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Human Factors and Ergonomics in Manufacturing in the Industry

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Abstract: *Manufacturing industries have experienced rapid technological advancement and growth as a result of the Industry 4.0 revolution. Changes in human work and efficient manufacturing processes brought about by technological advancement may pose new threats to employee well-being and test existing knowledge and skills. The scientific field of human factors and ergonomics (HF/E) aims to simultaneously improve both the overall performance of the system and the well-being of employees in a variety of workplace settings. The purpose of this scoping review is to provide an overview of the most recent HF/E research on the manufacturing industry 4.0 context.37 of the 336 research articles were analyzed with the help of a human-centric work system framework from the HF/E literature. In micro- and macro ergonomics work system frameworks, difficulties arising from technological advancement were examined. To optimize overall sociotechnical work system performance in the context of rapid technological development in manufacturing industries, we frame characteristics of an organization level maturity model on the basis of the review.*

Keywords: Manufacturing industries

I. INTRODUCTION

Digitalization, artificial intelligence, the Internet of Things, additive manufacturing, cyber-physical systems, cloud computing, and rapid increases in automation and robotics in manufacturing processes are all connected to the Industry 4.0 revolution [1,2].Manufacturing processes are becoming increasingly complex as a result of technological advancement, which is putting new demands on management practices and processes as well as personnel competencies and skills [3–5].Companies in the manufacturing industry with a high level of technological competence are better able to take advantage of this technological advancement than those with fewer competencies [2].Companies as well as their employees face challenges as a result of technological advancement [6].It is obvious that sociotechnical systems that combine organizational, technological, and human perspectives require a deeper comprehension of their complexity [7]. During the past century, obligations to ensure the safety of human labor have grown in tandem with technological advancements in production [8].When occupational diseases and accidents are taken into account, manufacturing work is safer than ever. However, conflicts between human safety and production are still prevalent in circumstances driven by profit, such as manufacturing [9].In production and manufacturing settings, operators frequently have to deal with the system as it is constructed, rather than as they might have imagined it [10].In practice, safety may be compromised by a lack of or inadequate communication between system development and operation [10].

All of the issues pertaining to human health, safety, and productivity in industrial manufacturing processes have not been addressed by technological advancement. Manufacturing processes will continue to involve humans actively. However, those positions may shift overtime. Humans now play more of an operator role in manufacturing processes, collaborating with and making use of new technologies [4, 6, 11, 12].Human factors and ergonomics (HF/E) knowledge, skills, and competitiveness of operators as well as production and technology designers play a significant role in ensuring and optimizing safe and fluent work processes now and in the future [4,13].In the design of new technologies, production processes, and products, there is a clear need for improved communication between various actors and a deeper comprehension of the human factors. In order to meet this challenge, industrial design and management procedures should more frequently incorporate engineering principles and theory as well as HF/E. This necessitates an understanding of the complexity of work systems' human interfaces and output products as well as production systems [4, 13].

1. In the context of Industry 4.0 [6] and the complexity of manufacturing industries in the 21st century, the current HF/E literature emphasizes the necessity of focusing on identifying new risks. A scientific framework for conducting research in such settings is provided by HF/E, a design-oriented field that focuses on human-technology interaction [3,4,15].We emphasize the dualistic goal-setting of HF/E in this study; to enhance human well-being and system performance in general. HF/E is comparable to general management and human resource management (HRM) sciences in this context [16,17].
2. By reviewing the most recent research on HF/E in the context of Industry 4.0, our goal is to contribute to the academic debate. In order to accomplish this, we carried out a scoping review [18] to summarize the findings of previous research. Second, based on our review, we propose a framework for comprehending and developing HF/E maturities in the context of manufacturing industries' rapid technological development.

II. KEY CONCEPTS

2.1 Industry 4.0

The concept of Industry 4.0 was first introduced in 2011 [1,2] and originated in Germany. The framework of the fourth industrial revolution can be found within Industry 4.0.Mechanization and the use of mechanical power in the 1800s marked the beginning of the first industrial revolution. The foundation for the second industrial revolution and mass production was laid by electrification. The introduction of microelectronics, automation, and digitalization marked the beginning of the third industrial revolution in the 1960s.The rapid advancement of technology and the development of information and communication technologies sparked the fourth industrial revolution [2].The current phase of the industrial revolution is referred to as Industry 4.0.Some insights into Industry 5.0 and beyond have already been provided, despite the fact that the technology-oriented Industry 4.0 is still in its infancy in practice. The more sustainable, human-centered, and resilient focus of Industry 5.0 has been viewed as a complement to the technology-oriented Industry 4.0 [19,20].

There isn't a single, well-defined definition for Industry 4.0, which makes it harder for researchers and practitioners to talk about it [21].In the literature, Industry 4.0 has been discussed, for example, from the viewpoints of technological solutions, operations, business, and work environment and skills [22].A radical development and utilization of new technologies, such as robotics, Big Data, and the Internet of Things (IoT), as well as an effort toward rapid development times, increased customization, flexibility, and resource efficiency are characteristics of Industry 4.0 [2,23].Industry 4.0 is making manufacturing plants into automated and optimized environments where production processes are connected horizontally and vertically within company systems. The core of the processes are reconfigurable manufacturing systems, optimized value chains, and value-added networks [24].With the promise of

First, we decided on the research question for our review (Stage 1 [29]):What is known about including HF/E in the Industry 4.0 context from the existing literature? We were aware of the general definitions of the HF/E and Industry 4.0 concepts; As a result, we chose a collection of search terms that we used to search databases. Regarding HF/E, the search terms "human factors," "ergonomics," and "work-life" were used, and "Industry 4.0," "smart manufacturing," "additive manufacturing," and "digitalization" were used for Industry 4.0.

We found relevant studies in the second phase (Stage 2 [29]).The search was conducted in November 2018 and was supplemented by a new, up-to-date search in the Scopus database in June 2020 using combinations of the aforementioned search terms. Only English-language scientific research documents from the 2010s were included in the search. The search covered all types of work tasks, work environments, and organizational levels in the Industry 4.0 context, so it was not limited to any one type of study.

Human problem Human tasks get harder to do, and digitalization makes it possible to give high-skilled employees a variety of tasks in addition to the core ones [30].However, technology implementation may give people the impression that they are adaptable [30].Human work in manufacturing has been emphasized as requiring more and softer skills like social and communication skills, teamwork, and self-management [31–35] in addition to technological skills. Training should be provided to meet the requirements of the essential skills needed to complete the tasks [36].Humans ought to have more opportunities for autonomous decision-making, work diversity, and social studies, such as interactions and qualitative, quantitative, and mixed methods studies [36].Values, attitudes, and literature reviews and overviews of humans are also included. The search yielded a total of 336 documents that included some mention of HF/E or Industry

4.0. The relevance of the literature was evaluated based on the titles and abstracts in the third and fourth stages of our review—namely, the selection (Stage 3 [29]) and the charting of the data (Stage 4 [29])—to identify the documents that focus on our core interest area of the HF/E in the context of Industry 4.0 in manufacturing. Manufacturing was taken into account broadly in this setting. When it became clear that the focus was still on manufacturing environments, support services like maintenance and logistics were included. At this point, two researchers independently read the titles and abstracts and chose the ones they thought best represented this study's primary focus. Together, these two researchers were able to agree on 44 research documents that met the criteria. The research documents were then thoroughly read by the researchers.

The full research document analysis's focus was on locating clues to the anticipated changes that will occur at the system level as a result of Industry 4.0 and technological advancement. From the 44 documents, 37 research papers covered aspects relevant to this goal. The majority of the documents offered some conceptual frameworks for evaluating and improving interactions between humans and technology in industrial settings. As the empirical portion of some documents, test settings, scenario work, and simulations were included. Additionally, questionnaires, interviews, and observations were utilized for data collection. The Appendix presents the included documents (n = 37) and their major results in this context. Only 16 of the 37 documents were published in scientific journals, and the remaining 21 were published as conference articles, indicating the topicality and novelty of the research. To address various HF/E challenges, we used a five-element categorization of the work systems [27];i.e., interactions between people, their workplace, work tasks, technology, and organization. During the microergonomics analysis phase, we focused on individual future challenges; i.e., what is anticipated for the human at the heart of the work system during the transition to Industry 4.0?We examined the difficulties from a macroergonomics work system perspective in the latter part of our analysis [28] to facilitate discussion at the organizational level. The final stage of our investigation was this phase of analysis and report (Stage 5 [29]).

III. RESULTS

With our classification of work systems, we provide a foundation for comprehending the difficulties that manufacturing companies face or are anticipated to face as a result of the revolution of Industry 4.0 and the rapid development of technology. The current understanding of the challenges posed by manufacturing processes on the human, technological. The literature (Refs., for example) identifies a number of well-founded Industry 4.0 maturity models and roadmaps.1,21,70–74], but their content and objectives do not align with our overarching goal of incorporating HFE into technological advancement in the Industry 4.0 context. Mittal et al.'s review of Industry 4.0 maturity models, for instance, [In this Industry 4.0 maturity context, 74] demonstrated how the maturity models have been tailored to meet the needs of larger businesses and struggle to identify the starting conditions of smaller businesses. In addition, their examination [74] revealed that these maturity models appear to lack a direct HF/E perspective. Instead, human-related issues are discussed, such as personnel, organizational culture, and human resources management.

To meet this need, we propose a framework for a maturity model that takes into account H/FE and technology maturities throughout the manufacturing process and handles them at a scale that makes it easier for newer, smaller businesses to be recognized and positioned in the Industry 4.0 space. Our review's findings are built into the HF/E element in this frame. As a result, we recognize the need to investigate HF/E maturity from the macroergonomics work system perspective. The three interconnected elements of the macroergonomics work system serve as the foundation for our maturity model's structure, and the precise evaluation criteria should be developed in subsequent research in light of the difficulties listed in Table 1.Regarding our frame's technological maturity, we acknowledge Sony and Naik's [75] observation that there is no universally agreed-upon definition of Industry 4.0 readiness. We acknowledge the review by Zheng et al. to support our perspective on technological maturity.76] who have summarized various manufacturing-related applications of Industry 4.0 technologies. In a perfect world, and in line with [77], the evaluation criteria in our framework ought to take into account HF/E in the variety of technologies that the company uses and has access to.Fig.1 provides a comprehensive and ideal description of our frame. H/FE and technological maturities both develop positively—step by step—in this ideal maturity development process, eventually leading to organizational and technological excellence.

However, this progressive and idealistic process of development is not the only outcome that is possible. In Fig.2, we depict four (I-IV) non-ideal maturity progression scenarios that could occur in any workplace. In scenario I, technological maturity grows in a positive direction, but HF/E maturity stays the same, preventing employees from making optimal use of technology and exposing them to various health and safety risks. In scenario II, technological maturity does not advance, but HF/E maturity does. Highly skilled employees use technologies that do not support their competitiveness in such a situation. This, in turn, might make productivity worse and make it harder for employees to stay committed to their jobs. High technological maturity is achieved in scenario III, but HF/E maturity declines, posing risks to human health and safety and a less effective use of technologies. In scenario IV, technological maturity declines, but HF/E maturity rises to a high level, resulting in non-optimal production and challenges regarding employee motivation and work commitment. These four non-ideal maturity scenarios are referred to as maturity paradoxes because they include both positive and negative development. At the very least, these undesirable maturation processes are likely to contribute to the low return on industrial investments or the decline in labor productivity. Employees and investors alike will be dissatisfied with the outcomes of the maturity parameter if it actually occurs. This is a fundamental reason to be interested in the challenge of developing two-dimensional maturity levels.

Capabilities required for the maturity of the organization

Incorporating HF/E into larger processes of organizational development necessitates a comprehensive comprehension of sociotechnical structures. Sociotechnical systems and system integration should be managed at three levels, as Sony and Naik [7] emphasize:1) vertically within the organization, 2) horizontally within the supply chains, and 3) from an end-to-end perspective, enhancing the value of the entire product life cycle. We use Carayon et al.'s three-layer structure to complement this three-dimensional framework [9].As a result, the production facilities, or local context in which work activities are actually carried out, make up the first layer. The social and organizational culture of the business are represented by the second layer, which is the socio-organizational context. The external environment with which the company interacts is represented by the third layer.

In keeping with the vertical and horizontal perspectives [7], we emphasize the importance of having a thorough understanding of the company's current manufacturing procedures, or the local context. This necessitates an understanding of microergonomics in relation to the performed work tasks. Applying HF/E study and design techniques to operational work activities is necessary for gaining this understanding. New analytical methods, which digitalization and big data analytics, for example, may be able to facilitate, may be required for data obtained from the premises. New methods for gathering more in-depth information on employee well-being and performance have already been introduced by digitalization. Concerns regarding individual privacy may result from this. establishing credibility with the employer. In this context, employees represent a growing obstacle for the organization a thorough comprehension of the work and production processes, as well as the ability to concretize and convey the problems within the organization to all relevant levels of the organization, demonstrating a positive socio-organizational culture. Evidence-based decision making at the highest levels of management is made possible as a result of this. Last but not least, we can see that the Industrial 4.0 revolution and the rapid technological advancement that manufacturing businesses are experiencing make this idealistic, evidence-based approach even more significant. This, in turn, shows how complicated the third layer is; the external setting. As shown in Fig., HF/E and technological maturities should be evaluated in relation to the entire manufacturing process for each of the three layers described above. Based on this, we point out that fig3.

IV. FUTURE STUDIES

There have been many different points of view on organizational capabilities [e.g., 78, 79].In general, organizational capabilities ought to be discussed as a whole, with different capabilities working together to complement one another rather than competing with one another. Lin et al.'s four-component dynamic organizational capability model [79] gives us a framework for expanding our HF/E-oriented analysis further. To successfully survive in their businesses, organizations require the following capabilities: (1) sensing capability for directional changes; (2) absorptive capacity for organizational learning; (3) relational capability for building relationships and the acquisition of social capital; and (4) interpersonal capability for communication and coordination. We believe that future empirical research ought to concentrate on analyzing and contextualizing these dynamic capabilities within the framework of our maturity model.

In order to facilitate and initiate long-lasting strategic changes at the company level, special attention should be paid to sense making and sense giving at the organizational level [79–81].In addition, we propose that future studies investigate the question of whether and how this organization-centric capability model can be used to organize individual level capabilities in the Operator 4.0 context, which is closely linked to the Industry 4.0 phenomenon (e.g., Ref.82]).

We emphasize the significance of comprehending an organization's capabilities and maturity for process analytics. Process analytics provides a comprehensive understanding of the technological subsystems, including manufacturing processes, technologies and their interfaces, and facilitates directional shifts. By comprehending and identifying the skills and competencies required for developing processes and incorporating new technologies and systems into these processes, further process analytics should cover personnel and organizational subsystems. Because companies, employees, processes, and products differ from one another, we emphasize the necessity of acquiring company-specific data for process analytics and learning within an organization. We observe that the rapid advancement and application of technologies without Human productivity can be complicated and new types of risks to human health and safety can arise from process analytics knowledge and data and HF/E principles. The first upcoming research challenge we see as a result of this review is the analysis of processes using HF/E.

We improve organizations' HF/E analytics maturity and capabilities. As a result, we emphasize the importance of thoroughly comprehending work tasks and their connections to manufacturing process performance, organizational structure, methods and technologies, and workplace environments. We emphasize the significance of comprehending and, if necessary, precisely measuring and analyzing the processes' work procedures and tasks. HF/E literature and standards, the company's production calculations and targets for human work in the processes, and the existing principles and safety limit values provided by occupational safety and health legislation should be compared with the findings of this analysis, which covers both micro- and macro ergonomics aspects. This knowledge aids in the identification of potential production bottlenecks, quality issues, and delays in addition to risks to human health and safety. The micro ergonomic work phase and activity level analyses, as well as the complexity and connections between the various work phases and, ultimately, the manufacturing system as a whole, should all be included in the analysis. In order to make it easier for potential directional shifts in connection with the selection and acquisition of new production technology and process models, the analysis should, at best, be carried out prior to the design phase of the manufactured output product.

In addition, we emphasize the significance of taking a HF/E approach to comprehending the technological maturity as well as the overall performance of manufacturing processes. The capabilities of the current technology will be evaluated in light of the requirements for the product, production goals, and customer requirements. In addition, in connection with the above-mentioned maturity of HF/E analytics, we emphasize the necessity of discussing these from the personnel subsystem perspective in order to link human capabilities to technology maturity and manufacturing process performance. It is necessary to train and acquire new skilled workers or to consider more advanced technological solutions if human capability is inadequate. In this context, we highlight the fact that radical and disruptive technological innovations typically result in greater difficulties than incremental small-scale innovations [83,84].Our next research challenge is to investigate, from an organizational capability standpoint, the factors that contribute to inadequate HF/E implementation when new technologies are adopted.

Lastly, we raise the maturity of integrated knowledge management and orchestration as a crossroads between all of the aforementioned maturity areas. The management of processes must be constructed in relation to the operational organization and their capabilities in this context in order to manage all the activities that produce the data and information required for integrating humans, new technologies, methods, products, and services into the manufacturing process—the macro-ergonomics work system. To make sense, the organization's structure, systems, and methods of acting and communicating about manufacturing process-related information—the organizational subsystem and relevant data gathered from technological and personnel subsystems—should be the focus. The management systems of an organization need to facilitate transparent and comprehensible communication within the organization in order to receive and utilize useful data and information for integrating all of the process's functions into processes that are productive, safe, high quality, and HF/E in order to achieve the highest possible output and quality across the board. This necessitates actions in macro-ergonomics that are capable of producing data and utilizing the information gathered from processes throughout the manufacturing process—from individual work tasks to the entire manufacturing process—along with an understanding of the company's external environment. This all-encompassing strategy that incorporates both microergonomics and macroergonomics is still an area of manufacturing that has not received extensive research.

V. CONCLUSION

The rapid technological advancements of Industry 4.0 reshape manufacturing, focusing on performance enhancements for the manufacturing process. New technologies, on the other hand, may also have unanticipated effects on processes and cause issues for workers. From the perspectives of ergonomics and human factors, the reviewed literature demonstrates that Industry 4.0 is still in its infancy. The transition to Industry 4.0 presents manufacturing businesses with complex challenges that necessitate dynamic organizational capabilities that take into account the manufacturing process as a whole. This review revealed a maturity paradoX, highlighting the significance of focusing on the simultaneous growth of technological and HF/E capabilities in the manufacturing context.

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