that system designers often have very limited awareness of design choices related to human work, and when they do, they rather "naturally" adopt a mechanistic approach to designing work (Campion & Stevens, 1991; Clegg, 1984; Parker, Andrei, & Van den Broeck, 2019). This means they divide labor based on specialized and narrow tasks and focus on standardization (Parker, Wall, & Cordery, 2001), usually resulting in low-quality jobs. Parker et al. (2017) underline the potential role of knowledge to guide the design process, yet there are limited empirical studies on this topic. Due to a lack of knowledge of individuals, the interdependencies of the technical and social system may not be apparent during the design process, or may be difficult to anticipate, and may only become apparent once the system is in operation. As one of the few recent studies, Parker, Andrei and Van den Broek (2019) found that explicit knowledge determined enriching work design behaviors of individuals. Explicit knowledge includes training in psychosocial work design theories (e.g., the job characteristics model, the demand-control model, and concepts such as motivation, work stress, or person-organization fit). They also highlighted the potential importance of the motivation driving the system designers, as pointed out by earlier studies (Blumberg & Pringle, 1982). Motivation can be driven by extrinsic pressures external to the individual, such as market pressures or regulations (i.e., extrinsic motivation), or by the individual's autonomous motivation, e.g., doing it because it is interesting or it is in line with your values (intrinsic motivation) (Ryan & Deci, 2017).

Beyond work design knowledge and motivation, which we consider to be individual influences, the design process of human work may also be influenced by political, social, or technological constraints or enablers in the organizational setting, i.e., organizational influences (Nielsen, Randall, Yarker, & Brenner, 2008; Parker, Broek, & Holman, 2017). Organizational influences can affect system designers' motivation or knowledge, which in turn shape the design choices they make (Parker et al., 2017). Organizational factors can include, for example, the organizational strategy, the HR practices, the organizational design, or the organizational culture. For example, despite possessing the required knowledge and motivation, system designers may not have the leeway or opportunity to focus on social issues (Molleman, 2000).

2.5. Research framework

To address the two aims stated in the introduction, we formulate the following research questions and summarize them in the conceptual framework proposed in Fig. 1.

Research questions addressing research aim 1:

1. How does the design process of work triggered by digitalization impact the characteristics of manufacturing engineers' jobs?
2. How does the design process of work triggered by digitalization impact the characteristics of operators' jobs?

Research questions addressing research aim 2:

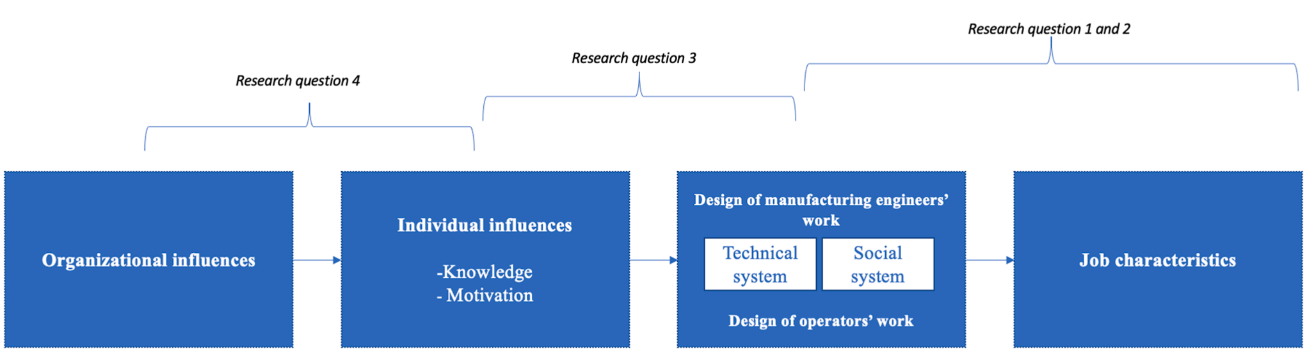

Fig. 1. Research framework.

3. How do knowledge and motivation of system designers influence the design process of human work?
4. Which characteristics of the organization influence the knowledge and motivation of system designers?

3. Method

3.1. Research design & case selection

The literature review indicated a lack of detailed industrial cases regarding the socio-technical considerations that emerge during the design and adoption of digital technologies. Empirical research is thus needed to support the growing number of theoretical claims and predictions and to provide important input for the further development of models and theories that have value for practitioners. A case study lends itself to this research goal as it enables exploratory investigations of a contemporary phenomenon in its real-life context (Yin, 2009), and is suitable to investigate and develop an initial understanding of complex problems (Stake, 1995).

The problem under investigation is complex since the complete set of relevant variables and their linkages (the factors that shape how and why human work is designed) is still unknown (Meredith, Jack, Raturi, Amoako-Gyampah, & Kaplan, 1989). Moreover, case research is appropriate when, as in our case, context knowledge is important (Voss, Tsikriktsis, & Frohlich, 2002). We perceive the phenomenon under study not isolated from its context, but rather of interest precisely because of its relation with the context, in this case, the organizational factors that shape the design process. This is also one of the reasons why we have chosen to adopt a single case study design. While we are aware that examining a single organization limits the transferability of the findings, it is a suitable strategy for theory exploration, thereby capturing and understanding the deep insights of the case (Dyer, Gibb & Wilkins, Alan, 1991), where there is only limited knowledge of the proposed relationships. Systematic description of the properties and relationships of processes in a single case, and of the contexts through which such processes emerge, is a critical form of knowledge for theoretical development (Pettigrew, 1985). Studying the single case in depth enables us to generate concepts and give meaning to the abstract theoretical propositions, which subsequently can be tested in other organizations to seek a higher degree of theoretical generalization.

The single case study can offer convincing results when the case is deliberately selected to provide insights that other cases may not (Siggelkow, 2007). The considered case allows us to study the complete development and adoption cycle of the digital technology in depth, as the case company is not buying and integrating an off-the shelf software where the majority of technical and social choices have already been determined. Moreover, the case company is in the process of digitizing its manufacturing processes involving blue-collar and white-collar work, where white-collar workers take on the role of work designers. The digitalization project at the case company was also perceived as an innovative project for this type of industry.

Since we aimed to focus on the antecedents and effects of socio-technical interactions, the unit of analysis is the design process of work triggered by digitalization, specifically the work of operators and manufacturing engineers.

3.2. Case setting

The case organization (named Aero) produces lightweight composite aerostructures for the commercial and defense industry. Aero underwent a digital transformation program called Aero 4.0 between 2015 and 2019. The program was seen as an innovative project for this type of industry and received an R&D innovation grant from local authorities. This was the reason to include a local research institute in the project and to involve IT suppliers who were willing to co-invest in this innovation. The case data was collected between 2015 and 2019, following the complete definition, development, and implementation cycle of the new technology. The research team, and in particular the first author, collaborated closely with the case company and had the opportunity to study the complete digitalization process extensively over the course of four years. The third author acted as member of the project steering committee over the whole period. A diverse and thorough picture of the important interactions and forces at play was captured, including rich contextual insights. More detailed background on the case study is provided in Section 4.

3.3. Data collection

To collect data for answering our research questions, we examined the design process of work over a period of four years between 2015 and 2019. We applied different data collection methods to enhance reliability and internal validity. A summary of the different data sources is provided in Table 1.

To increase the reliability of the study, a case study database was created in which case data was collected and documented. It contained case study notes, documents, tabular materials and case narratives. Starting in June 2015, the first author of the paper participated in the technology development team, and conducted weekly on-site visits, and participated in weekly progress meetings. We, therefore, observed the design process unfolding in real-time and we took field notes during these visits and observations, resulting in approximately 1536 h spent on site. In addition to observations taken during the team meetings, we also

Table 1
Overview data collection methods.

Data collection method	Data source
Formal observations	• Steering committee meetings (monthly) • Development team meetings (weekly) • Proof of concept testing sessions • User training sessions • Pilot implementation activities
Informal observations	• Regular weekly factory visits to observe users and to collect data input & feedback on technology
Interviews	• 24 interviews semi-structured interviews with different project stakeholders, including system developers and users
Informal conversations	• With different project stakeholders and case representatives during weekly factory visits
Documents	• Use-cases and functional requirements • Software • Meeting notes • Project and working groups presentations • Reports of issues, bugs and improvements regarding software • Project planning documents

Table 2
Overview interviewees after the start of the pilot implementation.

	Relationship with project	Number of interviewees	Daily function outside project
1	Member Functional Board	1	Site manager quality
2	Member Functional Board	1	Site manager operations
3	Member Functional Board	1	Site manager manufacturing engineering
4	Chairman Functional Board	1	Project manager investments
5	Member Functional Board	1	Logistics lead composite factory
6	Member Functional Board	1	Program managers of aerospace program
7	Member Functional Board	1	Site manager Supply Chain Management
8	Member Functional Board	1	Site manager Human Resources
9, 10	Member Development Team & user of digital technology	2	Manufacturing engineer
11	Member Development team -& user of digital technology	1	Quality engineer
12	Member Development team & user of digital technology	1	Process specialist (engineer)
13	Member Development team	1	Quality lead
14	Member Development team	1	Planning lead
15	Member Development team	1	Dedicated project manager
16	Chairman Steering committee	1	Site director
17–21	User of digital technology	5	Operator
22	User of digital technology	1	Team-lead operations
23, 24	Implementation team	2	Quality controller

observed and took field notes during the training and testing activities with future users, and the implementation pilot in the factory. We posed questions to the users of the new technology regarding their work before and after the adoption of the technology during many informal visits to the factory.

The observations were crucial in clarifying how the design process unfolded, but also in understanding the individual and contextual factors that shaped the process, as well as for mapping the work design changes. In addition, we participated in numerous informal conversations with the different stakeholders. Much interesting information was captured after spending time with the people involved, allowing us to see the routines, culture, and behaviors evolve. In addition, after the start of the pilot implementation on the shop floor (between June and December 2019), we conducted 24 semi-structured interviews with people involved in the digitalization program to triangulate our observational data. We focused on two groups of people.

First, we interviewed people that were actively involved in the design process of work as an active member of the project. We asked these interviewees to reflect on the technical and social changes, the motivation that drove their decisions, their knowledge regarding work design, and finally inquired about relevant organizational factors. Second, we asked the users of the new technology (i.e., operators and manufacturing engineers) to explain the work design changes that they experienced during the use of the technology. Through interviewing both system designers and users of the technology, we obtained a balanced view of the mechanisms and effects, which validated our extensive observational data. Table 2 provides an overview of the different interviewees, including their role in the project and their regular function at the case organization. All interviews were conducted face-to-face (lasting on average about an hour) and were recorded and transcribed verbatim. We used a semi-structured interview protocol that evolved over the course of the data collection. To supplement the observational and interview data, other secondary, documentary evidence was collected from the internal project database and included development and testing documents of the software, meeting notes of the different working groups, company and project presentations, and e-mails.

To limit observer bias, the observations made were discussed and validated with the whole research team to ensure that the researcher remained objective. Moreover, there were different moments during the research period to discuss and reflect on intermediate findings with the case company.

3.4. Data analysis

The data collection and analysis followed a highly iterative nature. We started with an inductive data analysis, but also used deductive (or abductive) reasoning by drawing on the existing literature and constructs (Eisenhardt, 1989). We defined an initial research question and broad a priori concepts before we entered the field, focusing initially on the changes in job characteristics occurring during digitalization. When starting to collect data, we allowed us the flexibility to take advantage of emerging themes and relationships and adapt our research focus accordingly (Eisenhardt, 1989; Eisenhardt, Graebner, & Sonenshein, 2016; Piekkari, Welch, & Paavilainen, 2009). Overall, we therefore followed an iterative process involving constant iteration backward and forward between the analysis steps to relate the data to the theoretical framework (Eisenhardt & Graebner, 2007). After further exploration, our research focus shifted from a deterministic assumption about the relationship between technology and the characteristics of jobs to acknowledging the importance of the socio-technical design process including the factors that influence it. It proved to play an important role when assessing, and fully understanding, the changes of human work triggered by digitalization. Our research focus then expanded to include the design process in our unit of analysis.

Since we drew on existing literature to develop our research questions, the data analysis was based on three types of coding suggested by Miles & Huberman, (1994) and Miles, Huberman, & Saldana, (2019). This coding scheme is followed by many researchers and is a prominent method for data analysis in case research (Voss et al., 2002). This coding process allowed the reduction and categorization of data to draw conclusions regarding our research questions. Guided by an initial coding scheme derived from the theoretical concepts identified in the conceptual framework, we first assigned codes to phrases and paragraphs to organize the data into broad conceptual categories (Miles & Huberman, 1994; Miles et al., 2019; Voss et al., 2002). Next, within each of these categories, we assigned descriptive first-order codes to further reduce the data for analysis. Third, based on these descriptive codes, we examined the data for emerging themes in relation to the broad conceptual categories, i.e., grouping codes that were conceptually similar. This process included detailed review and discussions among the authors on the conclusions, allowing us to define and refine the conclusions drawn. The themes reflected the relevant organizational influences, individual influences, technical choices, social choices and changed job characteristics identified in the literature. This analysis was conducted for the work of manufacturing engineers and the work of operators, which allowed us to identify similarities and differences.

To increase inter-rater reliability and strengthen the trustworthiness of the findings, each researcher separately coded a selected number of interviews, sharing and discussing the coding scheme afterward. We conducted several iterations of the coding process until we were satisfied with the type of codes and data. We used atlas.ti to build and maintain a database in a systematic manner. Although the data was coded manually, the software was helpful in fragmenting, organizing and re-coding the data.

We applied several techniques to ensure the trustworthiness and validity of our findings, including triangulation, multiple iterations of data analysis, and verification of findings with the case company.

4. Case study

In this section, we first provide background on the used terminology regarding manufacturing engineering and production execution. This is important input for understanding the nature of digitalization at the case company, which is described next.

4.1. Background terminology

In discrete manufacturing industries, it is quite common to structure manufacturing into a number of stages, where components or raw materials are transformed into intermediate products or final products. Each stage consists of several operations which transform materials or components into desired products. These operations are usually prepared before orders are released for execution to the shop floor. The documents which contain these preparations are called *work preparations or work definitions.* The organization which manages the life cycle of these documents is called *definition management.* The people who do the work preparation are called *manufacturing engineers* in our case. The people who execute the work are called *operators*. The organization which manages execution is called *production execution management* and includes team-leads, quality controllers and planners.

Operations consist of a number of detailed steps. Manufacturing engineers define operations by specifying the required detailed steps to be taken in executing the operation. For each step, they also specify the skills needed by operators, the tools, the machinery, and any additional components or materials required, and further instructions. Also, measurements to be performed and machine parameters to be monitored are specified in detail (Matisoff, 1986).

Traditionally, manufacturing engineers used texts to describe the work preparations, and operators were supposed to read these texts. However, experienced operators would skip the reading, because they know by heart what is needed to execute the operation. This may become a problem in case of changes of the work preparations: many operators will not notice a change in a long text unless they are explicitly notified. Therefore, modern work preparations tend to have little text, many visual explanations and changes accompanied by alerts.

Although work preparations describe the work content of operations, these documents do not completely determine the work design of an operator. Likely, operators have other tasks that are not specified in work preparations, such as machine maintenance, tool cleaning, and continuous improvement actions (e.g., Kaizen). Furthermore, the work organization around issues such as personal care, taking a break, rules for collaboration and support between operators also contribute to the overall work design of an operator. Decisions on these aspects are usually taken by line managers and HR representatives. Our study will consider all work design decisions within the digitalization project, including those related to product definition.

4.2. Nature of digitalization at the case company

The digitalization project aimed to improve efficiency and product quality by standardization of manufacturing execution. Before the digitalization program, manufacturing execution was based on paperwork that was printed when a workorder was released. Such a print (routing sheet) consisted of sheets of paper, where each sheet contained a list of steps required for the execution of an operation, including measurements. These steps were monitored by hand-written notes on the sheet. The same held for measurements. Some of the written values were entered in spreadsheets for quality control and other purposes.

The digitalization program acknowledged that a key role for standardization of the manufacturing execution resided in the nature and definition of the work preparation documents. The work preparation documents were written and managed by manufacturing engineers, who had quite some freedom in the structure and content of the work preparation documents. However, for quality-related measurement, they were supported by quality engineers, for maintenance-related work they were assisted by maintenance engineers, and for the machine settings and measurements they were assisted by process engineers. All these other engineers contributed texts which were compiled by a manufacturing engineer into the work preparation document, which was also referred to as shop-floor instructions. Also, drawings from CAD systems were copied into the work preparation documents. The configuration of these documents was completed per individual product in office applications and included process and product-specific information, more specifically process instructions on how to produce a product, with what tools, and the specifications required.

This way of working on product definition had a number of disadvantages. First of all, it was cumbersome. Work preparation documents were created and managed per individual product and often from scratch. Moreover, when writing these documents, texts of other engineers were rephrased by manufacturing engineers in their own words. Moreover, it was very difficult to manage changes in products or in procedures from other engineering disciplines. In case of a change request, first, all the relevant products where the change needed to be implemented needed to be identified by the manufacturing engineer, followed by an implementation of the desired change per product. For products that were already in production, engineers spent a lot of time running through the factory to find them, and consecutively informing the operator about the change or writing it on the work preparation documents. Finally, it was difficult for the operators to find their information in texts which were structured according to the preference of the individual manufacturing engineer, and which were often long and verbose. It was also not easy to relate the work preparation documents to the steps which were printed on the routing sheet corresponding to the operation to be executed. Registrations (e.g., measurements, quality checks) were hand-written on the work order, but regularly incomplete.

Accordingly, the digitalization project started by innovating the work preparation documents, and digitizing the processes related to the definition and management of these documents (i.e., definition management) and to activities of execution management (i.e., the way that operators receive the instructions). Next, we will present the findings regarding the resulting technical and social changes of the work of manufacturing engineers and operators.

5. Analysis

In Section 5.1, we answer research question 1 and 2 regarding the technical and social choices made in the design process of the work of manufacturing engineers and operators, respectively, including the resulting impact on relevant job characteristics. In Section 5.2, we answer research question 3 and 4 by presenting the factors that shaped the observed design processes.

5.1. Designing human work

5.1.1. The design of manufacturing engineers' work

The digitalization program started by innovating the work preparation documents, thereby affecting the configuration and change management activities (i.e., definition management) executed by manufacturing engineers. Regarding the technological changes of the work system, a key aspect was software centered on the provision of a digital library of instructions. The digital library implements a revised ontology model of the manufacturing domain, specifying and standardizing the manufacturing domain into (1) product-specific data, and

(2) process data and resources, each provided and controlled by different manufacturing disciplines (quality engineering, manufacturing engineering, process control). Templates are defined per product family that prescribe the required operations of a job, its activities, and the underlying methods to execute such activities. Workflow functionality enforces and partly automates the execution of the configuration and change management activities. Furthermore, a source & derived relationship of work preparation documents with the library enables digital revision control. Specifically, if the source text in the library changes, then the new text appears in all derived documents. This same principle holds for drawings and visuals. Finally, as-built information of the product is stored in a digital database.

These technological changes make activities related to configuration management and change management much less cumbersome. The library facilitates a shared understanding and specification of the structuring of manufacturing processes among manufacturing engineers. Specifically, it enables another way of structuring and controlling process and product data, a shift from thinking in the preparation of specific text documents linked to individual products to thinking in preparing and controlling structural and controlled process activities from a generic library in relation to products and product families. In other words, manufacturing engineers' work shifted from a product-focus to a generic process-focus. This shift was described as difficult and complex, as it required manufacturing engineers to think in abstract concepts to redefine their underlying data and process structure, with higher conceptual thinking requirements. However, once the structure of the library was defined and implemented, and after the users were trained and educated in the usage of it, it actually simplified their daily work.

Whereas previously work preparation documents were created in different office applications per individual product and often from scratch based on the manufacturing engineers' discretion, their configuration is now done in one system by following a template which predetermines approx. 80 % of the required content. This includes the required operations, the activities, and the methods. Moreover, changes to work preparation documents can now be implemented once at their source in the library, automatically updating the instructions across all linked product families, including manufacturing orders that are already in production. This new level of standardization and formalization reduced the number and variety of tasks and lowered manufacturing engineers' discretion concerning how the tasks are executed, that is, it affected their autonomy. Templates and workflows determine the sequence in which tasks are executed, reducing planning autonomy, and the methods used to execute (part of) their work.

Because the library was designed to contain generic standards applicable and used across production facilities, there is now an increased need for a broader harmonization for and interaction of manufacturing engineers with different stakeholders as opposed to taking decisions autonomously and locally. This can involve manufacturing engineers from other production departments, responsible for other product families or production facilities, or other disciplines (such as process engineering). Moreover, because manufacturing engineers configure and change work preparation documents with the help of validated and tested methods and instructions, they reported that there is less need for firefighting, and hence problem-solving activities for issues emerging on the shop-floor are reduced.

The development of the library facilitated the creation of a stricter and more transparent task division and specialization between the different engineering disciplines involved in configuration and change management. Whereas previously it was the case that manufacturing engineers executed different roles and thereby had more freedom to conduct a larger number of different tasks, in the new system, a clear role division is defined and enforced in terms of user's roles, their tasks, and responsibilities. Senior production quality engineers are now in charge of defining the standard templates of process plans per product family. Process engineers are responsible for the design of the methods to execute manufacturing processes. Manufacturing engineers use the templates and configure these to a specific product. This task specialization reduced their task variety.

Due to the described simplification and automation of repetitive and routine tasks, time was freed up for new tasks. These tasks include data analysis and improvement tasks, which are enabled by the richer amount of data that is available and can be analyzed to identify root causes of emerging problems related to a process or a product. Another new focus includes the continuous improvement of shop-floor instructions and their visual content (i.e., what is the best way to instruct operators on a certain task). To achieve this, manufacturing engineers are also increasingly encouraged to spend more time on the shop-floor to interact with operators to ensure that the instructions are feasible and that they closely resemble the 'real world'. These new tasks are characterized as more interesting and challenging, thereby enriching the job of manufacturing engineers.

The design and adoption process of the library required various design iterations. These iterations were primarily a result of the design methodology adopted in the project, in which the improvements to the functionality of the software are broken down into time-boxed iterations called sprints. A large share of these iterations for manufacturing engineers were planned iterations based on a concrete vision and roadmap of manufacturing engineering work in the digital future (i.e., work with standard libraries). Functionalities and improvements to the software were prioritized, and planned over a certain time period. For example, the design of the library took precedence at first, and at a later stage, the change management functionality needed to be advanced to further simplify manufacturing engineers' work.

In addition to the planned iterations, some changes resulted from progressive insights obtained during the usage of the software, and especially from learning on the job. For example, the ease of use of the user interface (UI) of the software was perceived by engineers as low, which resulted in an updated UI layout with more possibilities to work with different visuals and formats. Overall, the technical and social choices made were based on a concrete vision regarding digital manufacturing engineering, putting the work of manufacturing engineers central to the design process and actively involving users, that is developing technology that enables this vision. These observations allow us to characterize the design process, although probably unintentionally, as a socio-technical design approach.

In sum, the answer to research question 1 is that digitalization has led to changed but more appealing jobs. The digitalization of work preparation promoted a shift of work from a strong focus on repetitive, cumbersome, and routine tasks related to configuration and change management, to a focus on the continuous improvement and analysis of processes. This includes a higher degree of specialization, as well as more interaction and dependence between manufacturing engineers with other engineering disciplines (across facilities) and with operators. The system designers, which included several engineers from different disciplines, designed the work based on a concrete vision of manufacturing engineering work in relation to digitalization. They adopted a socio-technical design approach, thereby following a primarily planned yet highly iterative development process of the technology with room to learn, make mistakes, and adapt.

5.1.2. The design of operators' work

Innovating the work preparation documents through the design and implementation of a digital library implied technological and social changes related to the work of operators. The aim was to provide the operator with all information needed for precisely the step being executed and nothing more. This was achieved by the adoption of a digital system that provides detailed digital shop-floor instructions based on the work preparation documents of manufacturing engineers. The operators interact with the system to select, start and finish operations of a production order and to receive the relevant information for its execution (manufacturing instructions, sequence of steps within the operation). Enabled by workflow functionality, the shop-floor system enforces and controls the steps as pre-defined, including data verification of the conditions of the sequence.

In terms of changes in operators' tasks, we distinguish changes caused by (1) the revised structure of the work preparation document and (2) the functionality of the technology that implements this structure on the shop-floor. First, with the help of the digital library, manufacturing engineers create the manufacturing instructions for operators, thereby defining in detail the type and sequence of activities of an operation, and how these have to be executed, including a description of the methods, the steps, and the required tools. In other words, by defining the data structure and the content of the digital library, they determine in detail how and when operators have to execute tasks. Even though manufacturing execution processes were already highly formalized before digitalization, operators reported that they experience less discretion and flexibility in deciding how and when to execute a task after digitalization. This represents reduced planning and method autonomy. The revised instructions were described as more detailed, standardized, and formalized than before, yet also provided a new level of clarity and precision that reduced ambiguity. Moreover, the instructions were described as less verbose than previously and include more visual content, such as 2D and 3D models and short videos, reducing the time spent on reading the instructions.

Regarding changes caused by the technology, we found that the execution of the instructions is enforced and controlled by workflow functionality, discouraging the divergence from prescribed and standardized processes. Operators are guided through the process in a stepwise manner, and if specified, are requested to enter data on the spot. The system evaluates whether these data registrations meet pre-specified conditions, and can determine an alternative workflow based on its outcome. For example, operators are required to provide registrations regarding the measurements of the product, and if norms are not met, a standard-repair process can be determined. Operators perceived reduced job autonomy as a result of these technological changes.

To overcome human error and reduce the time spent on administrative tasks, where possible the digital shop-floor system was designed to automate data registration tasks and data control tasks, reducing the variety of tasks of operators. For example, this includes registering the start- and finish time of a product, validating the authorization requirements of an operator or checking if all data registrations are complete.

The user interface of the system was designed in such a way that the operator is provided with all the information needed precisely for the task being executed, and nothing more. Specifically, all relevant shop-floor information is synthesized clearly in one screen, reducing the time spent searching, scanning, and collecting information, allowing operators to focus on the actual production task and less on searching for relevant information. Operators are informed by the system if process conditions are not met, which increases the feedback they receive regarding their task performance.

Regarding the design process, various change iterations to the technology, but also changes to the instructions (i.e., work preparation documents) were required. However, in contrast to the design and development process of the digital library used by manufacturing engineers, a large share of the iterations was a result of interfering unforeseen human factor issues leading to problems and inefficiencies on the shop-floor, resulting in unexpected outcomes for operational excellence. For example, as opposed to reducing the number of administrative tasks (e.g., collecting data, checking data), the new technology initially led to a significant increase of such tasks. Triggered by operators' complaints, but also due to the realization of the inefficiency of this approach, system designers reevaluated the library structure, which in turn led to a significant reduction of data registration and data controls tasks for operators. Another interesting example addresses the ability of operators to diverge from enforced instructions. During the implementation, several situations emerged in which it was necessary and beneficial to diverge from the standard instructions to avoid disruptions, delays, and inefficient work processes, but impossible to do so using the active version of the technology. As a result, system designers defined conditions in which operators could diverge from the standards, for example, conditions under which a standard repair process could be executed, or an alternative production method could be chosen. These alternative processes, in turn, were also defined and standardized, yet provided operators with more flexibility, being less dependent on the input of team-leads in repeating situations that discourse from the standard.

Since less attention was given to how the technology should be designed to meet operators' needs, and the design focus centered on the design of the digital library, the redesign process of the work of operators can be characterized as techno-centric. Operators' revised work design was largely determined by the new technology, as system designers failed to consider different design options beforehand, and initially showed little awareness of human needs. However, the implications of such an approach included the necessity to adapt the technology, or the library, as a result of problems and inefficiencies on the shop-floor. By trial-and-error, and due to increasing awareness of the implications of the redesign for operators, the design process gradually shifted, again unintentionally, towards a more socio-technical design approach that addressed human factors.

In sum, the answer to research question 2 is that digitalization has led to simplified work of operators. We found that the design of the work had the strongest impact on operators' autonomy due to the further standardization, formalization, and enforcement of operators' tasks. Operators' work shifted to focus on the physical production tasks with less information processing requirements and task variety due to the reduction of administrative tasks related to the data registration and data control, and improved shop-floor instructions. Automatic feedback is now provided if certain quality parameters regarding the process or product are not achieved.

The design of operators' work was triggered by the design of a new way of working for manufacturing engineers, which largely determined operators' work. In contrast to the socio-technical design approach of manufacturing engineers' work, the design of operators' work reflected a techno-centric design approach. A large share of the implications for operators' work was not foreseen, resulting in issues and problems during the implementation process. As a result, several iterations were required after the initial implementation, based on a trial-and-error approach to learning.

5.2. Factors shaping the design process

In this section, we provide the answer to the second and third research question on how individual and organizational factors shape the redesign of work. First, we focus on the individual factors of work design knowledge and motivation (Section 5.2.1, research question 3), followed by the characteristics of the organization that influence these individual factors (Section 5.2.2, research question 4).

5.2.1. Individual factors: The role of knowledge and motivation

5.2.1.1. Individuals' knowledge of socio-technical design. We explored the nature and role of system designers' knowledge regarding socio-technical design. We found that system designers have very limited theoretical knowledge of work design theories, such as the job characteristics model, the demand-control model, STS, or concepts such as motivation, well-being, or work stress. Based on the observations and interviews, we characterize system designers' knowledge as primarily mechanistic (i.e., aiming for job simplification including job standardization and the control of work processes). They are trained in engineering and not in psychology and therefore look at their world with an engineering lens. They have experience in the design and operation of engineered systems, focusing on standardization and the control of work processes including processes where operators play an important role. Even more, during the interviews and conversations, system designers were puzzled about what the concepts of work design, job characteristics, or socio-technical system design actually mean, and described this way of thinking and designing processes as new to them. It was generally perceived as difficult by the researchers to discuss processes from a perspective that transcends the traditional mechanistic approach to system design. In addition, it was also mentioned by interviewees that it was challenging to predict the impact of designed changes on workers due to their limited experience of digitizing processes, thereby justifying the adopted trial-and-error approach.

Accordingly, during digitalization, system designers designed the work of operators from a technical, engineering perspective (i.e., they followed a techno-centric approach), and not by jointly considering both technical and social aspects as expected in a socio-technical approach. When system designers observed in the course of the project that the outcome was not what was expected due to human factors at the level of the operators, the responsible changes were repaired in several cycles as they emerged. They learned by doing (mistakes), which made them more aware that human factors matter throughout the project, thereby building up important tacit knowledge to potentially alleviate this collateral damage in the future. The lack of explicit work design knowledge was found to impede a more proactive work design approach.

For the work of manufacturing engineers, system designers balanced the technical and human aspects during the design of human work (i.e., they followed a socio-technical approach), albeit unconsciously. With unconscious we mean that they were not specifically aware of the adoption of such an approach. Similar to the design of operators' work, they followed an iterative process characterized by learning by doing, however to a lesser extent. They were guided by a clear and thorough vision of manufacturing engineering work in the digital future, however also identified some improvements and adaptations during the design process. Overall, explicit work design knowledge was largely absent and therefore a negligible factor in positively shaping the design process of manufacturing engineering work. A much stronger antecedent was their strong motive to keep or enhance the quality of manufacturing engineers' work.

5.2.1.2. Motivation. We found the motivation of system designers regarding the design to be an important antecedent. We specify two types of motivation, namely extrinsic motivation, which is driven by external factors, and intrinsic motivation, driven by the individual's own goals or interests.

The design process of operators' work was shaped by a strong extrinsic motivation driven by the digitalization project goals, which were focused on creating more efficient, transparent and controlled manufacturing processes through digitalization. In the course of the project, the system designers were also motivated to reduce and repair the unexpected outcomes for operational excellence caused by the interfering human factors (e.g., less productive operators).

For the work of manufacturing engineers, system designers designed the work not only with the mentioned project goals in mind, but with a strong motive to enhance the quality of their own engineering job based on a clear vision and roadmap of how technology can make the work less cumbersome and hence more appealing. This contributed to them balancing both technical and social factors when redesigning the work from the start.

In sum, the answer to research question 3 (impact of individual factors) is that explicit knowledge on work design was lacking, which shifted the emphasis to the design of the technical system. However, intrinsic motivation was found to be an important factor to include social aspects in the design approach of the work of manufacturing engineers. The engineering-based knowledge and extrinsic motivation drove the techno-centric design of operators' work. The finding suggests that intrinsic motivation is an important factor that mitigates the lack of knowledge regarding socio-technical design.

5.2.2. Organizational factors: the role of context

Now that we have presented the findings on how the lack of work design knowledge and motivation shaped the redesign process, we focus on the relevant organizational influences. These are the project goals, the project organization, and the organizational culture.

5.2.2.1. Project goals. The goals of the digitalization project centered on achieving operational excellence, and neglected human factors related outcomes. In particular, the formulated goals included the improvement of (1) operational efficiency concerning operations, manufacturing engineering and quality control, (2) product quality, and, (3) information availability and accessibility. The achievement of these goals was measured during the project to demonstrate the delivery of a sound financial business case to justify further investments and a broader rollout of the newly developed technology. Desired human factor effects were not formulated as part of overall project goals. In addition to the lack of awareness and knowledge, interviewees referred to their perceived inability of quantifying human factor effects in relation to the technological change.

The goals directed the activities of the project and provided system designers with leeway, or opportunity in terms of resources (e.g., person-hours, budget) made available. It particularly shaped the extrinsic motivation of system designers to design a digital work system that enabled these goals. For the work of manufacturing engineers and operators, efficiency and quality improvements were achieved through automation of repetitive and cumbersome tasks, through standardization and through formalization. Even though the contribution of the integration of human factors to the achievement of these goals was initially ignored, system designers became increasingly aware of them after the redesign due to interfering human factors. Hence, when human factors interfered with these goals, system designers adapted their design approach accordingly.

5.2.2.2. Project organization. Another factor that played a role is the adopted project organization for digitalization, specifically the different actors that were involved and responsible for the design process. Throughout the course of the digitalization project, the development of a digital engineering library became a crucial enabler of digitalization at the case company, shifting manufacturing engineering into the center of all design activities. Consequently, the manufacturing engineering discipline took on a leading role as system designers, receiving input from other involved disciplines during the design and adoption process. This organization of the design team implies that the redesign of the work of manufacturing engineers was to a large share steered by engineers themselves, who were provided with significant opportunity, or leeway, to design their work according to their defined vision. Accordingly, they were motivated to take this opportunity to create appealing jobs for themselves. While crafting their jobs, they balanced social and technical factors, albeit unconsciously.

Operators were involved in the design process to a limited extent. They formed a source of feedback later in the project during the adoption of the technology. Therefore, they had little opportunity to design or craft their work early during the design process. The majority of feedback they provided focused on the interaction of the operator with the technology on the shop-floor (e.g., how are the new instructions perceived, are instructions clear and usable). Other elements of the job which were not directly affected by the technology but are still relevant in the context of digitalization, and which are usually designed by supervisors or line managers, were not addressed during the design due to the limited involvement of operators. These other elements include for example what decisions are taken centrally, and which ones are decentralized; the accessibility of colleagues during the execution; the

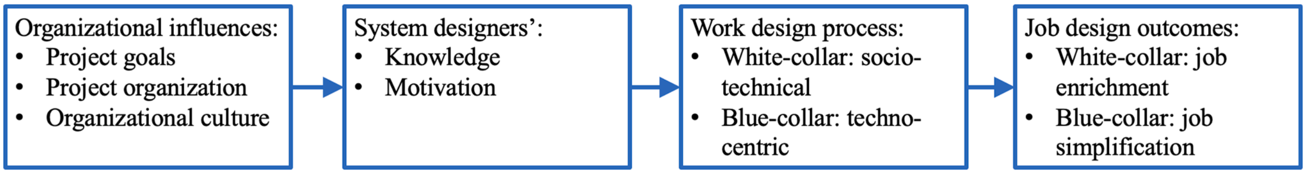

Fig. 2. Summary of the case study results.

tasks that operators can pick up when time is freed up due to digitalization. Moreover, team-leads and supervisors were hardly involved in the design team. Human factors specialists (i.e., human resources (HR)) were involved in the project primarily on a strategic level and provided advice on privacy issues and communication. They failed to advise on work design related issues. System designers also mentioned the absence of a set of best practices or organizational guidelines to address social aspects as a major constraint.

5.2.2.3. Organizational culture. The organizational culture and the nature of the industry were identified by interviewees as a contributor to the current state of knowledge regarding socio-technical redesign, and the focus on the achievement of operational excellence as the main driver of system design. The organizational culture was characterized by interviewees as engineering and technology-focused, placing top priority on the demonstration and execution of high engineering capabilities, reflected in the production of high-tech products meeting the highest quality standards. Interviewees referred to themselves as technicians that are highly focused and immersed in the technological aspects, focusing on producing high-quality products. An important aspect that shapes this organizational culture is the nature of the industry the case company operates in. They operate in an industry of highly complex, and safety–critical products, leading to very high compliance requirements towards their customers but also regulators. As a result, the compliance to requirements must be continuously monitored and demonstrated, for example, in terms of the manufacturing processes and the produced products.

6. Discussion and conclusions

6.1. Main findings

Through an in-depth industrial case study, this paper describes the interconnected design processes of white- and blue-collar work and explores how these processes influenced the job characteristics of manufacturing engineers and operators in a digitalization project. In addition, relevant individual and organizational factors are studied that explain why the overall design process unfolded in the way it did.

Digitalization to standardize manufacturing execution was found to not only influence the work of manufacturing engineers, who switched from a product focus to a generic process focus in order to efficiently create work preparation documents, but also the work of operators, who had to cope with the adopted digitalization solutions. Interestingly, the design processes of the work of manufacturing engineers and operators clearly differed. The design of the work of manufacturing engineers followed a socio-technical design approach, guided by a concrete vision of manufacturing engineering work and strong involvement of the manufacturing engineers from the start of the project. In contrast, the design of the work of operators focused on the technical system, did not sufficiently address the needs of operators from the start, and therefore required several iterations resulting from unforeseen human factor issues that led to problems and inefficiencies.

System designers had very limited explicit work design related knowledge, which explained the emphasis on the design of the technical system, especially within the design of the work of the operators. For the design of the work of manufacturing engineers, the strong motivation of the manufacturing engineers involved in the process to enhance the quality of their own work mitigated their lack of work design knowledge and led to a more socio-technical design approach.

Organizational factors that were found to play a role in the design process were the project goals, the project organization, and the organizational culture. The goals of the digitalization project strongly focused on achieving operational excellence and the integration of human factors to achieve these goals was initially ignored. The project organization provided manufacturing engineers a pivotal role in which they could craft their own jobs, balancing social and technical factors, whereas the role of operators stayed reactive. Finally, the engineering and technology-focused organizational culture enforced the emphasis on achieving operational excellence as the main driver of system design.

As a result of digitalization, the work of manufacturing engineers was simplified and routine tasks were automated. However, their initiative and leeway to take up new and more challenging tasks, including data analysis and continuous improvement tasks, resulted in enriched jobs. The work of operators was simplified due to digitalization, with decreased autonomy and a larger focus on physical production tasks enforced by the execution system. Iterative adaptations during the design process reduced some of these negative effects. The results are summarized in Fig. 2.

6.2. Theoretical implications

Our findings confirm the concurrent impact of digitalization on blue- and white-collar work. Specifically, we find a degradation scenario for blue-collar work and an enrichment scenario for white-collar work. In other words, collar matters. We found that operators' work is increasingly controlled by digitalization and consists of remaining tasks which cannot be easily automated for technical or socio-economic reasons, representing an 'automation scenario' (Hirsch-Kreinsen, 2016). This contradicts the enrichment scenario of operators' work as currently sketched in a part of the literature (Pinzone et al., 2020; Rauch, Linder, & Dallasega, 2020; Romero, Bernus, et al., 2016). The enrichment scenario envisions operators' work to become much more complex due to increasing product and process complexity on the one hand and the required interaction with computational automation devices on the other (Lazarova-Molnar, Mohamed, & Shaker, 2017). Also, the expectations that operators will take on an increasing number of white-collar tasks (e.g., engineering tasks) (Stern & Becker, 2017) is not supported by our findings. Rather, we found that blue- and white-collar tasks remained separated. Furthermore, despite an increased standardization and formalization within white-collar work, digitalization enabled new opportunities to be built into their work, resulting in job enrichment.

An explanation for these different outcomes that is well-known from previous research is that there is no pre-determined effect of technology on work design (Clegg & Corbett, 1986; McLoughlin & Clark, 1988; Waschull et al., 2020), rather there are many different choices concerning the work of humans during technological change. Our findings suggest that the human factor effects may depend on the extent to which, and at what moment, human factors are considered during the design and implementation process. As observed for the design of the work of operators, failing to actively consider the different work design options early in the design process led to interventions to repair human factor issues.

We support the recent evidence which showed that enriched work design does not 'come naturally' to managers and white-collar workers (Parker et al., 2019). The system designers were experts on the technology and involved processes and lacked work design knowledge. This is in line with earlier studies stating a knowledge gap of organizations and system designers regarding the nature and importance of human factors in the design. Considering that we currently observe an unprecedented number of technological innovations being developed or implemented at organizations worldwide with great potential to take on human tasks, this knowledge gap poses a major risk for the design of human-centric technologies. It reduces system designers' awareness of human factor issues but also constrains them to anticipate how technical and social systems are interdependent.

Therefore, it is important to determine how to move from a reactive to a proactive work redesign process, a challenge already posed by Davis et al. (2014). We found that an important enabler of a more socio-technical design approach was the motivation of system designers (manufacturing engineers), who had significant opportunity to redesign their work due to the organization of the project and their resulting involvement in the design. The idea that employees actively shape both the tasks and social relationships of their job in a bottom-up fashion to increase work meaning and work identity is a long-standing one and is also referred to as job crafting (Tims, Bakker, & Derks, 2013; Wrzesniewski & Dutton, 2001). Provided with the opportunity to craft their job in light of digitalization, system designers were strongly driven by their intrinsic motivation, and not by knowledge about work design, to create appealing jobs for themselves, thereby unconsciously ensuring that social aspects were considered alongside technological aspects.

Furthermore, the formulation of the organization's project goals can steer the external motivation of system designers to include human factors in work design. The prominent performance goals in manufacturing are speed, quality, costs, flexibility, and dependability (Slack, Chambers, & Johnston, 2010). Considering that overall system performance is influenced by employees' performance, which in turn depends on the human factors considerations (Sgarbossa et al., 2020), organizations should include desired employee performance in their goal formulation. This will motivate system designers to proactively design a socio-technical system that achieves both operational and human performance objectives.

6.3. Limitations and directions future research

This work has several limitations. The study focused on a single digitalization project that formed a pilot study as opposed to an organization-wide rollout. While we support the strength of the single case study as motivated in the research design, we recognize that our single case does not lend itself to represent a whole class of other cases, i.e., that it makes accurate theoretical generalizations of the topic under exploration. Generalization was not the main goal of this research, rather our study was motivated by the lack of studies on the inherent complexities of the design process of work. Theoretical generalization should be sought for on the basis of our insights and tested in future studies, e.g., by considering different industries, or types of technologies that are implemented. Nevertheless, we believe our results to be significant in terms of external validity and hence applicable to other cases. We chose an organization that started their digital transformation journey towards achieving their Industry 4.0 vision, thereby experimenting how to transform from a high degree of manually controlled processes to digital and more automated processes. This context is similar to many discrete manufacturing organizations that are starting to experiment with digital technologies, and which face similar challenges with regards to their current level of digitalization and lack of experience.

Finally, the pilot was funded by an innovation grant, and had only limited organizational reach at the time of data collection. Even though it allowed the research team to track the resulting redesign processes in-depth, it also constrained the system designers in terms of the resources they had available to focus their attention on the design process. Stakeholders involved in the project had other daily job demands, which they sometimes prioritized over the project demands.

Future research should deploy multiple-case studies of different industrial work contexts to replicate our findings. Furthermore, we suggest investigating different design processes in terms of the choices made by the different stakeholders. For example, how does the background of stakeholders such as engineers, information technologists, operations managers, or software architects influence the design process and the type of decisions made? Doing so would allow us to develop dedicated interventions that could help to facilitate a more proactive design approach in which human factors issues are considered alongside technology (Parker & Grote, 2020). A final recommendation based on our findings addresses the involvement of the end-user in the design process. We suggest to further examine the role of job crafting in relation to how exactly people might craft the impact of the new technologies during the selection, design, or adoption of new technology.

6.4. Practical implications

Enriched work design lies at the center of obtaining positive outcomes for not only the individual worker but also for the organization as a whole. In other words, having motivated workers not only contributes to making them happier but also more productive, which should provide a clear incentive to organizations to jointly design the technical and social systems and to include performance goals related to human effects in their overall project goals.

Despite the existence of various redesign approaches and frameworks focused on socio-technical design (Hughes, Clegg, Bolton, & Machon, 2017), generally they are not taken up by organizations, leading to an inadequate consideration of human issues: many practitioners take the technology as given, and they design the social system around it (Baxter & Sommerville, 2011; Clegg, 2000; Parker & Grote, 2020). To ensure technology better suits human needs, it is crucial to make organizations and the different stakeholders involved in the design or selection of new technology aware of human factor issues, and to train system designers in redesigning work and in using a socio-technical approach in their work. Explicit work design knowledge will enable system designers to more proactively shape the design of technology and (more quickly) meet the envisioned human needs.

Finally, organizations aiming to design or adopt new technology should ensure a diverse project organization. Preferably, this should include knowledgeable system users provided with enough leeway and resources to design work to take into consideration the many different aspects of the design process, including human factors. Since digitalization was found to impact blue- and white-collar work differently, the project organization should include representatives of all users impacted by it. In addition, team-leads, supervisors, or HR representatives should be involved to proactively consider the broader impact of digitalization on work design.

CRediT authorship contribution statement

S. Waschull: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization, Project administration. **J.A.C. Bokhorst:** Conceptualization, Validation, Writing – review & editing, Supervision. **J.C. Wortmann:** Conceptualization, Validation, Investigation, Writing – review & editing, Supervision, Funding acquisition, Project administration. **E. Molleman:** Conceptualization, Validation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported by the project WCCS (World Class Composites Solutions) which was funded by the Regional Economic Program (REP) of the North Netherlands Collaborative Partnership (SNN). The work belonged to Work Package 5 of this project. SNN aims to stimulate regional economic development. It is supported by the three northern provinces in The Netherlands. The WCCS project was sponsored by SNN with contributions by the participating companies.

References

Alcácer, V., & Cruz-Machado, V. (2019). Scanning the Industry 4.0: A literature review on technologies for manufacturing systems. *Engineering Science and Technology, an International Journal, 22*(3), 899–919. https://doi.org/10.1016/j.jestch.2019.01.006

Autor, B. D. H., & Dorn, D. (2013). The growth of low-skill service jobs and the polarization of the US labor market †. *American Economic Review, 103*(5), 1553–1597.

Baxter, G., & Sommerville, I. (2011). Socio-technical systems: From design methods to systems engineering. *Interacting with Computers, 23*(1), 4–17. https://doi.org/10.1016/j.intcom.2010.07.003

Blumberg, M., & Pringle, C. D. (1982). The missing opportunity in organizational research: Some implications for a theory of work performance. *The Academy of Management Review, 7*(4), 560–569.

Buer, S. V., Semini, M., Strandhagen, J. O., & Sgarbossa, F. (2021). The complementary effect of lean manufacturing and digitalisation on operational performance. *International Journal of Production Research, 59*(7), 1976–1992. https://doi.org/10.1080/00207543.2020.1790684

Campion, M. A., & Stevens, M. J. (1991). Neglected questions in job design: How people design jobs, task-job predictability, and influence of training. *Journal of Business and Psychology, 6*(2), 169–191. https://doi.org/10.1007/BF01126707

Cascio, W. F., & Montealegre, R. (2016). How technology is changing work and organizations. *Annual Review of Organizational Psychology and Organizational Behavior, 3*, 349–375. https://doi.org/10.1146/annurev-orgpsych-041015-062352

Challenger, R., Clegg, C., & Shepherd, C. (2013). Function allocation in complex systems: Reframing an old problem. *Ergonomics, 56*(7), 1051–1069. https://doi.org/10.1080/00140139.2013.790482

Cherns, A. (1987). The principles of sociotechnical design. *Human Relations*, 783–792.

Clegg, C. (1984). The derivation of job designs. *Journal of Occupational Behavior, 5*(2), 131–146. http://www.jstor.org/stable/3000123.

Clegg, C. (2000). Sociotechnical principles for system design. *Applied Ergonomics, 31*.

Clegg, C., & Corbett, M. (1986). Psychological and organizational aspects of computer-aided manufacturing. *Current Psychological Research & Reviews, 5*(2), 189–204.

Clegg, C., & Shepherd, C. (2007). "The biggest computer programme in the world... ever!": Time for a change in mindset? *Journal of Information Technology, 22*(3), 212–221. https://doi.org/10.1057/palgrave.jit.2000103

Clegg, C., & Spencer, C. (2007). A circular and dynamic model of the process of job design. *Journal of Occupational and Organizational Psychology, 80*, 321–339. https://doi.org/10.1348/096317906X113211

Da Xu, L., Xu, E. L., & Li, L. (2018). Industry 4.0: State of the art and future trends. *International Journal of Production Research, 56*(8), 2941–2962. https://doi.org/10.1080/00207543.2018.1444806

Davis, M. C., Challenger, R., Jayewardene, D. N. W., & Clegg, C. (2014). Advancing socio-technical systems thinking: A call for bravery. *Applied Ergonomics, 45*(2 Part A), 171–180. https://doi.org/10.1016/j.apergo.2013.02.009

Dyer, G. W., & Wilkins, A. L. (1991). Better stories, not better constructs, to generate better theory: A rejoinder to Eisenhardt. *The Academy of Management Review, 16*(3), 613–619.

Eisenhardt, K. M. (1989). Building theories from case study research. *The Academy of Management Journal, 14*(4), 532–550.

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *Academy of Management Journal, 50*(1), 25–32. https://doi.org/10.5465/AMJ.2007.24160888

Eisenhardt, K. M., Graebner, M. E., & Sonenshein, S. (2016). Grand challenges and inductive methods: Rigor without rigor mortis. *Academy of Management Journal, 59*(4), 1113–1123. https://doi.org/10.5465/amj.2016.4004

Findlay, P., Warhurst, C., Keep, E., & Lloyd, C. (2017). Opportunity knocks? The possibilities and levers for improving job quality. *Work and Occupations, 44*(1), 3–22. https://doi.org/10.1177/0730888416689813

Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics, 210*(January), 15–26. https://doi.org/10.1016/j.ijpe.2019.01.004

Frey, B., & Osborne, M. A. (2017). The future of employment: How susceptible are jobs to computerisation ? *Technological Forecasting & Social Change, 114*, 254–280. https://doi.org/10.1016/j.techfore.2016.08.019

Gorecky, D., Schmitt, M., Loskyll, M., & Zühlke, D. (2014). Human-machine-interaction in the industry 4.0 era. In *Proceedings - 2014 12th IEEE International Conference on Industrial Informatics, INDIN 2014* (pp. 289–294). Doi: 10.1109/INDIN.2014.6945523.

Grant, A. M., & Parker, S. K. (2009). 7 Redesigning work design theories: The rise of relational and proactive perspectives. *The Academy of Management Annals, 3*(1), 317–375. https://doi.org/10.1080/19416520903047327

Hackman, J. R., & Oldham, G. R. (1975). Development of the job diagnostic survey. *Journal of Applied Psychology, 60*(2), 159–170. https://doi.org/10.1037/h0076546

Hermann, M., Pentek, T., & Otto, B. (2016). Design principles for Industrie 4.0 scenarios. In *System Sciences (HICSS), 2016 49th Hawaii International Conference* (pp. 3928–3937). https://doi.org/10.1109/HICSS.2016.488

Hirsch-Kreinsen, H. (2016). Digitization of industrial work: Development paths and prospects. *Journal for Labour Market Research, 1–14*. https://doi.org/10.1007/s12651-016-0200-6

Holmström, J., Holweg, M., Lawson, B., Pil, F. K., & Wagner, S. M. (2019). The digitalization of operations and supply chain management: Theoretical and methodological implications. *Journal of Operations Management, 65*(8), 728–734. https://doi.org/10.1002/joom.1073

Hughes, H. P. N., Clegg, C., Bolton, L. E., & Machon, L. C. (2017). Systems scenarios: A tool for facilitating the socio-technical design of work systems. *Ergonomics, 60*(10), 1319–1335. https://doi.org/10.1080/00140139.2017.1288272

Humphrey, S. E., Nahrgang, J. D., & Morgeson, F. P. (2007). Integrating motivational, social, and contextual work design features: A meta-analytic summary and theoretical extension of the work design literature. *The Journal of Applied Psychology, 92*(5), 1332–1356. https://doi.org/10.1037/0021-9010.92.5.1332

Kadir, B. A., & Broberg, O. (2021). Human-centered design of work systems in the transition to industry 4.0. *Applied Ergonomics, 92*.

Kadir, B. A., Broberg, O., & da Conceição, C. S. (2019). Current research and future perspectives on human factors and ergonomics in Industry 4.0. *Computers and Industrial Engineering, 137*(August), Article 106004. https://doi.org/10.1016/j.cie.2019.106004

Kagermann, H. (2013). *Recommendations for implementing the strategic initiative Industrie 4.0: Securing the future of German manufacturing industry ; final report of the industry working group. Forschungsunion.*.

Lazarova-Molnar, S., Mohamed, N., & Shaker, H. R. (2017). Reliability modeling of cyber-physical systems: A holistic overview and challenges. In *2017 Workshop on Modeling and Simulation of Cyber-Physical Energy Systems (MSCPES)* (pp. 1–6).

Legner, C., Eymann, T., Hess, T., Matt, C., Böhmann, T., Drews, P., … Ahlemann, F. (2017). Digitalization: Opportunity and challenge for the business and information systems engineering community. *Business and Information Systems Engineering, 59*(4), 301–308. https://doi.org/10.1007/s12599-017-0484-2

Li, Y., Dai, J., & Cui, L. (2020). The impact of digital technologies on economic and environmental performance in the context of industry 4.0: A moderated mediation model. *International Journal of Production Economics, 229*. https://doi.org/10.1016/j.ijpe.2020.107777

Liao, Y., Deschamps, F., Loures, E. de F. R., & Ramos, L. F. P. (2017). Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal. *International Journal of Production Research, 55*(12), 3609–3629. https://doi.org/10.1080/00207543.2017.1308576

Lorenz, E., & Valeyre, A. (2005). Organisational innovation, human resource maangement and labour market structure: A comparison of the EU-15. *Journal of Industrial Relations, 47*(4), 424–442.

Matisoff, B. S. (1986). Manufacturing engineering: Definition and purpose. In *Handbook of manufacturng engineering* (pp. 1–4). Dordrecht: Springer.

McLoughlin, I., & Clark, J. (1988). *Technological change at work*. Open University Press.

Meredith, J. R., Raturi, A., Amoako-Gyampah, K., & Kaplan, B. (1989). Alternative research paradigms in operations. *Journal of Operations Management, 8*(4), 297–326.

Miles, M. B., & Huberman, M. A. (1994). *Qualitative data analysis*. Sage Publications.

Miles, M. B., Huberman, M. A., & Saldana, J. (2019). *Qualitative data analysis - a methods sourcebook* (4th ed.). Sage Publishing.

Molleman, E. (2000). Modalities of self-managing teams-The "must", "may", "can", and "will" of local decision-making. *International Journal of Operations & Production Management*.

Morgeson, F. P., & Humphrey, S. E. (2006). The Work Design Questionnaire (WDQ): Developing and validating a comprehensive measure for assessing job design and the nature of work. *Journal of Applied Psychology, 91*(6), 1321–1339. https://doi.org/10.1037/0021-9010.91.6.1321

Morgeson, F. P., & Humphrey, S. E. (2008). Job and team Design: Toward a more integrative conceptualization of work design. In *Research in personnel and human resource management* (pp. 39–91). Emerald Group Publishing Limited.

Neumann, W. P., Winkelhaus, S., Grosse, E. H., & Glock, C. H. (2021). Industry 4.0 and the human factor – A systems framework and analysis methodology for successful development. *International Journal of Production Economics, 233*. https://doi.org/10.1016/j.ijpe.2020.107992

Nielsen, K., Randall, R., Yarker, J., & Brenner, S. O. (2008). The effects of transformational leadership on followers' perceived work characteristics and psychological well-being: A longitudinal study. *Work and Stress, 22*(1), 16–32. https://doi.org/10.1080/02678370801979430

Oldham, G. R., & Hackman, J. R. (2010). Not what it was and not what it will be: The future of job design research. *Journal of Organizational Behavior, 31*(2–3), 463–479. https://doi.org/10.1002/job.678

Pacaux-Lemoine, M.-P., Trentesaux, D., Rey, G. Z., & Millot, P. (2017). Designing intelligent manufacturing systems through Human-Machine Cooperation principles: A human-centered approach. *Computers & Industrial Engineering, 111*, 581–595. https://doi.org/10.1016/j.cie.2017.05.014

Parker, S. K., Andrei, D. M., & Van den Broeck, A. (2019). Poor work design begets poor work design: Capacity and willingness antecedents of individual work design behavior. *Journal of Applied Psychology, 104*(7), 907–928. https://doi.org/10.1037/apl0000383

Parker, S. K., van den Broek, A., & Holman, D. (2017). Work design infleunces: A synthesis of multilevel factors that affect the desing of jobs. *Academy of Management Annals, 9*(1), 267–308.

Parker, S. K., & Grote, G. (2020). Automation, algorithms, and beyond: Why work design matters more than even in a digital world. *Applied Psychology An International Review*. https://doi.org/10.1111/apps.12241

Parker, S. K., Wall, T. D., & Cordery, J. L. (2001). Future work design research and practice : Towards an elaborated model of work design. *Journal of Occupational and Organizational Psychology, 74*, 413–440. https://doi.org/10.1348/096317901167460

Pettigrew, A. M. (1985). Contextualist research and the study of organizational change processes. In *Research methods in information systems* (pp. 53–72).

Piekkari, R., Welch, C., & Paavilainen, E. (2009). The case study as disciplinary convention. *Organizational Research Methods, 12*(3), 567–589. https://doi.org/10.1177/1094428108319905

Pinzone, M., Albè, F., Orlandelli, D., Barletta, I., Berlin, C., Johansson, B., & Taisch, M. (2020). A framework for operative and social sustainability functionalities in Human-Centric Cyber-Physical Production Systems. *Computers and Industrial Engineering, 139*. https://doi.org/10.1016/j.cie.2018.03.028

Rauch, E., Linder, C., & Dallasega, P. (2020). Anthropocentric perspective of production before and within Industry 4.0. *Computers and Industrial Engineering, 139*. https://doi.org/10.1016/j.cie.2019.01.018

Richter, A., Heinrich, P., Stocker, A., & Schwabe, G. (2018). Digital work design: The interplay of human and computer in future work practices as an interdisciplinary (grand) challenge. *Business and Information Systems Engineering, 60*(3), 259–264. https://doi.org/10.1007/s12599-018-0534-4

Romero, D., Bernus, P., Noran, O., & Stahre, J. (2016). The Operator 4.0: Human cyber-physical systems & adaptive automation towards human-automation symiosos work systems. In *Advanced Production Management Systems; The Path to* (Vol. 488, pp. 677–686). Doi: 10.1007/978-3-319-51133-7.

Romero, D., Stahre, J., Wuest, T., Noran, O., Bernus, P., Fast-berglund, Å., & Gorecky, D. (2016). Towards an operator 4.0 typology: a Human-centric perspective on the fourth industrial revolution technologies. In *CIE46 Proceedings, 29–31 October 2016, Tianjin / China, ISSN 2164-8670 CD-ROM, ISSN 2164-8689 ON-LINE*, (October) (pp. 0–11).

Ryan, R. M., & Deci, E. L. (2017). *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. Guilford Publications.

Saenz De Ugarte, B., Artiba, A., & Pellerin, R. (2009). Manufacturing execution system-a literature review. *Production Planning & Control, 20*(6), 525–539. https://doi.org/10.1080/09537280902938613

Sgarbossa, F., Grosse, E. H., Neumann, W. P., Battini, D., & Glock, C. H. (2020). Human factors in production and logistics systems of the future. *Annual Reviews in Control, 49*, 295–305. https://doi.org/10.1016/j.arcontrol.2020.04.007

Siggelkow, N. (2007). Persuasion wtih case studies. *Academy of Management Journal, 50* (1), 20–24.

Slack, N., Chambers, S., & Johnston, R. (2010). *Operations management*. Pearson Education.

Spath, D., Ganschar, O., Gerlach, S., Hämmerle, M., Krause, T., & Schlund, S. (2013). *Produktionsarbeit der Zukunft – Industrie 4.0*. Stuttgart: Frauenhofer Verlag.

Stake, R. E. (1995). *The art of case study research*. Sage Publications.

Stern, H., & Becker, T. (2017). Development of a model for the integration of human factors in cyber-physical production systems. *Procedia Manufacturing, 9*, 151–158. https://doi.org/10.1016/j.promfg.2017.04.030

Stolterman, E., & Fors, A. K. (2004). Information technology and the good life. In J. I. Kaplan, B., Truex, D.P., Wastell, D., Wood-Harper, A.T., DeGross (Eds.), *Information systems research: Relevant theory and informed practice* (pp. 687–692). Boston. Doi: 10.1007/1-4020-8095-6_45.

Tims, M., Bakker, A. B., & Derks, D. (2013). The impact of job crafting on job demands, job resources, and well-being. *Journal of Occupational Health Psychology, 18*(2), 230–240. https://doi.org/10.1037/a0032141

Trist, E., Higgin, G., Murray, H., & Pollock, A. (2013). *Organizational choice: Capabilities of groups at the coal face under changing technologies*. London: Routledge.

van Eijnatten, F. M., Shani, A., & Leary, M. (2008). Sociotechnical systems: Towards designing and managing sustainable organizations. In *Handbook of organization development and change* (pp. 277–309). Thousand Oaks, CA: SAGE Publications Ltd.

Voss, C., Tsikriktsis, N., & Frohlich, M. (2002). Case research in operations management. *International Journal of Operations and Production Management, 22*(2), 195–219. https://doi.org/10.1108/01443570210414329

Wang, L., Törngren, M., & Onori, M. (2015). Current status and advancement of cyber-physical systems in manufacturing. *Journal of Manufacturing Systems, 37*, 517–527. https://doi.org/10.1016/j.jmsy.2015.04.008

Waschull, S., Bokhorst, J. A. C., Molleman, E., & Wortmann, J. C. (2020). Work design in future industrial production: Transforming towards cyber-physical systems. *Computers & Industrial Engineering*. https://doi.org/10.1016/j.cie.2019.01.053

Wrzesniewski, A., & Dutton, J. E. (2001). Crafting a job: As active employees revisioning crafters of their work. *The Academy of Management Review, 26*(2), 179–201. https://doi.org/10.2307/259118

Yin, R. K. (2009). *Case study research: Design and methods*. Thousand Oaks, CA: Sage Publications.