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Using action research to develop human factors approaches to improve assembly quality during early design and ramp-up of an assembly line

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ABSTRACT

Engineers at a large electronics new product initiation site were interested in developing human factors (HF) approaches to help improve assembly quality during two stages of their production assembly design: early design of tasks, fixtures and tooling; and during early ramp-up of new assembly lines at outsourcing sites. Researchers worked in an action research approach with company engineers and ergonomists to integrate HF into both design stages. This paper presents the human factors approaches and discusses the challenges of using human factors to improve assembly quality. For the first stage of early design, a HF-design for assembly (HF-DFA) scorecard was developed with 22 items scored on a 0 (no risk or problem) to 2 (high risk or problems) scale. Items included physical risks, such as grip size and force, movement risks, such as re-grasping or re-orienting, visual risks, such as visual accuracy and inspection difficulty, and cognitive issues such as ability to detect a problem and risk of damage to part or component. High scores were associated with assembly tasks that were both reported as difficult by operators, and also had quality problems. The HF-DFA was adopted as a controlled engineering document and used to proactively score assembly tasks prior to final design of tasks, fixtures and tooling. In the second stage of early ramp, researchers combined the HF-DFA and other HF and performance-based metrics into a modified HF-house of quality (HF-HoQ) approach where the focus was on “worker” requirements rather than the traditional customer requirements. The HF-HoQ was evaluated using video of four identical tasks performed at different outsourcing locations that had a seven-fold difference in defect rates. The HF-HoQ successfully detected the site with the highest defect rate, but not the lowest. The authors recommend further testing and development of approaches that attempt to bring insight from HF to the issue of improving assembly quality.

Relevance to industry: Human factors is broader than injury prevention, and has been linked to assembly quality. Two HF approaches were developed to help improve quality in early design stages and during early ramp-up of assembly lines. Companies are encouraged to develop and evaluate HF approaches for improving assembly quality.

1. Introduction and background

Numerous studies have demonstrated an empirical link between human factors (HF, used here interchangeably with ergonomics) and production assembly quality and the issue has been discussed for many years (e.g. Zare et al., 2015; Drury, 1997; Eklund, 1997). In a recent scoping review (Kolus et al., 2014), 73 studies were identified showing human factors (such as process instructions and training, product complexity, difficulty and load, and workstation conditions) were related to quality outcomes (such as frequency of failures or reworked and spoiled parts). The relationship between poor human factors and quality deficits was strongly supported throughout the processes of product design, production process design, and workstation design. In all, over 200 different HF variables were identified. In studies manipulating these variables effect sizes of over 85% impact on quality performance has been observed (Kolus et al., submitted). Kulos et al.

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(submitted) also noted in their review that fatigue as an underlying conceptual issue was mentioned in about half of all of these studies. Dode et al. (2016) used biomechanically modelled workload patterns to calculate a cumulative muscular fatigue dose which, in turn, accounted for about one quarter of the variance in all quality deficits in an electronics assembly operation. While improving quality is itself a valid reason to pursue arguments, the relationship between the HF quality risk factors and injury risk factors suggests this might pose a strategic lever for gaining support for HF from design teams that are held primarily responsible for system performance rather than worker safety (Neumann and Village, 2012; Neumann and Dul, 2010).

Most studies that evaluate the impact of human factors on quality defects identify injury risk factors in the tasks, and either (a) compare the extent of injury risk with the extent of quality defects, or (b) seek to reduce the risk and measure the effect on quality. For example, Falck et al. (2010) rated physical risk in automotive assembly jobs as high risk, medium risk, or low risk. The authors' reported increased quality errors in the high and medium risk jobs, compared with low risk jobs. Using a different approach, Gonzales et al. (2003) chose a metal production task with known ergonomic risk factors where quality metrics could be measured. The authors quantified the risk (using Rapid Upper Limb Assessment or RULA, McAtamney and Corlett, 1993) then reduced the ergonomic problems, re-scored the risks with RULA, and reported a 45% reduction in loss of materials (a quality measure) as a result (Gonzales et al., 2003). A study by Eklund (1995) utilized worker perceptions of ergonomic risk factors based on interviews about tasks with the most physical demands, most difficult parts to assemble, and the most psychological demands and found five times more quality deficits in tasks with ergonomic problems. These studies show that assembly tasks that are well designed from a human factors perspective will result in fewer quality problems. However, we could not find human factors tools or approaches that would help engineers detect quality problems or improve assembly quality directly.

1.1. The need for human factors tools or metrics that can help improve quality during assembly design stages

While many studies have successfully established a relationship between poor human factors and quality problems, the human factors (HF) indicators in all literature reviewed by the authors were based on injury-risk models, rather than other human factors issues directly related to specific aspects of quality (such as worker detection of quality problems, feedback about assembly fit, etc.). Additionally, the studies reviewed were all performed with injury-based tools on jobs, such as automotive assembly, that have high physical demands and therefore high magnitude risk factors. Further, most studies have been conducted in stable manufacturing operational environments, as opposed to during early design stages or early ramp-up of assemblies in manufacturing. Tools based on injury or physical demands cannot be used proactively in design stages to indicate quality problems because workers are not yet performing the tasks. Therefore, a HF tool with leading indicators is needed.

Instead of further proving a link between HF and quality, we were interested to improve understanding of how HF knowledge and approaches can be used directly to help engineers design with improved quality. Unlike automotive assembly tasks, we were working in an electronic assembly and manufacturing environment, where the physical risk factors of awkward and forceful posture are minimal. We were interested therefore in other HF indicators and metrics that could lead to improved quality (such as those addressing visual or tactile issues).

We were working in a new product initiation facility where assembly tasks, tooling, and fixtures were in early design stages for hand-held communication devices. Engineers we worked with were interested in ways of using HF information to help improve quality during two particular design stages. The first stage is early design of assembly tasks, tooling and fixtures for the small parts. Quality metrics are monitored very closely during this stage. Once design of tasks, tooling and fixtures is stable, those tasks, toolings and fixtures are sent to various outsourcing sites to begin mass production. The second stage of interest was therefore in early ramp-up and refining of the new assembly lines at the various outsourcing sites, where quality metrics can vary greatly.

1.2. Case study collaboration, data collected, and objective of paper

This paper uses a subset of data pertaining to quality and HF from a three-year longitudinal industry-university case study collaboration. The new product initiation site was in a large electronics manufacturer in Southern Ontario. The goal of the collaboration between ergonomists and engineers at the company, and researchers at Ryerson University, was to find ways to integrate human factors into the design of the assembly production system for both improved worker health and system performance. A full description of the collaboration and action research approach and methods are found in Village et al. (2014a,b). The data in this study has not been reported in the previous studies.

During the three years of collaboration, researchers worked with company ergonomists and engineers to use HF principles to help improve quality metrics in several initiatives. Interviews were conducted with quality engineers ($n = 13$) and floor supervisors ($n = 2$) to understand the nature of the quality data collected in the organization, how it was used, and who monitored it. Researchers and ergonomists attended meetings with engineers through a full production assembly design cycle ($n = 22$). They also participated in shop floor quality meetings as workers provided input to early problems assembling parts and using jigs, tooling and fixtures. The goal was to find ways to use HF tools and approaches to help improve aspects of product assembly quality. Table 1 summarizes the activities and number of company personnel participating in each activity over the three year period of the collaboration. Each activity was digitally recorded. Data was transcribed into NVivo software and coded qualitatively for general inductive analysis.

This case study is an in vivo illustration of how practical HF development occurs in organizations, and provides indications of what is missing in the HF research to help support such development work. The specific objectives of this paper are to:

1. Identify the challenges of using HF information to help improve a company's assembly quality in early design stages, and show how a customized tool, called the human factors design-for-assembly (HF-DFA), might be created in vivo; and
2. Identify the challenges of using HF information to detect quality issues in early ramp-up of an assembly line, and report on a pragmatic approach called the HF house-of-quality (HF-HoQ) approach.

2. Developing HF approaches to improve quality in two stages of production assembly design

This section will present two in vivo attempts to develop HF approaches to improve assembly quality at two stages of the production assembly design. It will also present some of the limitations of using HF principles to improve quality of assembly in each stage. In the first stage - early design of the assembly tasks, tooling and fixtures - the goal was to help designers detect HF concerns related