Application of human errors analysis in manufacturing: a proposed intervention framework and techniques selection

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Abstract: In the manufacturing sector, human errors are somewhat prevalent although they do not necessarily lead to catastrophic outcomes. This paper proposes an intervention framework to conduct human error analysis in manufacturing. Available generic methodologies and techniques were explored. Techniques selection was based on such criterion as: simplicity, analyst oriented, high availability of resources, validity and skill/rule level of human performance. The final intervention framework comprises five steps: (1) statistical data analysis to select critical tasks, (2) HTA (Hierarchical Task Analysis) for task representation, (3) SHERPA (Systematic Human Error Reduction and Prediction Approach) for error identification, (4) HEART (Human Error Assessment and Reduction Technique) for error quantification and (5) error reduction.

Keywords: human error, manufacturing, quality, reliability analysis

1. Introduction

Several definitions of human error have been proposed in the literature. Most of these definitions agree on the fundamental aspects of error. The definition by Reason (2000) is in accordance with the principles of this paper: "a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency." Discussions have arisen as to the appropriateness of using the actual term human error (Hollnagel 1993; Dekker 2014) and while this is beyond the scope of this paper, it should be stated that throughout this paper the use of the classic term human error does not have any moral implications, as is congruent with Kirwan's view (1992).

Over the years, different techniques for the analysis of human error have been developed. The origin of these techniques stems from the need to quantify human error probability for reliability analysis in the nuclear sector (IAEA 1989) and other high risk environments. In the manufacturing sector, human errors are somewhat prevalent though they do not necessarily lead to catastrophic outcomes. However, product quality can be particularly affected by a high prevalence of human errors. Most methodologies and techniques for human error analysis have been developed for industries operating in high risk environments (Swain et al. 1963). Consequently, two questions arise when trying to conduct a human error analysis in a manufacturing context: What steps should be followed to properly conduct a human error analysis in manufacturing? Which of the available techniques are best suited for a quality-oriented human error analysis in manufacturing? This paper addresses these questions by proposing an intervention framework for conducting a human error analysis in a manufacturing context. Firstly, a short review of human error analysis in manufacturing is conducted along with a short discussion about human error identification (HEI) and the human reliability analysis (HRA) process. Then, a proposed intervention framework is described, which is intended to eventually guide a specialist during an actual human error analysis in a manual assembly line.

2. Human error in manufacturing

Quality problems, human errors and ergonomic problems often share a common cause, whether in the design of the work system or some elements of the work environment, for example: lighting or poor illumination, high physical loads, high work rate and complex work content (Eklund 1997). Since quality in production has become critical for the competitiveness of organizations, Bubb (2005) argues that human reliability is an important key to improving quality in the manufacturing sector. Human errors are therefore, in this context, associated with significant economic losses. It is argued that the identification and possible quantification of human error in manufacturing settings could lead to improved performance in terms of quality (Bubb 2005; Neumann et al. 2016).

Yang et al. (2012) proposed a method to analyse quality issues related to human errors in an engine assembly. A closer look at the method shows the use of techniques such as CREAM (Cognitive Reliability and Error Analysis Method) and FTA (Fault Tree Analysis) as part of the framework. Similarly, Paz-Barroso and Wilson (1999) propose a framework including a toolkit for the study of human reliability in the manufacturing sector, the authors associating human error with disturbances of the system instead of catastrophic events. Paz-Barroso and Wilson's (1999) main contribution is to be the first to attempt to specifically target manufacturing and as a result develop a guideline to support the HRA process in this sector. Similar contributions can be attributed to Yang et al. (2012) providing some guidance to evaluate and control the human errors directly related to quality issues. To the best of our knowledge, there does not seem to be an exclusive methodology framework or technique for the analysis of human error in manufacturing. It seems that the use of traditional methodology frameworks and techniques are still used in manufacturing with some modifications to match the intended use in this specific sector (Paz Barroso & Wilson 1999; Bubb 2005; Yang et al. 2012).

3. Process of human error analysis

The process of human error analysis requires several stages. According to Pan et al. (2016) these stages can be defined as: "(1) human error identification, (2) human error probability estimation, (3) human error consequence analysis and (4) consequence avoidance measure design". One well-established process of human errors analysis is a 10-step process proposed by Kirwan (1994). In general, the analysis process evolves from a qualitative-description type of analysis towards a more quantitative type of analysis involving the calculation of human error probabilities. We can argue that there are three core stages of analysis regardless of the number of steps involved in the process. The number of steps depends more on the level of detail that the author seeks to provide as a guideline to the potential practitioner. The three core stages of analysis are: detailed analysis of the task, analysis of the possibility of human error and analysis of the human error probabilities. However, the analysis of human error probabilities, is not always part of the process. Some techniques leave the quantification stage out of the analysis process and are more focused on a qualitative analysis. These are known as human error identification techniques (HEI) while other techniques focus on the quantification of human error in terms of probabilities and are known as human reliability analysis techniques (HRA). The choice of a technique to perform a human error analysis can represent a major challenge, because of the large number of techniques available in the literature both from the HEI perspective or the HRA perspective (Holroyd & Bell 2009; Lyons 2009). A few reviews have tried to facilitate this task. This paper provides considerations about HEI techniques and HRA techniques to guide the selection of the proper techniques for a manufacturing context.

3.1 Human error identification

The identification of human error is as critical as the quantification of error likelihood. A non-identified human error can render the quantification stage irrelevant (Kirwan 1992). Supporting this same idea, Oxtrand et al. (2010) illustrate how a well-conducted qualitative analysis reduces, to some extent, the importance of choosing a specific human reliability analysis method. Kirwan (1992) sees human error identification as an area of human reliability assessment. However, it could be argued that the identification of human error has evolved beyond merely an area or a stage of human reliability assessment. For example, some techniques only focus on human error identification without further concern with quantification. According to Baber & Stanton (1996) "the purpose of these techniques is the definition of interaction between humans and the system which are susceptible to errors". They seek to identify the possibility of human error and ways to avoid it and no mathematical consideration is involved in the process. Although fewer than techniques for quantification of human error (HRA), some structured techniques, as mentioned before, are available to conduct human error identification (Kirwan 1992; Baber & Stanton 1996).

3.2 Human reliability analysis

Although the origin of the probabilistic approach dates back to the early 1960s (Swain et al. 1963; Swain 1964), it is during the ‘80s in the wake of the Three Mile Island accident that its most important development occurred. This development has been linked to performance requirements for the U.S. nuclear sector based on the policies and procedures of the U.S. Nuclear Regulatory Commission (IAEA 1989; Kirwan 1995). Thus, mathematically, human error is treated similarly to the failure of a technical component. This approach assumes that a probability can be related to the occurrence of an error, this is called Human Error Probability (HEP). The simplified mathematical formulation is as follows (Kirwan 1994):

$$Human\ Error\ Probability\ (HEP) = \frac{Number\ of\ errors\ observed}{Number\ of\ opportunities\ for\ errors}$$

In this nuclear context, an important body of research became focused on the development of human reliability analysis techniques (probabilistic approach). These techniques have often been classified according to several criteria. A common way to classify these techniques is in terms of first and second generation (Holroyd & Bell

2009; Sharit 2012; Pan et al. 2016). The first generation includes techniques basically developed before the '90s and are often regarded as being focused on the external manifestations of error (phenotypes) without the underlying cognitive models (Pan et al. 2016). Second-generation techniques generally aim to deepen the cognitive aspect of human error and attempt to fill the gaps of the first-generation techniques (Sharit 2012). These techniques are focused on a cognitive basis of human behavior (Pan et al. 2016). However, the advantages of using second-generation techniques over first-generation techniques remain to be verified (Holroyd and Bell 2009). In fact, first generation techniques are specially suited for the skill/rule level of human performance (Pan et al. 2016) found in manual assembly operations.

4. Proposed human error analysis framework

In most cases, it would be unfeasible to conduct a human error analysis of the entire process. Thus, data analysis from quality records is an important first step in identifying critical tasks. Critical tasks encompass a significant source of quality-related issues. Once a preliminary list of critical tasks is obtained, a detailed description of tasks will be necessary to get a better understanding of the human factors contributing to human error. This can be done by using the Hierarchical Task Analysis (HTA) technique, which has been widely used to represent and describe tasks (Stanton 2006). HTA is based on the systematic decomposition of goals and subgoals and operations and suboperations to any desired level of detail. For example, SHERPA (Systematic Human Error Reduction and Prediction Approach) is considered to be an extension of the initial HTA technique based on FMEA (Failure Modes and Effects Analysis). In the proposed framework, SHERPA will be used for the identification of human error modes while HEART (Human Error Assessment and Reduction Technique) will be used for the quantitative analysis of human error and the identification of error-producing conditions associated to the tasks analysed. The selection of these two techniques was based on the criterion in Table 1, which are based on two major reviews of techniques (Holroyd & Bell 2009; Lyons 2009) and other sources (Baber & Stanton 1996; Pan et al. 2016).

Table 1. Description of the main criterion used in the selection of SHERPA and HEART techniques.

Criterion	**SHERPA**	**HEART**
Simplicity	"Can be done on individual basis, no previous experience required. The time requirements are low for training and medium for application." (Lyons 2009)	"Designed to be a relatively quick method to apply and is generally easily understood by engineers and human factors specialists." (Holroyd & Bell 2009)
Analyst orientated	"The assessor needs to be familiar with the task or be provided with a HTA prior to analysis." (Lyons 2009)	"An individual can carry out the assessment, but it is expected that they will discuss the task with experienced individuals to ensure understanding of the task." (Holroyd & Bell 2009)
Availability of resources	Public domain has been outlined in several conference papers and extensive information is available.	Public domain has been outlined in several conference papers and extensive information is available.

Some level of validation	In different evaluation of the techniques, SHERPA has shown good performance (Baber & Stanton 1996).	"One of the few HRA methods that has been empirically validated in a satisfactory way." (Holroyd & Bell 2009)
1st generation technique	Is considered a 1st generation technique (Pan et al. 2016).	Is considered a 1st generation technique (Holroyd & Bell 2009).

The final step in the framework concerned the search for error reduction strategies. This step is part of the SHERPA and HEART techniques process of analysis although it is identified as a separate step. The proposed intervention steps are listed in Figure 1.

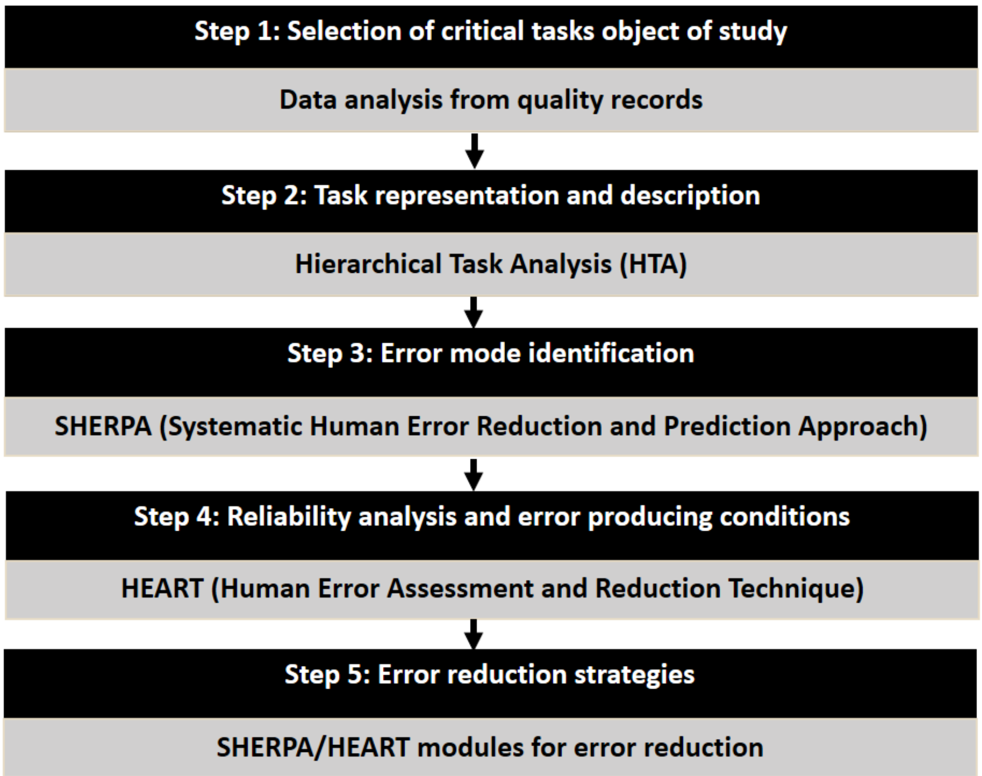

Figure 1. A proposed intervention framework for the analysis of human error in manual assembly.

5. Conclusions

The paper presents how the field of generic human reliability analysis developed mostly for high risk environments can be formulated into a simple and straightforward human error analysis process for the manufacturing sector. One point of considerable difference is the selection of critical tasks, which in high risk environments is rarely based on historical data but rather on the potential gravity of the scenario analysed. Another important point is that the selection of the technique follows a pragmatic approach based on operational criterion such as time, resources and personnel available. Expected benefits include shortened time of intervention, by compressing the realm of existing techniques to only two and preselecting validated and relatively easy-to-use techniques. Choosing tasks using a quality-oriented approach instead of an event-based approach is more appropriate to a manufacturing context highly familiar with quality perspectives. Validation is necessary, and the framework is expected to be deployed in a manual assembly line, which should give insight about the practical implications of its use.

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