

Causes and Impact of Human Error in Maintenance of Mechanical Systems

Mfundo Nkosi^{1*}, Kapil Gupta¹, and Madindwa Mashinini¹

¹Department of Mechanical and Industrial Engineering Technology, University of Johannesburg, South Africa

Abstract. The concept of minimizing human error in maintenance is progressively gaining attention in various industries. The incorporation of human factors when solving engineering problems, particularly in maintenance, can no longer be ignored where high standards of performance are expected. The journey of improving maintenance performance through the reduction of human error begins with the understanding of causes and impact of human error in maintenance. This paper evaluates previous scholarly writings on human errors, to specifically establish the causes and impact of human error in maintenance. This study relies predominantly on the existing literature on human error in maintenance derived from published and unpublished research. The primary findings emerging from the research exhibit a number of key factors that cause a human error in maintenance such as poor management and supervision, organizational culture, incompetence, poorly written procedures, poor communication, time pressure, plant and environmental conditions, poor work design and many more. The literature review also revealed that human errors have a negative impact on safety, reliability, productivity and efficiency of the equipment. It was further discovered that equipment failures leading to accidents, incidents, loss of life and economic losses are the major effects of human error. Human error in mechanical systems' maintenance is a serious problem which needs adequate attention in order to develop corrective and preventive measures. This review paper serves as a basis for maintenance practitioners and interested parties to develop corrective and preventive measures for minimizing human error in the maintenance of mechanical systems.

Keywords: failure, human error, human factor, maintenance, mechanical systems

1 Introduction

Most mechanical systems require regular maintenance for best performance. However, the human error committed during the maintenance phase lead to the system's substandard

* Corresponding author: mnkosi@uj.ac.za

performance. It is during the maintenance phase where a considerable portion of human errors are committed [1]. The manifestation of human error during the maintenance phase can impact the safety and performance of equipment in a number of ways [2]. Therefore, initiatives aimed at the identification and analysis of human error in maintenance are very important, since they can lead to the development of proper strategies for the reduction of human error. The occurrence of human error is regularly considered as a threat with the probability to lead to a significant rate of accidents [3]. In the maintenance of mechanical systems, human errors stem from a number of reasons which have led some industries to develop various initiatives for addressing the issue of human error. The investigation of measures and initiatives of minimizing human error in maintenance begin with the identification and understanding of the factors responsible for human errors. Consequently, this paper examines existing scholarly writings on the causes and impact of human errors in the maintenance of mechanical systems. The error causal factors presented in Figure 1 are among many that were discovered during the literature review process. These human factors are seen as the key causal factors responsible for human error in the maintenance of mechanical systems.

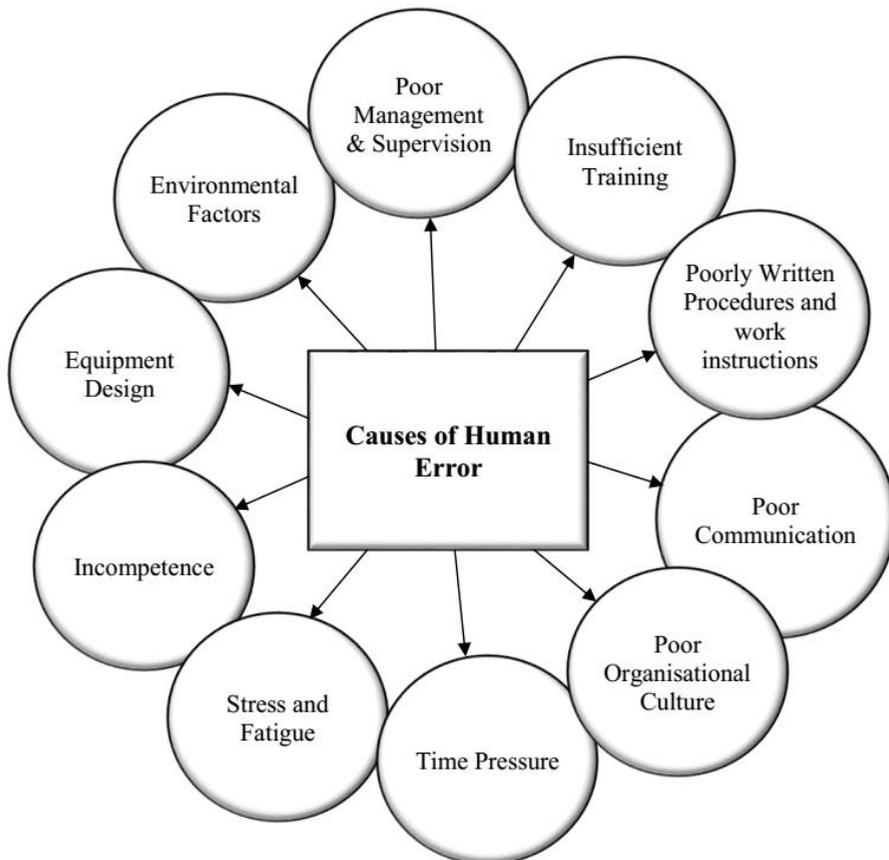


Fig. 1. Causes of human error in the maintenance of mechanical systems

In order to fulfil the aim of the research, the following research questions related to the study are addressed:

1. What are the factors responsible for the occurrence of human errors in the maintenance of mechanical systems?

2. What is the impact of human errors in the maintenance of mechanical systems and how intense is their effect?

This paper identifies the causes and impact of human error in maintenance by reviewing various scholarly writings. It begins with the introduction, follows with the literature search methodology, literature review, key literature review findings and ends with a conclusion that incorporates recommendations and proposed future work.

2 The Literature Search Methodology

The literature review research method was selected for this study. The literature review study is viewed as a “critical analysis of a segment of a published body of knowledge through summary, classification, and comparison of prior research studies, reviews of literature, and theoretical articles” [29]. Selected scholarly writings were reviewed in order to identify, evaluate and short-list the factors responsible for human error and the impact of human error in the maintenance of mechanical systems. The main was to understand the existing body of knowledge and to create a research agenda.

The study is based mainly on the analysis of the existing published and unpublished theoretical scholarly writings. The theme of this paper is predominantly a literature review concerned with human errors in maintenance of various mechanical systems. As a concept of human error in the maintenance of mechanical systems started gaining attention, a number of initiatives have been established with the aim of minimizing human errors. The establishment and improvement of initiatives aimed at reducing human error begin with the apprehension of the causes and impact of human error in the maintenance of mechanical systems. Hence, it is very crucial to analyze the causes and impact of human error. The paper follows a rigorous approach to merge, evaluate and clarify segments of findings of several research studies with specific attention to causes and impact of human error. Twenty-eight publications have been reviewed, of which twelve are aimed at aviation, seven intended for miscellaneous industries, four from a combination of chemical, oil and gas, refinery and petroleum industries and five from the amalgamation of the coal-fired and nuclear power plant, mining, electrical transmission and healthcare.

3 Human Errors in Maintenance of Mechanical Systems

There is a frequent occurrence of inadvertent human errors in the maintenance of mechanical systems. Due to the complexity of technology, it is progressively becoming hard for human operators to properly cognize the system’s behaviour [4]. Hence, there is a recurrent of human errors. Human error is defined as a non-fulfilment of a stipulated task (or the execution of an unacceptable action) having a potential to disrupt planned operations and resulting in property and equipment damages [6]. Virovac et al. [5], defines human error as an inadvertent error in the execution of work which leads to sudden system damage or it can be a dormant or latent error characterized as a potential to endanger the technical system’s worthiness. Based on the study by Myszewski [6], human errors are viewed as examples of the ineffectiveness of the organization. Human errors can be classified into, slips, lapses, and violations [4]. This classification is in agreement with the one put forward by Reason [7] and Siu [8]. These are slips of actions and lapses of memory both classified as distractions and loss of concentration while the violation is an intended action, especially where there is an expected reward of the violation.

The method which is easily adopted in various organizations when dealing with human error is to blame incidents or accidents on individuals performing the task and focus solutions on the mistakes of these individuals. Now, the idea of adopting the individual approach

in addressing human error, organizations disregards the dormant or latent conditions within the work systems under which the workforce operate that give rise to human error [3]. It is further stated that human error should be identified as a consequence of amalgamated factors, as opposed to the root cause of an incident or accident. This paper aims to unearth the various causal factors of human error in maintenance leading to mechanical system's substandard performance, hence become a source of incidents and catastrophic accidents. It is approximated by NOPSEMA [3]; Dumitru and Boşcoianu [9]; Drury [10]; Begur and Babu [11]; Wiegmann and Shappell [12] and Pons and Dey [4] that human error is a major causal factor of between 70-80% of most equipment failures, incidents and accidents. It is about 15% - 20% of failures, incidents and accidents that are due to maintenance error [10, 11].

In the study of Dhillon and Liu [1], human error was stated as a serious problem in maintenance emanating from the operation, assembly, design, inspection, installation and maintenance phase. The errors committed in other phases of the mechanical system are inherited by the maintenance phase, and failure to identify these latent conditions during maintenance can lead to disruptive situations. There is a serious need to identify human errors, their causal factors and impact in any maintenance department. A guide developed by Health and Safety Executive [13] is based on the thought that human errors in maintenance are to a great extent predictable, hence can be identified and controlled.

4 Causes of Human Errors in Maintenance

The issue of human error in the maintenance of mechanical systems needs to be properly addressed and to do that, one needs to begin with the appropriate analysis of the causes and impact of human error. There are a number of factors during the maintenance phase that can give rise to human error when not properly identified and controlled. Causes of human errors in maintenance are the factors responsible for the manifestation of errors on the tasks performed during the maintenance phase. A number of factors tabled in a study by Dhillon and Liu [1] as a source of human error are lack of skills, insufficient training, badly written operating manuals and maintenance procedures, poorly designed equipment, usage of unsuitable tools, insufficient work layout, limited lighting in the workspace and noise levels. On the other hand, various causal factors derived from Dhillon [2] include the complexity of maintenance tasks, inadequately written maintenance procedures and obsolete maintenance manuals, the fatigue of the maintenance personnel, insufficient training and experience, under-designed work layout, inadequacy of equipment design, unsuitable tools for specified work, substandard work environment. The substandard work environment can include a poorly designed plant with insufficient accessibility of components. In a study conducted by Virovac et al. [5], communication, equipment design and fabrication, working environment, work complexity, knowledge, work organization, documentation (manuals and procedures), work planning, pressure, fatigue, insufficient personnel for work, personal problems, and distraction while doing work were identified as major error causal factors. Management commitment, casual organizational cultures, and the organization's local context enable the continued existence of human error by preventing the proper implementation of initiatives for addressing human error [14]. In the analysis of human factors as a component of the management system's holistic performance, the key human factors that impact the maintenance performance such as competence and motivation, in contrast with supervision, workload, and performance feedback were derived [15]. Lack of competence, and the inclination to disregard the established instructions, are the core causal factors of human error as per research findings of Badenhorst and Van Tonder [16]. In research by Latorella and Prabhu [17], a number of human factors responsible for the existence of human error such as time pressure, inadequate feedback, difficult ambient conditions (environmental factor) and the common erring factor of human were identified.

It was revealed that the major error causal factors are inadequate communication, complacency, insufficient knowledge, disturbances, poor teamwork, scarcity of resources, pressure, the inadequacy of awareness, insufficiency of assertiveness, fatigue, stress, norms or cultures [18]. Hobbs [19] discovered that the manifestation of human errors is related with environmental factors, inadequate communication and coordination, time pressure, maintenance procedures and documentation, lack of integration in teamwork, change of shifts and handover, organizational and team norms, fatigue, sources of stress, lack of system knowledge, equipment design and fabrication deficiencies, insufficient design for maintainability, and absent-minded. The factors such as the following: inadequacy of supervision, memory and attention issues, poor decision making and judgment, poor design, inflexibility and inadaptability, poor light in the workspace, and confined work area were revealed as the major causes of human error [20]. Alonso and Broadribb [21] discovered that organizational and team cultures, odd situations, psychological issues, procedural factors, and organizational structure, complex environments, exposure to high stress and a tendency to remain in the background are key causal factors of human errors. In the research findings of Kovacevic et al. [22], non-fulfilment of the maintenance's technical instructions, the poorly organized or coordinated training process, insufficient equipment for diagnosis, and a failure to understand the work activities are classified as the key reasons for the occurrence of human error. While Laakso et al. [23] revealed that common human errors stem from plant modifications, planning and auditing, post-installation inspection, testing programs of the start-ups and training.

Dunn [24] established a number of factors responsible for human error such as, absorbed by extra emotional or sensory demands, failure to maintain concentration or attentional focus, the decrement attentiveness, repetition of work (routine work), fatigue, time pressure, stresses emanating from physical factors, social factors, work pace and personal factors, emotional decision making or clouding better judgement, confirmation bias when diagnosing a problem, the level of motivation or arousal, morale of employees, the competence (skills, knowledge and experience) of maintenance personnel (managers, engineers, artisans, etc.), tools availability, sufficient equipment and parts, shift changes, and sufficiency of work instructions and procedures. The research findings of Gould and Lovell [25] presented that the procedures can be both the origin and defense of human error. The substandard work environment can include a poorly designed plant with insufficient accessibility of components. By looking at these sources of human error, one can deduct that the same sources can be used as barriers or defences against human error in maintenance. Rashid [26] revealed the following main error causal factors: organizational process, documentation (manuals and procedures), maintenance personnel training, supervision, equipment design and fabrication, and resources. The substandard work environment can include a poorly designed plant with insufficient accessibility of components. By looking at these sources of human error, one can deduct that the same sources can be used as barriers or defences against human error in maintenance. It is very important to analyse the causal factors of human error in order to come up with sufficient strategies and initiatives for managing human errors in the maintenance of mechanical systems. The following event in the evolution of maintenance management is the inclusion of human factors in performance measurement [15].

5 Impact of Human Errors in Maintenance

The next step after determining the causes of human error in the maintenance of mechanical systems is to establish the impact of human errors. The impact of human errors represents the consequences or effects that are experienced when human errors occurring during the maintenance phase of mechanical systems are not properly managed, reduced and even

eliminated. Dhillon [2] unveils that the impact of human error is the loss of life due to accidents and cost constraints imposed by breakdowns and accidents or incidents. On the other hand, the impact of human errors such as delays, damage to equipment, repairs and accidents were revealed [5]. It is indicated in the Health and Safety Executive [13] guide, that human error poses risks to health, the effect on safety, impairment of performance and the increased likelihood of accidents, low quality of maintenance, increased operational costs, impairment on operating life of plant and risks of occurrence of accidents.

In a study by Latorella and Prabhu [17], it was revealed that human errors have the most acute impact resulting in accidents and loss of life, delays in availability of equipment, and obstruction of productivity of equipment and efficiency of operations. It has been established that substandard maintenance due to human error has a considerable contribution to accidents and incidents [19]. During the review, accidents kept appearing as the major impact of human error, and these accidents have a negative impact on the lives of people and economic activities of the organization. Now, Krulak [20] indicates that the impact of human error includes, the untold sums of equipment and lives that paid a price for human error, the occurrence of mishaps, and enabling the odds linked to the extremity of a mishap. Human error is a common cause of many key safety incidents involving a huge loss of life [21]. In a study by Dunn [24], it is shown that there is a huge impact on maintenance quality and costs, safety and reliability equipment, and work performance. Human errors have the following impact: high social and economic cost, equipment safety, maintenance performance efficiency and effectiveness, equipment productivity, incidents and accidents and fatality [26]. Propagation of loss of lives, damage to property and environment, and disturbances on the economic state of any organization are stated as major effects of human errors [27]. It is further stated that the economic impact significantly influences the workplace, employees, society and economy. Human errors in maintenance impose the safety and economic effects [28]. These effects are very costly imposing cost constraints in the maintenance department of any organization.

6 Key Findings of the Literature Review

A number of publications were examined with the intention of establishing the causes and impact of human error in the maintenance of mechanical systems. Figure 1 below presents the classifications of reviewed scholarly writings according to industry. It can be seen that a great amount of work has been done in the aviation industry to address the issue of human error in maintenance.

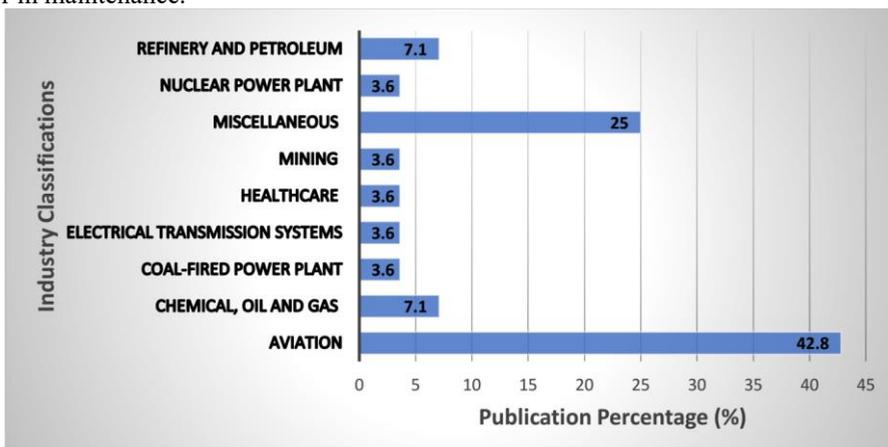


Fig. 2. Classifying reviewed scholarly writings in percentages in relation to industry

A great amount of error causal factors was discovered through the literature review and the key causal factors are presented in Table 1.

Table 1. Factors Responsible for Human Error in Maintenance

Causes	Authors
Leadership and Management Factors	
Poor management and supervision	Timmons, et al., 2014; Peach, Ellis & Visser, 2016; Krulak, 2004; Rashid, 2010
Insufficient Training	Dhillon & Liu, 2006; Dhillon, 2014); Kovacevic et al., 2016; Laakso, Pyy, & Reiman, 1998; Rashid, 2010
Work design/planning/layout	Dhillon & Liu, 2006; Peach, Ellis & Visser, 2016; B S Dhillon 2014; Dunn, 2004; Virovac, Domitrović & Bazij, 2017
Poorly written procedures, manuals and work instructions	Dhillon & Liu, 2006; Gould & Lovell, 2009; Hobbs, 2008; Dhillon, 2014; Dunn, 2004; Rashi, 2010
Poor communication and sparse feedback	Hobbs, 2008; Virovac, Domitrović & Bazij, 2017; Peach, Ellis & Visser, 2016; Laakso, Pyy, & Reiman, 1998
Time pressures	Laakso, Pyy, & Reiman, 1998; Hobbs, 2008; Dunn, 2004; Virovac, Domitrović & Bazij, 2017
Poor organizational culture	Timmons, et al., 2014; Alonso & Broadribb, 2018; Latorella & Prabhu, 2000; Rashid, 2010
Individual Factors [Cognitive Factors]	
Incompetence/Inadequate skills	Dhillon & Liu, 2006; Dunn, 2004; Peach, Ellis & Visser, 2016; Badenhorst & Van Tonder, 2004
Fatigue	Latorella & Prabhu, 2000; Hobbs, 2008; Dhillon, 2014; Dunn, 2004); Virovac, Domitrović & Bazij, 2017
Stress/Emotional demands	Dunn, 2004; Latorella & Prabhu, 2000; Hobbs, 2008; Alonso & Broadribb, 2018
Routine or repetitive work	Alonso & Broadribb, 2018; Dunn, 2004
Ignoring standard work instructions	Badenhorst & Van Tonder, 2004); Kovacevic et al., 2016; Dunn, 2004
Physical Factors	
Equipment design and construction deficiencies	Dhillon & Liu, 2006; Hobbs, 2008; Dhillon, 2014; Krulak, 2004; Rashid, 2010
Environmental Factors	
Poor work environment (e.g. lighting, noise levels and ambient conditions)	Dhillon & Liu, 2006; Krulak, 2004; Latorella & Prabhu, 2000; Dhillon & Liu, 2006

The major impact of human errors in maintenance was also discovered through the literature review, and key effects of errors are presented in Table 2.

Table 2. The Impact of Human Error in Maintenance

Impact	Authors
Incidents and Accidents	Latorella & Prabhu, 2000; Dhillon, 2014; Alonso & Broadribb, 2018; Virovac, Domitrović & Bazij, 2017; Health and Safety Executive, 2000; Rashid, 2010; Hobbs, 2008;
Loss of life	Latorella & Prabhu, 2000; Dhillon, 2014; Alonso & Broadribb, 2018; Rashid, 2010
Inefficiency, and impaired productivity of equipment	Latorella & Prabhu, 2000; Virovac, Domitrović & Bazij, 2017; Dunn, 2004; Rashid, 2010

Cost (economic loss)	Health and Safety Executive, 2000; Alkhaldi, Pathirage & Kulatunga, 2017; Dhillon 2014; Dunn, 2004); Rankin et al., 2000; Rashid, 2010
Safety/ risk to health	Rankin et al., 2000; Alonso & Broadribb, 2018; Dunn, 2004; Health and Safety Executive, 2000
Equipment damage or loss	Virovac, Domitrović & Bazij, 2017; Alkhaldi, Pathirage & Kulatunga, 2017; Krulak, 2004
Impaired maintenance quality or performance	Health and Safety Executive, 2000; Dunn, 2004; Rashid, 2010

7 Conclusion

This paper reports a review of past literature concerning human errors in the maintenance of mechanical systems. The review of the literature revealed that the causes of human errors vary from those caused by poor maintenance management (e.g. policies and procedures) and cognitive factors (stress and competence etc.,) to those that are caused by physical factors (environmental factors, component design). The literature review further revealed that there is a great negative impact of human errors in maintenance that can lead to failures and even catastrophic failures (major damage to plant and human and even lead to fatality). These failures negatively affect organizations' economic activities.

It is recommended that the errors and impact discovered in the literature review be examined in the local context of those industries that have not yet adopted human factors engineering in their maintenance policies. The training programs should be developed to assist in bringing awareness of the impact of human error at the individual and organizational level. The adoption of human factors principles in the maintenance policy and strategy development can assist the organizations to properly begin the journey of reducing and better managing human error.

The following are considered to be eligible for future research focus:

- The development of effective human error reporting systems to ensure the availability of sufficient data for the analysis and management of human error.
- Developing or improving tools for analyzing the probability of occurrence of errors in each industry to prioritize the predictive and preventive measures.
- The quantification of the impact of human error on maintenance performance and economic activities.

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