Analysis of Human Performance in Manufacturing Framework of Industry 4.0

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Abstract –The phrase "Industry 4.0" refers to the fourth wave of industrial change, which includes areas like smart cities that aren't often thought of as stand-alone industrial applications. Water power, steam power, and mechanization were all introduced during the start of the first industrial revolution. The second industrial revolution that followed was marked by the expansion of mass production and assembly lines made possible by the use of electricity. The third industrial revolution was sparked by the development of electronics, information technology, and automation. This was followed by the fourth industrial revolution, which was defined by the appearance of systems of cyber-physical. The goal of the scientific discipline of human performance is to increase a system's overall performance as well as the wellbeing of the people who are a part of it. A comprehensive search yielded a total of 336 scholarly papers, out of which 37 were examined using a human-centered system of work paradigm as described in the body of HFE literature. Within the frames of the macro- and microergonomics work system paradigms, difficulties related to technological growth were analyzed. We outline the essential components of an organizational maturity model using the study that was done. Within the unique context of the manufacturing industry's fast technological improvements, this model seeks to improve the overall performance of sociotechnical work system.

Keywords – Industry 4.0, Human Performance, Human Ergonomics and Factors, Micro and Macroergonomics Work System Frameworks, Technological Development in Manufacturing Industries.

I. INTRODUCTION

The Industrial Revolution is often regarded as a period characterized by the emergence of innovative technology and unique perspectives that prompted a significant transformation in economic and social frameworks. The term "Fourth Industrial Revolution" (or "4^{th} IR") describes the current period of digitization, which includes a number of features like digitally linked goods and services, advancements in smart cities and factories, and the rising popularity of task and service automation in both domestic and professional settings. Klaus Schwab, executive and founder chairman of the World Economic Forum, introduced the term "4^{th} Industrial Revolution" from the outset [1]. This revolution is distinguished by the convergence of various technologies, resulting in the blurring of boundaries between the biological, modern, and physical domains. These integrated systems, known as cyber-physical systems, are characterized by their unprecedented speed, extensive reach, and profound impact on societal structures. The Fourth Industrial Revolution (4^{th} IR) is anticipated to have extensive ramifications on almost all facets of everyday life, influencing the manner in which people engage with technology and reshaping the locations and methods of employment. The advent of the 4^{th} IR is leading to the emergence of a comprehensive interconnected digital era, facilitated by significant advancements in computer processing power and efficiency. These advancements have enabled actual-time data collection, analysis, as well as enhanced decision-making and predictive capabilities.

The potential opportunities are expanded by the convergence of cutting-edge emerging technologies like AI and cognitive computing, robotics, quantum computing, IoT, distributed ledger technology and blockchain, modern currencies, 3D printing, biotechnology, autonomous vehicles, and energy storage, as depicted in **Fig 1**. The advent of 3D printing technology is poised to usher in a paradigm shift in the realm of manufacturing concepts. Individuals possess the ability to fabricate expeditious and analogous objects with the use of 3D printing technologies. The transition from the construction industry to the healthcare sector, as well as the shift from production to post-consumption behavior of customers, marks the beginning of a new era characterized by efficiency and rapid advancements. The advancement of technology has not fully addressed and resolved all extant concerns pertaining to human health, safety, and productivity within the context of industrial production processes. It is anticipated that human involvement in industrial processes would persist in the future.

Nevertheless, it is important to acknowledge that these jobs have the potential to undergo transformation as time progresses. The role of humans in industrial processes has undergone a transformation, with humans now assuming the position of operators who collaborate with and make use of emerging technology. Currently, and particularly in the forthcoming years, the proficiency, expertise, abilities, and aptitude of individuals involved in operating machinery, as well as those engaged in designing production methods and technology ensuring and enhancing the efficiency and safety of work procedures. There exists a clear and evident need for enhanced communication among many stakeholders, as well as a profound comprehension of the human elements involved in the development of novel technologies, industrial methods, and products. To effectively address this problem, it is essential to enhance the integration and regular use of engineering concepts and the theory of Human Factors Engineering (HFE) inside industrial design and management processes [2]. A comprehensive comprehension of the intricacies involved in output goods, production processes, as well as the human elements and interfaces within work systems is necessary.

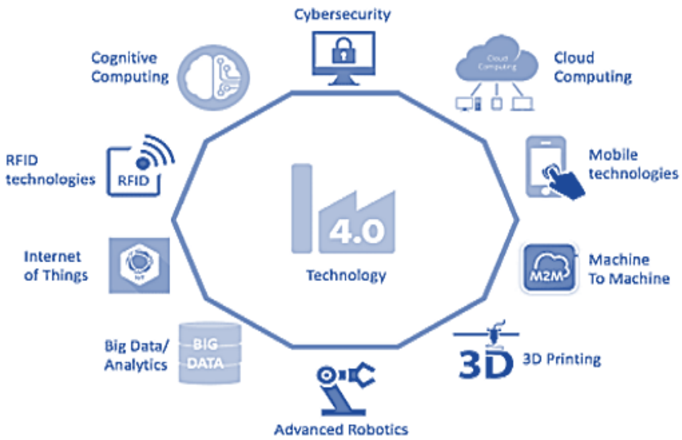

Fig 1. Technologies associated with the 4th industrial revolution.

Our objective is to provide a scholarly contribution by conducting a comprehensive evaluation of the existing body of research pertaining to HFE within the framework of Industry 4.0. In order to achieve the intended objective, a scoping review was undertaken to synthesize research results derived from the extant literature. Additionally, our analysis leads us to suggest a conceptual framework for comprehending and enhancing the levels of HFE maturity within the context of rapid technology advancements in the industrial sector. The rest of the paper has been organized as follows: Section II provides an overview of key concepts used in this article, such as industry 4.0 revolution, and human performance. Section III presents a discussion of the model presented in this paper. Section IV presents the findings of the research, discussion manufacturing from a macroergonomics work system viewpoint in the context of industry 4.0, and microergonomics work systems in the context of industry 4.0. Section V presents general discussion of this paper, highlighting concepts such as HFE maturity within the manufacturing sector, organizational capabilities needed for maturity, and HFE status and performance. Lastly, Section VI presents concluding remarks, as well as directions for future research.

II. OVERVIEW OF CONCEPTS

Industry 4.0 revolution

When first introduced, Industry 4.0 included nine fundamental pillars, including cyber security, cloud computing, cyber-physical systems, robots, Internet of Things, simulation, and big data. As the global community continues to delve into the intricacies of Industry 4.0 and its implementation, Halmosi [3] reveals that many ideas have undergone repositioning. There is a growing trend towards individualization in our interpretation of Industry 4.0, whether via the use of more appropriate terminology or additional explanations. **Table 1** presents a comprehensive glossary of terms, aimed at elucidating the technical jargon associated with Industry 4.0. Furthermore, this part offers concise explanations of key ideas, intended to facilitate the reader's understanding. The references include the necessary technical information.

Human performance

Human Performance Improvement (HPI) stands for "Human Performance Technology, which is a nascent discipline that traces its origins to the study of learning and programmed teaching. In order to advance towards professionalization, the field of HPT would benefit from increased emphasis on theory and research-driven, evidence-based practice [4]. This would enable HPT to attain a level of recognition comparable to that which is now seen in the legal and medical professions. In essence, similar to how a lawyer must possess knowledge of case law and adhere to legal precedents in order to secure a favorable outcome in a legal case, or how a medical doctor must be well-versed in the latest advancements in medicine and its underlying scientific principles to provide optimal patient treatment, an HPT practitioner should rely on theory and research to inform their decision-making process. This enables them to offer interventions that consistently enhance human competence and productivity within organizational settings. Experts in the area of HPT have consistently expressed apprehensions over methods that diverge from the established theory and research foundation of HPT.

One of the individuals who addressed this issue was Harold Stolovitch, who wrote an article titled "Human Performance Technology: Research and Theory to Practice" in the journal Performance Improvement (PI) in April 2000. Stolovitch [5] aimed to draw the attention of practitioners in the sector of HPT to this particular subject. After a span of fifteen years, the concepts he put forward remain applicable and continue to have significant relevance in the context of value-added practice of HPT. Harold Stolovitch has established a notable reputation as an educator, scholar, and advisor in the domains of learning and performance for about half a century, coinciding with the inception of our discipline. The individual in question served as a coeditor for the first 2 editions of the Handbook of HPT. Consequently, the author had a favorable vantage point to contemplate the advancements within the area and advocate for the continued utilization of study and theory as essential instruments for HPT practitioners. Nevertheless, the author approaches this issue with empathy, recognizing that practitioners of Human Performance Technology (HPT) sometimes face the demands of the commercial world, which might detract from the time required for theoretical exploration and study. The author demonstrates the potential of research and theory to enhance practice by using a game called "hit or myth." This game provides a detailed examination of commonly held misconceptions that form the foundation of treatments implemented by practitioners.

Table 1. A Glossary of Terminologies Associated with Industry 4.0

Application	Explanations
Shared economy	An economic system in which producers impose their will on consumers.
Pull economy	An economic system in which customers drive production in an effort to satisfy their needs.
Platform economy	Imagine an economy and a culture where technological platforms seamlessly connect service provider and end consumer.
Operational technology	In order to maintain the integrity and security of a process, a monitoring and control system will either identify deviations or begin them automatically.
Machine learning	One definition of artificial intelligence is "the science and practice of enabling machines to learn how to learn and develop by themselves," and this certainly fits the bill.
Lean manufacturing	A technique used in production that reduces waste while increasing output.
Digital literacy	Capabilities in digital information research, analysis, and production. A target for all workers in the post-Industry 4.0 era
Data literacy	Knowledge of how to analyze and interpret data, as well as share and create new knowledge from that data. A target for all workers in the post-Industry 4.0 era
Connected enterprise	For optimal end-to-end performance, it is essential that all involved parties in a business process communicate relevant data.
Circular economy	By reducing waste and the usage of non-renewable resources, this regenerative strategy makes it possible for enterprises, society, and the environment to coexist.
Blockchain	This is a distributed system that enhances global trade and commerce via coordinated efforts throughout the supply chain.
Artificial intelligence	A machine with human-like cognitive abilities; such a machine often has a large body of knowledge and can thus surpass a group of humans.
Smart city	Nearly every aspect of city life is optimized and modified automatically as needed, resources are distributed in response to changing demands, and the city's society and infrastructure work together to provide its residents the highest possible standard of living. This is the holy grail of Industry 4.0.
Smart product	Connectivity and communication with the network allow the product to function at its highest potential, thus the title "Internet of Things."
Self-organization	Decentralizing the spread of manufacturing inputs provides more flexibility in the supply chain and logistics, which in turn boosts productivity. "Learn how to learn" is a common phrase in the fields of robotics and AI.
Improved manufacturing, smart manufacturing, intelligent factory, smart factory, industry of the future	This is the cornerstone of the Fourth Industrial Revolution and a broad class of industrial ideas. They often use AI platforms and integrate with cutting-edge methods, such as data-driven automated decision making and robotics-enabled automated manufacturing. The end goal is to improve factory output and quality.

The concept of systems has been comprehensively examined within the framework of HFE. A system might range in complexity from a person using a manual instrument to a multinational organization or an organizational value network. Moreover, a system may be defined as a labor system in which a human assumes the role of a worker who carries out a particular operational activity or function within a designated environment. Alternatively, it can be categorized as a service or product system, whereby the human serves as either the consumer of a product or the recipient of a service. This article examines work systems from both microergonomics and macroergonomics viewpoints. From a microergonomics standpoint, our focus is on the challenges that individuals will encounter in forthcoming production environments. The macroergonomics approach focuses on the examination of the organizational, technical, and people subsystems that together constitute a work system of macroergonomics.

The human subsystem focuses on the individuals doing the tasks, while the subsystem technology encompasses both the habitat that is physical and the tools needed to execute the work. The organizational subsystem, which makes up the third component of the system of work, comprises of the system's management and organizational structures. Three interrelated dimensions—complexity, formalization, and centralization—can be used to study it. Centralization pertains to the structures involved in decision-making, while formalization refers to the extent of uniformity inside the organization. The concept of complexity may be examined by considering the segmentation of an organization and the coordinating mechanisms that exist between its portions.

III. ANALYTICAL MODEL

This article provides an overview of the existing understanding of HFE within the context of Industry 4.0, via a comprehensive examination of research results documented in the literature. Subsequently, drawing upon the analysis conducted, we put up a conceptual framework aimed at appraising and overseeing HFE inside the domain of Industry 4.0, alongside the expeditious advancements in manufacturing technology. The present study may be classified as a scoping review, as indicated by Kochan [6]. The researchers have used a modified iteration of the scoping review methodology, which consists of three distinct steps, as shown in **Table 2**.

Table 2. Stages of the Scoping Review

Steps	Explanation
Identification of research questions	In the first stage of our study, we established the research question: "What is the current understanding derived from the existing literature regarding the integration of HFE within the context of Industry 4.0?" The researchers had prior knowledge on the comprehensive delineation of the concepts of Industry 4.0 and HFE. Consequently, a set of carefully chosen search terms was used to conduct systematic searches inside the designated database. The search terms used for the topic of HFE included human factors, work-life, and ergonomics. In the context of Industry 4.0, the search queries utilized were Industry 4.0, additive manufacturing, smart manufacturing, and digitalization.
Relevant literature works	During the second phase, we conducted a comprehensive search to identify papers that were related to our research objectives. The search was conducted in November 2018 and subsequently updated in June 2020 using the Scopus database, using the aforementioned search phrases in various combinations. The scope of the inquiry was restricted to scholarly research papers published in the English language throughout the decade of the 2010s.
Selection and presentation of data	During the third stage of our review, specifically the selection and data charting, we evaluated the pertinence of the literature by examining the titles and abstracts Through this method, we were able to locate the publications that particularly addressed our main topic of interest—the use of HFE in the context of Industry 4.0 in the manufacturing industry.

The concept of manufacturing was generally addressed within this framework. The inclusion of support services like as maintenance and logistics was deemed necessary, given the prevailing emphasis on industrial settings. During this phase, two researchers conducted a thorough examination of the titles and abstracts, independently identifying the articles that they considered to be representative of the primary focal area of this study. A total of 22 research materials were selected to meet the established criteria, as agreed upon by both researchers. Ultimately, the researchers thoroughly examine the study papers.

IV. RESULTS

Manufacturing from a macroergonomics work system viewpoint in the context of Industry 4.0

It is essential to acknowledge that a challenge within this particular setting might yield both adverse and favorable outcomes. For instance, the effective management and use of advanced technology may facilitate the achievement of high-quality manufacturing outcomes. Nevertheless, if the skills of the organization and its workforce fail to align with the requirements imposed by advanced technology, it might provide a challenge for production. Moreover, the use of advanced technology may give rise to novel hazards to human well-being if not well handled. The advent of high technology necessitates a reevaluation of the people subsystem viewpoint, as it is likely to generate a heightened need for the acquisition of novel skills and knowledge. This, in turn, has the potential to assess the organizational subsystem, namely from the viewpoints of technology transformation, communication, and staff training systems. Segmented and centralized decision-making procedures may impose certain demands on the organizational subsystem. Alternatively, the advancement of technology may be seen as a formalization problem, whereby the degree of standardization in the internal procedures for implementing and developing new technologies is assessed, and if these procedures effectively facilitate or hinder practical changes.

Microergonomics work systems in the context of Industry 4.0

Macroergonomics is a scientific discipline that employs a sociotechnical approach, encompassing both top-down and bottom-up perspectives, to analyze and design work systems. This approach considers various elements such as organizational structures, policies, and processes, as well as the interfaces between individuals and their work environment, including interactions with technology and software. Scholars such as Moro [7] and Kleiner and Drury [8] have contributed to the understanding and development of macroergonomics. This implies that the enhancement of the processes and structures that comprise the entire system of work can be achieved through two approaches: (a) conducting an analysis and design of the overall system of work processes and structures, followed by a systematic examination of the factors and subsystems, or (b) analyzing the factors individually and subsequently constructing the overall system processes and structure in a methodical manner. The primary objective of Macroergonomics is to ensure the complete alignment and compatibility of work systems with their sociotechnical attributes, resulting in synergistic enhancements across various dimensions of effectiveness of an organization, including productivity, safety, health, and comfort.

Throughout history, Macroergonomics has been used across several sectors, including but not limited to construction, nuclear, aviation, petrochemical, military, industrial, and medical. In recent times, there has been a development of novel macroergonomic models [9]. These models encapsulate the representation of firms by including several macroergonomic elements that exert influence on the functioning of those organizations. The components of the aforementioned aspects include tasks, human factors, technology and tools, organizational circumstances, and environment. The primary aim of macroergonomic models is to examine organizations from the standpoint of these aspects in order to enhance the design or redesign of work processes. The optimization of macroergonomic parameters leads to improvements in several aspects, including organizational efficiency, productivity, quality of enterprises, as well as the safety and health of personnel. Hence, the use of macroergonomic methodologies serves as a strategic approach for enterprises to enhance their competitiveness within the context of a global marketplace.

Through our system of job categorization, we provide a framework for comprehending the obstacles that manufacturing enterprises have or are anticipated to confront as a result of the industry 4.0 revolution and the fast advancement of technology. In this summary, we provide an overview of the existing understanding of the difficulties encountered in manufacturing processes within the framework of Industry 4.0. These issues are examined at five distinct levels: 1) work environment 2) human, 3) organizational 4) technology, 5) work task.

Human challenge

The complexity of human jobs increases, and digitalization facilitates the allocation of a diverse range of duties to highly qualified personnel, in addition to their primary responsibilities. It is possible that individuals may see themselves as being very adaptable as a result of the technology integration. Furthermore, with the need for technical proficiency, there has been an increased focus on the role of human labor in the industrial sector. This shift necessitates the development of additional soft skills such as effective social and communication abilities, as well as the capacity for teamwork and self-management. It is important to identify the necessary abilities for job execution and thereafter give training to fulfill these requisites. There is a need to expand the opportunities available to individuals for independent decision-making, a diverse range of career options, and more opportunities for social connections. Humans possess unique qualities such as respect, attitudes, and values, which distinguish humans from technology equipment. It is crucial to highlight these aspects in management procedures.

Technology challenge

The advancement of technology has the potential to greatly impact the trajectory of human development in terms of enhancing its quality. This includes the emergence of alternatives to traditional methods of human evolution, which in turn has led to speculation about a revolution in human evolution and the growing influence of technology on this process. At the onset of the 21st century, the topic of enhancing human performance gained prominence inside the United States Department of Defense (DOD) as it was included on the Military Critical Technology List [10]. This inclusion marked the start of endeavors focused on developing technology for HPET (human performance enhancement). In 2012, the Technology Evaluation Office of the United States Department of military (DOD) recognized HPET as one of the five emerging technologies that are disruptive that have the capacity to significantly alter the dynamics of warfare. Consequently, the DOD assumed a proactive role in strategizing the advancement of military technology [11].

Benbya, Davenport, and Pachidi [12] have been consistently published by US and European consultancy organizations and intelligence agencies to assess and predict the future of High-Performance Electronic Technologies (HPET). The paper by Kefalaki and Diamantidaki [13] titled "Emerging trends in Media and Technology. Preface" provides clarification on the research emphasis and direction of High-Performance Embedded Computing (HPET). The Biotechnologies for Human Performance and Health Council's latest study emphasized the potential of four specific technologies: direct neurological enhancement, better vision, muscular control, and enhanced hearing. **Fig 2** illustrates the development paths of the High-Performance Event Timer (HPET). Subsequently, this section provides a comprehensive review of the development and issues associated with major technologies within these three categories.

The potential for unexpected applications of complex technology by humans may arise if the design phase neglects considerations of usability and cognitive processes. There may be a disparity between the requirements and desires of operators in the context of new technology transition, with an excessive focus on the perspectives of managers about digitalization and technological change. It is important to acknowledge, however, that the emerging technology is expected to provide more streamlined manufacturing processes that align with human requirements Job efficiency might be increased by implementing robotization, digitization, and the widespread usage of assistive technology like smart gesture and exoskeleton control systems.

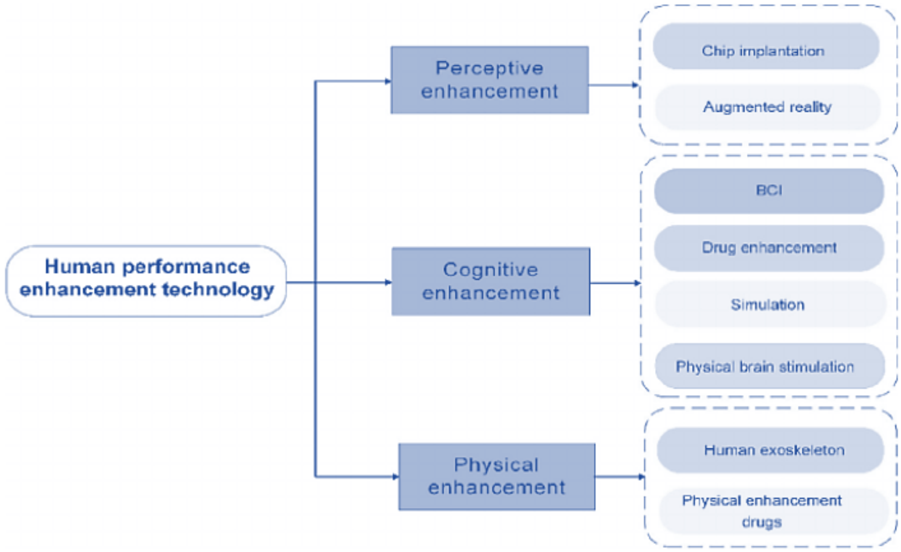

Fig 2. Directions for the development of technology for improving human performance.

This is mostly due to the elimination of non-productive activities such as waiting and searching, which may consume valuable time for human workers. The data suggests that there is a noticeable rise in human-robot contact, necessitating people to acquire the necessary skills to effectively and securely navigate such scenarios. Collaborative robots exhibit a lack of reflexivity, maybe stemming from inadequate comprehension of the technology, and may introduce new risks to human safety in addition to the alterations they bring to the industrial system.

Work environment challenge

The advancement of technology has led to an increased complexity in work settings, resulting in notable differences between contemporary human work places and traditional industrial environments. Employees are required to adapt to production and industrial settings that are characterized by a high level of computerization and automation. The concept of a "smart factory" encompasses several technologies that provide enhanced productivity and efficiency. However, these technologies also present distinct problems to the human workforce in terms of their work environment. In contemporary complex production systems, human workers will consistently collaborate with robotic counterparts throughout work contexts. The acquisition of new skills and the capacity to effectively work with technology are essential in this context. Moreover, the trust and privacy of workers may be compromised inside smart work environments, since the data gathered in these settings often includes sensitive personal information. It is possible that individuals may also need to acquire the necessary skills to navigate and interact within virtual reality settings. Furthermore, the development of new work environments that prioritize human needs might be enhanced by the use of advanced digitalization techniques, such as the deployment of digital twins.

Work tasks problem

In relation to work tasks, it is probable that certain duties are delegated away from human workers, resulting in a potential detriment or obstruction to their overall job performance. Nevertheless, human involvement remains prevalent in the execution of industrial procedures [14]. It is essential for individuals to possess fundamental proficiency in using novel technologies and exhibit a favorable disposition towards transformative shifts. A skilled worker has the capacity to mitigate human errors and blunders. Moreover, a proficient labor force has the potential to enhance their productivity via the use of emerging technology. The complexity of the jobs may increase, however it is plausible that the duties are in reality getting less complicated, as the help systems built for managing production systems are being mastered. The need of using advanced technologies and digitalization in the creation of comprehensive training systems to ensure the availability of a proficient workforce in the future is apparent. Furthermore, the implementation of task analyses to support the allocation of work tasks and management of production may need the use of novel forms of analysis and measuring equipment.

V. DISCUSSION

This scoping study provides a comprehensive overview of the discourse around HFE within the framework of Industry 4.0. The present research has synthesized existing literature to ascertain that the total elimination of human involvement in manufacturing processes is unlikely, given the quick and intricate technological advancements associated with Industry 4.0.

It is quite probable that the roles of individuals undergo transformations, hence raising concerns with the existing techniques and procedures of HFE within the industrial domain. The advancement of technology is anticipated to have a favorable influence on production; nevertheless, it may also provide challenges to personnel and process performance, as well as introduce novel threats to human safety and well-being. The successful implementation of HFE necessitates the deployment of organizational development strategies that include all levels of the organization, ranging from top-level management to the operational floor. Considering the intricate characteristics of manufacturing systems and the growing demand for comprehensive measures that promote corporate social responsibility in the context of Industry 4.0, it is imperative that the implementation of HFE extends beyond internal organizational initiatives. Instead, it should encompass the external value networks and value chains of companies as well.

While we acknowledge the promise of HFE in this particular context, we also voice our worry as our results reveal the present underdeveloped implementation of HFE in the Industry 4.0 context. Manufacturing businesses, in their pursuit of achieving organizational excellence, utilize strategic management and engage in continuous improvement initiatives. However, it is important for these organizations to not overlook the significance of their workers. Rather, they should recognize them as a crucial resource that plays a pivotal role in guaranteeing smooth manufacturing operations. Our argument is that HFE should be recognized as an intangible resource that requires improved integration into strategic design and management techniques and procedures.

HFE for status and performance

By optimizing the alignment between the human and environment factors, two interconnected system outcomes can be attained: performance (such as sustainability, productivity, reliability, efficiency, systems security and safety, effectiveness, innovativeness, quality, and flexibility) and well-being (including personal development, safety and health, learning, pleasure, and satisfaction). HFE experts are responsible for addressing many outcomes, including but not limited to practical and ethical considerations, inside systems. The relationship between performance and well-being is reciprocal, as performance has the potential to impact well-being, and conversely, well-being may have an effect on performance, both in the immediate and extended periods. The occurrence of diminished performance and well-being may be attributed to a discrepancy between the environment and the talents and ambitions of individuals.

As an example, individuals may exhibit suboptimal performance and fail to meet expected standards owing to various hindrances inside the system rather than a conducive environment. These hindrances may include time constraints, inadequate equipment, and insufficient assistance. The concepts of well-being and performance are intricately linked and should be seen as highly interconnected. The field of HFE acknowledges that any system inevitably yields two distinct outcomes: well-being and performance. Through the process of adapting the environment to suit human needs, HFE has the potential to enhance and optimize these collective outcomes, as suggested by Wahler [15].

HFE maturities in manufacturing

In order to foster discourse on HFE within the framework of strategic management and organizational excellence, it is essential to emphasize the clear need of recognizing and acknowledging the skills and maturity levels of firms in effectively managing both the technical and HFE elements of production. Several Industry 4.0 maturity roadmaps and models have been identified by Colli, Berger, Bockholt, Madsen, Møller, and Wæhrens [16]. However, these models and roadmaps do not align with our comprehensive objective of integrating HFE into technical development within the framework of Industry 4.0. In their analysis of Industry 4.0 maturity models, Myrodia, Randrup, and Hvam [17] highlight the customization of these models to cater to the requirements of bigger enterprises, while also acknowledging their limitations in accurately determining the initial circumstances of smaller organizations within the framework of Industry 4.0 maturity. Moreover, Zhang, Ouzrout, Bouras, and Savino [18] revealed that the existing maturity models lack a direct consideration of the HFE viewpoint. The discourse mostly revolves on human-related matters, such as human resources management, people, and organizational culture.

In order to address this need, we present a framework for a maturity model that incorporates the maturities of human factors and ergonomics (HFE) as well as technology across the whole manufacturing process. This framework is designed to accommodate smaller enterprises that are newly entering the industry 4.0 domain, enabling them to gain more recognition and positioning. The HFE aspect within this framework is constructed based on our comprehensive review results. Therefore, it is important to analyze the maturity of HFE from the standpoint of the work system of macroergonomics. The model of maturity we propose is based on the three interconnected components of the work system of macroergonomics. However, the specific criteria for evaluation should be determined in future research, taking into account the problems identified in this review. With regards to maturity technology maturity within our framework, we acknowledge the findings of Castelo-Branco, Cruz-Jesus, and Oliveira [19], who highlight in their review article that there is currently no universally accepted understanding of Industry 4.0 readiness.

In order to provide a foundation for our understanding of technical maturity, we recognize the comprehensive analysis conducted by Lepasepp and Hurst [20], which provides an overview of various application technologies of Industry 4.0 within the manufacturing domain. Ideally, it is important to consider the assessment criteria in our framework in relation to the HFE across the diverse range of technologies that are now being used and are accessible to the firm. **Fig 3** depicts a comprehensive and optimal representation of our framework. In the context of maturity development, it is seen that both human and technology maturities progress in a positive manner, gradually advancing towards the attainment of organizational and technological perfection.

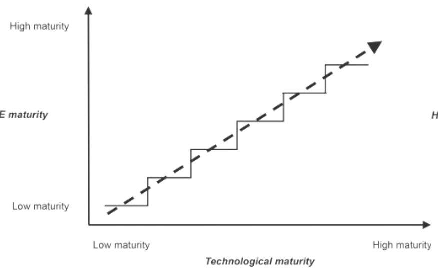

Fig 3. A framework for Industry 4.0 and HFE integration

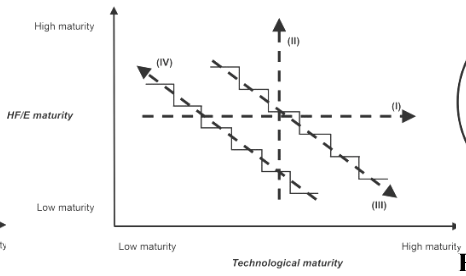

Fig 4. Four (I-IV) undesirable development possibilities

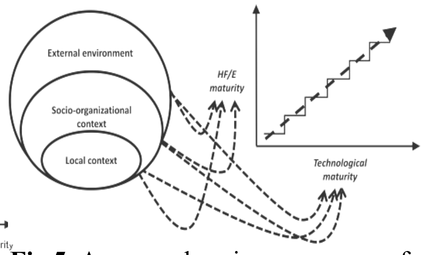

Fig 5. A comprehensive awareness of the organizational and operational environment is necessary for HFE and technical developments

Nevertheless, it is important to acknowledge that this progressive and idealistic growth process may not be the only conceivable end. **Fig 4** presents a graphic representation of four distinct non-ideal maturity advancement scenarios (I-IV) that might potentially occur inside any given work organization. In the given situation, it is seen that technical maturity exhibits positive growth, but the maturity of HFE remains stagnant. This lack of progress in HFE maturity leads to suboptimal application of the technology, hence exposing workers to various health and safety dangers. In the second scenario, the maturity of HFE exhibits positive development, whereas technical maturity does not demonstrate significant progress. In the given circumstance, individuals with advanced expertise are engaged in using technologies that are not aligned with their level of proficiency. Consequently, there is a potential for a decline in production and a potential hindrance to employee motivation and devotion to their task.

In the third scenario, there is a notable achievement in technical maturity, however there is a drop in HFE maturity. Consequently, the use of technologies becomes suboptimal, potentially leading to risks and hazards to human well-being and safety. In the fourth scenario, there is a drop in technical maturity, while the maturity of HFE grows to a high degree. This leads to non-optimized production and presents issues in terms of commitment and staff motivation to work. These four maturities of non-ideal situations are sometimes referred to as maturity paradoxes, characterized by the simultaneous presence of good and bad developments. It is probable that these particular forms of unfavorable maturation processes will, at the very least, have a negative influence on worker productivity or result in diminished returns on industrial investments. In the event that the maturity paradox manifests in practical scenarios, it is likely that either investors or employees may experience dissatisfaction with the outcomes. The development of maturity levels in two dimensions is a basic rationale for fostering interest in this area.

Organisational capabilities required to the maturity

The successful integration of HFE into broader organizational development initiatives requires a comprehensive comprehension of sociotechnical frameworks. According to Shani, Grant, Krishnan, and Thompson [21], the management of system integration and sociotechnical systems should be approached from three distinct levels. There are three key dimensions to consider when analyzing the impact of sustainability practices: vertical integration inside the organization, horizontal integration within supplier chains, and end-to-end value creation over the whole life cycle of the final product. In addition to using the three-dimensional framework, we have chosen to use the three-layer structure proposed by Wang, Cai, Si, and Cui [22]. The first layer includes the particular local setting where work is done, namely the production facilities. The socio-organizational context, or second layer, includes the enterprise's social and organizational culture. The third layer represents the organization's engagement with the outside world.

In accordance with the vertical and horizontal views, it is essential for the firm to have a comprehensive understanding of its existing production processes, particularly with regards to the local environment. In addition, a comprehensive comprehension of microergonomics pertaining to the executed labor activities is necessary. Gaining this comprehension necessitates the use of HFE research and design methodologies for operational job tasks. The data obtained from various processes may need the use of novel analytical methodologies, such as digitalization and big data analytics, which have the potential to facilitate this task. The advent of digitalization has already facilitated the use of novel methodologies for gathering comprehensive insights on employee well-being and performance. The importance of digital transformation in the realm of personnel management cannot be emphasized. The adoption of technology goes beyond mere implementation; it is a strategic need that influences the trajectory of enterprises. It involves integrating a business's tactics with broader goals. The implementation of automated processes for regular operations, the use of real-time data analysis, and the enablement of a geographically dispersed workforce are factors that contribute to the potential for organizational expansion, adaptability, and enduring viability. Organizations that adopt digital transformation strategies position themselves as frontrunners in an increasingly digitalized world by enhancing operational efficiency, fostering data-informed decision-making, and facilitating flexible workforce management.

The significance of an idealistic evidence-based strategy is heightened by the advent of the industry 4.0 revolution and the fast technical advancements confronting manufacturing organizations. This observation illustrates the intricate nature of the third layer, which pertains to the external world. Based on the aforementioned information, it is significant to note that each of the three layers mentioned above may introduce certain factors that need to be taken into account when evaluating HFE and technological maturities in connection to the whole of the manufacturing process, as seen in **Fig 5**.

VI. CONCLUSIONS AND FUTURE RESEARCH

Industry 4.0 is the fourth wave of industrial transformation that is now permeating the global manufacturing sector. This revolution amalgamates the prevailing phenomenon of intelligent automation with the AI, IoT, and big data to facilitate remarkable technological advancements, foster economic expansion, and drive substantial progress in companies of various scales, surpassing the limits of present-day imagination. The introduction of disruptive technologies in the context of Industry 4.0 signifies a significant advancement from conventional automation to the next level of industrial production, which relies on cyber-physical systems (CPS) that are totally web-based. The industry 4.0 advent has brought about important transformations in the manufacturing sector, driven by fast advancements in technology. These developments primarily aim to enhance the performance of production processes. Nevertheless, the use of novel technology might potentially yield unforeseen consequences in operational procedures, hence posing challenges to the workforce. The literature study emphasizes the lack of maturity in Industry 4.0 when considering human performance. The complexities associated with the shift to Industry 4.0 provide significant problems for manufacturing organizations, necessitating the development of dynamic organizational skills that include the whole of the production process. This analysis has found a paradox of maturity, emphasizing the need of simultaneously developing technology and HFE competencies in the industrial setting.

The topic of organizational skills has been examined from several viewpoints. It is commonly acknowledged that the discussion of organizational capacities should be approached from a holistic perspective, whereby various talents are seen as complementary rather than competitive. From this paper, it is argued that in order to thrive in their respective industries, organizations must possess four key capabilities. Firstly, they require a sensing capability to effectively identify and respond to directional changes. Secondly, they need absorptive capacity to facilitate organizational learning. Thirdly, they must possess relational capability to establish and foster relationships, as well as acquire social capital. Lastly, organizations need integrative capability to enable effective communication and coordination within their operations. It is imperative that forthcoming empirical research directs its attention towards the analysis and contextualization of these dynamic capacities within the framework of our maturity model. Particular emphasis should be placed on the process of sensemaking and sense giving at the organizational level. This is crucial in order to effectively enable and launch enduring strategic transformations at the corporate level. Additionally, we propose as a subject for future investigation the examination of the applicability and implementation of this organization-centric capability model in delineating individual-level capabilities within the framework of Industry 4.0, which is closely linked to the industry 4.0 phenomena.

Data Availability
No data was used to support this study.

Conflicts of Interests
The author(s) declare(s) that they have no conflicts of interest.

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