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Human Factors and Their Effects on Human-Centred Assembly Systems – A Literature Review-Based Study

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Abstract. If a product has more than one component, then it must be assembled. Assembly of products relies on assembly systems or lines in which assembly of each product is often carried out manually by human workers following assembly sequences in various forms. It is widely understood that efficiency of assembling a product by reducing assembly times (therefore costs) is vital particularly for small and medium-sized manufacturing companies to survive in an increasingly competitive market. Ideally, it is helpful for pre-determining efficiency or productivity of a human-centred assembly system at the early design stage. To date, most research on performance of an assembly system using modelling simulation methods is focused on its “operational functions”. The term used in a narrow sense always indicates the performance of the “operational system”, which does not incorporate the effect of human factors that may also affect the system performance. This paper presents a research outcome of findings through a literature review-based study by identifying possible human factors that mostly affect the performance on human-centred manufacturing systems as part of the research project incorporating parameters of human factors into a DES (discrete event simulation) tool.

1. Introduction

Manual assembly is, by definition, carried out by human workers and therefore this type of manufacturing system is human-centred as its performance largely depends on humans (or human performances) rather than machines. There are some studies in a view of socio-technical or psychological sciences to evaluate the effect of human factors relating to the design of manufacturing systems. These human factors may include cognitive elements (such as experience, IQ level and so on) and physical elements (age, gender, dexterity and so on). However, the outcomes of these studies are basically descriptive in a form of language that manufacturing engineers often find difficult to understand. Modelling techniques are used to consider such human issues as ergonomics to improve the environment for workers to perform at a workplace or in a production area with better conditions. Although this improvement may be useful to achieve a better performance of individual workers, it cannot provide an answer of human performance that may impact the overall system performance of such as a human-centred assembly line. Thus, a consideration of human performance often becomes a situation of uncertainty in designing a manufacturing system when human workers or operators are involved in production. In practice, this issue is often neglected by manufacturing system designers, and an adjustment of it in the actual system has to be made based on personal experiences and judgement from production managers. In other aspect, most modelling simulation practices in the production research literature focused on conventional systems in which operators are tied to specific tasks or stations. Moreover, current modelling simulation tools in the market for manufacturing systems evaluation do not provide facilities that allow system designers to combine human attributes



(or human performance) into an investigation of the overall system performance. This is because, for example, in a discrete event simulation (DES) model, workers are defined and treated as one of resources the same as parts, machines, conveyors and so on. The application of DES models is therefore restricted to predicting only such variables as the required number of workers, their shift patterns and routes. As a result of this, the accuracy of established DES models can be adversely affected without considering the effect of human performance [1, 2]. This paper presents a research work by investigating human factors and their mutual interactions relating to human performance using findings of a literature review-based study. The study was aimed at identifying and selecting the possible and most influential human factors against a number of key performance measures of human-centred manufacturing systems. The result shows that this approach may provide a useful basis for exploring the existing DES tools by incorporating considerations of human factors that may affect a human-centred manufacturing system into the DES models.

2. Human factors and effects of human performance

Human factors may be referred to such human attributes as their physical and knowledgeable abilities, physiological states and psychological traits. Giniger et al examined the effects of age and experience in the relevance to worker performance, absenteeism, safety and turnover, and suggested that it is the job experience rather than the age which determines the work performance [3]. Avolio et al confirmed this outcome using a polynomial regression analysis to predict the work performance in connection with age and experience [4]. By contrast, McEvoy et al presented a study auguring that there is no clear relationship between age and job performance [5]. Zwick et al observed that the average muscle strength (aerobic capacity) of a worker decreases by roughly 10% per decade over ages from 20 to 60, 15% from 60 to 80 and 30% after 80, i.e., around 1% per year [6]. Adam et al investigated the relationship between general cognitive ability and reaction time [7]. Berg et al stated that the reaction time can be affected by distraction and mental fatigue [8]. Ilmarinen observed that age negatively affects general cognitive abilities and positively affects experience; however, experience positively affects cognitive skills and directly affects job performance [9]. Kenny et al found a decrease in the aerobic and musculoskeletal capacity that leads to an average drop of 20% in the physical work capacity of workers aged from 40 to 60 [10]. Figure 1 shows the effects of human factors (age, experience and cognitive ability) on human performance against a number of performance measures (throughput, cycle time, in process inventory and cost) on a human-centered manufacturing system.

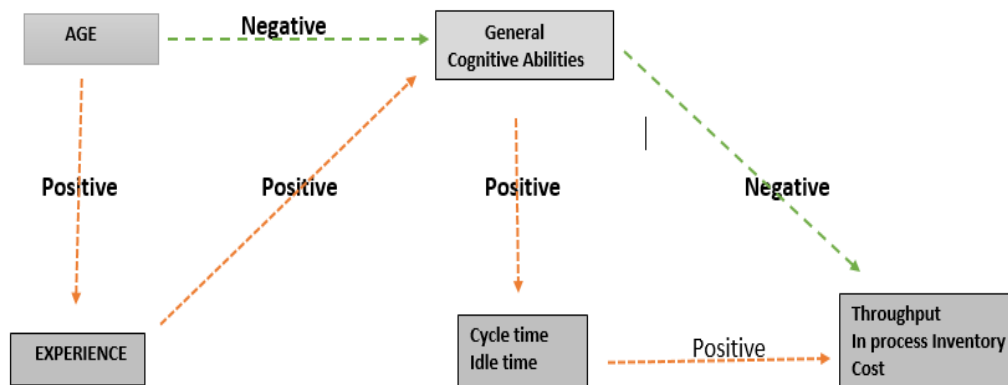


Figure 1. Effects of human factors on human performance against performance measures.

Learning and forgetting are both natural phenomena that directly affect the performance of individual workers. Two major factors of assembly processes, which mostly affect worker performances, are product variety and task complexity. As the product variety increases, it becomes more difficult to learn and easier to forget; higher complexity of selected manufacturing tasks may degrade worker proficiency for product assembly. The learning curve, also known as experience curve, describes the improved efficiency or performance obtained from repeating an operation of a specific task by a

worker; i.e. the time required to perform a task declines at a decreasing rate as experience with the task increases. Figure 2 illustrates a typical behaviour of a learning curve in an assembly process that is carried out by a fitter [1]. Performance improvement is often measured in terms of cycle time reduction, which is the result of the learning process. The learning process can be modelled using a DES tool to describe the physical elements and their logical interrelationship with specific rules, which interacts with external MS Excel worksheets to capture individual human workers' behaviours or human factor variables (such as worker experience, age and dexterity) in order to generate the variation of human performance by individual workers. This can be done by setting a value of each human variable to weight such as a worker's performance, which reflects to their working speed as an example. For instance, assuming that a walking-worker has an initial processing time of 150 s per unit (shown in Figure 2) at the beginning of a learning process, we name this amount of time as assembly learning limit (ALL). This value of processing time then declines during a learning process for this selected walking-worker until it reaches a steady state after producing a certain number of units of this product by repetitively performing the same amount of assembly tasks for making a unit of this product. This method enables system designers to evaluate a walking-worker's varying capability in terms of working speed per unit through a learning curve to meet a minimum proficient level of skills acquired from trainings.

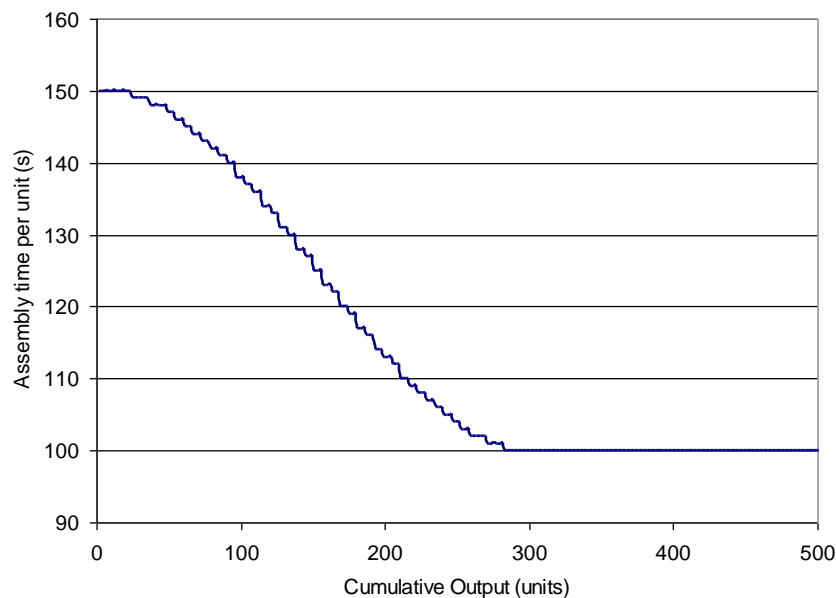


Figure 2. The behaviour of the learning curve during a learning process in assembly.

Table 1 shows a summary of related human factors that may affect human performance against a number of performance measures on human-centred manufacturing systems through a literature study.

Table 1. Human factors vs human performance measures on a human-centred manufacturing systems.

Human factors	Human performance measures	Literatures
Physical work capacity	Cycle time	Galen et al [11]; Govindaraju et al [12]; Boenzi et al [13]
	Job satisfaction	Govindaraju et al [12]; Narahari et al [14]
Age	Physical workload	Shepherd et al [15]; Schibye et al [16]; Bridger et al [17]; Stead et al [18]; Zwick et al [6]; Kenny et al [10]
	Reaction time	Woodson et al [19]; Der et al [20]; Salvia et

		al [21]; Svetina et al [22]; Doroudgar et al [23]
	Learning and forgetting	Zwick et al [6]; Stanley et al [24]; Boenzi et al [13]
	General cognitive abilities	Warr et al [25]; Boenzi et al [13]; Stanley et al [24]; Lmarinen et al [9]
	Job satisfaction	Rhodes et al [26]; Drabe et al [27]; Clark et al [28]; Kumar et al [29]
Gender	Physical workload	Bridger et al [17]
	Reaction time	Der et al [20]; Adam et al [7]
Experience	Cycle time	Reagans et al [30]
	Throughput	Reagans et al [30]; Hunter et al [31]
	Learning and forgetting	Shafer et al [32]; Hunter et al [31]; Reagans et al [30]
	Physical capacity	Giniger et al [3]
	Reaction time	Ando et al [33]; Visser et al [34]
	General cognitive abilities	Giniger et al [3]; Lmarinen et al [9]; Boenzi et al [13]
Learning and forgetting	Cycle time	Falck et al [35]
	Throughput	Shafer et al [32]; Hunter et al [31]
Job satisfaction	Throughput	Rodriguez et al [36]
Circadian rhythms	Reaction time	Berg et al [8]

3. Analysis of the impact of human factors on human performance

Figure 3 shows a study based on findings of the literature review by ranking and selecting the most influential human factor against one of performance measures of a human-centred manufacturing system using the Gephi network analysis method.

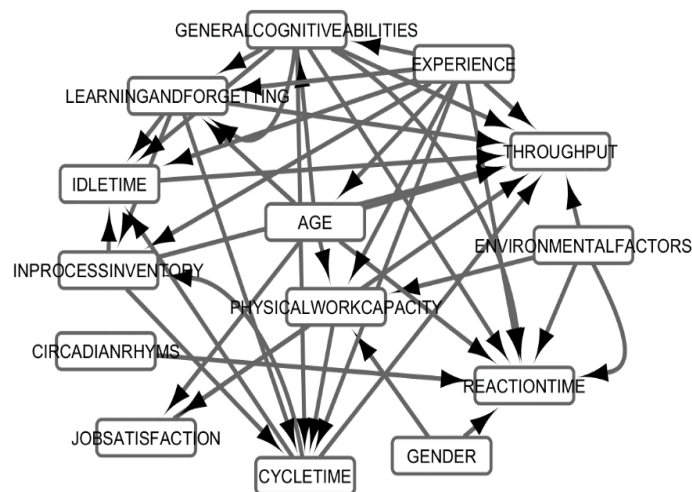


Figure 3. Importance of a human factor against one of performance measures using the Gephi method.

Figure 4 illustrates the result of impact rates of human factors in the form of eigencentality on cycle time as one of performance measures using the Gephi network analysis method. It shows that experience is the most influential human factor that significantly affects cycle time of completing a task or product, compared to other human factors, although age and general cognitive ability also play a significant role on human performance. The result also indicates that circadian rhythm has the least impact on human performance. Interestingly, gender is the second least human factor that affects the human performance.

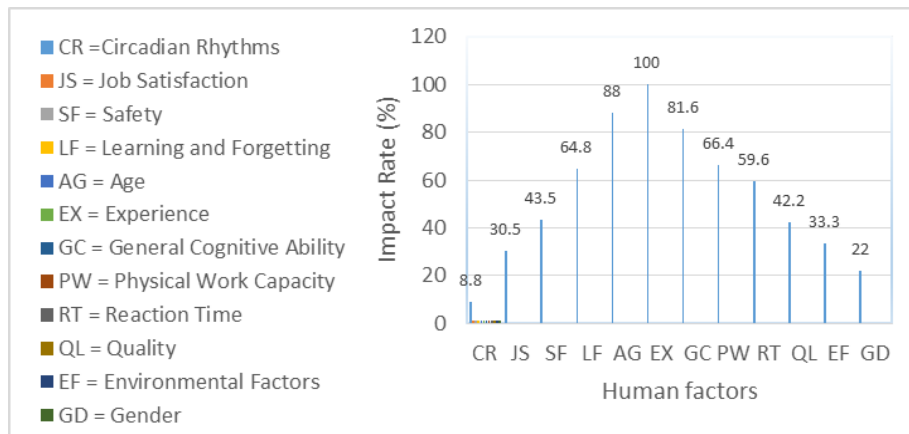


Figure 4. Impact rates of human factors on cycle time.

Figure 5 shows that age is the most influential human factor that affects throughput followed by experience and general cognitive ability. By comparison, circadian rhythm has the least impact on human performance and gender is the second least human factor that affects the human performance.

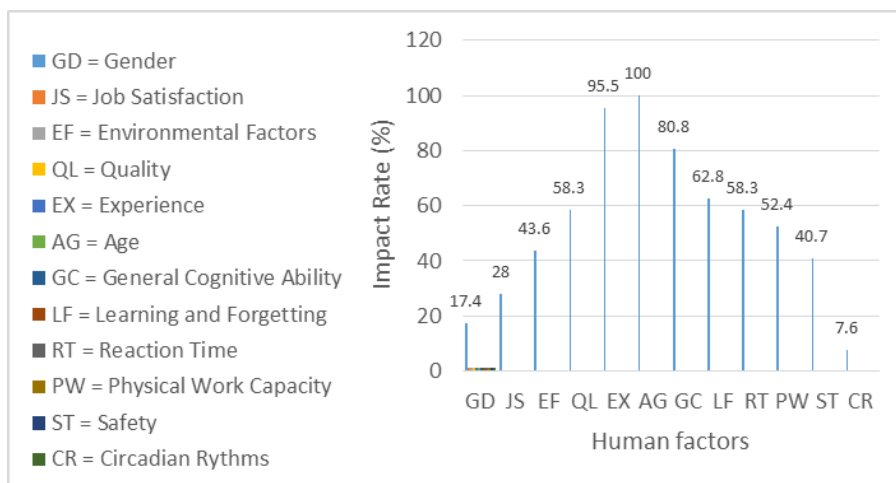


Figure 5. Impact rates of human factors on throughput.

Figure 6 shows that both experience and age are the most influential human factors on in-process inventory that also reflects the accumulation of idle times of human workers during production, while circadian rhythm is the least influential human factor that affects human performance.

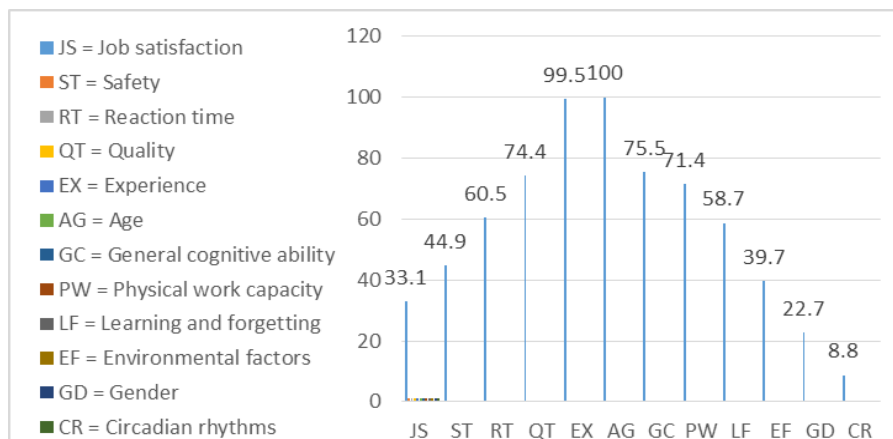


Figure 6. Impact rates of human factors on in-process inventory.

4. Conclusions and future work

The aim of this study was to identify human factors that affect human performance in human-centred manufacturing systems based on findings of a literature review. Much evidence from the literatures suggests that human performance is largely determined by experience rather than age in a view of socio-technical or psychological sciences. This study reports the initial research outcomes in terms of the interrelationship and the effects of human factors on human performance in manufacturing. The study also shows that both experience and age are the most significant human factors on human-centred manufacturing systems. In the latest developments of DES tools, although developers have been slowly introducing cloud-based technologies to facilitate the mobility of applications and the interoperability between different users or partners, none of these DES tools incorporate human factors as parameters used for manufacturing systems evaluation, which are still under developments. Research is required in order to develop more intelligent tools, autonomous and self-adapting systems for automated optimisation of system parameters.

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