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Human diversity factors in production system modelling and design: state of the art and future researches

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Abstract: Workforce diversity effects in manufacturing systems have attracted a wide range of researches in the last years. Differences between workers in terms of age, gender, physical measures, culture and skills have a large impact on production systems performance. This study investigates workforce diversity factors in production system modeling and design in order to highlight strengths and weakness in the present published literature. The paper categorizes a selection of papers in the last ten years and discusses how human factors are incorporated into manufacturing systems optimization and design approaches. Finally, a discussion on future research steps is provided.

Keywords: Human diversity, Human factors, Production system, Operation management, Literature review

1. INTRODUCTION

A wide range of tasks in the manufacturing sector are human centred and their performance largely depend on workers rather than machines (Abubakar and Wang, 2019; Calzavara et al., 2019). Therefore, providing human workers well-being can be considered as an important challenge, as it has a direct impact on the overall efficiency and costs. There are a wide range of human diversity factors that can affect human performance in manufacturing systems. Some studies have considered the impact of human diversity factors in general terms, without a direct focus on manufacturing activities or production systems (i.e. West and Travers, 2008) or have put large emphasis on ergonomics issues even if related to "mean workers" instead of considering the difference between workers (i.e. Battini et al., 2017). Other five works have previously investigated the literature regarding human factors in industrial context. De Bruecker et al. 2015, for example, developed the literature regarding workforce planning problems incorporating skills and presented the combination of technical and managerial knowledge. Loos et al. (2016) presented a state of the art regarding ergonomics in logistics and supply chain domains. Otto and Battaia (2017) put a particular focus on physical ergonomic risks and musculoskeletal disorders risks by providing an overview of existing optimization approaches for assembly line balancing and scheduling. Kolus et al. (2018) examined available empirical evidence on the impact of human factors consideration (in production and work station design) on product quality. They have investigated the quality risk factor in product design, process design and workstation design. Finally, Calzavara et al. (2019) recently have published a state of the art regarding Industry 4.0 technologies for ageing workers in manufacturing systems. However, the previous studies don't put attention on the different human diversity factors in production system design and modelling.

On the contrary, in this work, the authors aim to provide to the scientific community a new literature review concerning five human variability factors including age, gender, body and physical measures, anthropological aspects and skills and how these factors have been considered in production system design and management in the last 10 years. The classification of the 40 selected papers helps us to understand which types of human factors are more or less considered by previous studies and the present gaps in the literature. The final research agenda can support future research efforts in designing a manufacturing system when humans variability factors need to be considered among workers involved.

2. LITERATURE METHODOLOGY

To identify relevant works, we conduct a literature search based on the Scopus database and the year of publication is limited to the last 10 years from 2008 to 2018. Two main keywords sets have been used just in article title to identify studies that are 1) conducted in a production setting and 2) included measurement of human diversity factors. Papers have been screened to be in English language, published in journals or conference proceedings in relevant subject areas and are confirmed to be based in the manufacturing sector. After elimination of out of scope and irrelevant papers we finally applied a "snowball" approach to select more related papers. The overall procedure is summarized in Table 1.

3. LITERATURE CLASSIFICATION

Table 2 categorizes the selected 40 papers according to two different dimensions: 1) the human diversity factors consideration including: age, gender, body and physical measures, anthropological aspects and skills. (following and integrating the classification suggested by Abubakar and Wang, 2019).

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Table1. Review methodology and steps adopted

Step	Years	Keywords	Selection criteria	Exclusion criteria	Papers found	Papers used
1	2008-2018	Title= "worker variability" or "human factors" or "age" or "ageing workforce" or "gender" or "body and physical attributes" or "anthropological" or "skills" or "workforce skill" or "cognition skills" **And** Title= "assembly" or "assembly line balancing" or "assembly line sequencing" or "manual assembly lines" or "work assignment" or "job assignment" or " task assignment" or "job rotation" or "task switching" or "working space design" or "layout"			212	
2	2008-2018		LIMIT-TO Language= English **And** LIMIT-TO Source Type= "Journals" or "Conference Proceeding" **And** LIMIT-TO Subject Area= "Business, Management and Accounting" or "Computer Science" or "Decision Sciences" or "Economics, Econometrics and Finance" or "Engineering" or "Chemical Engineering" "Social Sciences" or "Medicine" or "Health Professions" or "Multidisciplinary"		132	
3	2008-2018			Papers are excluded when they are not directly considering the presence of workers variability in modeling and design procedures		31
4	2008-2018	Papers coming from the snow ball approach of the papers selected in row 3				9
Total 2008-2018						**40**

2) The kind of problem under development: assembly line balancing and sequencing, job/task assignment, job rotation or task switching and layout design.

3.1 Age

Nowadays, modern companies in developed countries are facing aging workers trend in assembly systems. Although they are more experienced in comparison with the youths, they may confront some problems in order to do high pressure manual tasks, highly repetitive and short-cycle operations. From the literature analysis become evident the presence of two different theories regarding ageing workers: one of them maintains that ageing workforce has a positive impact on human performance since provide workers the high level of expertise, while the other one recognizes a negative impact on functional capacities due to an increment in fatigue and physical limits. There are only two studies in the presented literature, able to consider both aspects of age in manufacturing systems (Gajewski et al., 2010; Boenzi et al., 2015). For example, Boenzi et al. (2015) considered both functional decline and experience aspects of age considering the compensation theory (ageing workers use experience to compensate declines in physical capacities). They developed an age-related integer linear mathematical programming to find the optimal job rotation schedules in work environments characterized by low load manual tasks with a high frequency of repetition (e.g. assembly lines). Gajewski et al. (2010) asserted that, no age differences are found between younger and older participants regarding the local switch costs, whereas clear performance decrements are in the memory-based in the group of older employees with repetitive work demands.

3.1.1 Age-Related Functional Capacities

Functional problems can be categorized into physical and health problems or cognitive disorders. Nardillo et al. (2017) collected data from male and female participants with the age from 19-65 years in order to determine the influence of age and gender on heart rate variability in simulated assembly line task. In their study, statistical differences between age groups are notable which gives notion that workplace tasks should consider age and gender classification when designing work structures for employees. If older workers are employed in assembly jobs, it is necessary to identify the problems and risk factors which they are exposed. To address this issue, Landau et al. (2008) developed two different types of scenarios: the first scenario implies on early retirement of older workers before musculoskeletal problems arise and the second one proposes that the ergonomic and medical danger points should be identified and eliminated by modification of the work model. These two opposed solutions were examined on an assembly line for middle class cars manufactured and the results indicate head–neck–shoulder symptoms occur more frequently in older workers working under unfavorable conditions and postures. Other papers indicated that older workers require greater attempt and time than younger to do repetitive tasks in assembly systems (Boerner et al., 2012; Gilles et al., 2017). Jeon et al. (2016); Botti et al. (2017); Efe et al. (2018) proposed different models in assembly line balancing and job rotation to indicate the negative relation between age and workers' capabilities and health.

3.1.2 Age-Related Experience Level

The current theory cannot confirm that older workers are less productive than younger workers. The results of the study presented by Borsch-Supan and Weiss (2016) illustrate that productivity in a large car manufacturer which is typical for large-scale manufacturing does not decline at least up to age 60. Experience can be defined as the knowledge or skill to be gained over time by using a given manufacturing equipment, a given technology or through involvement of a specific task. According to this definition some studies illustrated the direct relation between age and experience (Grosse et al., 2013; Costa et al., 2014; Lazzerini and Pistolesi, 2018). Furthermore, the results reported by Xu et al. (2014) indicate that age does not have a considerable effect on hand movement time thanks to set of experiments performed on twenty females

Table2. Classification of human variability factors in production system modelling and design (all the papers that make use and provide real industrial data are underlined in the table)

Human factors	Assembly line balancing and sequencing	Job / task assignment	Job rotation and task switching	Working space design, layout design and facility location
Age				
Functional capacities	Landau et al. (2008); Boerner et al. (2012); Gilles et al. (2017); Nardolillo et al. (2017); Efe et al. (2018);	Gajewski et al. (2010); Botti et al. (2017)	Gajewski et al. (2010); Boenzi et al (2015); Jeon et al. (2016)	
Experience	Neumann and Medbo (2009); Xu et al. (2014); Börsch-Supan and Weiss (2016); Abubakar and Wang (2018)	Gajewski et al. (2010); Grosse et al. (2013); Costa et al. (2014); Lazzerini and Pistolesi (2018)	Gajewski et al (2010); Boenzi et al (2015)	Grosse et al. (2013)
Gender	Saptari et al. (2015); Rohrer- Vanzo et al (2016); Nardolillo et al. (2017); Efe et al. (2018)			
Body and physical measures	Gao et al. (2016); Gilles et al. (2017); Comberti and Demichela. (2018)		Yoon et al. (2016)	Lan and Zhao (2010); Baykasoglu et al. (2017); Li et al. (2018)
Anthropological		Lazzerini and Pistolesi (2018)		
Skills				
personal and professional capabilities	Neumann and Medbo (2009); Koltai and Tatay (2013); Mori et al. (2015); Dalle Mura and Dini (2016); Asgari et al. (2017); Martignago et al. (2017); Tsao et al. (2017); Salehi et al. (2018)	Grosse et al. (2013); Koltai and Tatay (2013); Costa et al. (2014); Lazzerini and Pistolesi (2018); Salehi et al. (2018)	Aryanezhad et al. (2009); Azizi et al. (2010); Mossa et al. (2016); Hochdörffer et al. (2018)	Grosse et al. (2013); Öner-Közen et al. (2017)
cognitive abilities	Duan, et al. (2012); Duan et al. (2013); Duan et al. (2016); Comberti and Demichela. (2018); Fan et al. (2018)		Gajewski et al (2010)	Li et al. (2018)

with no history of musculoskeletal disorders in assembly work. The relationship between age and experience level has been supported by other two studies that incorporated human attributes of learning and ageing into discrete event simulation (DES) (Neumann and Medbo, 2009; Abubakar and Wang, 2018).

3.2 Gender

Efe et al. (2018) analysed six different age categories in textile firm in order to assess the impact of age and gender on physical workload capacity. Their study mainly focuses on productive workload differences with respect to age and gender of workers to minimize the number of workstations for assembly line worker assignment and balancing problems. The effects of gender differences on human error and cognitive aspects of gender differences in assembly line were studied only in three studies (Saptari et al., 2015; Rohrer-Vanzo., 2016; Nardillo et al., 2017).

3.3 Body and Physical Measures

Considering the physical measures of workers such as height, weight, strength and body shape can be very effective for assigning the most appropriate task to the right worker. The contribution of this factor into production system can lead to higher adaptability among workers and workforce condition. Comberti and Demichela (2018) considered two macro factors including physical and mental workload requirements and individual physical and cognitive abilities to reduce the risk of human error in an assembly line. Gao et al. (2016) quantified human factors including visibility of an assembling part, posture, fatigue and physical attributes of operators (e.g. Mass, shape and size) in the assembly process to analyse the influence of the human factors on assembly performance. Yoon et al. (2016) developed a mathematical model for job rotation schedule and applied it to an automotive assembly line in order to decrease cumulative workload from the successive use of the same body region. In their model the entire workers' body is assessed to prevent the exposure to high workloads on the same body region. Lan and Zhao (2010) applied the measure to improve facilities layout of a workshop of an opto-electrical company. They focused on matching facilities layout considering work environment and human factors, particularly body posture and other physiological capacities, to avoid occupational muscle skeleton injury for operators. Li et al. (2018) built a mathematical model by considering human factors in facility layout to find the best solution including safety, sustainability, high efficiency and low cost. From the view of human factors, in their study, it is essential to consider both mental and physical health of the workers. Baykasoglu et al. (2017) proposed a systematic approach for designing of assembly system and solving layout problem in order to achieve efficient production. They considered interrelation between technological variables, such as time and methods, and environmental variables, such as workers' physical attributes and ergonomics evaluations. Gilles et al. (2017) did an experiment to evaluate the effect of age on motor adaptation capacities of employees to a repetitive task under two different imposed paces. They measured characteristics of Sixty-five right-handed men such as age, body mass index and height.

3.4 Anthropological

Anthropological factor includes behavioural, cultural, linguistic and physical differences aspects. It can be regarded as important factor since a wide range of variation among humans coming from different cultures and countries. An anthropological analysis in production systems can put positive influences on safety improvement since it helps managers to reconcile the work environment with the human dimension. For this reason, Lazzerini and Pistolesi (2018) presented an integrated optimization system to help companies assign each task to the most appropriate worker according to operators' behaviour.

3.5 Skills

Skills as human diversity factors have attracted the majority of the researchers in the last ten years, followed only by age factor. Identifying workers' skill precisely can improve the production quality and ensure managers that the right worker is assigned to the right task. Skills can be defined as general skills (personal and professional capabilities) such as: 1) the ability of learning, motivation, experience and physical attributes and 2) cognitive skills.

3.5.1 Personal and Professional Capabilities

Asgari et al. (2017) presented a multi-objective linear mathematical model to illustrate main attributes of human such as operator's personal capabilities, like motivation and learning capabilities, and operator's professional capabilities like skill level and experience. Other papers followed different approaches and models incorporating workers' skills and qualifications such as psychomotor skills, physical, speed and dexterity into the manufacturing unit (Dalle Mura and Dini, 2016; Tsao et al., 2017; Hochdörffer et al., 2018; Salehi et al., 2018). Öner-Közen et al. (2017) developed different scenarios to test the impact of inhomogeneous workforce in terms of experience and speed in assembly line. In their study, paced and unpaced assembly lines are compared to determine guidelines that suggest which line configuration is best under which production circumstances. Koltai and Tatay (2013) provided a general framework to model skill requirements and skill conditions for assembly line balancing. In their research, three types of skill constraints are defined based on the workers' capabilities. Low skill constraints define workstations for workers who can do just some simple tasks. High skill constraints regard tasks which require higher than average skills of workers. And the last one exclusive skill constraints consider situations where a group of workers is specialized in a subset of tasks. Costa et al. (2014) proposed a Mixed Integer Linear Programming model to address worker allocation issue for enhancing the performance of a manufacturing system. In their model, multiple skill levels of workers for each level of expertise are defined. The skill level of each worker depends on the experience has earned over time by using a given manufacturing equipment or a given technology. Other studies evaluated the effect of workers' skill level variation and capability differences in terms of learning, training and experience in production systems (Aryanezhad et al., 2009; Neumann and Medbo, 2009; Azizi et al., 2010; Grosse et al., 2013; Mori et al., 2015; Mossa et al., 2016; Martignago et a., 2017; Lazzerini and Pistolesi, 2018).

3.5.2 Cognitive Abilities

Fan et al. (2018) developed a model to measure the human factors' complexity and described the effect of the worker's cognition on operation time of human-based stations in assembly line. The assembly performance in cellular manufacturing system is largely depends on the operators' cognition skills, since the assembly tasks in this part mainly comprise cognitive tasks. For this reason, Duan et al. (2016) extracted assembly skills to improve novice operators' assembly performance and accelerate training period of novice operators. There are other studies on cognition skills and operator's ability in cellular manufacturing system (Duan et al., 2012; Duan et al., 2013). Gajewski et al. (2010) compared the effect of cognitive control functions among young and middle age employees of big car factory either in assembly line production involving highly repetitive tasks or in service and maintenance sector without repetitive job demands. Comberti and Demichela (2018); Li et al. (2018) have considered the cognitive skills in their studies which have been explained in part 3.3.

4. FUTURE RESEARCHES AND CONCLUSION

Based on the findings of the literature review presented in table 2, the following conclusion can be derived:

- Much evidence from the literatures indicates that majority of studies have been done on workers' differences in terms of age and skill, while few studies investigate other aspects of human factors. Therefore, it can be concluded that age and skills are the most investigated factors in manufacturing sector, particularly, in assembly line systems. The functional damages, including physical and cognitive arising from age, are underestimated and studies are mainly focused on the correlation between age and experience level. Also, only two studies consider both aspects of age in manufacturing systems. Therefore, the impact of fatigue, uncomfortable postures and functional capabilities decline with an ageing workforce are urgently required to be taken into account with developing new models both in assembly line balancing and sequencing and in layout design. The final aim is to help manufacturers and decision makers to identify the disruption areas of ageing workers and provide them appropriate equipment and safe/ergonomics working conditions.

- The majority of the papers consider different skilled workers with respect to the level of experience, learning and motivation. Rare studies consider physical and cognition aspects of workers as influential abilities. Also, in the selected literatures, there is no variety in working space design and facility layout according to workers' physical attributes differences in terms of body, strength, height and gender. These important factors can influence decisions regarding layout configuration design and work-space characteristics. Therefore, future research is required to incorporate human diversity factors into layout design techniques to promote the level of conformity among workers and work environment to avoid fatigue and health disorders.

- Anthropological and behavioural aspects of workers seem to have not been largely considered in the selected literature if compared with the skills and age factors. However, in some specific industrial settings (Robey, 1974) they can become important since a wide range of variation among humans coming from different cultures and countries can impact on their abilities and productivity. This variability factor can also become in a near future highly effective for working space designing and worker assignment as it considers the workers' specification in terms of culture, linguistic and physical aspects. For example, linguistic anthropology, cultural anthropology, biological or physical anthropology study differences in native languages, cultural variation, biological developments and physical measures respectively. There seems to be a high potential need for future works in this research stream. Regarding the gender factor, by itself is not often considered in the analysed literature. The reason is probably that there is no specific need to consider it as a separate factor, since gender is already often coupled with skills evaluation and ergonomic risk assessment by managers and industrial engineers.

- Even if a good number of the presented studies here concern real cases, there is still in the literature a high necessity to provide researches with higher statistical sample, new statistical data, field studies and real measurements in order to better understand and measure human variability factors and validate future human-oriented models (Börsch-Supan and Weiss, 2016).

- Finally, the major limitation of this research regards to space limits that confines authors to consider only the last ten years. As future step, this work will be expanded by considering a larger time frame and a larger set of keywords.

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