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Human factors in production and logistics systems of the future

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ABSTRACT

The way humans work in production and logistics systems is changing. The evolution of technologies, Industry 4.0 applications, and societal changes, such as ageing workforces, are transforming operations processes. This transformation is still a "black-box" for many companies, and there are calls for new management approaches that can help to successfully overcome the future challenges in production and logistics.

While Industry 4.0 emerges, companies have started to use advanced control tools enabled by real-time monitoring systems that allow the development of more accurate planning models that enable proactive managerial decision-making. Although we observe an increasing trend in automating human work in almost every industry, human workers are still playing a central role in many production and logistics systems. Many of these planning models developed for managerial decision support, however, do not consider human factors and their impact on system or employee performance, leading to inaccurate planning results and decisions, underperforming systems, and increased health hazards for employees.

This paper summarizes the vision, challenges and opportunities in this research field, based on the experience of the authors, members of the Working Group 7 (WG7) *"Human factors and ergonomics in industrial and logistic system design and management"* of the IFAC Technical Committee (TC) 5.2 "*Manufacturing Modelling for Management and Control*". We also discuss the development of this research stream in light of the contributions presented in invited sessions at related IFAC conferences over the last five years. The TC 5.2 framework is adapted to include a human-centered perspective. Based on this discussion, a research agenda is developed that highlights the potential benefits and future requirements for academia and society in this emerging research field. Promising directions for future research on human factors in production and logistics systems include the consideration of diversity of human workers and an in-depth integration of Industry 4.0 technologies in operations processes to support the development of smart, sustainable, human-centered systems.

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1. Introduction

Operations processes in production and logistics are important drivers of customer service and competitive advantage in many industries. It is therefore not surprising that the management of production and logistics processes has attracted the attention of researchers for many years. Operations processes are typically characterized by a high amount of manual human work, especially in areas such as materials handling and assembly. Despite the opportunities that the automation of production and logistics systems offers, many companies still rely on human work in several areas due to their flexibility and their cognitive and motor skills that machines cannot imitate economically yet. Given the high impact these processes can have on the total cost of a company, the focus of prior research in this area has been on the development of mathematical planning models that help managers find solutions for decision problems that reduce costs (see, for the example of order picking, de Koster et al., 2007).

Most planning models that have been proposed to support managerial decision-making in production and logistic systems have, however, neglected the specific characteristics of human workers. This often leads to unrealistic planning outcomes or work schedules that underperform and may even be harmful to workers (Grosse et al., 2015, 2017a). To guarantee a high level of productivity and efficiency and to make sure that planning models reflect reality as much as possible, it is necessary to consider human factors (HF) in designing production and logistic systems to create workplaces that are reliable, efficient, and safe (Battini et al., 2011; Battini et al., 2015). Even though recent research has started to integrate HF issues into mathematical planning models for production and logistics, for example by modelling learning effects (Givi et al., 2015; Grosse and Glock, 2015) or human energy expenditure (Battini et al. 2017; Calzavara et al. 2019; Finco et al., 2020), there still seems to be a large gap in the literature, highlighted also by recent literature reviews, concerning the development of mathematical planning models for production and logistics systems that take account of the interaction between the human worker and such systems. The latter can, unlike the worker, be (strongly) influenced by the system designer making it the preferred domain for engineering improvement efforts.

Generally, HF (including the perceptual, cognitive, physical and psychosocial aspects in the workplace) determine the human performance in production and logistics systems. This aspect becomes more challenging in light of an ageing workforce, which will likely put human factors-related issues in production and logistics, such as the risk of making errors at work or of developing musculoskeletal disorders, on top of the agendas in many companies and international standards organizations, such as ISO/TC 314 "Ageing societies" and the "inclusive workforce" in ISO/CD 23617.

In addition, the concept of Industry 4.0 has become a new trend in industrial and systems engineering (e.g. Liao et al., 2017; Xu et al., 2018). This concept has the potential to radically change operations processes by virtually integrating existing physical, information and financial flows using digital technologies along the entire value chain (Pfohl et al., 2015; Ben-Daya et al., 2019; Winkelhaus and Grosse, 2020). While this digital transformation promises increased productivity and profits to companies, there has been less discussion on how the implementation of these new technologies might affect human workers in production and logistics systems (Kadir et al., 2019). Neumann and Dul (2010) have suggested that new technology implementation benefits substantially when HF principles are applied. There is, however, little discussion of what the HF design requirements in a highly digitized working environment might be in the Industry 4.0 context. In addition, the consequences of using Industry 4.0 technologies that assist human workers in their manual work, such as augmented reality, adaptable workstations, or collaborative robots (cobots), are not yet fully understood in terms of human performance, errors, work motivation, and technology acceptance.

The aim of this work is to provide a vision of the research challenges and opportunities in the field of HF in production and logistics systems of the future. The experiences of the authors, who chair the Working Group 7 (WG7) of the IFAC Technical Committee (TC) 5.2 "Manufacturing Modelling for Management and Control", support the discussion. The contributions presented during the last five years at IFAC conferences are analyzed to illustrate the development of this research field within the IFAC community, and to highlight current challenges. Based on a framework that advocates a human-centered perspective of the main objective of TC 5.2, the analysis of invited sessions at IFAC conferences, and insights obtained from related existing literature reviews, a comprehensive research agenda is proposed that synthesizes the current state-of-knowledge and highlights the future challenges and opportunities for academia and society in this emerging research field.

The remainder of this paper is organized as follows. The next section summarizes the importance of considering HF in production and logistics systems. Section 3 gives an overview of the objectives of the WG7 and TC 5.2 offering the new human-centered perspective. In addition, a summary of papers presented during the invited sessions "*Human factors in production and logistics systems*

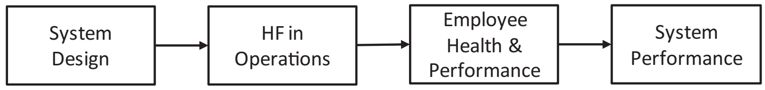

Fig. 1. Model illustrating impacts of HF on system performance.

of the future" at several IFAC conferences is presented. Based on the outline of the development of this discipline and the emerging digital transformation, a research agenda is deduced and discussed in Section 4. The paper concludes in Section 5.

2. Human factors in production and logistics systems

The International Ergonomics Association defines ergonomics (and synonymously HF) as follows: *"Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance"* (*IEA, 2019*). Crucial in this definition is the recognition that designing systems that match human capabilities can serve both social and business goals. While most research studies tend to address only one of these domains at a time, a review of studies addressing both dimensions has shown that, in the vast majority of cases, the human and system outcomes tend to co-vary (Neumann and Dul, 2010; Goggins et al. 2008). They degrade or are enhanced jointly with attention to HF in the design of the system. This relationship is central to the sociotechnical systems view of engineered systems which rose out of research from the 1970s (Van Eijnatten et al. 1993) and retains its currency in dealing with complex engineering problems today (Salmon et al., 2018).

HF has been, arguably, a blind spot in engineering education and practice. Nevertheless, every engineering design engages people in some way throughout its lifecycle. Someone has to assemble the design, use the design, maintain the design, and dismantle and recycle the design at the end of its life-cycle; here, we will use the umbrella term "user" to refer to all of these human interactions. With humans intimately engaged in the engineered system lifecycle, it should not be surprising that the HF in the design of the system affects ultimate system performance (Fig. 1).

Design teams in their projects, including here industrial engineers and operations managers, determine the perceptual, cognitive, emotional, and motor demands on the user. If these demands exceed an individual's capacity, then negative consequences, for both the user and subsequently system performance, can be expected. This chain of effect is illustrated in Fig. 1. The design of the system establishes the HF demands on users that, in turn, will affect both the health and performance of the individual. If HF conditions are good, then user effects can include improved performance due to learning effects as experience is gained (Jaber et al., 2013; Givi et al., 2015). If HF demands are excessive, then fatigue, discomfort, and eventual injuries can be expected. Under conditions of fatigue and presenteeism (injury and pain experienced while still on the job), designers can expect increases in errors and declines in productivity (Zhang et al., 2015; Lohaus and Habermann, 2019). These human effects will subsequently have negative consequences on system performance. System designers, therefore, who do not adequately consider the HF of all system users in their system decisions, should expect their systems to underperform as their calculations fail to consider the impact of human outcomes on the system.

The financial impacts of (unaccounted for) HF effects have been referred to as "phantom profits" (Rose et al., 2013), where anticipated profits are eroded by the negative consequences of poor HF in the system design. New costing models developed for manufacturing systems suggest that a substantial fraction of total production cost can be attributed to HF in the design of the system (e.g., Sobhani et al., 2015, Sobhani et al., 2016, Sobhani et al., 2017). Most companies, however, do not fully understand the costs associated with HF as these are distributed widely across the accounting system. While companies may point to their direct costs associated with injury and absence, they do not consider the wide array of indirect costs associated with the range of HF problems that are "hidden" within the accounting system (Rose et al., 2013). Applying HF in the design of systems will help ensure that these projects meet their potential and can ensure a double win from both human and technological perspectives.

3. Manufacturing Modelling for Management and Control

3.1. TC 5.2 scope and areas of interest

WG7 "*Human factors and ergonomics in industrial and logistic system design and management*" was established by the authors in 2015 and is part of the IFAC TC 5.2 "*Manufacturing Modelling for Management and Control*". This working group aims at investigating the development of innovative approaches for the integration of HF in production and logistics system design. TC 5.2 is devoted to promoting the *"development of management decision support systems (DSS) in digital, resilient and sustainable manufacturing and supply chain systems in the era of Industry 4.0 based on a combination of Industrial Engineering, Operations Research and Data Science."*

In the TC 5.2 vision, all these DSS models, from optimization, knowledge-based models to simulation, focus on the design and management of manufacturing systems and supply networks. Recently, emphasis has been put on the developments of Industry 4.0-based models to make manufacturing systems and supply chain networks smarter, more sustainable and resilient (e.g., Ivanov et al., 2018).

The contribution of the WG7 to the vision of the TC 5.2 is to introduce and promote human-centered approaches in manufacturing and supply chain modelling, here focused on production and logistics systems, based on typical industrial engineering contexts. Thanks to the developments and implementation of the Internet of Things (IoT), data capture technologies and low-cost sensors, industrial engineering systems, from production and logistics systems to supply networks, can be controlled in real-time (Panetto et al., 2019). Advanced operations research (OR) techniques and methods have been developed to support practitioners in the management of complex systems. Finally, new data science techniques, such as business analytics, supply chain and operations analytics, advanced predictive analytics and simulation and prescriptive optimization, are able to solve more complex problems in the industrial engineering field connecting different levels of analysis including the strategic, tactical and operational levels (Addo-Tenkorang et al., 2016).

3.2. A Human-centered perspective of TC 5.2

Based on the TC 5.2 vision and the developments discussed in the previous sections, a human-centered perspective of production

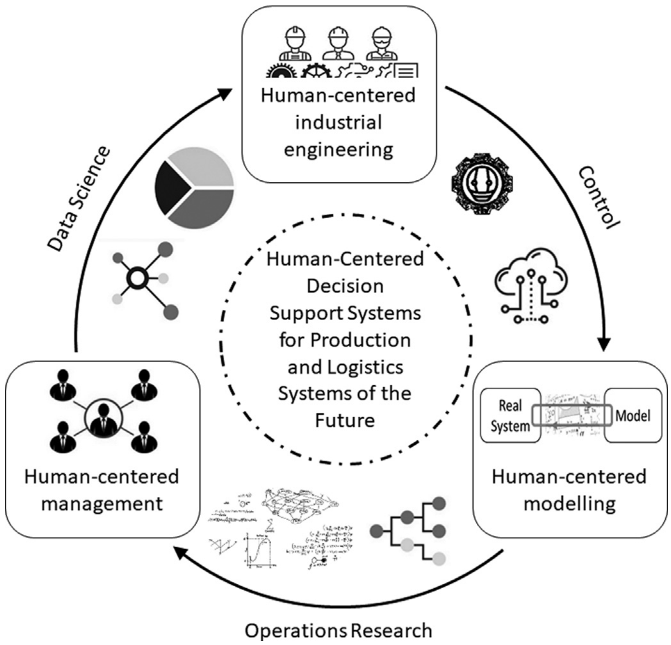

Fig. 2. Human-Centered perspective of TC 5.2 (adapted from Panetto et al., 2019).

and logistics systems in the Industry 4.0 era is briefly introduced below. Then, in the following sub-section, an analysis of the contributions received at several sessions organized by the WG7 since 2015 will show how the topic has been investigated and developed by the international academia attending the related IFAC conferences (INCOM, MIM and IFAC World Conferences).

The framework shown in Fig. 2 advocates the development of Human-Centered Decision Support Systems for Production and Logistics Systems of the Future (Panetto et al., 2019). It is motivated by changes in the perspectives of three main research areas: Human-Centered Industrial Engineering, Human-Centered Modelling and Human-Centered Management.

First, it becomes more and more important to consider the worker in the design phase of the production and logistics systems by extending traditional industrial engineering approaches to enable the design of more individualized and customized workplaces. HF need to be considered as an important design consideration that can improve system productivity and quality as well as advance working conditions and outcomes for employees simultaneously. HF aspects should pose mandatory requirements when new production and logistics systems are designed. It has been widely demonstrated that an integrated approach enables win-win solutions (e.g., Battini et al, 2011; Glock et al., 2019; Neumann & Dul, 2010). Recently, the development of Industry 4.0 technologies has started to change the way systems are designed. For example, the use of motion capture systems and virtual reality can speed up the design phase and allow designers to engage users at early stages of the design process (Sundin & Medbo, 2003). Moreover, they can improve the accuracy of operations and ergonomics assessment allowing a better selection of alternatives (Peron et al., 2020). Industry 4.0 technologies can also assist the operators in executing their activities, reducing their workload (for example when using cobots), or simplifying cognitive activities (e.g., when using augmented reality or other assistive technologies in the context of order picking systems or assembly workstations; see, e.g., Stoltz et al., 2017).

Secondly, new technologies allow the collection of large quantities of data, and this can be used for improving the knowledge of the system under study. New integrated modelling approaches have to be developed and validated using this data. These data-driven models should include HF aspects (such as fatigue, workload, personality, ageing etc.), linking worker health and system productivity and quality. In addition, they should also consider the use of Industry 4.0 technologies and their impacts on the users across the life of the technology (Calzavara et al., 2020).

Finally, resulting from the application of advanced OR techniques, the integrated models can be extended and applied at the management level to find best practices and managerial implications on how to use human resources, how to support workers with new technologies, and how to plan and control human-centered production and logistics systems. The use of data science techniques can give feedback to Human-Centered Industrial Engineering, such as which factors are more significant, predicting the behavior of the systems and thus suggesting how to optimize the design in order to have adaptive and smart human-centered production and logistics systems.

3.3. Insights from previous literature reviews

Almost two decades ago, Boudreau et al. (2003) called for research that integrates insights from human resources management into operations planning. Since then, publication numbers of related works have been increasing, and several reviews exist that surveyed the literature with respect to the consideration of HF in operations management. Neumann and Dul (2010), for example, highlighted the gap in the literature linking HF to operations performance, and the need to integrate HF into operations system design was discussed by Neumann and Village (2012). De Bruecker et al. (2015) reviewed the literature on workforce planning problems that incorporate workers' skills, with a special emphasis on realistic planning models and useful solution techniques. Also with regard to planning models, Grosse et al. (2015) reviewed the literature on order picking, one of the most critical processes in internal logistics, and discussed how HF can be incorporated into planning models to achieve more realistic planning outcomes and to improve performance, quality and worker well-being. A follow-up study of Grosse, Glock, & Neumann (2017a) presented further evidence that HF had largely been ignored in planning models for order picking. Loos et al. (2016) conducted a bibliographic review on the use of ergonomics principles in logistics with a focus on well-being and safety. Otto and Battaïa (2017) also concentrated on physical ergonomic risks, in particular musculoskeletal disorders, and classified existing optimization approaches for assembly line balancing and job rotation that consider HF. Padula et al. (2017) found weak evidence that job rotation contributes to preventing musculoskeletal disorders, as their review indicated that only little reduction of the exposure to physical risk factors was achieved. They did, however, find positive correlations between job rotation and job satisfaction. Besides reviews dealing with performance and physical HF, some works also linked HF to production quality. Kolus et al. (2018) examined available empirical evidence on the impact of HF in production and workstation design on product quality, highlighting specific HF-related quality risk factors, in particular fatigue as a key intermediate variable. Yung et al. (2020) extended their analysis to examine how human fatigue has been conceptualized and measured in the literature and quantified the relationship between human fatigue and quality deficits in production.

Focusing on digital technologies, Kadir et al. (2019) presented an overview of the literature on Industry 4.0 that considers HF. They concluded that only few works were published on this topic so far, and that, consequently, more research is strongly needed. Recently, Calzavara et al. (2020) reviewed the literature on the role of an ageing workforce in production and focused especially on functional capacities and on how to exploit the expertise of older

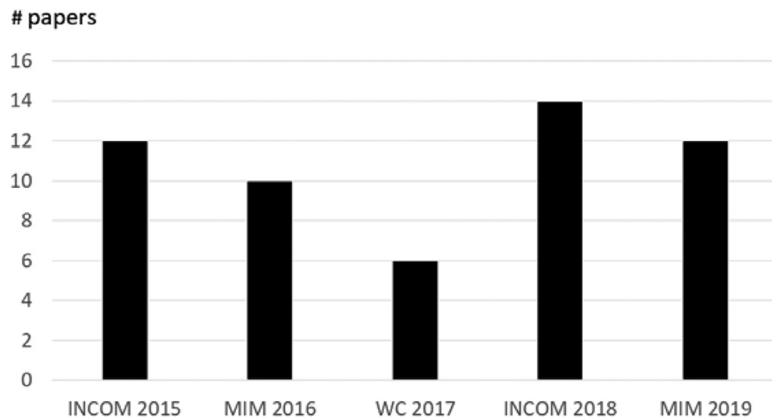

Fig. 3. Numbers of papers presented in invited sessions organized by WG7 at IFAC conferences.

workers, as well as how the implementation of technologies can assist older workers in production. Di Pasquale et al (2020) also focused on an ageing workforce and examined its impacts on production quality, finding a complex relationship modified by both the nature of the task and the experience of the employee.

This overview of existing literature reviews shows that there is an increasing interest in investigating HF in an operations management context; yet, there are many facets of this multidisciplinary research area that have still not been explored. In line with the objective of this work, the next section reviews the invited sessions organized by the authors at IFAC conferences to gain insights into the development of works that consider HF in manufacturing modelling for management and control.

3.4. Insights from IFAC conferences

WG7 of TC 5.2 was established several years ago based on the common interests of the leading members with the main objective to support the human-centered perspective in the design and management of production and logistics systems. Seeking for a paradigmatic change, our vision was that industrial engineering and operations management research needs integrated planning approaches that do not solely minimize cost parameters, but that also consider the implications on human workers (see, for example, Grosse et al., 2015; 2017a; 2017b; Glock et al., 2017a). Considering HF in the design and management of production and logistics systems can, we argue, help increase performance and minimize errors. This results in higher service levels and, most of all, can improve the working environment for employees and reduce work related illnesses and injuries. Thus, to promote this interdisciplinary research field, the members started to work jointly in publications and research projects organizing special issues and invited sessions in relevant journals and conferences.

The first invited session was organized at INCOM 2015 entitled "*Human factors in industrial and logistic system design*". In 2018, the title was revised to "*Human factors in production and logistics systems of the future*" to account for current developments and challenges within our discipline. The sessions have been very popular with a high number of submissions; Fig. 3 displays the number of papers presented at each IFAC conference: the 15th IFAC Symposium on Information Control in Manufacturing (INCOM 2015) (Ottawa, Canada); the 8th IFAC Conference on Manufacturing Modelling, Management and Control (MIM 2016) (Troyes, France); the 20th IFAC World Congress (WC 2017) (Toulouse, France); the 16th IFAC Symposium on Information Control Problems in Manufacturing (INCOM 2018) (Bergamo, Italy); and the 9th IFAC Conference on Manufacturing Modelling, Management and Control (MIM 2019) (Berlin, Germany). In total, 54 papers were presented in the invited sessions. For the analysis of the papers presented in the invited sessions at these conferences, we used the framework of Glock, Lange, Grosse, & Das (2017b) for methodologies employed, and Grosse, Calzavara, Glock, & Sgarbossa (2017b) for topics studied.

From the invited sessions organized in the last five years, we can see a promising trend to include HF in manufacturing modelling for management and control, and in particular for the design and management of efficient and sustainable production and logistics systems of the future. Thus, it is not surprising that the majority of papers presented have had a strong focus on modelling, in particular with regard to the development of mathematical/analytical models considering HF and related solution methodologies (Fig. 4). Other methodologies, such as simulation models and literature reviews, have been rare. We also note that most papers have not employed real-life data to test the developed models (e.g. as an illustrative case) or used case study data to gain explorative insights.

Regarding the topics studied, we observed a strong trend over the years to focus on Production and Assembly line design and Management (P&AM), as illustrated in Fig. 5. This is followed by Intralogistics and Warehouse management (I&W). Only few works focused on Inventory Management and Lot-Sizing (IM&LS). Interestingly, as Fig. 5 illustrates, papers studying HF in the context of Industry 4.0 developments have only recently been presented, with a strong increase at MIM 2019. This trend is expected to continue in future conferences, as we observe an increased attention to HF in Industry 4.0 research.

In terms of the types of HF aspects that have been considered in the presented papers, we observed a strong tendency to investigate physical HF such as human energy expenditure and physical fatigue, which have been considered, for example, as constraints in analytical models. Fewer works focused on perceptual, mental, or psychosocial aspects (Fig. 6).

We also noticed that the majority of works focused on the objective of improving operations performance, followed by improving worker well-being (e.g. avoiding work related injuries). Despite evidence that HF can have significant impact on operations quality (Kolus et al., 2018), only few works considered quality (Fig. 7). 16 out of 54 papers, in total, could be categorized as "integrated" in the sense that they simultaneously consider performance and worker well-being. The remaining 70% of the papers only considered one domain of benefits available from good HF in system design.

In sum, the invited sessions have shown a diverse mix of topics, methodologies, and interdisciplinary approaches, with a very promising trend in further developing this research stream. However, we also note that considering HF in managerial planning and

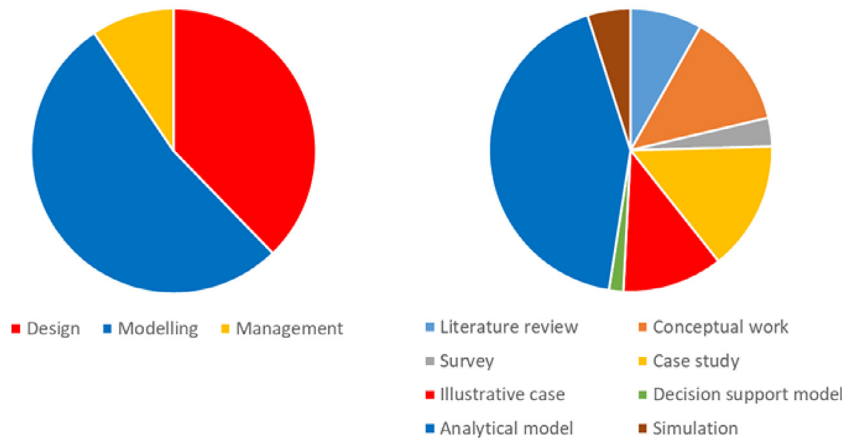

Fig. 4. Methodology and TC 5.2 perspective of the presented papers.

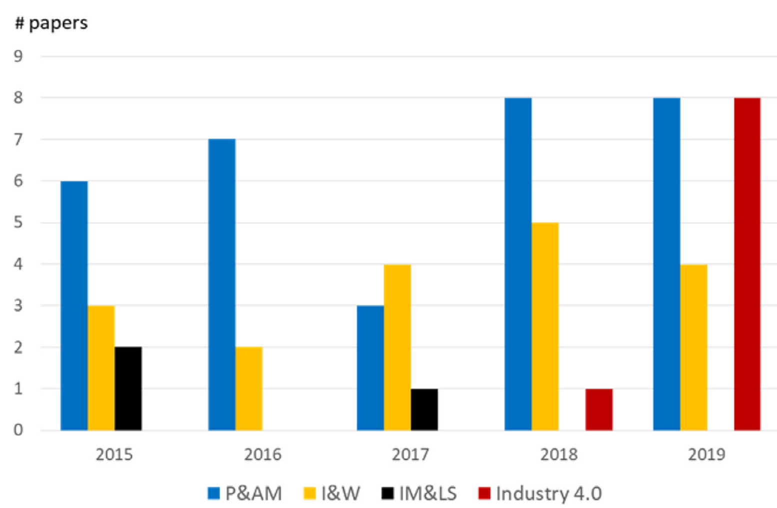

Fig. 5. Topics of the presented papers per year.

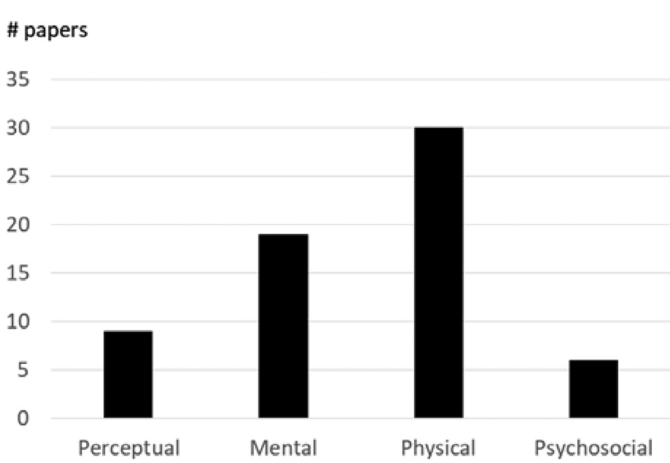

Fig. 6. HF aspects considered in the presented papers.

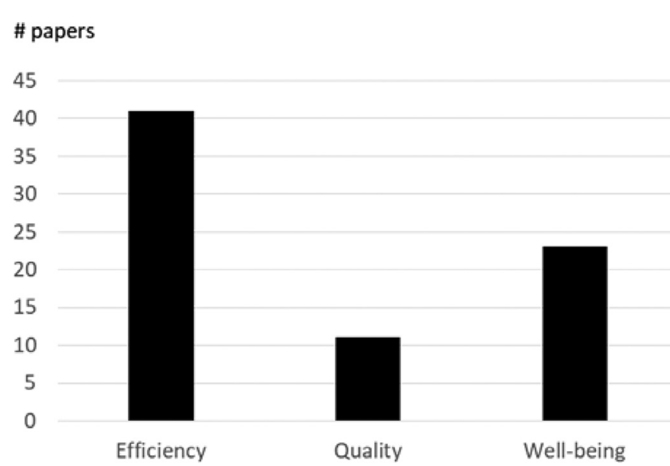

Fig. 7. Objective of the presented papers.

design, instead of solely focusing on cost, is still at its start. Studying the implications of the digital transformation on the future of industrial work, also in light of other societal challenges, such as demographic changes, is still under-developed. We strongly believe that the invited sessions can help to define relevant criteria for HF aspects that can be integrated, for example, into analytical models in order to change conventional operations management approaches to improve working conditions in existing systems with final adjustments of postures, equipment and work assignment. Moreover, we emphasize again that the majority of the works still focus only on performance or only on physical HF, in order to reduce, for example, musculoskeletal disorders, rather than on mental, perceptual or organizational related HF issues.

4. Research Agenda

In the light of the theory and current research reviewed, the authors have attempted to determine directions that might be fruitful for future research on human-centered decision support systems for production and logistics systems of the future. The research agenda described in this section is based on and directly derived from the previous analysis. In addition, insights from recent literature reviews in related fields are considered to derive a comprehensive research agenda. The authors have subdivided these research priorities into the three research arenas defined in Fig. 2 based on the human-centered perspective of TC 5.2.

4.1. Human-Centered Industrial Engineering

4.1.1. Human-centered workplace design methods for individualized solutions

As described in the introduction, there is a strong need for the design of individualized, customized solutions in the context of handling increased diversity in employees including a range of perceptual, cognitive and physical capabilities and needs. This becomes even more important when we consider the so-called "ageing-challenge" of the industrial workforce (Calzavara et al, 2020). For example, working populations in most of the Organization for Economic Co-operation and Development (OECD) member countries are ageing and there is currently a strong consensus regarding the urgent need to design workplaces that will support the management of "age-friendly" production and logistics systems. Due to this development, there is a growing demand of applications with arm-based robots, exoskeletons, smart and intelligent working tools, or immersive virtual reality technology. All these technologies, if well applied and investigated, could have the potential to preserve the productivity, quality and well-being of the aging workforce by better utilizing their experience and extraordinary skills without overloading the employees.

The aim should be to design smart, age-friendly workplaces, in which advanced technologies are collaborating with human workers and enhancing their capacity, not substituting them. An example of future assistive workstation for older workers allowing them to produce personalized products close to the customer has been developed by Linner et al., 2016. Of course, this approach is valid also for the development of individualized solutions for different people, novices or experts, younger or older, people with or without disabilities. Opening workplaces to disabled persons frequently excluded from employment poses an opportunity for these approaches to contribute also to broader societal goals of labor market inclusivity. This can be achieved through multi-disciplinary research related to industrial engineering, social science and ergonomics, operations research and management science, and digital technologies and data science. Consequently, a new multi-disciplinary culture should be created supporting the design and use of technology supporting diversity in the people able to contribute to organizational goals. Thus, there is also a strong need for international standards able to guide practitioners, both engineers and managers, in the implementation of human-centered approaches in production and logistics systems of the future.

4.1.2 Human-centered workplace design in the presence of assistive and collaborative technologies

According to one of the principles of Industry 4.0, there is a need to support humans by conducting a range of tasks that are unpleasant, too exhausting, or unsafe thanks to the integration of assistive and collaborative technologies into new human-centered workplaces. Romero et al. (2015) define the Operator 4.0 as the "operator of the future", a smart and skilled operator who performs work "aided" by machines if and as needed. The production and logistics systems should be modular, integrating operators and technologies by means of human cyber-physical systems, e.g. digital twins. This should also have an integrated monitored system where data about system performance, both from operators and machines, are collected and analyzed in real-time thanks to advanced predictive analytics tools. Advanced technologies for creating digital twins of human-centered workplaces, such as immersive reality and motion capture systems, are very helpful in order to optimize and validate the workplaces with particular attention to the human demands and their relations with system performance (Battini et al., 2018; Peron et al., 2020). However, the introduction of assistive and collaborative technologies in production and logistics systems continues to be arbitrary. Accurate and comprehensive decision support systems have to be developed to study the conditions under which the implementation of assistive and collaborative technologies is economically beneficial.

4.1.3. Challenges in human-centered working space design

As described in the introduction, it is necessary to seek a paradigmatic change to re-think the traditional Industrial Engineering approaches. Engineers need to take responsibility for the human consequences of their designs. Researchers need to provide better knowledge about the links between human demands and system performance. High perceptual demands can lead to mistakes, errors and low quality. High cognitive demands could trigger high stress, errors, ill health and lead consequently to low quality. High physical demands have direct consequences for fatigue and injuries and so for quality. Detailed design level knowledge and methods are needed if engineering teams are to account for these aspects appropriately in their design work.

Moreover, engineers have to pay more attention to the secondary effects of automation and assistive/collaborative technologies. There is a need to understand the correct balance between automating manual activities and those tasks remaining for the human worker. There might be the risk of overloading the worker with monotonous activities leading to negative effects with regard to his/her well-being and so, consequently, to the system performance (Neumann et al., 2002). Furthermore, as technological systems become more complex, engineers will need to attend to the needs of other users such as maintenance and installation personnel. If HF is poor for these tasks, then errors and down-time will increase and the lifecycle costs of the system will soar, compromising the investment in new technology.

Other important aspects are the perceptual and physical demands of new technologies on the workforce. Many questions here remain unanswered, such as "which is the effect of font size and glare using devices for digital worker instruction (e.g. tablets, augmented reality, laser and light assistance tools)?"; "which is the demand of wearing a smart glass device of 1 kg for 8 hours?"; "are exoskeletons really helpful for the workers or do they just move the efforts to other parts of the body, typically lower parts?". Thus, it is necessary to have tools and methods that can guide the engineers in quantifying these demands when new workplaces are designed. Without methods and knowledge, designers may simply, and unwittingly, create new problems for employees as they try to solve old problems.

4.2. Human-Centered Modelling

4.2.1. Age-friendly modelling for production and logistics systems

The majority of research studies reviewed here have ignored the age of the workforce, despite its strategic importance. New analytical models should consider both cognitive and physical load constraints for ageing workers in order to improve the work assignment in production and logistics systems, such as the sequencing of jobs in manual production/assembly workstation or workload management in manual materials handling systems. Such models would support the introduction of new, age-oriented management approaches in production and logistics systems. New models are also required to integrate ageing, for example, in learning curves estimation, rest-allowance assessment, or in terms of the training of novices, job enlargement and enrichment, or "age-oriented" job rotation (Calzavara et al., 2020).Finco et al. (2019) the challenge for managers here is to capitalize fully on the knowledge and experience of older employees, while respecting the gradual decline in work capacities that all humans experience with age.

4.2.2. Modelling for production and logistics systems in presence of collaborative/assistive technologies

New models for operational planning of cooperative human-robotic production and in smart and digital working environments should be developed. In this context, it would be important to consider and predict human effects of adopting a new tool/instrument and subsequently, the impact of HF on system performance and not only on investment cost. This also leads to the question of what the secondary costs of new technologies across the lifecycle of the systemare. New approaches will be needed to model these secondary costs, resulting, for example, from injuries, worker turnover, fatigue-related errors, and absenteeism, also taking into consideration the acceptability of these technologies by the workers.

4.2.3. Challenges in human-centered modelling in production and logistics systems

In this context, future modelling efforts need to address choices surrounding model granularity and temporal resolution. The effects on humans may range from milliseconds, for example looking at electrophysiological fatigue responses in muscle contraction patterns, to months, when considering emotional fatigue and burnout responses to over-work. Granularity in the work process also poses a modelling issue: "how fine a resolution in task scope is appropriate for the modelling activity?" This issue is similar to the choice of MTM level (as predetermined motion time analysis) where level 1 uses a very fine gradation of each sub-movement required to complete a task, so a fine granularity level that comes with increased time-costs to implement. Similarly, identifying the critical granularity level in human modelling poses a challenge. "Do we need to model forces at each human joint, for each muscle or for each motor unit?"; "what about fatigue effects in the same anatomical structures?"; "what about perceptual and emotional demands?"; "how should these be included appropriately in a given model?" We anticipate a process of analysis being required to identify and justify what HF aspects are to be included, and which excluded, from a given modelling project. Professional model builders working in practice will need tools and methods to support the decision-making around these issues.

4.3. Human-Centered Management

4.3.1. Management approaches in production and logistics systems towards an ageing workforce community

The previously noted demographic shifts imply that special attention needs to be dedicated to the learning capacities, physical and cognitive capacities for employees over 55 years of age, especially when they are involved in production and logistics systems with extensive materials handling activities. New decision support systems for human resource and operations managers should be developed in order to support the decision-making and help managers identify the best solutions for enhancing their large capabilities while assuring a safe and motivating working environment. In this context, from a management point of view, it will become strategic also to predict the investment cost on assistive technologies (and related training activities) and their capabilities to really support the workers and be accepted by them in the long run. Without models that can predict secondary, especially negative, human effects of system design, cost performance models will unrealistically overpredict the benefits of adopting a new technology resulting in what has been dubbed "phantom profits" (Rose et al., 2013). "Phantom profits" refers to the anticipated profits of an investment that fail to appear as they are eroded by HF problems and resulting underperformance of the system. Characteristically, the "phantom" nature of the profits is not anticipated by management or their cost models as they do not account for HF effects.

4.3.2. Management procedures with HF paradigms in production and logistics systems of the future

HF has both implications on social sustainability and performance of the production and logistics systems. However, HF and management research streams and applications tend to be still separated in practice. Indeed, Dul and Neumann (2009) argued that, if ergonomics is only seen from the social and ethical perspective without connecting to financial and profit issues, then it will be isolated from management research and decision-making. The consideration of HF as a means to achieve both social goals as well as economic goals simultaneously is a promising approach to push towards the creation of a more integrated management approach. These new procedures should also foster consideration of new work environments in which humans are employed. The introduction of advanced technologies can drive the implementation of new management strategies, more decentralized, more autonomous, more intelligent, based on data science techniques, e.g. advanced predictive analytics and simulation and prescriptive optimization. Here, also knowledge management strategies need to be changed and adapted accordingly to foster effective uptake and use of these technologies by employees.

Finally, the management strategy will need to consider any possible factor that could affect employee performance, from health well-being to career development. In this perspective, the quality of working life will also play a central role in the evaluation of the companies' efforts, and thus there will be a need to find a new set of measures/indexes in order to better evaluate the human-centered solutions and practices the companies are developing at different levels.

4.4. Academic and managerial insights

Grounding on the analysis of the state-of-knowledge, Table 1 systematically summarizes the main research challenges, possible methods to help readers in solving problems and defining future research topics, and the industrial and societal challenges emerging in the current transformation of manual work in production and logistics systems.

Based on our vision of the research field of integrating HF in the design and management of operations processes, we observed increasing publication numbers of works that consider HF over time. However, we also note that most research focused predominantly on physical HF, such as reducing human energy expenditure or fatigue. Very little attention has been paid to the interactions between engineering choices and psychosocial factors such as job satisfaction and motivation, which can influence long-run system performance. Furthermore, works that consider multiple objectives and that emphasize employee well-being and operational performance need to be addressed simultaneously are still rare. Researchers in this area should, as a matter of routine, include attention to both human performance and its precursor, human well-being-related indicators such as fatigue, workload, discomfort and injury risk. This is particularly important in the long term and for

Table. 1
Overview of future research streams for each research arena identified in Fig. 2

Research Arenas		Research Challenges	Methodological Challenges	Industrial and Societal Challenges
Human-Centered Industrial Engineering	Individualized solutions	Considering employee diversity. Accounting for intra-individual changes.	Multi-disciplinary design procedures not based anymore on the “average operator”. Methods to compare demands to individual capabilities.	Multi-disciplinary culture and new international standards. Managing diversity in inclusive work systems.
	Assistive and collaborative technologies in workplaces	Developing cost-efficient human cyber-physical systems. Understanding HF demands of new technologies.	Integrated monitored system for creating digital twins of human-centered workplaces. Assessment methods quantifying HF demands of the use of new technologies.	Low-cost sensors and data collection. Impact of workers’ privacy issues. Setting acceptable performance and risk levels for employees.
Human-Centered Modelling	Age-friendly modelling	Integrating ageing factors in the modelling of human capability.	Analytical/simulation models to include cognitive and physical aspects.	Implementation of models with different granularity and temporal resolution.
	Modelling of assistive and collaborative technologies	Integrating assistive and collaborative technologies in modelling. Anticipating and minimising side effects.	Analytical/simulation models for human-technology interaction.	Assessment of total costs including also secondary costs. Understanding long-term physical and psychological effects.
Human-Centered Management	Management approaches for the ageing workforce community	Interactions between different management decision-making processes.	Decision support systems for human resource and operations managers. Methods to quantify the benefits of inclusive OM.	Development of inclusive workplaces considering also phantom profits. Spanning the responsibility gap between OM and HR.
	Management approaches with HF paradigms in production and logistics systems of the future.	Joint consideration of social and economic impacts of new technologies at different decentralized decision levels.	Decision support systems for more decentralized, more autonomous, and more intelligent management strategies.	Implementation of new data-driven management approaches for improving overall well-being. Managing the psychosocial dimensions of work appropriately.

more vulnerable employees. In addition, most papers did not use real data or case studies to support the results of their models. More empirical work is required if valid predictive models are to be built. For instance, while we see a strong need for advanced analytical models, quantitative approaches, and simulation studies, we also see the need for qualitative approaches and case studies that give insights into behavioral issues and the interactions of humans and new technologies in production and logistics systems (Grosse et al., 2016). This research should focus on physical, cognitive and psychosocial human factors in production and logistics systems, and integrate quality issues, such as human errors, in the analysis. Connected with the chances and challenges of using assistive and collaborative technologies in manual industrial work, we see a clear need for research on technology adoption, reliability and maintainability in these systems, all of which have HF implications. It remains an underlying question as to the extent to which applying emerging technologies, such as those proposed in Industry 4.0, will outperform conventional engineered systems when these are developed using human-centered design approaches that engage end users in the formation and implementation of the technology, as compared to the status quo approach in which technology is developed in isolation and implemented without regard to the needs of the extended set of system users.

This work can also provide insights for practitioners, in particular industrial engineers and operations managers, who need to be sensitized for the impacts of the technical design of the production and logistics systems (including the use of Industry 4.0 technologies) on their employees and contract workers. In addition, engineers and managers may take notice of psychosocial aspects influenced by the design of technically assisted work, such as motivation, boredom, or technology adoption that affect employees’, and hence operational, performance and quality. To further improve the performance of production and logistics systems in light of demographic changes, engineers and managers should consider HF, in particular the individual requirements and abilities of workers, in designing or redesigning manual working processes.

5. Conclusion

This paper discussed the vision of the IFAC TC 5.2 WG7 “*Human factors and ergonomics in industrial and logistic system design and management*” about the future development of research on HF in production and logistics systems. Based on the aim of TC 5.2, this paper first outlined the importance of HF in production and logistics systems design and management, integrating HF issues in mathematical planning models for these systems, as it is still common practice in engineering design to neglect HF to a great extent. Thus, we call for the development of a human-centered perspective of TC 5.2, which takes into account the necessary changes in the perspectives regarding system design via human-centered industrial engineering, the modelling of the analyzed system using human-centered modelling and the management of the modelled system with human-centered management approaches and perspectives. This human-centered perspective on the development of decision support systems can help to overcome current challenges companies face, such as digital transformation and demographic change, and can set the stage for the development of future work to achieve long-term sustainable operations processes.

To highlight the development of the research stream on HF in production and logistics system design and management within the IFAC community, an analysis of previous literature reviews and the most recent papers presented in invited sessions organized by WG7 at the last five IFAC conferences was presented. Then we derived a research agenda highlighting the most promising topics that should be considered in future research. This agenda is supposed to stimulate further research promoting human-centered decision support systems. These new human-centered approaches can facilitate the design of production and logistics systems and give guidance for considering HF in managerial decision-making. This requires researchers and organizations to overcome the organizational divide between a human resource view of HF and the traditional approach to operations management that is still prevalent in many companies. This vision article emphasizes that considering HF in design and management of production and logistics systems is a crucial aspect for business success. HF will be particularly important in successfully managing the ongoing, and revolutionary digital transformation of industrial work. We are confident that the actions taken within IFAC TC 5.2 (such as invited sessions) can make a major contribution to this development and encourage other researchers to contribute to this important area, for instance in future IFAC conferences.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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