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HUMAN-AUTOMATION COLLABORATION IN MANUFACTURING: IDENTIFYING KEY IMPLEMENTATION FACTORS

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ABSTRACT

Human-automation collaboration refers to the concept of human operators and intelligent automation working together interactively within the same workspace without conventional physical separation. This concept has commanded significant attention in manufacturing because of the potential applications, such as the installation of large sub-assemblies. However, the key human factors relevant to human-automation collaboration have not yet been fully investigated. To maximise effective implementation and reduce development costs for future projects these factors need to be examined. In this paper, a collection of human factors likely to influence human-automation collaboration are identified from current literature. To test the validity of these and explore further factors associated with implementation success, different types of production processes in terms of stage of maturity are being explored via industrial case studies from the project's stakeholders. Data was collected through a series of semi-structured interviews with shop floor operators, engineers, system designers and management personnel.

Keywords: human-automation collaboration, human-robot interaction, industrial ergonomics, human factors.

1 INTRODUCTION

In a traditional manufacturing environment, industrial robots work in isolation from human operators (Wilcox, Nikolaidis and Shah 2012). However, this segregation does not assist the need to increase production and reduce costs while maintaining a high quality product output in manufacturing (Buckingham *et al.* 2007). As considerable benefits can be gained when shop floor operators collaborate in real time with intelligent automation this has led to significant attention to the potential for human-automation collaboration (HAC) in certain manufacturing applications, such as the installation of large sub-assemblies (Walton, Webb and Poad 2011). In light of recent advances in technology which will enable HAC potential, health and safety regulations are also being advanced and updated to reflect that in some circumstances it is safe and viable for humans to work more closely to industrial robots (International Standards Organisation 10218:2-2011).

Despite recent developments, we do not yet fully understand how human operators will behave in these collaborative environments because it has still not yet possible to implement industrial HAC under current health and safety legislation. It has long been realised that neglecting human factors issues can be detrimental to the successful introduction of advanced automated systems (Friscia 1990). Parasuraman and Wickens (2008) claim that despite advances in automation, the vital link for successful operation of intelligent automation is still human presence. However, as the development of HAC systems in manufacturing is still at an emergent stage there remains a paucity of literature identifying the key human factors that are likely to influence successful adoption. There has simply not yet been real examples of industrial HAC implementation in which to research antecedent factors and impacts.

The aim of the investigation described in this paper is to address the current gap in knowledge by identifying and evaluating the human factors of most influence in relation to the introduction of HAC in manufacturing. The following sections describe how a theoretical framework of factors was derived from literature that might be comparable to the HAC context and this was examined for validation purposes in the collection of data from a case study of real operational automation implementation.

2 HUMAN FACTORS INFLUENCING HAC: THEORETICAL FRAMEWORK

This section describes the process employed to identify the human factors likely to influence the adoption of HAC and the set of key factors or themes that emerged in this process.

2.1 Classification of Selected Human Factors

As this study is aiming to capture human factors at different levels across the organisation, the factors identified were classified into two sub-categories based on their relevance to the human operator or the wider organisation:

(i) Factors at the individual level: influencing the human operator
(ii) Factors at the organisational level: influencing the organisation

2.2 Human Factors at the Individual Level

Trust in robots/automation: Trust in human-automation collaboration has been cited as an important factor because it can influence the success of the interaction (Billings *et al*. 2012). Hancock *et al.* (2011) suggest that robot-related factors such, performance can have the highest impact on trust.

Mental Workload: For HAC collaboration to succeed, both agents need to interact in an effective manner. According to authors, automated systems have reduced physical demand on humans but have introduce additional cognitive demands which increase workload, hence hindering the effectiveness of the collaboration (Megaw 2005).

Loss of Situation Awareness (SA): Automating a manual process can potentially leave human operator out-of-the-loop, passively monitoring the system and intervening only during a system failure. This condition can lead to loss of SA resulting costs to human performance (Parasuraman, Sheridan and Wickens 2000).

Introduction of Varying Levels of Automation: Introduction of automation is based on the notion that it will assist human operators and facilitate optimal operation (Balfe *et al*. 2012). However, full automation can change the role of human operators to passive monitoring. This has been found to cause skill degradation, loss of SA and complacency (Parasuraman, Sheridan and Wickens 2000).

Stress, Anxiety and Safety due to HAC: Collaboration in real time between humans and robots is bound to have the two agents in close proximity with evident the possibility of collision. However, it is not yet understood how the interaction will influence acceptance by human users (Zecca *et al*. 2007). More recently, Aria *et al.* (2010), in a novel cell production assembly experiment, found that robot size and robot speed had increased mental strain.

Effects Automation Reliability: Automation reliability can influence successful co-operation between humans and automation. Parasuraman *et al.* (1993) in their study found automation reliability can potentially introduce automation-induced complacency effects. Similarly, Rovira, McGarry and Parasuraman (2007) found that higher automation reliability increased complacency which can have a significant cost during automation failure.

Perceived Attentional Control (PAC): Automating a process will require the operator to monitor the supervise the state of the system. In such applications, operators will be required to divide attention across a number of processes in order to gain information about the system while looking for critical events (Talluer and Wickens 2003). Previous research has found that poorer allocation of attention, can significantly detriment human performance particularly during a system failure (Chen 2011). This can pose an obstacle towards the success of a HAC system.

Attitudes towards Robots/Automation: Recent evidence suggests that people tend to perceive assistive robots more as companions and social actors rather than tools and this can potential enhance acceptance positively (Torta *et al.* 2012). Furthermore, Nomura *et al.* (2006a) found that negative attitude towards robots can barrier interaction with robots in daily life. Although these occasions mostly relate on social robots, it would be important to investigate whether negative attitudes can barrier interaction in a manufacturing environment

2.3 Human Factors at the Organisational Level

Communication to the Workforce: Communication of quality information during an organisational change can alleviate the associated uncertainty which has been linked with negative effect on psychological well-being (Allen, *et al*. 2007). Hence, lack of communication can induce a psychological state of doubt and endanger acceptance of the system.

Training and Development of the Workforce: A key theme appearing on the literature is the training and development of the workforce (Waldeck 2007). It has been declared that, workforce development is an important feature during AMT implementation that can promote organisational performance.
Formation of a Multidisciplinary Team: Investigation of the factors that enabled the successful implementation of AMT on the shopfloor indicated that the establishment of multidisciplinary teams from various departments can have a major positive impact (Bidanda, *et al*. 2005).
Worker Involvement in the Implementation: Worker involvement has been linked with successful implementation of a technological system (Sohal 1999). Therefore, the degree of employee participation can be a potential enabler for successful adoption of HAC.
Identification of a Process Champion: The presence of a technology champion during the implementation phase can be a significant factor. This can be a knowledgeable person, who understands the technology and its benefits so that it can motivate people around them. Also, it has to appear credible to the workers in order to reduce resistance (Chung 1996).
Organisational Flexibility and Top Management Commitment: According to a number of studies, top management commitment can be a key factor. The management team needs to be involved throughout the process and not simply with technical aspects of the project. Also, Zammuto and O'Connor (1992) support that an organic culture is the key to exploiting the benefits of advanced automated technologies.
Trade Unions: The degree of a firm's unionisation level has been reported to influence the introduction of automated systems. Certain studies have indicated that unions do not always resist the introduction of technology (Small and Yasin 2000). Some others have found that union involvement from the beginning can be a way to handle such a sensitive issue.

3 DEVELOPMENT OF METHODOLOGY

This section describes the methodology used to (i) investigate the validity of the set of human factors identified in the theoretical framework and (ii) capture additional human factors as they appear from the collected data.

3.1 Case Study Selection

To identify and evaluate the key factors that are either enablers or barriers in relation to HAC in manufacturing, a range of appropriate production processes in various manufacturing settings were considered as case studies. Two types of processes in terms of stage of maturity will be explored: (i) a relatively mature, post-automation process and (ii) an example of in-progress automation implementation. To date, the second example of in-progress automation has been investigated to explore the factors that are affecting the process change and its adoption.

3.2 Data Collection and Analysis

The lack of previous industrial HAC research or existing guiding framework meant that for this study an exploratory approach was appropriate. Instead, the list of human factors themes that had been identified in the literature was used as an *a priori* guiding framework within a semi-structured interview approach to gather individual experiences and accounts of the transition from a manual to an automated process. Interview participants were personnel who were involved in the implementation such as: shopfloor operators, engineers, system designers, and management personnel. Interviews were fully transcribed and analysed using the Template Analysis' in accordance with guidelines provided by Crabtree and Miller (1999), and King *et al.* (2002). The process involves the development of a coding template representing the major themes identified in a hierarchical form so that top level codes represent broad themes while lower level codes represent composite sub-themes. The template structure was revised iteratively to ensure it reflected the data in the most suitable manner.

3.3 RESULTS AND DISCUSSION

Through the data analysis, several enablers and barriers have emerged. Due to space limitations the most important are outlined below:

Enablers

<u>Worker involvement in implementation</u>: Shop floor employees can input their knowledge and experience to successfully implement the new automation. At the same time, through their involvement shop floor employees gained ownership of the new system which enhanced acceptance.

Communication to the workforce: Results indicated that early communication regarding the benefits of the new automated process to the workforce is an important enabler. Through communication employees were kept informed and reduced resistance when the automation arrived on-site.
Top management commitment and support: Commitment of senior management was found important to ensure the project can progress and be implemented. At the same time, it was pointed to be vital for keeping personnel at all levels focussed on the aims of the project and to raise morale.
Training of the workforce: During the early implementation stages, provision of offsite training to a number of end-users was found to be an important enabler. It allowed end-users to gain confidence and ownership of the new system. Also, the end-users trained initially were able to translate their knowledge and experience to the rest of their colleagues on the manual cell. This reduced negativity regarding the system, prepared the rest of the employees and enhanced acceptance.
Organisational flexibility through worker empowerment: Empowering operators with additional control over the new system was found to be an enabler. Results pointed that this gave operators a more active role rather than passively monitoring the automation.

Barriers

Communication interface between union-local management: Results suggested that effective communication with local union leaders regarding the rationale of introducing the automation and the impact on employees is important.
Awareness of manual process complexity by system integrator: It was pointed that system integrator needs to have a comprehensive understanding of the variability of the manual process to be automated. Insufficient understanding can cause delays to the development of a robust and process capable system.
Capturing manual process variability: Lack of capturing the source of variation of complex manual processes can pose significant challenges. As highlighted above, capturing the manual process variability can be fed to the system integrator to support the provision of a process capable system.
Resources required for the development of the automation: Resource allocation to the development of the automation is likely to have a negative impact on the production rates. This was found to create confusion between the production and the development teams. Moreover, it was identified that the confusion can have a negative effect on shop floor employees assigned to support the automation.

4 CONCLUSION AND FUTURE WORK

This paper has presented research work in progress that is being conducted to advance the potential for HAC to be developed and implemented. It has presented the key human factors that were identified through a literature review as most relevant to successful implementation of industrial automation as well as the methodology developed to collect and analyse data to test the relevance and validity of these factors for industrial HAC contexts. It is evident that a single case study will not provide robust and generalisable findings. Hence, to identify factors that are barriers or enablers to the implementation of HAC, a survey has been constructed based on the findings of the case study. The survey has been administered to appropriate subject matter experts (SME) who were involved in the automation of manual processes. Ten SMEs have been approached and data is currently being collected. Future work involves the administration of surveys to different sized and structured organisations to observe any variability of the factors and identify where any antecedents or impacts are specific. Also, Different manufacturing sectors will also be covered in order to identify context-specific factors.

By capturing further data this research will be able to produce a valid framework of general organisational level factors that need to be considered for the implementation of HAC systems into manufacturing processes. At the same time this cross-organisational, multi-sector approach will be able identify more context-specific antecedents and likely outcomes.

Apart from investigating how organisations implement intelligent automated systems, it is equally important to investigate the key factors that will enable effective interaction between operators and robotic assistants. One of the most important aspects for successful interaction identified in the literature is the level of trust of the human operator to the robotic teammate (Yagoda and Gillan, 2012). Facilitating appropriate levels of trust can determine acceptance of a system and reduce negative performance outcomes (Yagoda 2013). However, very little research has focused on the development of a trust measurement inventory for industrial human-robot interaction (HRI). For this purpose an exploratory experimental study is in progress to develop a psychometric scale to measure trust in industrial HRI.

By collating the organisational level and individual level factors, will provide a highly useful design aid for implementing industrial human-robot collaboration.

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