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How and why we need to capture tacit knowledge in manufacturing: Case studies of visual inspection

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ABSTRACT

Human visual inspection skills remain superior for ensuring product quality and conformance to standards in the manufacturing industry. However, at present these skills cannot be formally shared with other workers or used to develop and implement new solutions or assistive technologies because they involve a high level of tacit knowledge which only exists in skilled operators' internal cognitions. Industry needs reliable methods for the capture and analysis of this tacit knowledge so that it can be shared and not lost but also so that it can be best utilised in the transfer of manual work to automated systems and introduction of new technologies and processes. This paper describes two UK manufacturing case studies that applied systematic task analysis methods to capture and scrutinise the tacit knowledge and skills being applied in the visual inspection of aerospace components. Results reveal that the method was effective in eliciting tacit knowledge, and showed that tacit skills are particularly needed when visual inspection standards lack specification or the task requires greater subjective interpretation. The implications of these findings for future research and for developments in the manufacturing industry are discussed.

1. Introduction

Visual inspection (VI) is a traditional manual activity that involves careful and critical assessment of an object with reference to a predefined standard (Drury and Watson, 2002; Drury and Dempsey, 2012; See, 2012). In manufacturing, VI is used to identify and diagnose defects, which is essential for ensuring products meet satisfactory quality standards (Garrett et al., 2001). Despite typical error rates of between 20% and 30% (Drury and Fox, 1975), human VI has remained essential in manufacturing because the accuracy and efficiency of human visual acuity has remained superior to the visual inspection capabilities offered by available automated alternatives. Thus, although highly labour-intensive, VI continues to be particularly important in safety critical and high value manufacturing (HVM) processes where the consequences of missed defects are of a higher cost for both human and commercial reasons, e.g. "*injury, fatality, loss of expensive equipment, scrapped items, rework, or failure to procure repeat business*" (See et al., 2017, p. 262). As visual inspection is highly skilled, best practice knowledge and techniques are valuable, and as it is labour-intensive it is a prime candidate for process improvement/automation to enhance process efficiency in the future.

Visual inspection relies on 'tacit knowledge': an intrinsic understanding of how things work and are organised which enables humans to intuitively produce strategies and solutions in new circumstances (Reber, 1989). Whereas 'explicit knowledge' can easily be described, aggregated, codified and catalogued in written instructions for formal learning, tacit knowledge is less tangible. It is the personal and contextual awareness that we typically keep in our mind and its cognitive processes that is difficult to capture, classify or communicate, and typically "*can only be acquired through practical experience*" (Lam, 2000). Unlike explicit knowledge in training manuals and programmes, tacit knowledge is typically learned by observation, imitation and practice which is difficult to communicate (Smith, 2001). Therefore, tacit knowledge refers to the informal 'know-how' about how to do things that we all develop over time and experience, often unconsciously, which is typically retained in our individual memories but not formally recorded or shared.

In the context of manufacturing VI operations, there has been little research to specifically explore the role of tacit knowledge. We know that operators are typically provided with reference manuals and standard operating instructions (SOIs) which set out explicit knowledge about the task. However, it must be that operators build up their tacit knowledge 'know-how' about how to accurately identify/classify product defects through experience and repeated performance of VI tasks. Consequently, a considerable degree of more detailed contextual information about how best to detect and diagnose product defects must

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exist in skilled operators' personal memory stores and cognitive processes. Although it has been practical for this personal 'know-how' to remain undocumented and simply be applied as needed by skilled operators, there is a growing need for a formal method to capture and understand tacit knowledge in manufacturing VI tasks in order to transfer it to other human or automated processes. The following sections provide more detail to explain the three main reasons why tacit knowledge should be captured within manufacturing.

Firstly, tacit knowledge capture is needed for *transfer to other operators*. As it involves a far more comprehensive understanding of a task's content and protocol than could be derived simply from observation or design methods, sharing tacit knowledge with new or transitory members of the workforce is valuable. Without such an in-depth understanding of the 'know-how' that experienced operators employ to identify and diagnose defects, the formal training given to new operators is obviously more limited. Capturing this knowledge is going to be increasingly important as workforce mobility continues to rise (Favell et al., 2007; Pitts and Recascino Wise, 2010). Organisations will need to rely less on the well-established experience and skills of long-term workforces and, instead, rely more on utilising the capabilities of available less-experienced personnel. Thus, to effectively transfer the task procedure in instruction and training programmes an in-depth understanding of how the task is performed, in detailed steps, is inevitably going to be of great benefit. Without in-depth tacit knowledge the nuances of experienced 'know-how' will not be transferrable to transient and evolving workforces which is highly likely to impact negatively on production performance and efficiency.

Secondly, the capture of tacit knowledge is also going to be important to *inform the design of new and emerging technologies*. Advances in vision and sensing technologies are going to offer new opportunities for the automation and digitisation of VI processes (Caggiano et al., 2015; Huang and Pan, 2015; Borrmann et al., 2016). However, in order to be effective these new systems will not be designed to merely replace original human activity because a) that would not utilise the new potential technological capabilities and b) it would not be possible to match human performance for many task steps, particularly those requiring flexibility and intelligence (Ding and Hon, 2013; de Winter and Dodou, 2014). Therefore, the design of these new systems will not be based on a simple transfer of the original human task protocol but on a detailed analysis of it in which unnecessary or human-specific functions can be identified and eliminated or redesigned. This will require an accurate and thorough breakdown of the original manual work content which, therefore, should include tacit knowledge. Whether entirely new systems are being designed to replace human VI, or whether systems are redesigned to augment/assist human operators in their manual VI activities, a thorough understanding of the original human performance and procedure will be needed to appropriately revise or reallocate functions.

Thirdly, tacit knowledge applied in VI manufacturing tasks needs to be captured to *optimise the introduction and implementation of new systems and processes*. It has long been recognised that the success of new industrial systems and technology can be highly dependent on how well their design and application has included consideration of human/social factors (Chung, 1996; Battini et al., 2011). Clearly then, a good understanding of key human/social requirements and work activities is needed at the design stage so that key factors which will enhance a new system's introduction and operational effectiveness can be considered and included (and so that factors which are likely to have negative impacts on its success can be avoided). This means it is not only important that the manual work content of new systems is derived but that the wider human/social impacts are accurately predicted. Thus, to improve the likelihood of successful implementation of new systems, particularly with greater levels of automation and workforce diversity, there is a need for a reliable method to capture and analyse the tacit knowledge underlying VI work so that key barriers and enabling factors can be considered.

As the above examples illustrate, there is a need to capture tacit knowledge to accommodate forthcoming industrial challenges such as the evolving requirements of mobile workforces, advancing technology design, and effective new system implementation. To meet these challenges a reliable method for capturing, understanding and sharing tacit knowledge in manufacturing VI work is needed. This paper describes two case studies that have been conducted to address this industrial problem. First we present a selection of relevant background literature on the topic of VI in manufacturing.

2. Background

2.1. The process of visual inspection

The manual process of VI involves five principal steps: *Set up, Present, Search, Decide* and *Respond* (Drury and Watson, 2002; Drury and Dempsey, 2012). Of these five steps, the 'search' and 'decide' activities appear to have received the most interest in previous investigations, probably because they are most cognitively complex and error-prone (Rao et al., 2006; Drury and Dempsey, 2012; See et al., 2017). The 'search' step of VI has been found particularly time-consuming and prone to error, particularly in relation to omissions where a defect is missed rather than 'commissive errors' or false alarms (See, 2012). VI searching tends to not only involve visual skills but also the scrutiny of other sensory cues, such as touch and sound for tactile and auditory feedback (Garrett et al., 2001). In manufacturing VI tasks, operators are often provided with additional equipment to assist their 'search' accuracy, such as additional lighting and magnifying devices (Charles et al., 2015).

Although 'search' and 'decide' activities are totally independent processes (Spitz and Drury, 1978), if a search has led to identification of an anomaly or imperfection the inspector will then proceed to the 'decide' step to determine its type/class and the subsequent action that needs to be taken. In manufacturing VI tasks, the 'decide' step will require examining the object with reference to pre-defined standard criteria which is typically provided in reference manuals in written and graphical form. In addition, measurement equipment may be provided for the operator to more accurately classify the defect and its severity, and determine the action that needs to be taken. However, despite human sensory capabilities skill and the provision of equipment aids, there are still a number of factors which may impair VI.

2.2. Factors that affect visual inspection

A great deal of literature from research studies has examined VI in manufacturing contexts, and more recently in relation to the development of new automated inspection systems (e.g. Golnabi and Asadpour, 2007; Lin, 2007; Lyu and Chen, 2009; Kumar and Kannan, 2010; Sun et al., 2010; Mar et al., 2011; Ravikumar et al., 2011; Sun et al., 2012; Huang and Pan, 2015; Mumtaz et al., 2012; Caggiano et al., 2015). There appears to have been little or no dedicated exploration of tacit knowledge in these various studies. However, in a wide review of the visual inspection research literature, See (2012) compiled a table listing the wide range of factors have been identified as influential to VI performance across different types of production (Table 1).

These task, individual, environmental, organisational, and social factors will undoubtedly be relevant in varying degrees across specific manufacturing environments and VI processes. The enormous number of potential features that these factors comprise is too large for review here, and many are not directly relevant to tacit knowledge. However, some factors are especially and directly relevant to the development and application of tacit knowledge in manufacturing VI tasks and these will be discussed: Task – *complexity*, *standards* and *pacing*; Individual – *scanning strategy*; Organisational – *training*.