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Human well-being and system performance in the transition to Industry 4.0

Abstract

The transition to Industry 4.0 and the introduction of new digital technology in industrial companies are evoking profound changes in their work systems. It is estimated that the emerging changes will affect both the overall performance of systems and the well-being of the humans working in and interacting with systems elements. However, descriptive empirical evidence focusing on the pertaining effects of these emerging changes is minimal. Moreover, without the support of such empirical evidence, it will be challenging to provide prescriptive actions for how industrial companies might navigate through the transition to Industry 4.0.

In this paper, we address this research gap and present empirical evidence collected through ten industrial case studies illustrating how the introduction of Industry 4.0-enabling technologies may affect human well-being and system performance before, during, and after implementation. Hereafter, we provide several implications and recommendations for practitioners.

Relevance to industry: The results serve to assist organizational decision-makers, and Human Factors and Ergonomics experts with prescriptive guidelines and recommendations for dealing with and overcoming challenges related to human well-being and system performance in the transition to Industry 4.0.

Keywords

Cyber-physical systems; Human factors; Digital transformation; Change Management; Digitalization

1 Introduction

The introduction of new digital technologies in industrial companies is creating new socio-technical interactions between physical and virtual elements, leading to human-related, technical, and organizational changes (Becker and Stern, 2016). In order to deal with these changes and the related emerging challenge, there is a need for descriptive empirical data that can serve as the foundation for prescriptive, e.g., theories, models, and frameworks that can guide future research as well as practitioners in their journey towards Industry 4.0. However, such empirical data is currently minimal (Hoffmann et al., 2019; Kadir et al., 2019; Schneider, 2018). In this paper, we address this gap and present empirical evidence that illustrates how new digital technologies affect human well-being and system performance before, during, and after implementation. In addition, we introduce Carroll and Fidock's (2011) model of technology appropriation as a means to understand the change process and put forward recommendations on how to stage the process of transitioning to Industry 4.0.

Optimizing human well-being and overall system performance is the main objective of the scientific discipline of Human Factors and Ergonomics (HF/E) (IEA, 2019), which makes it a highly appropriate approach for designing and implementing new digital solutions. Indeed, researchers such as (Pacaux-Lemoine et al., 2017; Romero et al., 2016) suggest that overcoming challenges emerging with the changes evoked by new digital technologies might require new human-centric design and engineering philosophies. Such approaches can create a holistic understanding of the complex relationships and interplay between the various organizational elements and could have an essential impact on overall system performance and human well-being in all of the transitioning phases leading to Industry 4.0.

1.1 The current state of HF/E research on Industry 4.0

In a literature review focusing on the intersection between Industry 4.0 and HF/E, Kadir et al. (2019) highlight that the majority of the limited academic research publications in this area are from non-HF/E related publication outlets. Most of the empirically driven research in this intersection are focusing on technical or isolated aspects of the new digital technologies. Thus, they do not manage to explore the emerging changes and identify relationships and interdependencies between system elements (Schneider, 2018). In addition, HF/E publications also seem to have a narrow scope and mostly focus on conceptual frameworks, simulations, and laboratory experiments. The following are some examples of such research. A human factors taxonomy to model workers' behavior developed on experts' opinions (Longo et al., 2019), and testing digital twins to enhance the integrations of ergonomics in workplace design with experiment (Caputo et al., 2019). While such research studies are highly valuable and necessary for the development of new novel solutions and the research field in general, they fall short of addressing the socio-technical changes and support claims and predictions on how work and work organization is changing (Horváth and Szabó, 2019).

Over the past few years, the number of academic publications from non-HF/E outlets that use case studies to research HF/E in Industry 4.0 has increased. Similar to this paper, publications such as Cagliano et al. (2019), Ghobakhloo and Fathi (2019) and Hoffmann et al. (2019) apply an inductive approach using industrial case studies to create new theories and generate new theoretical implication. The majority of the remaining publications (e.g., Fantini et al. (2018), Kaasinen et al. (2019), Peruzzini and Pellicciari (2017) and Stern and Becker (2019)) use case studies as part of a deductive approach to test and validate novel conceptual frameworks and methodologies. However, it is essential to highlight that, in general, theoretically driven research dealing with the topic of Industry 4.0 outweighs empirical driven research (Cagliano et al., 2019; Frank et al., 2019; Kadir et al., 2019).

One of the reasons for the limited empirical data might be a symptom of the current level of digitalization and implementation of industry 4.0-enabling technologies in industrial companies. The futuristic vision of an interconnected, highly digitalized, and automated smart factory is still just a vision for most companies. While most industrial companies are aware of the potential benefits of achieving such a vision and are investing in Industry 4.0 capabilities and technologies, the majority are still in a transitioning phase, experimenting and piloting standalone solutions and working on establishing a digital foundation. Thus, most industrial companies have started their Industry 4.0 journey, but have yet to successfully apply the newly gained capabilities across their operations (KPMG, 2017). Chien et al. (2017) describe this transition phase as Industry 3.5. While this transition is predominantly focusing on upgrading technical aspects and ensuring compatibility between new and old systems, there is also another aspect, which is the impact on the organization and the individuals in it.

1.2 Organizational transition and technology appropriation

In the past, digital technologies in the context of work have predominantly been information technologies (IT) (which have often mostly affected knowledge and administration workers) and secluded automation technologies such as fenced industrial robots (which have had limited direct contact with human workers and other organizational elements.) Still, it is relevant and useful to look back at some theories and models dealing with organizational and human-related challenges in the introduction of new digital technologies from before the concept of Industry 4.0. Such a look back might enable a better understanding of the similarities and differences between past efforts and the current transition to Industry 4.0.

Because the journey to Industry 4.0 is a transition that industrial companies are going through, it might be beneficial to clarify the meaning *transition* in this context. Bridges (2003) describes a transition as a multiphase psychological process that organizations and individuals

go through as they come to terms with a new situation, which new changes have created. Change without transition will usually lead to disappointing results, and end up costing a lot of money (Bridges, 2003). In the context of IT projects, Markus (2004) argues that the implementation of new IT solutions that trigger organizational changes needs a more human-centric approach that combines IT project management and organizational change management and proposes an approach called *technochange*. A technochange approach is an iterative process spanning over three phases (before, during, and after implementation), which involves both IT functionality and related organizational changes, e.g., training, new performance metrics, and (re)design of business processes (Markus, 2004). While Markus (2004) is more than a decade old and solely focuses on IT projects (which often have a limited effect on shop-floor workers), an approach such as technochange might still be relevant and useful in the context of Industry 4.0. The approach has similarities with an HF/E approach since it considers both technical, organizational, and human aspects.

How humans use and react to new technologies is not a notion unique to Industry 4.0. Indeed, user resistance is a crucial factor in the successful implementation of information systems and has been an essential theme in information systems research (Beaudry and Pinsonneault, 2005). Another concept related to user acceptance and user resistance is technology appropriation. Similar to resistance models, technology appropriation deals with the process of how users "take possession" of new technology and incorporate them into their existing work over time (Carroll, 2004). Often, users end up using new digital technologies in unexpected ways, less than expected, or not using them at all (Janneck, 2009).

When organizations introduce new digital technologies, three types of organizational changes emerges; Anticipated changes (the changes that are planned and prepared for ahead of time), emerged (change that arises unexpectedly, which were not anticipated initially), and opportunity-based (unplanned changes that are introduced intentionally) (Orlikowski and

Hofman, 1997). Thus, the successful implementation of new digital technologies and type of related changes depend on the process from introduction to the usage of the technologies Janneck (2009). The users need to make sense of how the new technologies fit with their work tasks and routines and receive support on how to use and work with the new technologies. If the new technologies do not accommodate the users' needs, the users might end up disappropriating the technology or aspects of it (Carroll and Fidock, 2011). Carroll and Fidock (2011) argue that disappropriation of new technology might not be an act of resistance, but are instead a reaction to the failure of gaining any value of the technology. Figure 1 shows the appropriation process developed by (Carroll and Fidock, 2011).

Figure 1

Figure 1 – Carroll and Fidock's (2011) *Model of Technology Appropriation recreated for this paper*

As mentioned at the beginning of this section, compared to IT projects, the changes emerging with the implementation of new digital technologies have more significant implications on human-work and organization, which makes the application of an interdisciplinary approach that accounts for humans as well as technologies useful (Pacaux-Lemoine et al., 2017). The increasing implications amplify the benefits of viewing the journey towards Industry 4.0 as an organizational transition with multiple phases. Thus it is essential to understand the appropriation process and of how new digital technologies affect human well-being and overall system performance before, during, and after implementation. Such an understanding is especially important when considering that organizational factors such as lack of appropriate competences and skill, inadequate organizational structure and processes, and organizational resistance to change might be some of the barriers of the transition to Industry 4.0 (Horváth and Szabó, 2019).

In this paper, we use empirical data to present industrial experiences of implementing and working and appropriating with new digital technologies. We highlight how new digital technologies affect human well-being and overall system performance before, during, and after implementation. We have conducted several retrospective industrial case studies and collected empirical data documenting work and work organization changes, as well as the appropriation of new digital technologies in connection with the transition to Industry 4.0. Understanding these changes could serve as a foundation for the development of new theories, practical frameworks, and prescriptive principles for aligning humans, technology, and organization in Industry 4.0 work systems.

We present the empirical findings by highlighting positive and negative effects on perceived well-being and perceived performance throughout the transition phases of before, during, and after implementation. In addition, we provide a summary of factors that positively and negatively affect perceived well-being and overall system performance, as well as several implications and recommendations for practitioners.

The organization of this paper is as follows: In Section 2, we present the methodology used to collect and analyze the empirical data. In Section 3, we showcase the results from the analysis and present the factors affecting perceived well-being and performance in the three transition phases. In section 4, we discuss the findings from Section 3; see how they relate to the technology appropriation model, as well as present implications and recommendations for practitioners. In Section 5, we discuss the limitations of the paper. Lastly, in Section 6, we summarize the paper, give final remarks, and draw a conclusion.

2 Methodology

Case studies are an efficient method for using qualitative data to develop theories inductively and bridging these theories to popular deductive research (Eisenhardt and

Graebner, 2007). Thus, in this paper, we used qualitative data collected through exploratory retrospective case studies following the approach of Yin (2009), at ten different sized industrial companies, all located in Denmark. The data collection included observation of the work systems in operations, demonstration of work with new digital technologies, and semi-structured interviews with employees on strategic, tactical, and operational organizational levels. We use the results of these case studies to highlight the variety and range of possible effects on well-being and performance.

2.1 Case studies

To get a heterogeneous sample, the case companies were of various sizes and operated in different industries. However, they were all similar in that they had started focusing on digitalizing work systems and investing in new digital technologies. Most of the companies had been public around their strategy of implementing new digital technologies and had shown a positive attitude toward the changes associated with industry 4.0. Some of the companies had been the center-point of articles in Danish newspapers, discussing the changes new digital technologies were creating in their companies, while others had representatives giving keynote speeches about their industry 4.0 and digitalization initiatives at industrial seminars.

The digital technologies the companies had introduced in their work systems differed from company to company. However, the similarity between them was the novelty of the technologies in the work systems and the companies' lack of experience in working with them. In most cases, the companies aimed at either automating or digitalizing parts of processes in their work systems. However, it is important to note, that not all of the cases had been through all of the three transition phases, and some were still in the *During* phase at the time of the case studies. Refer to Table 1 for an overview and description of the digital technologies included

in the case studies and Table 2 for an overview of the case companies and implemented digital technologies.

Table 1 – Overview and description of the digital technologies included in the case studies.

Table 1

Table 2 – Overview of case companies and implemented digital technologies.

Table 2

2.2 Data collection

The primary source of the data was semi-structured interviews. In total, we interviewed 35 participants (15 workers and 20 decision-makers) across the ten case companies, where the interview durations ranged between 30 – 90 minutes. The interviews were face-to-face interviews that were audio-recorded and transcribed in Danish. The only exception was Company E and two of the interviews at Company D. In Company E, it was not possible to record due to company policies and the Non-Discloser Agreement. In the case of the two interviews at Company D, it was not possible to record interviews, due to technical issues with the audio recording equipment. Thus, we stored the data from these cases in the form of hand-written notes taken during the interviews. In addition, we note that due to NDAs with the case companies and to ensure the promise of complete anonymity to the interviewees, we refrain from using third-person pronouns (e.g., he or she and his or hers) and use the third plural pronoun (e.g., they and their) when mentioning specific interviewees. Refer to Table 3 for an overview and division between workers and decision-makers interviewed at each case company.

Table 3 – Overview and division between workers and decision-makers interviewed at each case company.

Table 3

These interviews focused on uncovering how the introduction of new digital technologies had affected the workers' well-being and overall performance before, during, and after implementations. In addition, the interview guide included probes and prompts for how the changes affected the three main domains of HF/E (physical, cognitive, and organizational), change management, and organizational learning. Because of the retrospective nature of the case studies, the interviewees had to recollect from memory the effects on well-being and performance during the different transition phases. In addition, we used passive participation as described by Spradley (1980) when observing how the workers used and interacted with the new digital technologies. Passive participation entails that we were present at the scene as observers, but did not participate or interact with the workers to any great extent.

2.3 Data analysis

We organized all of the collected data in the computer software *Atlas.ti 7* and followed a systematic coding process comparable to a template analysis as described by (Brooks et al., 2015). We used the framework shown in Table 4 to code all of the data collected data. The *Before* phase is the initial phase where a company has decided to invest (and possibly has chosen) in new digital technologies but has yet started implementing. The *During* phase is the phase where a company is implementing and testing out the new digital technologies. Lastly, the *After* phase is the final phase when a company has implemented the new digital technologies and has decided to continue using them.

Table 4 – The coding framework we used to code the collected data.

Table 4

We used the three main domains of HF/E (Physical, Cognitive, and Organizational) defined by (IEA, 2019) as a guiding framework for coding human well-being related aspects. For system performance-related aspects, we used a framework that covers five measures of performance, which we adopted from (Jenkins, 2017). These five measurements are; Efficacy (the ability to meeting the needs of the employees and organization) Flexibility (the ability to do more and adapt to changes faster), Usability (the ease of use and understanding), Efficiency (the ability to work faster), Safety (the level of safety-related risks).

We divided the coding and analysis of the data into five phases that followed a general inductive approach, as described by Thomas (2006). In the first phase, we read all of the data highlighting and coding statements related to well-being and performance. In the second phase, we categorized the codes into the three categories of before, during, and after implementation. In the third phase, we categorized and analyzed the codes using a bottom-up approach and building affinity diagrams (Holtzblatt and Beyer, 2016) for each of the three categories of before, during, and after implementation. The purpose of the affinity diagram was to identify the various themes that had a negative or positive effect on well-being and performance. In the fourth phase, we summarized the main themes emerging in the affinity diagram, which we present in the following section (Section 3). Lastly, in the fifth phase, we identified several factors impacting perceived well-being and performance before, during, and after implementation of new digital technologies, which we present in Section 3.13.

Refer to Table 5 for an overview of the overall procedure from data analysis to the results presented in Section 3. Furthermore, Table 5 also includes a detailed description and outcome of each of the mentioned five phases.

Table 5 – Overview of the overall procedure from data analysis to the results presented in Section 3.

Table 5

3 Results

In this section, we present the results from the case studies and answer how the introduction of new digital technologies affect perceived human well-being and system performance before, during, and after their implementation. In the parts on well-being, we highlight notions on how the well-being of the workers was affected, while in the parts on performance, we highlight notions that had affected performance. Furthermore, we have divided the results into two categories, positive and negative effects. It is essential to mention that the results we present in this section are the variety and range of possible effects impacting perceived well-being and performance that emerge in conjunction with the introduction of new digital technologies. Thus, not every presented effect had occurred in all of the case studies. Refer to Table 6 for an overview of the results related to perceived well-being and Table 7 for perceived performance.

Table 6 – Overview of the effects on well-being before, during, and after the implementation of new digital technologies.

Table 6

Table 7 – Overview of the effects on performance before, during, and after the implementation of new digital technologies.

Table 7

3.1 Before – Positive effects on well-being

Before the implementation of any new digital technologies, the majority of the companies had informed their workers on the upcoming changes to some degree. This information had both created excitement as well as some uncertainties. Regardless, informing the workers and engagement from the management team seemed to play an essential role in how workers had perceived the upcoming changes. All companies had different approached and degrees for informing and engaging their workers. Nevertheless, the workers all expressed their appreciation for receiving the information before the implementation of any new digital technologies.

Workers were generally excited about working with new digital technologies. When asked, almost all of the workers expressed that they were excited about working with new digital technologies when they initially received the information. This excitement was especially apparent in the cases of tangible technologies such as industrial robots, cobots, and AGVs. Several of the workers mentioned that after hearing of the news, they spend time reading about and watching videos on the technologies in their own spare time.

In addition, the workers also perceived the need for learning new skills and competences as positive. While some of the workers believed the new skills could help them perform better at their current jobs, others viewed it as an opportunity to grow and improve their job profile in case of future hiring outside of their current company. One of the workers at Company H

mentioned that they were highly aware of the benefits of learning to work and operate new digital technologies and solutions.

> *I know that the more I learn about these new digital technologies and robots, the more competences I will gain. And having these competencies will not hurt if my boss one day decides that the company does not need me anymore.* – Worker (Company H)

3.2 Before – Negative effects on well-being

The information on the upcoming implementation of new digital technologies might also lead to uncertainties affecting well-being. While many workers might be excited about working with the new digital technologies, others might find it worrying. Several of the interviewed workers explicitly expressed that they initially were worried about working with the new digital technologies, and the majority mentioned they had at least one colleague who had been very worried.

While most of the interviewed workers perceived the possibility to gain new knowledge and learn new skills positively, several expressed they also had feared that they would not be able to keep up with the new requirements demanded of them. Some workers feared that they would not be able to keep up working with the new digital technologies, while others feared that they would not have the capacity to learn new skills and competences. Besides, several decision-makers and workers across the cases expressed that this fear was predominantly shared by their aging (>45 years old) colleagues and workers. All of the aging workers we interviewed expressed that they had experienced this fear to a certain degree.

The questioning of own skills and competencies becomes even more prominent in cases when the decision-makers promote the new digital technologies as performance improving tools. This definition puts pressure on the workers even before the workers have started working with the new digital technologies. Company A, C, and E, all had experienced workers

directly expressing their lack of enthusiasm to work in new ways if this meant that they had to work faster or increase the number of outputs. Several workers at Company E had been very vocal against working in a new setup that would include an industrial robot, which would increase the work cell's output by 100%. Similarly, before the digitalization of a work cell, the decision-makers at company C had to address several workers that had been worried about the increase of workload resulting from working in new ways.

> *Before we had even started implementing anything, several of the workers told us [the management team] that they would quit if the number of items they currently produced were to increase.* – Decision-maker (Company C)

In the case of cobots and AGVs, workers might initially become worried about personal health and safety because of the technologies' autonomous nature and ability to share the same physical workspace as the workers. The majority of the workers who had experienced working with such tangible technologies mentioned that, before working with the new technologies, they were worried about being hit and getting hurt. To overcome this worry, a decision-maker at Company G mentioned that their company had made the experience of getting hit by a cobot a mandatory part of the training the workers had to go through before they could start working with the cobots.

With the information about investments in new digital technologies combined with the mentioned uncertainties, some workers had become worried about their future as workers at their company. While few of the workers we interviewed mentioned that they had feared for their jobs, all of them highlighted that they at least knew of at least one worker that have had concerns in this regard. In the extreme case of company A, because they believed that getting fired was inevitable, several workers had decided to quit just after the management team had announced that they would invest in AGVs.

I understand if people are afraid (of being fired). I know that several of my colleagues quit their jobs when they heard we were getting AGVs. I believe they feared for their future at the company. – Worker (Company A)

3.3 During – Positive effects on well-being

Involving the workers in the implementation of the new digital technologies were mentioned in all of the case studies. The decision-makers emphasized the workers' satisfaction with being actively involved, and the interviewed workers who had been actively involved confirmed this notion. Several of these workers mentioned that having influence and contributing to how the final solution ended up, gave them great pleasure and motivation in their daily work.

This active participation and involvement meant that some workers had to learn and gain additional non-technical skills, such as project management and systematic problem-solving skills. Thus, while the workers were excited about getting the opportunity of gaining new knowledge and competences in the *Before* phase, they seemed equally happy once the learning and competence upgrade had started in the *During* phase.

I gained a lot of knowledge on how to manage projects. I was able to get an active role in the project management part… I had no previous experience in project management, so it took time to learn, and I also made some mistakes along the way, but I learned a lot. It was a great experience – Worker (Company I)

The excitement about working with the new digital technologies from the *Before* phase tended to continue for some workers into the *During* phase. Besides, some of the worries from the previous phase (e.g., getting fired) had decreased when the workers had started working with the new technologies and begun to understand the technologies' limitations. One of the workers at company A emphasized their relief as they slowly became accustomed to working

with the company's newly acquired AGV as they realized how many limitations the new technology had in comparison to the human forklift drivers.

3.4 During – Negative effects on well-being

While in some cases, the workers had played an active role in the redesign of the work system and implementation of the new digital technologies, in other cases, they had not. In the latter cases, and in instances where the workers had not received adequate information on the changes, the level of frustrations had increased tremendously for some workers.

In some cases, the workers' frustration had resulted in a reluctance to work with the new digital technologies. Company A had digitalized and automated a significant part of a process in a work system, without involving and informing the workers as well as not eliminating the old ways of working. Thus, because they had not removed the ability to work in the old way, several workers had directly refused to work with the new digital technologies and had continued to operate using the old manual process. The consequence of several workers refusing to use the new digital technology and comply with the new ways of working had created a division between the team members as well as with the decision-makers. Both workers and decision-makers mentioned that this division had resulted in a decrease in morale and performance. Ultimately, the reluctant workers had received written reprimands with the threat of being fired if they did not comply.

Working with new digital technologies can evoke different types of worries. Several workers expressed that they initially were apprehensive about causing errors or breaking the new digital technologies. Knowing the high price of the new digital technologies and being unfamiliar with using them had created a certain level of cautiousness and nervousness. Such cautiousness and nervousness were especially relevant when workers had received limited training in using the new digital technologies and working in new ways. Several decision-

makers mentioned that such worries might ultimately lead to real, costly, and irreversible errors and mistakes.

> *We have observed that our workers typically make more mistakes when they feel unsafe and uncertain. It is one of the reasons we push automation and digitalization in the first place* – Decision-maker (Company A)

Partially developed new digital technologies and solutions had also resulted in frustrations for the workers. Because the new digital technologies are continuously developed and implemented throughout this phase, technical errors are almost unavoidable. Several workers and decision-makers mentioned this issue and highlighted the frustrations it caused. Such issues were mentioned to cause a break in the workflow, errors, and worsen cognitive and physical strain. To avoid such issues, Company B makes a great effort to develop any new digital solution as much as possible before testing them in their shopfloor operations.

> *We know that immature technologies that create more complexity for our operators lead to frustration and the operators not using the new technologies at all* – Decision-maker (Company B)

In the case of automation, the organization of work and division of labor between workers and new digital technologies had lead to stressful situations, where the workers had ended up having additional roles and taking on additional tasks. One of the workers at Company A explained that the new industrial robot, which had replaced his coworker, was only able to take on 50% of his coworker's tasks. Thus, the worker had to perform all of his tasks as well as the remaining 50% of his former colleague’s tasks. The worker expressed that the extra tasks had created much stress and negatively affected his well-being.

The increase of alarms and red numbers introduced with new digital technologies that serve to give warnings and alerts might result in frustration and stress, especially when the

warnings and alerts are a result of technical and system errors, which the operators have no control over. One of the new digital solutions at company A had been programmed with a countdown timer that indicated how long the workers had to complete a maintenance task. If the worker did not complete the task within the set time, the software would automatically notify the worker's manager with a direct email. As a worker explained, both the countdown and notification to the manager felt very demoralizing and stressful, mainly because the time the software developers had accounted for was not enough. Thus the workers were never able to finish the task in the set time.

3.5 After – Positive effects on well-being

In almost all of the cases, once a solution had been fully implemented and standardized in operations, the workers experienced that there had been an improvement in their well-being. Thus, the workers had become much happier with the new ways of working in comparison to the *During* phase. Almost all of the workers and decision-makers expressed this notion of improved well-being. Tangible automation technologies were mentioned in all of the cases to have improved physical ergonomics. Besides, the majority of workers working with digitalization solutions expressed similar notions concerning cognitive ergonomics.

In general, the workers seemed fond of working with the new digital technologies in the *After* phase. Despite ongoing challenges, and the new digital technologies not being flawless, the majority of the workers expressed that they were satisfied with the new ways of working and use of the new digital technologies. While in several of the cases, the final implemented solution had still contained errors and not optimized, the workers expressed that they were still pleased with the new digital technologies and felt that the benefits outweighed the challenges.

It is what it is. You learn to accept and live with it (referring to the flaws of the companies implemented digital solution). That is how new technology works. Nothing is perfect. – Worker (Company H)

As mentioned in Section 3.2, some workers had been worried about their health and safety before the implementation of their new digital technologies. However, this worry seemed to disappear as the workers got used to the new ways of working. No workers expressed that they had any worries in this regard in the *After* phase.

Most workers tended to view the new changes in a positive light in the *After* phase and were less worried about losing their jobs to the new digital technologies. Indeed, the majority of the workers mentioned that they did not believe that they would lose their jobs in the near future because of their company's investment in new digital technologies. The reason for this notion was often related to the workers' understanding of how limited the new digital technologies are regarding flexibility and adaptability in comparison to human workers.

Losing our jobs is not something we the workers fear here in our company… These machines cannot do everything by themselves. Someone has to take care of them, work around them, and make sure that they are operating as they are supposed to. – Worker (Company F)

The above statement is highly representative of how the majority of the workers expressed their feelings on the idea of being replaced by new digital technologies and machines.

3.6 After – Negative effects on well-being

Decision-makers' commitment to anchor the new digital technologies and new ways of working in the work systems, might affect workers' wellbeing. For example, while the decision-makers at Company H had been very good at information the workers on the upcoming changes, they had not been equally efficient at following up on the emerging

changes. The management team had spent little time on adjuring and setting up the necessary frameworks for support and feedback after the implementation of the new digital technologies. This limited follow up had resulted in frustration for the workers.

Several workers expressed frustration concerning limited training in the new ways of working, usage of the new digital technologies as well as lack of standard operation procedures (SOP). In several of the cases, limited training and lack of SOPs had lead to workers performing tasks and using the new digital technologies in various ways, thus resulting in errors, misalignment, and reproducibility issues.

3.7 Before – Positive effects on performance

The majority of the decision-makers agreed that performance-related factors drive investment in new digital technologies. The companies had invested in new digital technologies because they believed that their investments would increase competitiveness and place them in a better market position. Also, several decision-makers mentioned that they believed new digital technologies could assist them in meeting increasing customer demands. However, all the decision-makers from the small and medium companies highlighted that the decision to invest in new digital technologies was a necessity for the survival of their company.

> *We are facing constant competition from companies all around the world. We knew that our company would not survive if we did not change from serial production to order production… We could only achieve this [surviving] by investing in these new digital technologies. We would not have been here today if we had not taken this decision* – Decision-maker (Company I)

Informing and involving the workers in the upcoming changes might reduce organizational friction and ease the transition. The majority of the decision-makers shared this notion and believed that their initiative in this regard had positively affected the performance

of the new implemented digital solutions. Besides, the majority of the companies had relied heavily on the workers to come up with ideas for how their company could use new digital technologies. In company D, the senior management team had started an internal competition within their company, looking for innovative ideas for using additive manufacturing technologies. The workers/departments with the best ideas had received a small 3D printer, which they had used to test their ideas. In 12 months, the management team had, in total, distributed 35 3D printers. This initiative had been received so well by the organization that Company D had created a new department focusing on servicing all departments with 3D printed prototypes of components and products.

Several decision-makers mentioned that involving workers early on in (re)designing the work system might result in better solutions. The notion was that the workers are usually very familiar with how the different elements of the work systems operate and interact with each other, thus having their involvement is essential in creating the best solutions.

> *The workers had an essential role in the redesign of the work system. They designed the workflow based on how they were actually working and not how we thought they were* – Decision-maker (Company C)

However, several decision-makers and well as workers mentioned that it is highly essential to involve the "right" workers and not just any worker. In this context, the decision-makers described the "right" workers as someone who has an exceptional understanding of how the given work system operates and interacts with other work systems, the capability to provide constructive feedback, and does not have a negative attitude towards changes and new digital technologies.

3.8 Before – Negative effects on performance

Several decision-makers highlighted that assessing organizational maturity and readiness to adapt to- and work with new digital technologies can be very challenging. Company D had previously failed with the implementation of several new digital technologies in their operations because of worker's limited understanding and technical maturity to work in new ways. To overcome this challenge and ensure that it did not repeat, a decision-maker at Company D explained that they had hired an external consultancy to assess their organizational maturity and identify the necessary competencies before deciding to move forward with any new digital technologies.

While informing and involving workers early on might have a positive effect on well-being and performance, it is challenging to get all employees on board with the emerging changes. The decision-makers all agreed that, while it is an essential element, getting organizational buy-in and reducing organizational friction is a great challenge. One of the decision-makers at Company E highlighted the difficulties their company faced in getting buy-in from the employees in regards to digitalization and implementation of new technologies. This decision-maker mentioned that it is difficult to convince people to get on board with a digitalization strategy, especially when the decision-makers have limited data supporting the claim that working with the new digital technologies will be better than the “old” ways of working.

While some workers find it easy to use and work with new digital technologies, others do not. Several decision-makers and workers mentioned that aging workers find it more challenging to work with new digital technologies compared to younger workers. Several workers and decision-makers mentioned that this challenge was usually due to the aging workers having limited experience with computers in general. Having many aging workers, the decision-makers at Company H team had decided to provide every worker with training in

basic computer use. Basic computer use had included simple tasks such as turning computers on and off, and opening and closing basic computer programs.

3.9 During – Positive effects on performance

As mentioned in section 3.7, involving workers in the design process in the *Before* phase was considered to have a positive effect on not only well-being but also performance. Similarly, involving workers and receiving their continuous feedback as they work and test the new digital technologies in the *During* phase was mentioned to be constructive and essential in developing successful high performing solutions. Almost all of the large case companies had, to a certain degree, involved the workers and considered their feedback while developing and implementing their new digital solutions. In the small case companies, not only had the workers been involved, but they had also been in charge of almost every aspect of the development and implementation of the new digital technologies.

Several decision-makers mentioned that in most cases, the development of new digital solutions and implementation of the new digital technologies had been quick and straightforward. The notion of quickness and straightforwardness was especially emphasized in the case of digital solutions that were solely software-based in comparison to solutions that included both software and hardware. Thus, depending on the complexity of the chosen new digital solutions, a company could rather quickly start developing, testing, and working with the new digital technologies. Several decision-makers expressed that this relative quickness was highly valuable because they could evaluate the usefulness of the new digital solution in a short period without wasting too many recourses.

3.10 During – Negative effects on performance

In several of the cases, the decision-makers had decided upon which technology to invest in and implement before having identified how they were going to use it. Thus, once they had acquired the new digital technology, they found it challenging to find appropriate tasks and use-cases. This challenge was especially relevant in the case of cobots. Several decision-makers from different companies mentioned that they had invested in cobots because they found the idea of the technology exciting; however, after acquiring the cobots, they struggled to find appropriate tasks the cobots could partake. One of the decision-makers at Company D explained that upon learning about cobot, they believed the technologies sounded interesting had the potential of being in their department.

> *I asked my manager if we could get a cobot to see if we could find some use for it in our department. My manager replied that we already had one stored away somewhere. Apparently, another department had bought it one year ago but had not able to find any use for it.* – Decision-maker (Company D)

Limited understanding of work system elements and processes can prolong the development and implementation process. This understanding includes, e.g., how work is planned and performed in the work system, how departments communicate with each other, how inputs are processed, and output delivered. Almost all decision-makers noted that they had experienced particular challenges because they overlooked or not accounted for some elements or interactions within and between their work systems. In the case of company C, the digitalization of paper flow in a shop floor work cell had resulted in communication challenges and information errors with the planning department. These challenges and errors had occurred because the decision-makers in charge of the redesign of the work cell had overlooked how the new changes might affect the particular way the work cell processed and used inputs.

Most of the decision-makers mentioned that they had experienced several drawbacks and challenges related to integration between the new digital technologies and the existing IT system infrastructure. It was highlighted that system integration was both technically challenging and resource-consuming and had limited full utilization of their new digital solutions. Several decision-makers had avoided connecting the new digital technologies with the current systems to bypass the challenges of system integration. These companies had initially used the new digital solutions as stand-alone solutions and had not connected them to the rest of the existing IT systems. For example, Company E had invested in a new, highly digitalized solution for picking-lists that could potentially vastly increase performance. However, due to challenges with IT system integration, the workers could not use the majority of the features of the solution. Thus, the workers had resorted to taping a piece of A4 paper on the machine's screen and a pen hanging on an elastic band, which they used to document the items they picked.

Because the *During* phase is a transitioning phase between the old and new ways for working, in some cases, the old and new had overlapped. As mentioned in section 3.4, in such scenarios, some workers had been reluctant to use the new digital technologies and chosen to keep working in the old ways. A decision-maker from Company A mentioned that when the workers had not used the new digital technologies, the performance of the entire work system had drastically decreased, and resulted in poor product quality and lost profits.

> *One of the workers who refused to use the new solution had a large order worth around €55.000. At the end of the line quality control, we realized that everything this worker had produced in that order had to go straight into the trash* – Decision-maker (Company A)

As mentioned in section 3.4, partially developed solutions can have a negative effect on the workers' well-being in the *During* phase. Similarly, partially developed solutions can also negatively affect performance in this phase. Several workers mentioned that the general

workflow and work efficiency had initially decreased because of technical errors and deficiencies. In some of the cases, the new technologies had added new tasks, steps, and sub-processes the workers had to account for while the new digital solution was taking its final form. While developing and testing their AGV solutions, Company A had experienced several challenges that had negatively affected both the workers' well-being and overall system performance.

> *We have had several stops in the operations because of technical error. These errors and stops created an annoyance for the workers and were also very time-consuming. In busy periods, we observed that the workers would push the AGVs to the side and not use any time on restarting them.* – Decision-maker (Company A)

Several workers mentioned that they viewed partially developed solutions as unreliable and felt an increase in uncertainty regarding their tasks and operation of the new digital technologies. Consequently, such uncertainties had resulted in longer lead times and decreased deficiency. A worker at Company H expressed that initially, they did not find their new digital paper flow system very reliable, and at times, felt very uncertain when using it. In many instances, the received information had seemed wrong, which had resulted in the worker being forced to go around the entire shop floor and find the people responsible for the provided information to ensure the validity of the received information. This additional task had required much effort and, in several instances, taken hours to complete.

3.11 After – Positive effects on performance

While system performance might decrease in the initial stages of the *During* phase, it tends to increase once the companies have fully developed the new digital solutions and implemented the new digital technologies and transitioned into the A*fter* phase. The Efficiency and workflow improved as new digital solutions mature and are sufficiently developed and implemented. The

majority of the decision-makers, as well as several workers, highlighted this notion and expressed contentment with the new ways of working. In the case of digital paper flow at Company C, one of the decision-makers mentioned that once they had developed and implemented one of their new digital solution, the changeover time for that specific work system had vastly decreased. This improvement had been a great accomplishment because the mentioned work system had never managed to live up to the targeted changeover time as defined in the protocols. However, the new digital paper flow had enabled them to reach and go beyond the target changeover time.

Digital technologies that grant access to existing or newly created data had, in some cases, increased transparency in the process and information flow within as well as between work systems. Such transparency had had a positive effect on performance across the majority of the companies' supply chains. In the cases of digital paper flow, i.e., case company C and company H, both the decision-makers and workers mentioned how the new digital solutions had created such transparency.

> *In the past, I could not follow the orders, but today I can look and see where in our facility the order is. This is highly valuable information because we usually have very tight deadlines with customers all over Scandinavia… Knowing where an order is at all times ensures that I can react timely if something goes wrong* – Worker (Company H)

Thus, data availability and transparency had made it easier to communicate and identify problems and challenges within and across the work systems as well as enabling better decision-making. Several decision-makers and workers mentioned and highlighted such notions as positive effects on system performance.

The implementation of new digital technologies was also mentioned to have had improved production lead times, and product quality and uniformity as well as reducing error rates and

customer claims. Several decision-makers highlighted that such improvements had had a positive effect on customer satisfaction, which they had experienced through direct communication with their customers and customer claim. One of the decision-makers at Company A mentioned that after a few months, their investment in automation with advanced vision systems had decreased customer claims, as well as product waste by a noticeable amount.

3.12 After – Negative effects on performance

The development of the new digital solutions seemed to be continuous, which in some cases had continued even after the final digital solution has been developed. Over time, as the workers work with the digital solutions and use the new digital technologies in various ways, new errors and technical issues can emerge that need to be handled and solved. Such challenges can have a negative effect on system performance, and dealing with them can be highly resource consuming. In cases where it is not possible to change back from the new way (working with new digital technologies) to the old way of working, technical issues and errors can bring the entire work system into a halt. Also, because the individual work systems become increasingly dependent on each other's input and output, technical issues in one work system might have an impact on other work systems across the supply chain. While none of the decision-makers or workers let to believe that such scenarios had occurred, several decision-makers expressed that they feared it would eventually happen.

Several decision-makers highlighted that their company had invested in new digital technologies to grow without hiring any additional workforce. However, most decision-makers expressed that ultimately, an increase in employee turnover is inevitable. All but one of the decision-makers at company A mentioned that they had initially not believed that their investment in new digital technologies would result in workers being laid off. However, once

they had fully implemented the new digital technologies, they had been forced to lay several workers off because they could not find new tasks suitable tasks for them.

We have laid off several forklift drivers because of our new AGVs. It is a way of rationalizing our investments. This is given, because we have to pay for the AGVs in one way or another, and in this case, we had to optimize our staffing to justify our investment – Decision-maker (Compay A)

3.13 Summary of the results

In the results presented in the previous sub-sections of section 3, we highlighted how new digital technologies affected perceived performance and well-being before, during, and after implementation. Based on these results, we have identified several factors that impact the perceived well-being and performance in the three phases. Refer to Table 8 for an overview of these factors.

Table 8 – Factors impacting perceived well-being and performance before, during, and after the implementation of new digital technologies.

Table 8

4 Discussion

The contribution of this paper is twofold. On the one hand, it provides empirical evidence collected through case studies on how perceived human well-being and overall system performance changes before, during, and after the implementation of new digital technologies. On the other hand, it highlights implications for practitioners as well as giving recommendations for how to ensure human well-being and performance.

4.1 Results discussion

The way new digital technologies affect human well-being and system performance are subject to change before, during, and after implementation. Indeed, the results indicate that each of these three phases evokes different positive and negative perceptions of how well-being and performance changes.

In the *Before* phase, well-being is almost equally affected both negatively and positively. While the workers tend to have some fear regarding the upcoming changes and their particular situation in their company, they also tend to showcase some excitement about the new digital technologies and working with them. In regards to performance, the perception of how new digital technologies might affect performance is in some ways similar to how they affect well-being. While there are some positive perceptions and expectations on how the new digital technologies are going to affect performance positively, there are almost the same amount of negative perceptions and expectations.

In the *During* phase, the negative aspects affecting well-being and performance tend to outweigh the positive ones. Because most of the new digital technologies are not fully developed and might have errors and flaws when used in the *During* phase, the workers might view them as unreliable. Thus, new digital technologies become a source of uncertainty. Unreliable digital technologies and increased uncertainty might result in stressful situations and scenarios that will have a negative impact on both performance and well-being. Besides, the development of a new digital solution and successful implementation requires a holistic understanding of elements and interactions within, and between work systems Thus, limited knowledge in this regard might become a contributing factor to some of the other negative aspects such as finding an appropriate use for new digital technologies, providing limited training, and poor work division.

In comparison to the *During* phase, in the *After* phase, after the new digital technologies have been implemented, both perceived well-being and performance tend to improve. Performance improves in the form of efficiency, workflow, and transparency, which also play a contributing factor to the improvement of well-being in the form of physical, cognitive, and organizational ergonomics. However, not every negative aspect disappears in this phase. Limited standardization and insufficient management involvement tend to negatively affect perceived human wellbeing, while dependency on- and continuous improvement and development of the new digital solutions can negatively affect performance.

In summary, perceived well-being and performance are in a neutral position in the *Before* phase, worsen in the *During* phase, and improve beyond the neutral *Before* phase in the *After* phase. Figure 2 shows this simple overview of how perceived well-being and overall system performance changes in the three transition phases.

Figure 2

Figure 2 – Simple overview of how perceived well-being and overall system performance changes before, during, and after the implementation of new digital technologies.

How perceived well-being and performance change throughout these three phases are not surprising. These findings fall well within popular change and organizational transition concepts and models such as “Bridge’s model of transition” (Bridges, 2003), which we introduced in section 1.2. Such models can explain the process organizations, as well as individuals, go through when transitioning into something new and unfamiliar. What they have in common is the description of transition being a multiphase process that will potentially experience a decrease in performance and well-being. This decrease will usually occur approximately mid-transition, which is similar to the results of this paper.

A common theme reemerging in both the *Before* and *During* phase is information and involving employees. Employee involvement and the application of human-centered design is a prominent topic when discussing the design of Industry 4.0 work systems (Kadir et al., 2019). Pacaux-Lemoine et al. (2017) argue that a human-centered design approach to intelligent manufacturing systems would have a positive effect on both global system performance and human well-being. Similarly, as highlighted in Sections 3.1, 3.3, 3.7, and 3.9, the results of this paper indicate that employee involvement affects perceived well-being and performance. These findings fall in line with the findings of Tortorella et al. (2018), which uses the empirical results from a survey with 146 Brazilian manufacturers. Tortorella et al. (2018) argue that companies reinforcing employee involvement in their Industry 4.0 journey and implementation of new digital technologies may be able to improve their operational performance. However, successful technology appropriation requires user involvement not only in the design phase but also in the adoption phase (Janneck, 2009).

Informing and involving workers early on can also affect the appropriation of new digital technologies. In Carroll and Fidock's (2011) model of Technology Appropriation shown in Figure 1, the first level of technology appropriation focuses on expectations of the new technology. Thus, before working with new technologies, the users will have some expectations that will affect the choice of adoption or non-adoption. As presented in Section 3.4, Company A had experienced several workers not adopting the newly introduced digital technology and refusing to comply with the new ways of working. Thus, the decision to not use the new digital technologies became a barrier to the appropriation process.

As mentioned in Sections 3.4 and 3.10, in the *During* phase, the perceived well-being and performance tend to worsen before it improves again and move past the baseline of the *Before* phase. Fullan (2001) refers to this phenomenon as the “Implementation Dip” and describes it as

…a dip in performance and confidence as one encounters an innovation that requires new skills and new understandings (Fullan, 2001).

The implementation dip seems to describe the reason behind the decrease in perceived well-being and performance. The workers need to have sufficient information on the changes, understanding of the new digital technologies, their future role in the organization, as well as getting the necessary training and education to perform their jobs adequately. Furthermore, partially developed technologies might also have a significant impact, which explains Company B's decision not to introduce new digital technologies before they are sufficiently developed. The decrease in perceived well-being is a common trait in transition and change processes.

In "Bridge's model of transition" (Bridges, 2003), a transition consists of three overlapping phases, which begins with an ending, then moves into a "neutral" zone and ends with a new beginning. The neutral zone is comparable with what we in this paper described as the *During* phase. Bridges (2003) highlights that in the neutral zone, people's well-being and performance is often negatively affected. This decrease in well-being fit well with the results presented in Section 3.4. This effect on well-being and performance might also affect the technology appropriation process. In Section 3.4, we highlighted that some workers were worried about using the new digital technologies because of the fear of breaking them. Having such fear might limit the users' aspiration to explore the new digital solution (as in level 2 in the model of technology appropriation in Figure 1), thus learning by doing, which is a highly regarded technology appropriation activity (Janneck, 2009).

In the *After* phase, Section 3.10, limited standardized operating procedures and training and lack of decision-makers' involvement and commitment were the main factors affecting the workers' perceived well-being. We argue that decision-makers' involvement and commitment might also contribute to some of the factors negatively affecting perceived performance, e.g.,

continuous development and dependency on the new solutions. Such factors are highly dependent on the decision-makers prioritizing and allocating the necessary resources to ensure that the new digital technologies are operational and live up to the expectations. Failing to do so can lead to subpar- or, in worst cases, unsuccessful transition. Hindshaw and Gruin (2017) refer to this phenomenon as the "Valley of Death." The valley of death is a phase in organizational transitions where the initial excitement and energy about the transition have vanished, and the people involved have grown tired of the project. We believe that company H, might have gone through this phase and that the management team's lack of commitment and resource allocation after the implementation of the new digital technologies is because of the lack of excitement the digitalization project possessed in the initial phases.

Improved performance (e.g., productivity, competitive advantage, and financial gains) is the essential driver of the move towards Industry 4.0 and the implementation of new digital technologies (Müller et al., 2018). However, performance and well-being are closely related, and they can influence each other in both the short and long-term (Dul et al., 2012). Thus, understanding how the implementation of new digital technologies affect performance and well-being plays an essential part in realizing the expected benefits of the new digital technologies. The findings of this paper pave the way for a more holistic understating of how new digital technologies affect human well-being and overall system performance before, during, and after implementation. This knowledge and understanding can assist in establishing a foundation for prescriptive tools and methods that can ensure a successful (re)design of new digitalized industrial work systems. Such prescriptions might be essential in aligning humans, technologies, and organization, thus ensuring human well-being and overall system performance in the journey towards Industry 4.0 and a smart interconnected digitalized factory.

Because of the nature of case studies, it is challenging to generalize the findings. However, the richness of the empirical data provides a great insight into some of the different challenges

related to well-being and performance that might emerge with the implementation of new digital technologies. Thus, enabling us to provide prescriptive measures to deal with these specific challenges.

People are, in general, reluctant to change and need to be informed and engaged with in order to comply and adapt to new changes. This reluctance is not much different in the case of the journey towards Industry 4.0 and digital transformation scenarios. However, one of the elements that might be different in this aspect is that industrial companies have limited experience with these new digital solutions. Thus, it might be challenging to articulate the benefits and challenges to the employees in the *Before* and *During* phases. Not having this specific knowledge might lead to an increase in organizational friction and stakeholder alignment throughout the different layers of an organization, ultimately leading to negatively affecting human well-being and overall system performance.

4.2 Implications for practitioners

In this section, we will highlight several implications and recommendations for practitioners that might be embarking on an industry 4.0 journey and considering implementing new digital technologies. By practitioners, we refer to internal decision-makers on strategic, tactical, and operational organizational levels that might be in charge of the digital transition as well as internal and external consultants (e.g., ergonomists and HF/E specialists) who might be assisting organizations in their digital transition.

The implementation of new digital technologies is an organizational transition that requires a holistic understanding of the organization in its entirety and acknowledged as a process of overlapping phases that will affect human well-being and overall system performance. While it might be tempting to begin and rush the transition process in expectations of achieving the benefits in the shortest time as possible, it might be wise to slow

down and ensure this holistic understanding. Such understanding might lead to crucial insights that could potentially reduce or assist in mitigating uncertainties and risks. Besides, informing and involving employees seems to have an impact on the success and final performance of the implemented new digital technologies.

Practitioners need to be aware of the likelihood of decreasing well-being and performance during the implementation of new digital technologies. However, in successful implementations, it is most probable that both well-being and performance will increase and surpass the baseline level before the implementation.

4.3 Recommendation for practitioners

In the following section, based on the results, we will present several recommendations for practitioners on how to ensure human well-being and system performance throughout the three different phases of *Before*, *During*, and *After*. Decision-makers can use these recommendations as guiding principles when moving through the transition phases, while internal and external consultants can use them to assist their clients in this transition.

4.3.1 Recommendations for the Before phase

- Link digital strategy with the strategic objective to ensure what everyone in the organization understands the reason behind the investment in the new digital technologies.
- Inform and engage all relevant stakeholders on all organizational levels to reduce organizational friction and obstacles as well as aligning expectations.
- Evaluate if the workers have the necessary competences or if there is a need for additional training and education.
- Develop and follow a systematic approach for (re)designing the work systems with the new digital solutions.

- Gain a sufficient understanding of elements and interactions within and between the targeted work system(s). Such an understanding will increase the potential of highlighting technical, as well as organization-related challenges that could have adverse effects on human well-being and overall system performance.
- Apply a human-centered design and involve the affected employees early on in designing the new digital solutions. The benefits of involving the workers are twofold. On the one hand, these employees have much more excellent knowledge about the work systems function in day-to-day operations. On the second hand, involving the workers at this stage might reduce the adverse effects on well-being and performance in the *During* phase.

4.3.2 Recommendations for the During phase

- Apply a systematic, iterative approach for introducing new digital technologies and developing new digital solutions.
- Plan and allocate the necessary resources.
- Continuously inform the organization of the ongoing changes.
- Ensure that the workers know how to use the new digital technologies, but also leave room for exploration and adaptation.
- Establish a system for continuously capturing feedback from the users.
- Get a sufficient understanding of the new digital technologies to generate a basic yet realistic idea on the pertaining limitation.

4.3.3 Recommendations for the After phase

- Standardize the new ways of working after the implementation of new digital solutions.
- Develop standard operating procedures and training materials. Replace and altogether remove non-applicable old materials from sight.
- Establish a program for how to train workers (new workers).

- Develop a life cycle management to ensure maintenance, updates, and continuous improvement of the new digital solutions. This life cycle management plan should include a system for collecting, storing and using continuous feedback from the users to ensure optimal usability and performance.

5 Limitations and future research

Because we have collected the presented empirical data through ten different case studies at ten different companies, it might be challenging to draw broad generalizable conclusions. Thus, the reason we present the data as a sample of various examples that might affect the well-being and performance before, during, and after the implementation of new digital technologies. Also, we might have been able to generate an even greater collection of data with more depth if it had been possible to follow the cases proactively as well as having greater access to the companies and their employees.

Future research could include in-depth prospective case studies that run over an extended period. Because the option of data collection is more extensive and can include a wide variety of both quantitative and qualitative data and measurements, such case studies might generate an even greater understanding of how the transition to Industry 4.0 might affect human well-being and overall system performance. Such an understanding is essential in creating a solid foundation for predictive estimations, preventive measures, and prescriptive guidelines and frameworks, which can ease the transitioning process and increase the success rate of digital transformation initiatives.

6 Conclusion

While the concept of new digital technologies are highly attractive and promising many benefits, most industrial companies have yet to reach a level that can be considered as entirely

industry 4.0. The journey towards industry 4.0 involves creating a digital foundation for carrying new digital solutions in the future. However, most companies are not used to using and working with new digital solutions. Thus even small-scale digitalization efforts can create challenges that might affect well-being and performance before, during, and after the implementation of the new digital technologies.

In this paper, we presented empirical data from ten different industrial case studies conducted in ten different industrial companies in Denmark. Using the data from these case studies, we presented a range of factors that have positive and negative effects on perceived human well-being and overall system performance. In summary, the results indicate that during the implementation of new digital solutions, both well-being and system performance are negatively affected, while after a successful implementation, both well-being and performance improve. In addition, we highlight implications for practitioners as well as several recommendations for how practitioners might overcome the challenges presented in the findings.

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