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Modelling worker reliability with learning and fatigue

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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

A mathematical model is developed that estimates the human error rate while performing an assembly job under the influence of learning–forgetting and fatigue–recovery. Despite other Human Reliability Analysis (HRA) models that are not capable of anticipating how and when an error occurs, this model is able to dynamically measure the human error rate and reliability with time. An experimental analysis is performed to examine the effect of the model parameters on the error rate and the model behaviour is investigated through five research questions. Numerical examples are provided to illustrate the results.

1. Introduction

The costs of reworking or scrapping defective items are of concern to many manufacturers. Unnecessary rework and disposal costs of scrapped items require committing additional resources that increase production costs [1]. Human error a major contributor to the generation of imperfect products that are costly for companies and the environment [2]. According to Akinci et al. [3], cited by Nahangi and Haas [4], more than 50% of the rework cases are related to human error.

Human error not only increases the cost, but negatively affects health and safety [5]. According to Matthews [6], the safety community believes that 90% of all workplace injuries are the result of human error or unsafe behaviour in the workplace with the remaining 10% is caused by non-human factors. Also, human error negatively affects product and process quality and subsequently the competitive advantage a firm may have in a market [7,8]. The above studies indicate that human error is a multidimensional problem. It affects the reliability of a system and the quality of the output (products and services). So, it is necessary for a firm to reduce human error so as to improve performance. To manage the human error and consequently workforce reliability, it is, in turn, necessary to identify its cause(s) and understand the mechanism by which errors occur.

While the available Human Reliability Analysis (HRA) methods have been successful in addressing human error and human reliability to some degree, they have not, to our knowledge, done so analytically. The lack of analytical models that describe the relationship(s) between the factors that cause human error, and the outcomes of the process may provide a more in-depth analysis than the available HRA methods, and help identify possible solutions that reduce human error.

This paper is an attempt to address this problem and to identify some of the factors that affect human error, i.e. learning–forgetting and fatigue–recovery, and provides a novel analytical model to measure and excel human reliability when those factors are present. The paper also investigates how the interaction between learning–forgetting and fatigue–recovery affects human error and suggests provisions for improvement via research questions.

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The rest of this paper is organised as follows: Section 2 presents a literature review of Human Reliability Analysis models and their shortcomings. It also discusses the effects of learning–forgetting, and fatigue–recovery on human error. The methodology of the research is presented in Section 3. Section 4 is for the experimental design. Results are provided in Section 5 and discussed in Section 6. Section 7 concludes this paper.

2. Literature review of HRA models

This section presents a review of HRA models and their shortcomings in modelling and analysing human error. The review helps in identifying some of the factors that cause human error, specifically learning–forgetting, and fatigue–recovery, and their interactions.

According to Cacciabue [9], Human Reliability Analysis (HRA) predicts human error rates and evaluates the degradation to the human–machine system that is caused by declines in human functioning, operational procedures, and practises, and other system and human characteristics which affect the system behaviour.

In HRA models, human error probability (HEP) is calculated based on the operator's activities and her/his performance shaping factors (PSF) which are either related to the working environment, or the physical and mental capabilities of the workers, or both. Identifying the PSFs is then essential in HRA processes [10].

HRA models are classified into two main categories of first and second generations. First generation models are quantitative models such as the Technique for Human Error Rate Prediction (THERP) by Swan and Guttman [11] and Human Cognition Reliability (HCR) by Hannaman et al. [12]. These models treat a worker as a mechanical element that does not have any interaction with her/his surrounding environment. For such models, HEP is determined from task characteristics and PSFs by fuzzy success/failure modes, and the causes and reasons of human error are not considered [10].

The second generation of HRA models are qualitative models that use methods like Cognitive Reliability Error Analysis Method (CREAM) [13] and Standardized Plant Analysis Risk HRA method (SPAR-H) [14]. These models pay more attention to the causes of human error, and the dependency (interaction) of PSFs of one factor on (with) other factors. The cognitive models in this category, describe the man–machine interactions by considering a human cognition system in deciding situations where the operator is in possession of "awareness" and "judgement" [10]. Unlike the first generation, the models of the second generation have not been empirically validated and in the majority of the proposed models, implicit functions relate the PSFs to numeric probabilities [10,15]. Based on the study of HRA models, it is concluded that the available HRA models have the following shortcomings: Firstly, there is no available empirical data to validate them. Secondly, they do not consider human behaviour objectively, and thirdly the available models are limited to distinct areas (such as nuclear power plants or transportation systems) and their HEP estimation depends on the applied methodology. Moreover, HRA models require an expert's judgment to determine/estimate the PSFs values [16]. Another problem with HRA models is that these models were developed primarily to analyse the causes and occurrences of accidents in the work environments that are restrictive in nature and subject to stringent measures. Therefore, they are more concerned about the outcome of a decision making process rather than analysing the dynamics of the error generation process. They also cannot be used to predict when and how often an error occurs. Therefore, the management and reduction of error and improving the workers' reliability remain as concerns in labour-intensive systems.

Research indicates that learning and fatigue strongly affect the error making mechanism. Noroozi et al. [17] argued that human error in a manufacturing environment increases with the lack of training or unclear (confusing) operating procedures, which are contributors to the workers' learning. Giuntini [18] and Myszewski [19] suggested that human error increases with increasing fatigue or fatigue inducing conditions [17]. It has also been discussed in the literature that human error reduced after implementing some ergonomic solutions and worker training and education programs to reduce fatigue and improve learning [8].

While it is globally accepted that learning–forgetting and fatigue–recovery contribute to the human error, the combined effect of learning and forgetting along with fatigue and recovery has not been investigated or analysed in the HRA and error modelling literature. The aim of the current study, therefore, is to model the error rate of a worker taking into account the PSFs of learning and physical fatigue and their opposites, forgetting and recovery.

2.1. The sources of human error

Kirwan [20] has defined failure or error as: "*The failure to perform an act within the limits (of time, accuracy, etc.) required for safe system performance, or else the performance of a non-required act which interferes with system performance*". Dhillon [21] categorised the common human errors in engineering processes as: maintenance error, operator error, design error, assembly error, inspection error, handling error, and contributory error. Error in assembly has been associated with worker's capabilities such as knowledge and competence; worker fatigue; task parameters such as workload and repetitiveness; and the work environment [22–24]. These errors can occur as a result of performing tasks non-sequentially, using the wrong parts, apply the wrong force or torque, misalignments, loose joints, missing parts, and etc. [22].

In this research, human error is defined as a mistake in performing a task that results in producing a quality deficit. Errors are corrected at a cost and are affected by the worker's personal capabilities and the work characteristics. The worker's capability in performing a repetitive task, or competence, is presented by her/his learning curve. Also, the work characteristics