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Human work in the shift to Industry 4.0: a road map to the management of technological changes in manufacturing

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ABSTRACT

The fourth industrial revolution tempts manufacturing companies to transform into smart factories, which in turn affects the human work. We examine this complexity from the perspective of human factors and ergonomics (HF/E) by analysing the organisational capabilities needed when seeking and selecting new technology solutions, and designing and implementing them into local application. This qualitative study focuses on manufacturing companies that have pioneered adopting high technologies in their processes. Empirical material was collected from 15 Finnish manufacturing companies of different sizes. Particular attention is paid to how HF/E are present when companies (1) sense new opportunities for technological development of their production, (2) seise these opportunities through design actions, and (3) shift the solutions into use. Analyses revealed that companies, regardless of their size and the technology being implemented, do not fully understand the fundamentals and value of HF/E, resulting in technology and production-oriented solutions in which human skills and capabilities are often neglected. A novel road map is proposed for integrating HF/E expertise and knowledge when seeking, selecting, and utilising new production technologies. This study increases understanding of the role of HF/E when adopting new technologies in manufacturing. The road map improves possibilities for fact-based decision-making.

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Dynamic capabilities; ergonomics; human factors; Industry 4.0; road map; technologisation

1. Introduction

Successfully implemented new technologies enable companies to transform their manufacturing systems to flexible and safe entities where intelligent solutions support optimised and less labour-intensive production. Discussion on technological transformation can be associated to broader considerations on industrial revolutions, and especially on their current manifestation that is in manufacturing often referred to as Industry 4.0 (or to similar concepts like smart manufacturing or digital transformation) (e.g. Koh, Orzes, and Jia 2019; Schneider 2018; Zheng et al. 2021). Technologisation is not a guarantee for future success, as it also brings along various challenges, including 'wicked problems' that are hardly solved by single actors (Cagnin, Havas, and Saritas 2013). These 'wicked problems' might require new mindsets and better understanding about sociotechnical systems (Di Pasquale, Miranda, and Neumann 2020; Dugan et al. 2022; Grewatsch, Kennedy, and Bansal 2021; Kaivo-oja and Lauraeus 2018; Marcon et al. 2022; McMillan and Overall 2016).

The sociotechnical perspective is often neglected in the production-pressurised and technology-oriented discussion on manufacturing (Broday 2021; Duggal et al. 2022; Marcon et al. 2022; Neumann et al. 2021; Sony and Naik 2020). Various researchers (e.g. Bonekamp and Sure 2015; Duggal et al. 2022; Enang, Bashiri, and Jarvis 2023; Lu et al. 2022; Mourtzis, Angelopoulos, and Panopoulos 2022; Panagou, Neumann, and Fruggiero 2023; Rožanec et al. 2023; Xu et al. 2021) and organisational influencers like European Commission (2020; 2021) and International Labour Organization (2023) have highlighted the need for better understanding of the human perspective when discussing the future of manufacturing in the context of Industry 4.0 and on the visions related to the following Industry 5.0 phenomenon. Future research activities have been proposed to focus more on the organisational and individual capabilities needed for successful technology adoption (Dolgui, Sgarbossa, and Simonetto 2022; Reiman et al. 2021; Singh et al. 2022; Wiggins et al. 2020), on human-related barriers and incentives in new technology transformation processes (Cugno, Castagnoli, and Büchi 2021; Hashemi-Petroodi et al. 2021; Panagou, Neumann, and Fruggiero 2023; Stornelli, Ozcan, and Simms 2021), and on occupational health and safety (OHS) (Badri, Boudreau-Trudel, and Souissi 2018;

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Min et al. 2019; Zorzenon, Lizarelli, and de A Moura 2022).

Human factors and Ergonomics (HF/E) provide a design-science-oriented approach to analyse and develop complex sociotechnical systems. When HF/E methods and knowledge are fully applied, they direct to optimise both the well-being of the employee and the overall system performance (e.g. Dul et al. 2012; Kolus, Wells, and Neumann 2018; Sgarbossa et al. 2020), including the business perspective (e.g. Dul and Neumann 2009). In manufacturing, however, HF/E seems to be in reality too bound to risk prevention and individual-centric development approaches whilst the overall sociotechnical system perspective is neglected (Greig et al. 2023; Grosse et al. 2023). Actors responsible for creating and managing manufacturing systems in the companies need support and guidance to implement HF/E skills and knowledge when designing (Zizic et al. 2022), orchestrating and managing new technology implementation processes (Reiman et al. 2021). Our study aims to facilitate discussion on the utilisation of HF/E in the manufacturing context when new production technologies are sought, selected, and implemented into use. Focus is on the companies that can be considered having a pioneering orientation of technology adoption (e.g. Ruiz-Ortega, García-Villaverde, and Parra-Requena 2018), as they have actively decided to seek first mover advantages from new production technologies. In our analysis, we focused on organisational level practices and processes, as we intended to study how these pioneering companies orchestrate and manage their new technology implementation processes when considered from the HF/E perspective. For that purpose, we applied the established, yet generic theory on dynamic organisational capabilities by Teece (2007) supplemented with initiatives arising from the HF/E literature. We examined the utilisation of HF/E knowledge in the manufacturing companies when they are (a) sensing new opportunities for production technology development, (b) seising these opportunities, and finally (c) adopting them into practical use to reach competitive advantages. Finally, the findings are discussed in the form of a novel road map. The road map serves as a managerial decision aid framework for systematically tying HF/E in technology adoption processes at the company level.

2. Literature review

The background of our study is based on three core concepts brought together in this article. They are presented briefly in the following subchapters: (I) technologisation in manufacturing, (II) HF/E, and (III) dynamic organisational capabilities.

2.1. Technologisation in manufacturing

In addition to technological evolution, all four industrial revolutions have also affected human work (e.g. Duggal et al. 2022; Lucassen 2021; Mourtzis, Angelopoulos, and Panopoulos 2022). The first industrial revolution dates to the eighteenth century, and the development process resulted in mechanised manufacturing processes where machine-assisted labour remained the key resource (Duggal et al. 2022; Lucassen 2021; Von Tunzelmann 2003). The second industrial revolution is associated with a shift from machine-assisted labour to labour-assisted machinery with the development of mass production and assembly lines (Duggal et al. 2022; Von Tunzelmann 2003). From the HF/E perspective, this second industrial revolution also initiated the first time-and-motion studies (Schachter 2010), which later led to the development of work study techniques (Kanawaty 1992), which in turn share many similarities with HF/E (Kanawaty 1992; Singh 2016). The third industrial revolution in the latter half of the twentieth century was associated with automation and computerisation and the development of information and communication technologies (Duggal et al. 2022; Von Tunzelmann 2003). Despite not being synonyms as such, Industry 4.0 is in practice considered representing a continuum to the previous industrial revolutions, i.e. in the manufacturing context it is discussed as the fourth industrial revolution (Schneider 2018). Practical and scientific discussion on future industrial revolutions is lively and scattered future scenarios for the next industrial revolutions (Industry 5.0 and Industry 6.0) have already been proposed and framed (e.g. Duggal et al. 2022; European Commission 2021; Ivanov 2023; Mourtzis, Angelopoulos, and Panopoulos 2022; Xu et al. 2021; Yao et al. 2022).

Various smart technologies are commonly discussed under the broad umbrella of Industry 4.0. These include for instance the industrial Internet of Things, artificial intelligence, machine learning, virtual and augmented reality, digital twins, cloud computing, big data mining and analytics, cyber security solutions, simulation and automation solutions, additive manufacturing, horizontal and vertical system integration, robotics and cobotics, wearable devices, and exoskeletons (e.g. Alcácer and Cruz-Machado 2019; Bai et al. 2020; Culot et al. 2020; Dornelles, Ayala, and Frank 2022; European Commission 2020; Gruetzemacher and Whittlestone 2022; Kaivo-oja et al. 2020; Knudsen and Kaivo-oja 2020; Luo, Thevenin, and Dolgui 2023; Makridakis 2017; Oztemel and Gursev 2020). When properly implemented, these technologies provide possibilities to increase competitiveness. However, these technologies also carry limitations in their usage (Dornelles, Ayala, and Frank 2022).

To gain competitive advantage, the technologies adopted should fit a company's strategic criteria and the implementation should follow organisational design recommendations including the sociotechnical system perspective (Da Rosa Cardoso, de Lima, and Gouvea da Costa 2012; Dornelles, Ayala, and Frank 2022; Geels 2020; Marcon et al. 2022; Roth et al. 2020; Schwab 2016). Obviously, these new technologies bring along demands and possibilities to develop companies' information and knowledge management practices and processes (e.g. Carlucci, Kudryavtsev, and Bratianu 2022; Luo, Thevenin, and Dolgui 2023) and to follow and develop employees' competences to utilise them efficiently and safely (Dornelles, Ayala, and Frank 2023; European Commission 2020; Mahlmann Kipper et al. 2021; Sony and Mekoth 2022). The road map presented in this article supports companies in this Industry 4.0 technological change management process from the HF/E perspective.

2.2. Human factors and ergonomics (HF/E)

The domain of HF/E covers micro- and macroergonomic perspectives. The first focuses on individuals at their workstations while the latter is used on the organisational level (Dul et al. 2012; Kleiner 2006). The core of HF/E is to understand the interactions between humans and other elements of the system (Dul et al. 2012; Wilson 2014). The system should be understood broadly: in microergonomics the system might be as simple as one individual using a tool, whereas in macroergonomics (or systems ergonomics) the system should be seen as a complex sociotechnical entity, like a production line, a manufacturing plant or a multinational corporation (e.g. Hendrick 2008; Kleiner 2006; Wilson 2014). When examined from the macroergonomics perspective, such system should be seen consisting of the people involved (personnel subsystem), using the technologies available (technological subsystem) within an organisational subsystem (structures and policies), and the system is influenced by the internal environment (both physical and cultural) and the external environment (e.g. business demands, regulation, etc.) (Kleiner 2006; 2008; Marcon et al. 2022).

When HF/E development activities are carefully designed and properly managed, they also have a high probability of being successful (Abdous et al. 2023; Heidarimoghadam et al. 2022; Hendrick 2003; Lyon and Popov 2023; Morse, Kros, and Nadler 2009). The benefits may be realised in various forms though they still mainly relate to improved employee well-being and to reduced numbers of different adverse outcomes, including reduction in sick-leave days (Goggins, Spielholz, and Nothstein 2008; Heidarimoghadam et al. 2022; Neumann and Dul 2010; Teufer et al. 2019), yet there is also evidence on the financial merits of HF/E interventions in the manufacturing industry (Tompa et al. 2010). Several case studies on HF/E have shown how concrete benefits can be achieved in the form of improved employee health and safety but also as improved productivity and quality (e.g. De Looze et al. 2010; Falck and Rosenqvist 2014; Neumann et al. 2006; Quenehen et al. 2023).

The need to better understand the human perspective in the future manufacturing context is evident (Broday 2021; Neumann et al. 2021; Reiman et al. 2021; Sgarbossa et al. 2020). Especial interest should be paid to HF/E in assembly lines, as they involve the largest proportion of the labour force (Abdous et al. 2023). Highly digitalised and automatised production systems likely ease the physical human work for instance by removing boring, dirty and repetitive tasks, but they also bring along new demands for cognitive skills and knowledge (e.g. Badri, Boudreau-Trudel, and Souissi 2018; Di Nardo, Forino, and Murino 2020; Gladysz et al. 2023; Longo, Nicoletti, and Padovano 2019; Mourtzis, Angelopoulos, and Panopoulos 2022; Pauliková, Babel'ová, and Ubárová 2021; Quenehen et al. 2023) and their management (Kadir and Broberg 2020; Thun et al. 2019). It is also good to remind that the physical ergonomics perspective should not be forgotten (e.g. Abdous et al. 2023).

In the literature, referring to the concept of Industry 4.0 (and Industry 5.0), employees are discussed as Operators 4.0 (or 5.0) (Longo, Nicoletti, and Padovano 2017; 2019; Mourtzis, Angelopoulos, and Panopoulos 2022; Romero, Stahre, and Taisch 2020; Sun et al. 2020). Smart technologies provide new possibilities to collect data from the production system to facilitate data-based decisions (Rožanec et al. 2023; Zizic et al. 2022). This also includes the possibility to collect data on employee health and performance. However, such data can include individual personal information, which in turn is a challenge considering trust and privacy (Javaid et al. 2021; Mannhardt, Petersen, and Oliveira 2019; Stefana et al. 2021).

2.3. Dynamic capabilities

Organisation's resources, strategy, and capabilities constitute a system that determines its competitiveness (Teece 2007). In an organisational context, capabilities do not represent a single resource, but a distinctive way to allocate, integrate, and reconfigure organisation's resources (Eisenhardt and Martin 2000; Felin et al. 2012; Schreyögg and Kliesch-Eberl 2007). Dynamic capabilities refer to a subset of homogenous and substitutable capabilities that help organisations to build competitive advantage by maintaining evolutionary fitness over time (Helfat and Raubitschek 2018; Teece 2007). These can be conceptualised as tools for manipulating resource configurations by enhancing existing ones or, more frequently, for building new resource configurations to survive in a continuously changing business environment (Eisenhardt and Martin 2000; Pisano 2017; Teece 2007). The psychosocial foundations of the dynamic capabilities should not be neglected; at the end companies are still managed by individuals whose skills, knowledge, thoughts, and feelings affect their decision-making (Hodgkinson and Healey 2011; Pavlou and el Sawy 2011).

Schreyögg and Kliesch-Eberl (2007) argue that the most prominent approach towards a theory of dynamic capabilities has emerged from the conceptualisation by Teece, Pisano, and Shuen (1997). Accordingly, the dynamic capabilities were categorised in terms of sensing, seising, and reconfiguring, where sensing refers to sensing, filtering, shaping, and calibrating different opportunities and threats; seising refers to addressing these sensed opportunities to new products, processes, or services; and reconfiguring refers to the ability to orchestrate an organisation's assets and structures to match their internal processes with these seised opportunities (Teece 2007; Teece, Pisano, and Shuen 1997). The term reconfiguring has also been referred to continuous renewal, shifting, and transforming (e.g. Teece, Peteraf, and Leih 2016). In this study, we adopt the term shifting to describe the phenomenon where selected technological solutions are shifted in practical use by the companies.

The theory of dynamic capabilities has also served as a framework for the studies of technologisation and the Industry 4.0 context. Lin, Sheng, and Wang (2020) highlight the need for holistic management approaches and note that adjustments to process, technological, organisational, and transformation capabilities are necessary for Industry 4.0 organisations. Pervan, Curak, and Kramaric (2018) and Rotjanakorn, Sadangharn, and Na-Nan (2020) stress vital capabilities needed to survive in the business, e.g. recognising changes in the markets, collecting, and analysing related data and information, and understanding newly available technologies and overall business ecosystems. Coping with rapid technologisation requires a rapid understanding of the disruptive potential of new technologies, which in turn might require capabilities to make changes in organisational hierarchies but also require an inclusive understanding of profit-making beyond monetary objectives (Garbellano and da Veiga 2019).

3. Material and methods

This study was based on a qualitative research process (Azungah 2018; Polsa 2013) where existing knowledge on HF/E and dynamic capabilities was implemented iteratively to the empirical data collected. The study included three phases (I–III) as visualised in Figure 1 and described in subsections 3.1 and 3.2.

3.1. Data collection

Empirical material was collected between March 2020 and January 2021. We intended to go in detail into sociotechnical organisational contexts, and hence a qualitative research approach was chosen. As the focus was on pioneering companies, the principles of purposeful sampling (Palinkas et al. 2015) were followed. In Phase I, potential target companies were identified with experts from three national networks representing Finnish industrial companies. Three workshops, one for each network, were arranged in March-April 2020 and the experts (2–3 from each network) proposed the most suitable companies. The following inclusion criteria were used: (1) companies represent manufacturing with physical end products, (2) companies have pioneered adopting new manufacturing technologies, and (3) companies are aware of the Industry 4.0 phenomena. A total of 32 potential companies were identified.

In Phase II, we contacted the companies via telephone. 15 companies meeting the inclusion criteria described above agreed to participate. To secure anonymity for the participating companies, who represent a relatively small business environment in Finland, we give only partial information about them. The companies differed in their sizes and by their end products (see Table 1). All companies had manufacturing facilities in Finland, but they also operated abroad.

In Phase III, company-specific data collection included (1) a web questionnaire (secondary data, see Appendix 1), (2) company-specific Internet searches focusing on publicly available material from the companies and their production systems (e.g. web pages and published academic theses) (secondary data), and (3) an interview (primary data, see Appendix 2).

In the interviews conducted between June and November 2020, the focus was to deepen the knowledge of HF/E in the context of new technology implementation. Especial emphasis was given to the technologies the informants considered representing so-called Industry 4.0 technologies. Due to the ongoing COVID-19 restrictions in Finland, the interviews were arranged remotely. The interview questions were sent beforehand to informants. The informants (1–4 per company, see Table 1) were appointed by the company management to be people who knew the production processes thoroughly. To facilitate a confidential interview session, the interviews

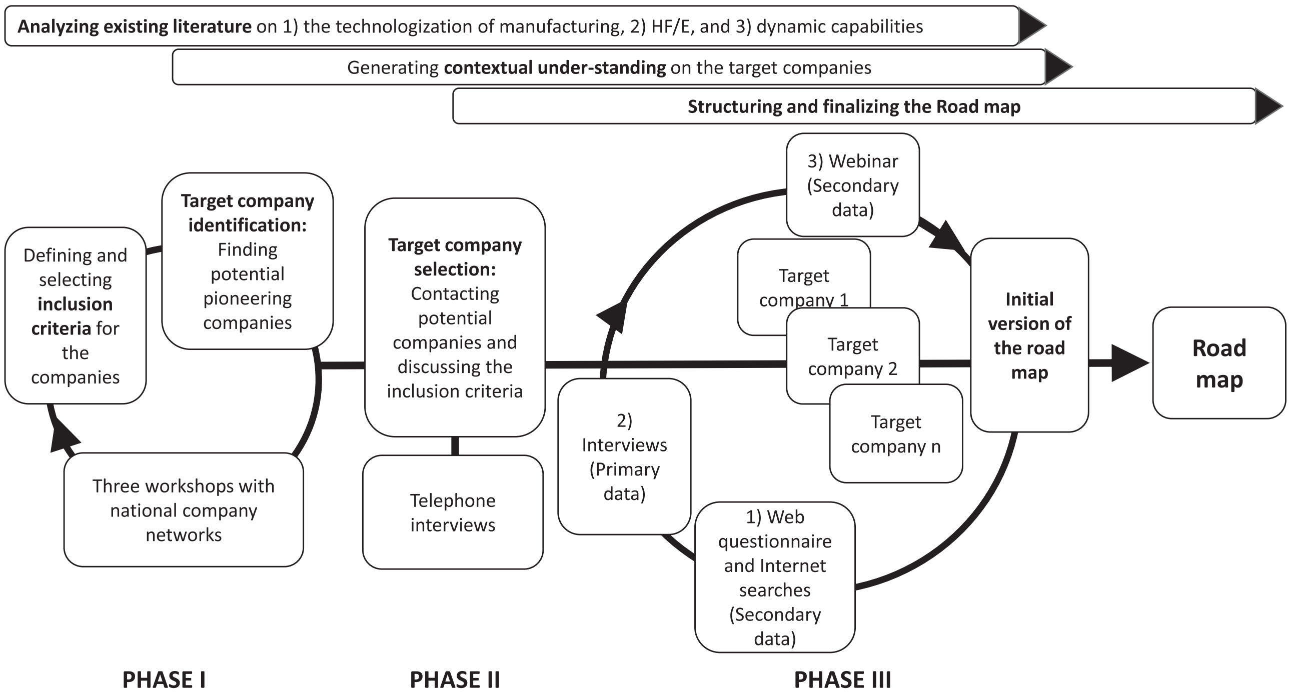

Figure 1. Study process for creating the road map.

were not recorded. In each interview (lasting 1–2 h), one of the researchers acted as the main interviewer, another made official notes, and 1–3 researchers participated as observers. To increase validity, the observers made their own notes that were later added to the official interview notes. In addition, the observers and the secretary could ask specified questions at certain moments of the interview. The first interview was also considered a test interview, after which some minor adjustments were made to the interview questions.

The last measure for data collection and as a check to validate the outcomes of the analysis, a three-hour webinar for the interviewed people was arranged in January 2021. In total 13 experts, representing ten target companies, participated in the webinar. In the webinar, the researcher group presented their preliminary findings to facilitate discussion on the structure of the road map. Afterwards, the webinar material was distributed to the participants for possible feedback.

3.2. Analysis

The secondary and primary data were analysed through an iterative content analysis approach (e.g. Azungah 2018; Orton 1997; Polsa 2013). During the analysis, the researchers constantly cycled back and forth between the theories and data to produce new knowledge. An inductive analysis was first adopted to secondary data to capture contextual understanding about the companies, their manufacturing processes and the technologies they had implemented, and their instant views on HF/E utilisation. The latter part of the analysis was based on abductive reasoning (e.g. Patokorpi and Ahvenainen 2009; Polsa 2013) as the interviews and their analyses were based on a process where two system theories (dynamic capabilities and HF/E) were adopted as analysis frameworks. In the analyses, the researchers first read two interviews independently and identified items they deemed relevant with respect to the research objectives. Then the findings were compared with those of the other researchers, discussed, and the consensus on the themes was added to the analysis framework. Thereafter, the next interviews were read using this updated framework, discussed again and the consensus updated in the framework. This iterative process continued until all the interviews had been analysed. Finally, the built knowledge was introduced to the webinar participants to test its validity.

4. Results

In the web questionnaire, all companies reported how new manufacturing technologies commonly associated to Industry 4.0 technologies had been implemented in their processes. Most companies indicated how they had succeeded in these technology transformation processes,

Table 1. Company classification and informants for the interviews.

Company size∗	Products	Informants
Small	Parcelled goods	- Chief operating officer
Small	Parcelled goods	- Chief operating officer
Small	Vehicles	- Plant manager - Production manager - Supply chain manager
Small	Technological devices	- Production manager
Medium-sized	Parcelled goods	- Development director - Production manager
Medium-sized	Vehicle parts	- Chief operating officer - Production manager - OHS manager
Medium-sized	Machine parts	- Production manager
Medium-sized	Alimentary products	- Chief executive officer - Production manager
Large	Alimentary products	- Technology director
Large	Machine parts	- Development manager
Large	Vehicles	- Production manager
Large	Technological devices	- Program manager (manufacturing technologies)
Large	Drugs	- Vice president (production digitalisation)
Large	Vehicles	- Manager (information and development) - Manager (manufacturing engineering and supply chains) - Production manager - Project manager
Large	Technological devices	- Plant manager - OHS manager

∗Based on the classification by the European Union (n.d.): small companies (10–49 employees), medium-sized companies (50–249 employees) and large companies (over 250 employees). Classification made by the number of employees in Finland.

yet only a couple of the largest companies reported how they had considered the solutions from the human work perspective. These solutions were related to the safe utilisation of collaborative robots and virtual reality environments for design purposes and the adoption of remote maintenance applications. For the rest, HF/E appeared as a conservative concept, i.e. they associated it as a part of their routine OHS processes and indicated how they had actively identified and improved work tasks that had required heavy manual handling or awkward body postures. Around one-third of the companies (including smaller and larger) reported that work studies had been conducted in this context, but they did not express in detail how human work had been evaluated and measured. One company reported on the utilisation of new Industry 4.0 related wearable technologies to collect data from their employees. Other companies reported that they relied on the data from their human resources department or from their occupational health care provider. In these cases, the data were specified to sick leaves.

4.1. HF/E when sensing, seising, and shifting new technological opportunities into use

Interviews revealed how the processes for sensing new technologies were often triggered by practical needs to find ways to develop manufacturing processes to stay competitive in the markets by improving effectiveness and quality performance. Only in two companies had the trigger for seeking new technological solutions been the improvement of the human work itself. In these cases, the triggers to initiate technological development had arisen from the manufacturing process, as OHS indicators had shown increases in the number of sick leaves.

At first sight, the processes for sensing new technologies seemed systematic, with process owners allocated to provide expertise in their subject area. Most of the companies mentioned that they constantly collected and analysed HF/E-related data from their manufacturing processes, and that this knowledge was utilised when new technologies are sought. As discussed in the interviews, this HF/E-related data were produced by the OHS experts and their focus was on the possible effects new technologies might bring to individual workers in a microergonomics perspective. No sign of broader production system-level macroergonomics approaches could be identified in the interviews. Around one-third of the companies noted how they utilised work study techniques and data to collect information on their existing production systems. However, the work study approaches were also deficient from the HF/E perspective, i.e. they produced data from the process and system perspective but ignored the human perspective.

The interview material concerning the seising phase also revealed the narrow role of HF/E when new technologies were designed for local application. Again, from the macroergonomics orchestration perspective, HF/E was considered mainly as an element supplementing other parts of the process and no signs of the utilisation of in-depth HF/E expertise or formal HF/E process ownerships were identified. Interviewees highlighted how various kinds of documents were produced in this phase, e.g. plans and layout drawings. The data and documentation that the interviewees considered HF/E-specific were mainly produced by the experts that the companies considered to represent HF/E experts, namely those in OHS services. This data and documentation aimed at personnel risk management purposes, i.e. consisted of material collected from individual employees' working postures and their perceived workload, or whether the new technology fulfilled the requirements set by law. Thus, the approach did not take HF/E into account in full and did not reach considerations to the human performance. A similar approach to HF/E was seen in the evaluation of risks from the perspectives of the future personnel (that would be operating the technology) and concerning support services, such as maintenance and cleaning. Only few interviewees mentioned that some internal HF/E standards and guidelines were constantly utilised during this phase.

Concerning the shifting phase, the interviews revealed the immature utilisation of HF/E also when the technologies were implemented in the manufacturing processes. The orchestration of the development team was driven by the technology and production-oriented process while relevant expertise from the HF/E perspective was missing. Similarly, with the previous phases (sensing and seising), HF/E was considered to be acquired from the OHS experts.

4.2. Synthesis of interview findings

In conclusion, the interviews revealed how narrowly HF/E was present in all three phases (sensing, seising, and shifting) (see Table 2). This is a clear sign of organisational immaturity, indicating system-level weaknesses in understanding potential benefits from the optimised human work perspective. From the beginning of the whole system development process, neither the companies' structure nor their current processes were capable of providing enough information from the HF/E to the following process phases where site-specific decisions and design actions were conducted to facilitate new technology implementation. As the HF/E expertise in the orchestration was inadequate, the decisions made and the design processes conducted in the latter phases were supplemented by insufficient input from the HF/E viewpoint, resulting in technology and business-oriented perspectives being potentially excessive.

Table 2. HF/E challenges observed from company interviews.

Phase	HF/E related challenges
Sensing	- HF/E data were insufficiently collected and utilised concerning existing manufacturing processes and for the identifying of the triggers for initiating development processes: (a) ○ HF/E data were mainly associated to OHS data that do not acknowledge manufacturing process factors effecting human work performance. (b) ○ In companies where work study methods were applied, the focus was on the factors of the system performance but not on human work. - When new technologies were sought, the process did not involve HF/E expertise. - As the HF/E data and expertise were only narrowly utilised, human work performance issues were not documented in full. Hence, they were not considered in decision-making concerning the next phases.
Seising	- When new technologies and their implementation into local applications were designed, HF/E expertise was acquired from OHS experts. (a) ○ Their considerations were limited and focused mainly on human health and safety. Their experience concerning human work performance factors and engineering design was limited. - Data and documentation provided in this phase were mainly oriented to personnel risk. Hence the human work performance aspect was considered only narrowly when making design documentation to be used in decision-making concerning the next phases.
Shifting	- When new technologies were implemented in practice, HF/E expertise was sought from OHS specialists. Their expertise was limited when human work performance is considered. (a) ○ As the design documentation from the previous phases was inadequate from the HF/E perspective, human work performance factors were not considered in detail when implementing the technologies in practice.

5. Discussion

All four industrial revolutions have changed human work in manufacturing (e.g. Lucassen 2021). Now, during the wave of the fourth industrial revolution, with also human-centric Industry 5.0 visions insight, manufacturing environments are changing to smart factories, filled with different sophisticated technologies. Still, humans have remained a vital element of the manufacturing system (Reiman et al. 2021; Singh et al. 2022; Sony and Mekoth 2022; Sony and Naik 2020). Within our multidisciplinary HF/E approach, we contribute to the discussion on smart working in manufacturing (e.g. Dornelles, Ayala, and Frank 2022; Frank, Dalenogare, and Ayala 2019), on micro and macro-organisational dimensions in technology transformation (Cagliano et al. 2019; Kleiner 2006; Marcon et al. 2022), and on the discussion on barriers and enablers for successful new technology adoption (Cugno, Castagnoli, and Büchi 2021; Marcon et al. 2022; Stornelli, Ozcan, and Simms 2021; Sun et al. 2019). In this technology-driven context, we enrich the well-established business management theory on dynamic organisational capabilities uniquely with an HF/E perspective.

The companies in our study represent a good sample of pioneering companies in high technology adoption as they were identified by the national industrial networks. Based on their pioneering trait, we assume that they were also forerunners with respect to the dynamic capabilities. We see, referring to Eisenhardt and Martin (2000), that in the external business environment these companies operate, their organisational routines and processes must be in order, but they should also have the capabilities for strategic planning and development, solving emerging problems effectively, and making decisions sometimes under uncertainty. However, when it comes to HF/E we consider their processes and practices being deficient emphasising OHS and neglecting the macroergonomics view on the human work factors. We argue that this kind of an approach likely leads to a need for reactive and often more expensive actions later. This wicked dilemma related to late timing and reactive design actions has been constantly criticised in the HF/E literature (e.g. Abdous et al. 2023; Hendrick 2003; 2008; Village et al. 2015).

Our criticism of a too-narrow understanding about HF/E and often too-late implementation parallels well with Xu et al. (2021) who stress the technology-driven nature of this fourth industrial revolution. Inspired by Liu et al. (2020) and their considerations on the evolution of OSH management during the industrial revolutions, we argue that many companies, even when considered forerunners, have not found ways to fully benefit from the technological development when considered from the HF/E perspective. For instance, the utilisation of wearable devices and sensor solutions came up only in a few interviews as solutions that had been utilised at some level for collecting employee data from the process.

5.1. HF/E expertise in technology transformation

Paralleling the general idea of process ownership in business development (e.g. Berg Danilova 2019), we ask whether HF/E should be considered a process that has ownership inside the company, which holds the responsibility for its development, maintenance, and preferably controlled evolution? As our study shows, HF/E tasks and duties have been mostly allocated to OHS personnel who rarely are in a position where they can be considered HF/E process owners. We see that this current practice observed from the interviews represents the lowest level of maturity of process ownership (see Berg Danilova 2019) with very little power, support, and dedication to truly implement HF/E in development processes. This seems not to be restricted to the Finnish context but is a more general challenge. For instance, Sgarbossa et al. (2020) and Ross et al. (2013) have argued that HF/E is a blind spot in engineering education, reducing the number of potential experts, and Dul and Neumann (2009) and Mulaomerovic and Wang (2023) have concluded that HF/E issues are often neglected when making business development decisions.

The companies lacked skills and knowledge around how to plan, analyse, and design work with the help of HF/E expertise, while production and quality development-oriented objectives dominated the design and development processes and practices. From the HF/E perspective, we see here deficiencies related to the understanding of (macroergonomics) sociotechnical systems (Kleiner 2006), and the collection, analysis, and utilisation of relevant data (De Bem Machado et al. 2022; Korherr and Kanbach 2023; Luo, Thevenin, and Dolgui 2023). We see that these deficiencies are reflections of immaturities in companies strategic planning and orchestration processes (Araújo, Kato, and Del Corso 2022), which may in turn indicate immature capabilities of knowledge management process (Kaur 2022). This challenge is not limited to the Finnish manufacturing context but seems to be global. Scholars (e.g. Bentley et al. 2020; Dul and Neumann 2009; Mulaomerovic and Wang 2023; Ross et al. 2013; Zare et al. 2016) have constantly highlighted the ineffective use of holistic HF/E expertise whilst a strong emphasis has been paid to the prevention of disorders on workstation-level. Such a microergonomics approach is natural for HF/E professionals with a background in health sciences. Based on our study, to facilitate a general discussion on broader organisational capabilities with respect to HF/E, we propose to pay attention to five human-related capabilities (see Korherr and Kanbach 2023) that we discuss in Table 3.

5.2. Road map for HF/E utilisation in new technology adoption processes

To reach a competitive advantage, companies must have the capability to allocate, integrate, and reconfigure their resources to optimise manufacturing systems without neglecting humans as key contributors to this entity. To enable a better utilisation of HF/E in technology implementation processes, and hence responding to a future research call by Sun et al. (2019), we introduce a novel

Table 3. Key elements of HF/E related to the context of human-related organisational capabilities proposed by Korherr and Kanbach (2023).

Human-related capabilities (Korherr and Kanbach 2023)	Key elements for modern HF/E utilisation elaborated from our empirical findings
Personnel capability	Technical skills on HF/E, functional expertise, and collaboration and social expertise should be recognised as assets that need continuous monitoring and consequent development actions.
Management capability	HF/E data should be collected from the process along with other production line data. HF/E data should be processed with analytical methods to support data-based management decision-making.
Organisational capability	Organisational structures and processes should enable successful development processes that acknowledge human factors as one central element of the manufacturing process.
Culture & governance capability	Corporate culture, morals, and values should steer governance, standards, and policies that allow seeing humans as key contributors to a successful manufacturing process.
Strategy & planning capability	Humans should be seen as keen contributors to the manufacturing process now and in the future. HF/E data should be collected from the process to support evidence-based decision-making.

road map (see Figure 2) that should be seen supplementing other business and technology-oriented road maps (e.g. Duman and Akdemir 2021; Ghobakhloo 2018; Mittal et al. 2018). Within the road map, we aim to shift the discussion on HF/E from traditional singular workstation development (microergonomics) to system-level optimisation of the manufacturing system (macroergonomics). Within our generic macroergonomics road map structure, we share the views presented by Hendrick (2008), who claims how properly implemented macroergonomics management principles steer on selecting and implementing efficient design solutions at microlevel. Given the variety of different technologies associated to Industry 4.0 (e.g. Alcácer and Cruz-Machado 2019; Culot et al. 2020; Dornelles, Ayala, and Frank 2022), our road map is intentionally of a general perspective. It does not take a stand with any technology being implemented, but it makes HF/E visible and enables systematic actions for incorporating HF/E into their new technology implementation processes. We consider that our road map in practice can steer companies when they are considering how to transform their thinking from technology-centric Industry 4.0 towards Industry 5.0 visions that promote human-centricity (e.g. Enang, Bashiri, and Jarvis 2023; Ivanov 2023).

To locate HF/E expertise into broader contexts, we present it along with the design process and the management process. These two general processes are described in the road map only from the HF/E perspective to keep the focus strictly on HF/E. In this respect, HF/E expertise can be considered as an area of special skills and knowledge that is embedded in the overall design process. These skills and knowledge, often in the form of a set of microergonomics actions can be provided, for instance, by an industrial engineer with relevant HF/E expertise or an OHS specialist with an in-depth understanding about production design. Furthermore, the expertise can be purchased from outside the company. The process is based on the key challenges presented in Table 2.

5.3. *Applying the road map in practice*

Our road map makes HF/E visible when adopting new production technologies in manufacturing. For the general management it is important to understand that HF/E expertise should be applied in a systematic way throughout the process. In the sensing phase, HF/E expertise is needed to (1) contribute to concept design with analyses of user requirements, and (2) describe how HF/E expertise can be orchestrated in the latter process phases. Based on our study, and as a reflection of the narrow HF/E conception, we recommend discussing HF/E orchestration already in this phase although asset orchestration is in research literature mainly associated with seising and shifting (e.g. Helfat et al. 2007). Based on our study, we question the companies' capabilities to orchestrate HF/E as described above. Differing from Hodgkinson

	Sensing	Seizing	Shifting
Management process	• Acknowledges human work perspective when making strategic decisions on new technologies. • Utilizes HF/E data for management and decision making. • Orchestrates HF/E expertise into design processes. • Defines HF/E goals for the design process.	• Facilitates and orchestrates the overall design process. Utilizes HF/E data provided in decision making. • Oversees the overall design process and orchestrates HF/E expertise in it.	• Manages and facilitates the overall new technology implementation process. Utilizes HF/E data provided in decision making. • Oversees the overall design process and orchestrates HF/E expertise in it.
Design process	• Utilizes HF/E expertise to identify possible HFE threats and bottlenecks in the production system. • Seeks for new technological opportunities and utilizes HF/E expertise to analyze their suitability from the human work performance point of view.	• Utilizes required HF/E expertise in the design phase. • Utilizes data produced in the HF/E process when designing new technologies into local application. • Plans the shifting phase and produces documentation including HF/E specifications for it.	• Utilizes required HF/E expertise in the implementation phase. • Utilizes HF/E data produced in the sensing and seizing phases. • Manages the implementation process and documents the process including HF/E related aspects.
HF/E process	• Evaluates the HF/E status of the current manufacturing process. • Provides expert opinions from the HF/E perspective concerning the new technology solutions being discussed. • Utilizes current process data, HF/E standards and guidelines while forming the above expert opinions. • Evaluates possible development needs from the future system user perspective.	• Contributes to design specifications and work method descriptions from the HF/E perspective. • Identifies potential risks factors and evaluates their effects on human well-being and productivity. • Estimates physical and cognitive workload required for using the new technology in relation to given targets and time.	• Supports the implementation process. • Participates in risk management processes from the HF/E perspective. • Gives recommendations how to react to possible human errors and deviations. • Provides feedback for the future technology design and implementation processes.

Figure 2. Road map concerning HF/E for sensing, seising, and shifting new production technologies into use.

and Healey (2011), we call for core orchestration capabilities more than capabilities to incorporate intuition in the sensing process.

In the seising phase, the selected opportunities for new technologies are designed for use in the company, utilising the documentation produced in the sensing phase. Here, the design process should be supplemented with existing micro- and macroergonomics knowledge and data. These can be gathered, for example, from the company and its existing manufacturing system, but they can also acknowledge topical HF/E literature, guidebooks, and standards. In this respect, HF/E expertise should be applied for (1) evaluating the technology adoption with respect to human capabilities, (2) defining skills and knowledge needed for using the technology (this includes also the support services needed), (3) identifying and analysing possible risks for physical and cognitive over- and underloads and safety hazards and their possible effects on other work tasks in the manufacturing process, and (4) describing the required work methods and related work instructions needed. Based on our study, the above description of an idealistic HF/E approach in this phase seems somewhat unattainable. Paralleling with Hodgkinson and Healey (2011), we suggest investing in capabilities needed to unlock fixations with existing processes and routines to overcome observed misconceptions on the role and potential of HF/E.

Finally, in the shifting phase, HF/E knowledge should be embedded in the overall implementation process by design and risk management activities. In this phase, HF/E expertise should be used to (1) analyse the implementation process with respect to the human work and workload, (2) identify and analyse possible risks related to human-technology (or human-system) interfaces with effects on other work tasks in the manufacturing process, (3) produce verifications for the documentation of work methods and instructions, and (4) provide plans how to collect and analyse HF/E data from the process to follow the targets set concerning HF/E. The overall development process as such should be continuous, and lessons learned during the design and implementation processes can be collected to facilitate successful new technology implementation processes in the future. Such a macroergonomics approach enables shifting the focus from technology-dominated organisational discussion to broader considerations of the synergies between system performance and employee well-being. We point out that such a holistic HF/E approach (as presented in our road map) requires expertise that is in practice only rarely acquired from the OHS personnel, but it requires considering the expertise more broadly. We see that our road map serves as a strategic framework supporting management decision-making and production design processes, making it possible to leverage HF/E.

5.4. Areas for future research and strengths and limitations of the study

The road map we present in this study is conceptual and it has not been tested in practice in manufacturing contexts. We see this a future research challenge. Further, HF/E knowledge is not bound to any specific industry (Dul et al. 2012), the phenomenon of technologisation is a megatrend, and the theory of dynamic capabilities is generally accepted within management science (Leemann and Kanbach 2021; Teece 2018). Thus, we argue that it should be possible to apply and modify our manufacturing-oriented road map to other industrial branches and areas of work. The transferability of our road map is a future research challenge. We recommend future research to examine HF/E process ownership at design and operational levels and related to support services (e.g. Van Oudenhoven et al. 2023; Vijayakumar et al. 2022). Further, we recommend examining whether there can be any potential HF/E implementation barriers related to internal business environment (like existing company strategies and policies) or external business environment (like business market and supply chain demands, and government policies and regional culture) (e.g. Kleiner 2008; Marcon et al. 2022). The durability and transferability of HF/E capabilities inside the company should also be examined. We are interested in best practices, and how they can be rooted in organisational practices and processes. On the other hand, we see that HF/E skills and knowledge are often tied to certain individuals' tasks. Hence, we ask whether the deficiencies on individual and organisational HF/E capabilities may turn out a bottleneck for the production system if that individual leaves the company (e.g. Subramaniyan et al. 2020) or does not continuously develop own skills and competences. Therefore, HF/E capabilities should be studied also from the viewpoint of human resources management (e.g. Dul and Neumann 2009; Richards 2022) and within a framework of a sustainable organisation striving for long-lasting work careers for its employees (De Lange, Busch, and Delgado-Ceballos 2012; Dugan et al. 2022; Lu et al. 2022).

Finnish manufacturing has been considered a forerunner, yet severe concerns have been raised about how manufacturing is struggling with its competitiveness (see Calligaris et al. 2023). Our inductive study material does not allow us to argue for or against the effectiveness of HF/E in this context. However, this study reveals how all our subject companies, regardless of their size, struggled with HF/E. Based on the HF/E literature, we argue that better utilisation of HF/E skills and knowledge would provide additional and yet unseen means for manufacturing companies to improve their performance. Hence, a topic for future research is the effectiveness of applying HF/E knowledge when new technologies are sought and applied. Finally, to reach practical impacts, we highlight the need to prepare a practical guideline for this road map.

This study is context sensitive as it builds on qualitative data from Finnish companies which may limit the generalisation of the results. As we intended to focus on management level practices and processes, we focused our interviews on informants working at managerial or senior expert positions. We did not collect data from the employee level. We consider this (for instance employees' reactions and expectations to new technologies) a topic for future research. For instance, Hignett, Wilson, and Morris (2005) provide guidance on arranging such participatory study approaches systematically and Kleiner (2004) guides how to design technology implementation keeping macroergonomics in mind. Concerning external validity, the number of pioneering companies identified was limited. It is, however, in line with earlier research on the early adopters of new technologies (e.g. Antony et al. 2021; Heinonen and Karjalainen 2019). Still, our sample with companies of different sizes and types of organisational structures increases the validity. In addition, the findings were saturated through the study in the iterative study process. Concerning internal validity, we highlight our multidisciplinary study process and interview arrangements.

6. Conclusions

Technologisation brings along complex new demands for human work. Technological development has turned manufacturing environments into smart factories where humans constantly interact with complex technologies. A need to develop human work, i.e. employees' skills and knowledge, is evident. Still, companies lack an understanding of how to view humans as parts of their manufacturing systems. As a design-oriented discipline, HF/E has the tools and techniques to meet this challenge in practice. In its premises, HF/E seeks to find solutions to develop both human well-being and system performance. Based on this study, the first objective of developing human well-being dominates the latter. In other words, companies do not use HF/E expertise and knowledge to develop their system performance but see it as a part of their OHS practices and processes. This came out clearly when the companies were asked to describe how they implement HF/E expertise and knowledge when sensing new technological opportunities and designing and implementing them into their manufacturing systems. Orientation mainly to technology and production has led to a loop where human-centric issues are implemented in production merely with a preventive OHS approach instead of a proactive design-oriented approach.

A novel road map for the better utilisation of HF/E in technology transformation processes was developed in this study. The road map facilitates incorporating HF/E in production systems when new technologies are implemented into use. When properly utilised, HF/E contributes to synergistic development of well-being and system performance. The road map is structured into three main areas: (1) sensing technological opportunities, (2) seising these opportunities, and (3) shifting them into use. All these three areas are supplemented with key observations for the company to consider HF/E from the process perspective. The observations were formed through an iterative process in which 15 manufacturing companies participated.

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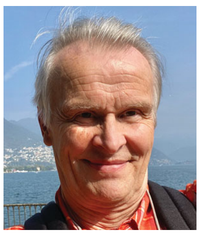

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Data availability statement

Data not available – participant consent.

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Appendices

Appendix 1. Structure for the web questionnaire

Section A: (1) Company name, (2) Respondent information, (3) How familiar is your company with the concept of Industry 4.0 (free text).

Section B: New technology adoption and utilisation in: (4) Raw material, material, and component acquisition, warehousing, and related logistics, (5) Manufacturing and related logistics, (6) End product warehousing and deliveries to the customers, and (7) Maintenance. Each subsection (4–7) includes questions (free text) to define (a) what kinds of new technologies are in use, (b) what kinds of systems are in use to enable machine to machine communication, (c) How are the new technologies connected to networks, and (d) how humans are considered in these systems.

Section C: New technologies production design: (8) What kinds of tools are in use, (9) How is process data utilised in production design and development, (10) How are work phases that contain human work identified and analysed, (11) What are the most essential work phases where HF/E has been taken into account, (12) How is HF/E acknowledged when selecting and adopting new technologies, (13) Is human work measured and, if yes, how has that data been analysed and utilised, (14) Are digital competencies tested among the employees, (15) How has new technologies' influence on total productivity been evaluated, (15) Have the costs related to bad HF/E been evaluated and (16) What kind of data has been used for those evaluations.

Appendix 2. Structure for the interviews

Section A: (1) Company name, (2) Respondent information, (3) General info on the company.

Section B (Sensing): (4) How are the needs for development concerning manufacturing processes identified, (5) How is information on new technological solutions sought, (6) How systematic are these processes, (7) How systematically are development needs considered from the human work perspective, (8) How is process data utilised from the HF/E perspective.

Section C (Seising): (9) How is the process organised and designed for adopting new technologies in use, (10) How are expected effects evaluated, (11) How is the process orchestrated and what kind of expertise is needed, (12) How are the expected changes in human work load and the amount of human work required evaluated, (13) How are the expected requirements for human skills and knowledge evaluated, (14) How is the data from the existing process utilised for those evaluations, (15) What kinds of HF/E metrics are used, (16) What kind of additional data would be useful to support new technology adoption, (16) How is the decision-making process organised concerning new technology adoption.

Section D (Shifting): (17) How is the new technology implementation organised and orchestrated, (18) How are the possible effects considered for the whole manufacturing process, (18) How has the company managed to implement new technologies in use from the perspectives of economics, quality, and employee well-being, and (19) Has the company succeeded in new technology implementation from the employee well-being perspective.