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# Key human factors and their effects on human centered assembly performance

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A R T I C L E  I N F O

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A B S T R A C T

Today in the increasingly competitive market, consumers prefer to have a great variety of products to choose from; this preference is often coupled with demands for a relatively smaller lot size, shorter lead time, higher quality and lower cost. Consequently, manufacturing companies are being forced to consistently increase flexibility and responsiveness of their production systems in order to accommodate changes of the fluctuating market. Among various forms of production systems, human-centred manufacturing systems can offer such a capability in dealing with product variations and production volumes as human workers can always adapt themselves to perform multiple tasks after a learning process. However, human performance can also be unpredictable and it may alter due to varying psychological and physiological states, which are often overlooked by researchers when designing, implementing or evaluating a manufacturing system. This paper presents a study aiming to address these issues by exploring human factors and their interactions that may affect human performance on human-centred assembly systems. The study was carried out based on a literature review and an industrial survey. Critical system performance indicators, which are affected by human factors, were evaluated and the most significant human factors were identified using the fuzzy extent analysis method. The research findings show that experience is the most significant human factor that affects individual human performance, compared to age and general cognitive abilities in human-centred assembly. By contrast, both human reaction time and job satisfaction have the least effect on human performance. The significance of ageing on human performance was also studied and it was concluded that average assembly time of human workers rises by average 1% per year after the age of 38 years old.

## 1. Introduction

In the past decade, most industrial companies have been shifting their manufacturing activities from mass production to mass customization aiming to increase product varieties and production volumes with small lot sizes, short lead times, high quality and low cost. One form of production systems is human-centred assembly systems, which can deal with variations in term of product mix and production volume as human workers can always adapt to production changes with varying demands from the competitive market. However, human capacity or performance in production is often affected by a variety of human factors interacting in a complex way (Schmid, 2005). Nevertheless, such a phenomenon is often under or overestimated or simply neglected in manufacturing systems design, evaluation and implementation (Boenzi et al., 2015; Digiesi et al., 2006; Baines et al., 2004).

Most studies have focused on the impact of human factors on human performance in general terms, which are not specifically related to manufacturing activities or production systems. Govindaraju et al. (2001) investigated the relations among ergonomic work conditions, human performance and quality based on a number of case studies. Boenzi et al. (2015) examined the variation of human performance between older workers and younger workers and concluded that this was insignificant. Giniger et al. (1983) observed that the effects of age and physiological fuctions were not significant, and both cognitive and physiological decline can be compensated by experience. By contrast, Hunter (1986) argued that some cognitive abilities may decline with age, while others may stabilise over the life cycle, although fluid abilities (such as reasoning and working memory) can decline over age. However, crystallised abilities, which depend on accumulated knowledge, tend to remain stable (Zwick and Gobel, 2009; Deary et al., 2001; Warr, 1994). Hunter and Schmidt (1996) observed that a higher human performance can be attained by people who learn and transfer their skills to new tasks, although varying levels of individual performance

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may depend on their individual learning rates. Hunter (1986) concluded that it is the general cognitive ability that may determine human performance as it controls human capability with how much and how quick a person can learn.

A study by Belbase and Sanzenbacher (2016) indicated that even workers with less ability to process information may also maintain productivity with the advancing age. Zwick and Gobel (2009) observed that the average muscle strength of a human decreases by roughly 10% per decade from 20 to 60 years old, 15% from 60 to 80 years old and 30% after 80 years old. This may be due to aerobic capacity that reaches its peak at ages of 20s and after these ages it declines by around 1% per year. Shephard (2000) reported that age affects the occupational performance of older individuals due to their decline in aerobic power. Moreover, Wang et al. (2012) stated that some costs in production may incure due to learning and forgetting of human operators who offer flexibility and responsiveness of a manufacturing system. Reagans et al. (2005) examined the relationship between worker experience and human learning and forgetting; it was observed that effect of forgetting was not significant when dealing with relatively less complex tasks.

A study shows that human reaction time tends to be fastest at the age of 20 years old; after this age it declines slowly until the age of 60 years old. It declines much faster after age of 70 years old and onwards. The study also shows that the reaction times of females are more volatile, compared to males (Deary et al., 2001). Doroudgar et al. (2017) used a simple visual reaction test to measure reaction times between a group of younger adult drivers (age from 18 to 40 years old) and a group of older adult drivers (60 years old and above), the experiemental result shows that the group of older drivers had the significantly poorer performance in reaction time leading to slower driving speed and more accidents. Adam et al. (1999) investigated the relationship between general cognitive ability and reaction time and concluded that there is a correlation between intelligence and reaction time, which, for males, is faster than females in almost all aging groups. However, Berg and Neely (2006) stated that human reaction time can be affected by other issues of such as distraction and mental fatigue.

This paper reports an investigation of human factors and their interactions that may affect human performance on human-centred assembly systems; the work was carried out based on a literature study and an industrial survey. Critical system performance indicators, which are affected by human factors, were also evaluated, and the most significant human factors were identified using the fuzzy extent analysis approach.

## 2. Review of previous studies

A study by Broadbent (1971) indicated that human activity, which requires visual alertness, may be affected by sound, which distracts information intake and analysis. Avolio and Waldman (1990) used the polynomial regression analysis to predict work performance in connection with age and experience; the research outcome indicates that experience rather than age determines human performance. Schmidt et al. (1986) developed a model using a path analysis approach to examine the underlying influence of worker experience and job knowledge. The research result suggested that worker experience is the most influencial factor affecting human performance. The study by McDaniel et al. (1988) indicated that there is a direct relationship between job experience and job performance regardless of job complexity. llmarinen (2001) observed that age may negatively affect general cognitive abilities but positively affect experience of a human worker, although experience may positively affect cognitive skills, which directly affect job peformance. llmarinen (2001) also stated that physiological ability may decline due to aging; but it can also be compensated by experience gained as the age increases. Despite the decline of both cognitive and physical functions of a human worker due to aging, Giniger et al. (1983) and Stead & page (1983) argued that the influence is not significant for older workers who may attain satisfactory job performance by applying cautions and restraints. Zwick and Gobel (2009) stated that human performance may be affected more by experience than aging. Kenny et al. (2015) investigated the physiological effect on decline of aerobic and musculoskeletal capacity due to aging; the study shows an average drop of 20% of physical work capacity at ages from 40 to 60 years old. A study by Avolio and Waldman (1990) shows experience rather than age of older workers is the key factor that is used for determining human performance as experience may offer an equal or even higher performance in comparison with their younger counterparts. In particlar the effect of experience appears to be more significant when performing a complex task. Rhodes (1983) suggested that human performance is more affected by age and Waldman and Avolio (1986) challenged some of Rhodes's conclusions arguing that the method used for the study may lead to unclear or even wrong interpretations. Furthermore, a study by McEvoy and Cascio (1989) showed that there is no clear relationship between age and job performance. Waldman and Avolio (1986) suggested that the effects of age and experience on performance may be subject to the cognitive demand of a task. Stanley (1985) investigated the influence of age on productivity of individuals and concluded that the effect of age on job performance may depend on the complexity of a task as complexity requires a strong mental capability that may deteriorate with ageing. A study by Skirbekk (2008) showed that the performance of individuals may differ for many reasons; this includes length of work experience, cognitive abilities, physical abilities and other relevant factors (such as environmental factors). Table 1 provides a summary of the effects of human factors on human performance for production, the results were obtained based on a literature review.

In this work, an industrial survey was also conducted to compare the findings with the corresponding outcomes obtained based on the literature study. This process was involved in testing and selecting 33 effective respondents, of whom, 60% were researchers in the field of engineering, 30% were industrialists and 10% were from other sectors. The relationship between identified human factors on human-centred performance were rated using the Likert scale (Allen and Seaman, 2007). Respondents were asked to rate the influence of one human factor over another using a five-point scale; it gave a mean of 3.0 based on scales rated by respondents to all the questions. Table 2 shows the calculated mean value of the cumulative responses for each question using a statistical package for social science (SPSS). In this study, any value obtained below 3.0 was considered as a weak relationship and these values were filtered out. The mean values, as shown in Table 2, were assigned to the linguistic terms depicting the amplitude of effects between human factors. As an example, a mean value of 3.54 indicates a relatively weaker impact of ageing on learning and forgetting. Further, these mean values are categorised into four classes as shown in Table 3.

## 3. Analytical hierarchy process and fuzzy set theory

Human behaviours can be difficult to measure; their interdependence or relationships are often ambiguous and still not well understood. Descriptions of human behaviour or performance are generally linguistic (Karwowski and Mital, 1986). Therefore, a multi-criteria decision making tool, namely the analytical hierarchy process (AHP), was used for selecting the solution based on the subjective judgements. AHP, however, is criticised for disregarding the vagueness and prejudice of human judgements, i.e., it does not account for human thinking, especially as it relates to human attributes or human traits, which may not be easily evaluated using conventional numbers, apart from the language expression (Tzeng and Huang, 2011; Saaty, 2008; Aggarwal and Singh, 2013). Zadeh (1965) developed a methodology using fuzzy sets as a way in which sharp numerical values can be represented using overlapping boundaries of fuzzy numbers taking into account inherent human imprecision in a decision making process