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Human factors and ergonomics in manufacturing in the industry 4.0 context – A scoping review

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ABSTRACT

Industry 4.0 revolution has brought rapid technological growth and development in manufacturing industries. Technological development enables efficient manufacturing processes and brings changes in human work, which may cause new threats to employee well-being and challenge their existing skills and knowledge. Human factors and ergonomics (HF/E) is a scientific discipline to optimize simultaneously overall system performance and human well-being in different work contexts. The aim of this scoping review is to describe the state-of-the-art of the HF/E research related to the industry 4.0 context in manufacturing. A systematic search found 336 research articles, of which 37 were analysed utilizing a human-centric work system framework presented in the HF/E literature. Challenges related to technological development were analysed in micro- and macroergonomics work system frameworks. Based on the review we frame characteristics of an organisation level maturity model to optimize overall sociotechnical work system performance in the context of rapid technological development in manufacturing industries.

Author statement

Arto Reiman:Conceptualization, Methodology, Article analysis, Writing; Jari Kaivo-oja: Conceptualization, Methodology, Writing; Elina Parviainen:Conceptualization, Writing; Esa-Pekka Takala: Conceptualization, Methodology, Article Analysis, Writing; Theresa Lauraeus: Conceptualization, Writing.

1. Introduction

Industry 4.0 revolution is associated with various technological megatrends, such as digitalization, artificial intelligence, Internet of Things, additive manufacturing, cyber-physical systems, cloud computing, and rapid increases in automation and robotics in the manufacturing processes [1,2]. Due to technological development, the manufacturing processes are getting more and more complex and they are setting new kinds of demands for companies' management practices and processes as well as for the personnel competencies and skills [3–5]. Manufacturing companies with high technological competencies are capable of utilizing and benefitting from this technological development while companies with fewer competencies are likely not to succeed in the competition [2]. Technological development puts challenges not only for the companies but also to the workforce inside the companies [6]. A need to better understand the complexity of such sociotechnical systems combining organisational, technological and human perspectives is evident [7].

Obligations to safe human work have increased alongside the development in production technologies during the last century [8]. Work in manufacturing contexts is safer than ever when the occupational accidents and diseases are considered. However, in profit-driven circumstances, such as in manufacturing, conflicts between human safety and production are still common [9]. Operators in production and manufacturing settings often have to cope with the system as it is constructed and not as it may have been envisioned [10]. A lack of or inadequate communication may exist between the system development and system operation, which may hamper safety in practice [10].

Technological development has not handled and solved all existing challenges related to human health, safety, and productivity in industrial manufacturing processes. Humans will continue to play active roles in manufacturing processes. However, those roles may change over

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time. Human's role in the manufacturing processes has shifted towards roles where the human acts as an operator collaborating with and utilizing new technologies [4,6,11,12]. Now, and especially in the future, human factors and ergonomics (HF/E) knowledge, skills, and competence of both operators and production and technology designers have a significant role in guaranteeing and optimizing fluent and safe work processes [4,13]. There is an obvious need for better communication between different actors and for in-depth understanding about the human factors in the design of new technologies, production processes and products. In order to respond to this challenge, the principles and theory of engineering and HF/E should be integrated more closely and routinely adopted in industrial design and management processes. This requires understanding about the complexity of not only the output products and production systems but also on the humans and the human interfaces in work systems [4,13].

Current HF/E literature emphasises the need to focus on identifying new risks emerging out of the complexity of manufacturing industries in the 21st century [3,4,14] and in the Industry 4.0 context [6]. HF/E as a design-oriented discipline focusing on human-technology interaction provides a scientific framework for research in such settings [3,4,15]. In this study, we highlight the dualistic goal-setting of HF/E; to optimize both overall system performance and human well-being. In this context, HF/E comes close to general management and human resource management (HRM) sciences [16,17].

Our aim is to contribute to the academic discussion by reviewing the current state-of-the-art in research related to HF/E in the context of Industry 4.0. For this purpose, we conducted a scoping review [18] to summarize research findings from the existing literature. Secondly, based on our review we propose a frame for understanding and developing HF/E maturities in the context of rapid technological development in manufacturing industries.

2. Key concepts

2.1. Industry 4.0

The concept of Industry 4.0 origins from Germany and was for the first time introduced in 2011 [1,2]. Industry 4.0 can be located in a larger industrial revolution framework. The first industrial revolution dates to the 1800s when mechanization and the utilization of mechanical power revolutionized industrial work. Electrification set the premises for the second industrial revolution and mass production. The third industrial revolution took place in the 1960s when digitalization with an introduction of microelectronics and automation were seen. The fourth industrial revolution has been triggered by the development of information and communications technologies and rapid technological development [2]. Industry 4.0 represents the current wave of industrial revolution. Even though technology-oriented Industry 4.0 is still in its' infancy in practice, some insights into Industry 5.0 and beyond that have already been given. Industry 5.0 has been considered complementing technology-oriented Industry 4.0 with a more sustainable, human-centric and resilient focus [19,20].

The concept of Industry 4.0 lacks a clear and common definition which in turn complicates the discussion between the researchers and practitioners [21]. Industry 4.0 has been discussed in the literature for instance from the perspectives of technological solutions, operations, business, and work environment and skills [22]. Characteristic to Industry 4.0 is a radical development and utilization of new technologies, robotics, Big Data, and Internet-of-Things (I-o-T), and an endeavour towards rapid development times, increased customization, flexibility, and resource efficiency [2,23]. In the manufacturing context, Industry 4.0 is transforming manufacturing plants into automatized and optimized environments in which production processes are connected horizontally and vertically within the company systems. Reconfigurable manufacturing systems and optimized value chains and value-added networks constitute the core of the processes [24]. As promising the above technological development may seem, in reality many manufacturing companies are struggling in this technological transition for instance because of their financial position, unmatured IT processes and challenges in maintaining integrity within the manufacturing process [21].

2.2. Human factors and ergonomics (HF/E)

HF/E is a design-oriented framework for improving compatibility, effectiveness, safety, the ease of performance, human well-being, and quality of life [25]. HF/E as a scientific discipline applies theoretical principles, data, and methods, and it is concerned with the understanding of interactions among humans and other elements of a system. HF/E has its roots in physical ergonomics, i.e. in anatomical, anthropometric, physiological, and biomechanical characteristics related to physical activities performed by humans [26]. In addition, HF/E has paid much attention to cognitive ergonomics that focus on mental processes, such as perception, memory, information processing, reasoning, and responses [3,25]. However, such human-centric approaches to HF/E can be narrow, if the focus is only on the individual level of performance and the other relevant aspects of human work are left out of the investigation. Current understanding about HF/E emphasises design driven systems' approach, stakeholder interaction, networking and the proactive role of HF/E [3,15]. A concept of organisational ergonomics has been introduced as a framework for shifting understanding from individual-centric microergonomics to organisational and systems centric macroergonomics. It should be noted, however, that this shift towards the understanding on the organisational level means that the individual level microergonomics should not be forgotten. Instead, effective macroergonomic design drives much of the microergonomic design and ensures the optimal ergonomic compatibility of different components with the overall system structure [14].

Systems have been understood broadly in the context of HF/E. A system may be as simple as a single individual using a hand tool or as complex as a multinational organisation or organisational value network [15,27,28]. Furthermore, a system can be described as a work system, where the human is a worker performing a specific operational task or function within a specific environment, or a product or service system, where the human is the user of a product or the person who receives the service [15,27,28]. In this article, we discuss work systems both from the microergonomics and macroergonomics perspectives. From the microergonomics perspective, we are interested in the issues the human will face in future manufacturing settings. From the macroergonomics perspective, we are interested in organisational, technological and personnel subsystems that form a macroergonomics work system. The personnel subsystem considers the people doing the work whilst the technological subsystem constitutes from the physical environment and the technologies used for work [28]. The organisational subsystem, as the third element of the work system consists of the organisational and managerial structures of the system, and can be discussed from three interacting dimensions; complexity, formalisation and centralisation [28]. Centralisation is concerned with decision-making structures, whilst formalisation relates to the degree of standardisation inside the organisation. Complexity can be discussed from the perspectives of segmentation of the organisation and from the coordinating mechanisms between different segments [28].

3. Analysis framework

In this article, we first summarize current knowledge on HF/E in Industry 4.0 context by reviewing research findings from the literature. Then, based on the review, we propose a frame for evaluating and managing HF/E in the context of Industry 4.0 and the rapid technological development in manufacturing. Our study can be referred to a scoping review [18,29]. We have followed a modified version of the scoping review process of five stages as depicted by Arksey and O'Malley

[29].

First, we identified the research question (Stage 1 [29]) for our review: "What is known from the existing literature about the inclusion of HF/E in the Industry 4.0 context?". We were aware of the broad definition of the concepts of HF/E and Industry 4.0; thus we selected a compilation of search words that we used for our database searches. "*Human factors*", "*Ergonomics*" and "*work-life*" were the search words concerning HF/E, and for Industry 4.0 we used "*Industry 4.0*″, "*Smart manufacturing*", "*Additive manufacturing*", and "*Digitalization*".

In the second phase, we identified relevant studies (Stage 2 [29]). The search was performed in November 2018 and supplemented with a new up-to date search in June 2020 in the Scopus database with combinations of the search terms described above. The search was limited to scientific research documents published in the 2010s in English. The search was not limited to any certain type of study, thus, all types of studies including qualitative, quantitative, mixed methods studies, literature reviews and overviews were included. The search identified altogether 336 documents in which HF/E and Industry 4.0 had been covered at some level.

In the third and fourth stages of our review – i.e. the selection (Stage 3 [29]) and charting the data (Stage 4 [29]) – the relevance of the literature was assessed based on the titles and abstracts to identify the documents that focus on our core interest area of the HF/E in Industry 4.0 context in manufacturing. Manufacturing was considered in this context broadly. Support services like logistics and maintenance were included when it was evident that the focus was still on manufacturing environments. At this stage, two researchers independently read through the titles and abstracts and selected the ones that they deemed to represent the core focus area of this study. Based on a mutual agreement by these two researchers altogether 44 research documents were defined to fit the criteria. Finally, researchers read through the research documents in full.

The aim of the full research document analysis was to focus on identifying the indications of the expected changes at work system level due to Industry 4.0 and technological development. Altogether 37 research documents from the 44 documents covered aspects relevant to this aim. A majority of the documents presented some conceptual frameworks for assessing and developing human-technology interaction at industrial contexts. Some documents included test settings, scenario work and simulations as the empirical part of the document. In addition questionnaires, observations and interviews were utilized as data collection methods. Documents included ($n = 37$) and their major outputs in this context are presented in the Appendix.

Only 16 of the 37 documents were published in scientific journals and the rest (21) were published as conference articles, which indicates the topicality of this research area and novelty in research. We adopted a five-element categorisation of the work systems [27] to approach different HF/E challenges; i.e. interactions between the 1) human, 2) work environment, 3) work tasks, 4) technology and 5) organisation. In the microergonomics analysis phase, we focused on future challenges from an individual perspective; i.e. what is expected for the human in the center of the work system to face in this Industry 4.0 transition. On the latter part of our analysis, to facilitate organisation level discussion, we analysed the challenges from a macroergonomics work system perspective [28]. This analysis and report phase comprised the last stage of our analysis (Stage 5 [29]).

4. Results

4.1. Microergonomics work systems in industry 4.0 context

By our work system categorisation, we provide a basis for understanding the challenges that manufacturing companies are facing or are expected to face due to the Industry 4.0 revolution and rapid technology development. Below we sum up the current knowledge on the challenges that are met in manufacturing processes on the 1) human, 2) technology, 3) work task, 4) work environment, and 5) organisational levels in the Industry 4.0 context.

4.1.1. Human challenge

Human tasks become more complex and digitalization enables that high-skilled employees may be provided with a variety of tasks in addition to the core tasks that have been issued [30]. Humans may, however, have a feeling that they are easily changeable due to technology implementation [30]. In addition to the technological skills, human work in manufacturing has been emphasised requiring more and softer skills like social and communication skills, and team-work and self-management skills [31–35]. Essential skills to perform the tasks should be identified and training should be provided to meet these requirements [36]. Humans should be provided with more possibilities for autonomous decision-making, work diversity, and possibilities to social interactions [36]. Humans are also seen having their values, attitudes, and respect for others, which attributes separate them from technological devices, and this should be emphasised in management processes [33].

4.1.2. Technology challenge

Companies face various technology cycles and novel technical solutions. Technological change is an everyday reality of industrial organisations and the service sector. Companies should be aware of the maturity level and compatibility of their technologies and at the same time be aware of possible safety and security challenges that new technologies may bring along [36]. New technologies may incur new kinds of problems for operators due to insufficient information provided from the manufacturing systems and more attention should be paid to the design of interfaces between humans and new technology and to integrating these design aspects in practice into manufacturing processes [37–41].

Complex technologies may incur possibilities to unintended uses by the humans, if the usability and cognitive processes are neglected in the design phase [37,42,43]. A gap between the needs and wishes of operators in new technology transformation might exist and too much emphasis is paid to managers visions on digitalization and technological transformation [44]. It should be noted, however, that the new technology most likely enables smoother production processes that fit to the needs of the humans [45]. Digitalization, robotization and extended use of assistive technologies, like exoskeletons and smart gesture control systems may lead to more efficient work, as humans do not need to loose time on non-productive actions like waiting and seeking [30,46–48]. It is also evident that the human-robot interaction increases and the humans have to learn how to act in these situations efficiently and safely [33,46]. Collaborative robots are not reflective, they might not be implemented properly due to a lack of in-depth knowledge of the technology, and they may induce new threats to humans besides to the changes of the manufacturing system [49].

4.1.3. Work environment challenge

Work environments become more complex due to technological development and the human work areas will become different when compared with earlier manufacturing environments [50]. Employees have to cope with highly computerized and automated production and manufacturing environments [50]. Different technologies characterize a "smart factory" that enables faster and better output but also pose different work environment challenges to humans [51]. In the new complex manufacturing systems, humans will constantly act in work environments together with robots. That requires new skills and ability to collaborate with the technology [33,52,53]. Further, employees' trust and privacy may be threatened in such smart work environments where the collected information also contains individuals' personal information [54]. Humans may also need to learn to act in virtual reality environments [33] and human-centric design of new work environments may benefit from the use of more sophisticated utilization of digitalization like the digital twins [55,56].

4.1.4. Work tasks challenge

Concerning work tasks, it is likely, that certain functions are taken away from the humans and their work is consequently impaired or even hindered [37]. However, humans still continue to have an active role in manufacturing processes. Humans must have the basic competence to act with new technology and a positive attitude towards changes [33]. Skilful workforce has the ability to avoid human errors and mistakes. Further, skilful workforce has the possibilities to increase their efficiency with the use of new technologies [57,58]. The tasks may become more complex, although there is a possibility that the tasks are actually becoming simpler, as the mastering of the manufacturing systems is handled by developed assistance systems [30,39]. The need to develop more comprehensive training systems utilizing new technologies and digitalization to secure a skilled workforce in the future is evident [33,51,59]. In addition, task analyses supporting work task allocation and production management may require new kinds of analysis and measurement equipment [60–62].

4.1.5. Organisational challenge

Organisational decision making and decision support systems are challenged by more complex production systems [65]. Companies should analyse and understand their production systems comprehensively and provide participatory possibilities for innovations emerging from their personnel to enable success in the future competition [33]. Technological development may lead to digital manufacturing and cyber-physical systems that require new organisational practises and processes for instance on risk management [37]. In addition, an organisational challenge is how to articulate potential benefits and problems to employee level before and during the technological transformation and development process [63]. Still, it is likely that improvements to human work and great benefits to productivity are achieved, if this transformation phase is successfully managed [64].

Human work requires more and deeper understanding about the cognitive, physical and psychosocial aspects of the systems [34]. Already now a noticeable shortage of suitable experts can be identified in certain specialist areas [30] and for instance the ageing workforce in general in various industrial countries should be acknowledged from an engineering and operational development perspective in manufacturing companies [33,36,66].

4.2. Macroergonomics work system perspective in manufacturing in industry 4.0 context

The subchapters above summarized the findings from the human-centric work system perspective. From an organisation-centric macroergonomics point of view, the findings were recategorised in three subsystem categories (Table 1). Eventhough presented in three categories, the subsystems should be seen as an interlinked entity forming a macroergonomics work system. It is important to notice that a challenge in this context may have both negative and positive consequences. As an example, high technology enables high quality production when managed and utilized properly. However, when the organisational and human capabilities do not meet the demands set by this high technology, it may also be a problem for the production. In addition high technology may bring along new threats to human health when managed inproperly. High technology sets demands for the personnel subsystem perspective, as it likely brings along an increasing need for new skills and knowledge. This in turn may test the organisational subsystem for instance from the technological transformation and communication and personnel training system perspectives. Segmented and centralised decision making processes may also put requirements for the organisational subsystem. On the other hand technological development can also be seen as a challenge from the formalisation perspective, i.e. how standardised are the internal processes for new technology development and implementation and whether they actually support or complicate the changes in practice.

Table 1
Macroergonomics viewpoints in manufacturing in Industry 4.0 context.

Subsystem	Identified perpectives
Technological	• High technology sets complex demands for production and may bring along new threats to human [33,37,50,51,57,58] • Demands for the safety and security of the technologies and work environments increases [32,33,36,46,49,52,53] • Quality and usability of the user interfaces of technologies gets more complex [37,39–43] • Production systems provide complex data, which in turn increases the need for more sophisticated analysis methods and skills to utilise them [37,38,50,65] • Assistive technologies used to ease human work bring along new threats to humans [30,39,46–48] • Demands for skills to utilise new technologies increase [30,33,39,46–48,55,56]
Organisational	• Demands for organisational skills supporting technological transformation and development activities increase [60,62–64] • Personnel training systems are challenged to fit the needs and demands technological development brings along [33,36,51,59] • Mutual trust between the employer and the employee is threatened [30,33,54]
Personnel	• Human tasks become more demanding and complex [30,33,34,37] • Demands on personal cognitive and social and communication skills increase [31–35] • Demands on employee autonomy and self-management skills increase [36] • Employee shortage is faced; due to e.g. ageing workforce or concerning the lack of highly skilled experts [30,45,66]

5. Discussion

This scoping review summoned up how HF/E has been discussed in the Industry 4.0 context. Our review collected evidence from earlier literature and concludes that humans will not be completely removed from the manufacturing processes due to the rapid and complex technological development Industry 4.0 brings along. Still it is likely that their roles change which in turn questions current HF/E practices and processes in manufacturing context. Technological development likely has a positive impact on production but it may also challenge employee and process performance and induce new kinds of risks to human well-being and safety. Efficient implementation of HF/E requires organisational development actions that reach all the layers of the organisation from the top management to floor level. Given the complex nature of manufacturing systems, and an increasing need for holistic actions supporting corporate social responsibility in Industry 4.0, HF/E implementation should not, however, be limited to intraorganisational development actions, but they should cover also companies' external value networks and value chains [21,67].

While we emphasise the potential of HF/E in this context, we also express our concern as our findings cruelly expose the current, unmatured utilization of HF/E in Industry 4.0 context. While the manufacturing companies seek organisational excellence through strategic management and continuous development actions they should not ignore their employees, but instead consider them as a key resource ensuring fluent manufacturing processes [68,69]. We argue that HF/E should be identified as an intangible resource which needs to be better positioned in strategic design and management practices and processes.

5.1. HF/E maturities in manufacturing

To facilitate discussion on HF/E in strategic management and organisational excellence context, we highlight the evident need to identify and acknowledge companies' capabilities and maturity levels for mastering both the technical and HF/E aspects of production.

Various well-founded Industry 4.0 maturity models and roadmaps can be identified from the literature (e.g. Refs. [1,21,70–74], however their contents and aims do not respond to our holistic aim to integrate HFE into technological development in Industry 4.0 context. For instance in their review on Industry 4.0 maturity models Mittal et al. [74] brought out how the maturity models have been tailored to meet the needs of larger companies and struggle in identifying the starting conditions of smaller companies in this Industry 4.0 maturity context. Furthermore, their review [74] exposed that these maturity models seem not to include a direct HF/E perspective. Instead human related issues are discussed for instance from the perspectives of human resources management, personnel or organisational culture.

To respond to this need, we propose a frame for a maturity model that integrates H/FE and technology maturities in the entire manufacturing process and handles them in a scale that allows smaller companies that are just entering the Industry 4.0 field being better recognised and positioned. HF/E element in this frame builds up of our review findings. Accordingly, we see that HF/E maturity should be examined from the macroergonomics work system perspective. The structure for our maturity model builds up on the three interlinked elements of the macroergonomics work system, whilst the exact evaluation criteria should be formed in future studies based on the challenges identified in Table 1. Concerning the technological maturity in our frame, we acknowledge Sony and Naik [75] who bring out in their review article that there is no generic and common understanding for the Industry 4.0 readiness. To ground our technological maturity perspective, we acknowledge the review by Zheng et al. [76] who have summarized different applications of Industry 4.0 technologies in manufacturing context. Ideally, paralleling with [77] the evaluation criteria in our frame should take into account HF/E in the variety of technologies in use and available for the company. Fig. 1 shows an ideal and integrated description of our frame. In this ideal maturity development process, H/FE and technological maturities both develop positively – step by step, eventually leading to organisational and technological excellence.

However, this idealistic and progressive development process is not the only possible outcome. In Fig. 2, we visualise four (I-IV) non-ideal maturity progress scenarios possible in any work organisation. In scenario I technological maturity develops positively while the HF/E maturity does not change resulting in a non-optimal utilization of the technology and exposing the personnel to different types of health and safety hazards. In scenario II, HF/E maturity develops positively, but technological maturity fails to develop. In such a scenario, highly skilled personnel works with technologies that do not support their competence. This in turn may decrease productivity and challenge personnel motivation and commitment to work. In scenario III, high technological maturity is achieved, but HF/E maturity decreases, resulting in non-optimal use of technologies and possible hazards to human health and safety. In scenario IV technological maturity decreases, yet HF/E maturity develops into a high level resulting again in non-optimized production and challenges on personnel motivation and commitment to work. We call these four non-ideal maturity scenarios as *maturity paradoxes* where some positive development is achieved, however, some negative development occurs also. Likely, these types of undesirable maturity processes will at least contribute to the decrease of labor productivity or to the low return on industrial investments. If the maturity paradox happens in reality, either investors or workers will be unsatisfied with the results. This is a fundamental reason to be interested in the challenge to develop maturity levels in two dimensions.

5.2. Organisational capabilities needed to the maturity

Incorporating HF/E in larger organisational development processes requires holistic understanding of sociotechnical structures. As Sony and Naik [7] highlight, sociotechical systems and system integration should be managed at three levels: 1) vertically within the organisation, 2) horisontally inside the supply chains and 3) from the end-to-end perspective adding value to the whole life-cycle of the end product. Supplementing this three-dimensional framework, we adopt the three-layer structure by Carayon et al. [9]. Accordingly, the first layer comprises the local context in which work activities are in practice performed, i.e. the production facilities. The second layer represents the socio-organisational context, referring to the social and organisation culture of the company. The third layer represents the external environment where the company interacts.

Paralleling with the vertical and horizontal perspectives [7] we point out that the company should understand its' current manufacturing processes profoundly, i.e. to understand the local context. That requires also microergonomics understanding about the work tasks performed. Acquiring this understanding requires applying HF/E study and design methods for operational work activities. Data acquired from the processes may require new analytical approaches that for instance digitalization and big data analytics may enable. Digitalization has already introduced new ways to collect more in-depth knowledge on employee well-being and performance. This may wake up worries about the individual privacy perspective. Creating trust between the employer and

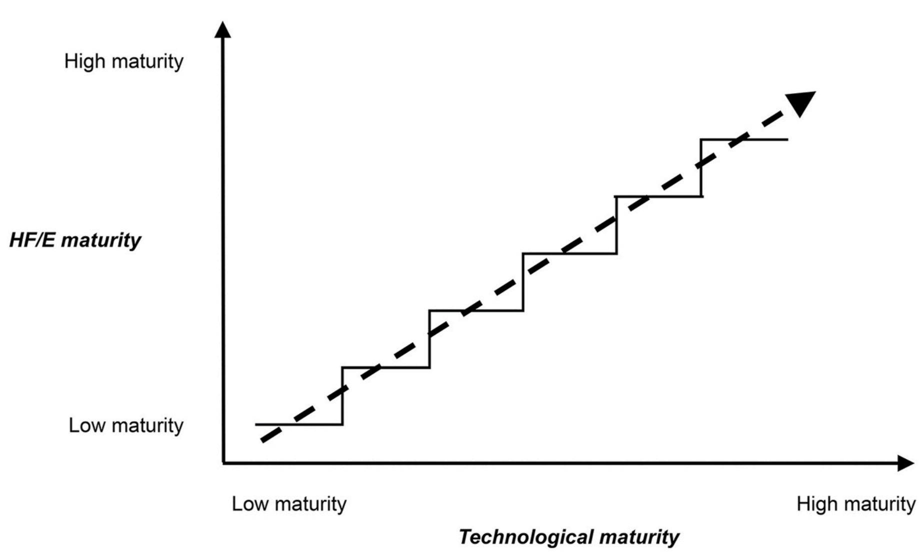

Fig. 1. Ideal and integrated frame for integrating HF/E and Industry 4.0.

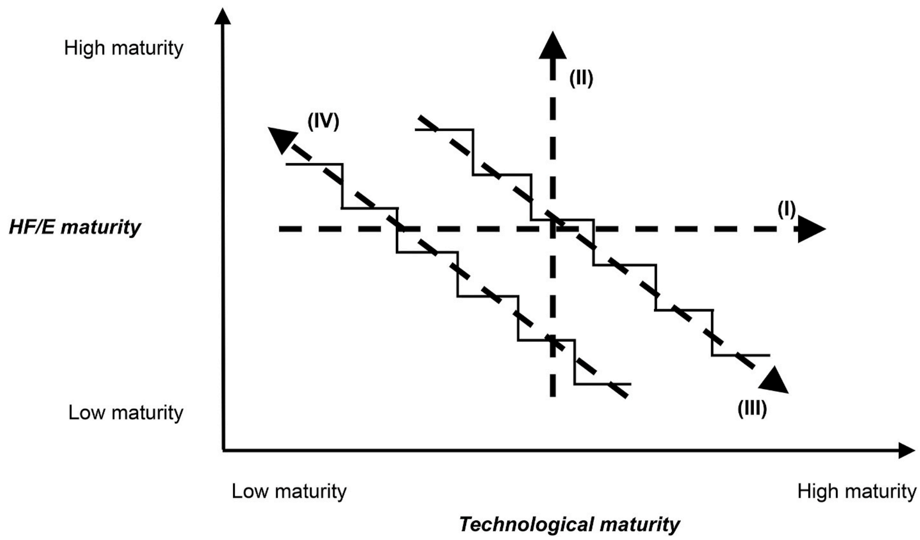

Fig. 2. Four (I-IV) non-ideal development scenarios.

the emplyees in this context is a rising organisational challenge. A profound understanding about the work and production processes allows concretising and communicating of the challenges inside the processes to all relevant levels at the organisation, representing good socio-organisational culture. This, in turn, enables evidence-based decision making at the top management level. Finally, we see that this idealistic evidence-based approach is even more important due to the Industry 4.0 revolution and the rapid technological development that manufacturing companies are facing. This, in turn, we see representing the complexity of the third layer; the external environment. Based on this, we point out that all the three layers described above may bring along aspects that should be considered when HF/E and technological maturities are evaluated in relation to the entire manufacturing process as illustrated in Fig. 3.

5.3. Future studies

Organisational capabilities have been discussed from a variety of different perspectives [e.g. 78,79]. Generally, organisational capabilities should be discussed as a holistic entity, where different capabilities supplement – not compete with each other. A four-component dynamic organisational capability model by Lin et al. [79] provides a framework to deepen our HF/E-oriented analysis. According to their model [79], organisations need (1) sensing capability for directional changes, (2) absorptive capacity for organisational learning, (3) relational capability for building relationships and social capital acquisition, and (4) integrative capability for communication and coordination to succesfully survive in their businesses. We see that future empirical research should focus on analysing and contextualising these dynamic capabilities in our maturity model context. Especial attention should be paid to organisation level sensemaking and sensegiving [79–81] to facilitate and initiate long-lasting strategic changes at the company level. Further, we pose as a topic for future research to consider whether and how this organisation-centric capability model is applicable in structuring individual level capabilities in Operator 4.0 context that is keenly associated to the Industry 4.0 phenomenon (e.g. Ref. [82]).

We point out a need to understand organisation's *capabilities and their maturity for process analytics*. Process analytics facilitates directional changes and covers profound understanding about the technological subsystems, including work environments, technologies and their interfaces and manufacturing processes. Further process analytics should cover personnel and organisational subsystems by understanding and identifying skills and competencies needed for developing processes, and for implementing new technologies and systems into these processes. We highlight the need for organisational learning and acquiring company-specific data for process analytics because companies, personnel, processes, and products differ from each other. We see that the rapid development and implementation of technologies without the

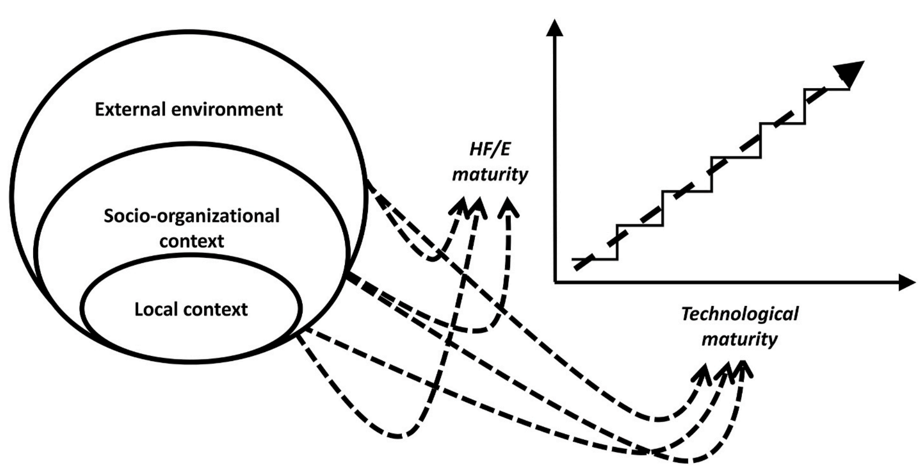

Fig. 3. HF/E and technological maturities require holistic understanding of the organisational and operational context.

HF/E principles and the knowledge and data on process analytics can complicate human productivity and provide potential to new kinds of risks to human health and safety. We see the analytics of processes combined with HF/E as the first future research challenge arising from this review.

We raise up organisations' *capabilities and their maturity for HF/E analytics.* For that we highlight the need to understand in-depth the work tasks and their relationsship to manufacturing process performance, organisation, methods and technologies, and work environments. We highlight the need to understand and – if necessary – exactly measure and analyse the work tasks and work methods utilized in the processes. The results of this analysis covering both micro- and macroergonomics aspects should be compared with the existing principles and safety limit values provided in the occupational safety and health legislation, HF/E literature and standards, and the company's production calculations and targets set for the human work in the processes. This knowledge helps to identify not only the potential risks on human health and safety but also the potential bottlenecks, quality problems, and delays in the production. The analysis should reach all the way from the microergonomic work phase and activity level analyses to the complexity and connections of the separate work phases and eventually to the whole manufacturing system. At best the analysis will be done already in the design phase of the manufactured output product to facilitate possible directional changes related to possible new production technology and -process model selection and acquisition.

Further, we point out the need to understand the *maturity of technologies and entire manufacturing process performance* from the HF/E perspective. The capability of the current technology shall be rated in relation to the product requirements, production targets and customer needs. In addition, connected with the maturity of the HF/E analytics described above, we highlight the need to discuss these from the personnel subsystem perspective in order to connect the human capabilities to the maturity of technologies and performance of the manufacturing process. If the human capability is inadequate, there is a need to train and acquire new skilled workforce or consider more advanced technological solutions. In this context, we point out that radical and disruptive technological innovations usually create bigger challenges than incremental small-scale innovations [83,84]. Our future research challenge is to study, what are the reasons from the organisational capability perspective for inadequate HF/E implementation when new technologies are adopted.

Lastly, as an area crossing all the above-mentioned maturity areas, we raise up the *Maturity of integrated knowledge management and orchestration.* For managing all the activities that produce the data and information needed for integrating humans, new technologies, methods, products and services in the manufacturing process, i.e. the macroergonomics work system, the management of processes needs to be built in relation to the operational organisation, and their capabilities in this context. The structure, systems, and the ways of acting and communicating inside and outside the organisation about manufacturing process-related information, i.e. the organisational subsystem and the relevant data acquired from technological and personnel subsystems should be in focus to facilitate the sensegiving process. For reaching the best output and quality of the entire activity in an organisation, the management systems need to support transparent and understandable communication in the organisation for receiving and using useful data and information for integrating all functions in the process into productive, safe, good quality and HF/E processes. This requires holistic macroergonomics management actions, that are able to produce data and utilise the information gathered from the processes all the way from singular work tasks to the entire manufacturing process supplemented with understanding on the external environment where the company acts. This holistic approach, combining microergonomics and macroergonomics is still an area that has not been studied profoundly in manufacturing. Studies covering all personnel and decision-making levels and the three layers (vertically within the organisation; horisontally inside the supply chains; from the end-to-end perspective) described above are needed to provide more understanding about the underlying reasons for the poor implementation of HF/E in manufacturing settings.

6. Conclusions

Industry 4.0 reshapes manufacturing with rapid technological development that focus into improvements of the manufacturing process performance. However, new technologies may also have unexpected effects in processes and cause problems to the workers. The reviewed literature highlights the unmaturity of Industry 4.0 from the perspectives of human factors and ergonomics. The challenges manufacturing companies face with the Industry 4.0 transition are complex and require dynamic organisational capabilities that take into account the manufacturing process as a whole. A maturity paradox was identified in this review, highlighting the need to pay attention to the simultaneous development of technological and HF/E capabilities in the manufacturing context.

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Authors' contributions

AR: Conceptualization, Methodology, Article analysis, Writing; JK-O: Conceptualization, Methodology, Writing; EP: Conceptualization, Writing; E-PT: Conceptualization, Methodology, Article Analysis, Writing; TL: Conceptualization, Writing.

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Declaration of competing interest

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