Understanding, identifying, and managing maintenance errors in The Royal Bahraini Air Force (RBAF)

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Understanding, Identifying, and Managing Maintenance Errors in The Royal Bahraini Air Force (RBAF)

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A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy at the School of Risk and Safety Sciences

University of New South Wales

2011

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Abstract

The Royal Bahraini Air Force (RBAF) has recently experienced a series of maintenance-related incidents which have prompted investigation into the factors that contributed to them. The primary aim of this research project was to understand the nature of maintenance errors in the RBAF, with a view to developing an improved tool for identifying and managing these errors.

We analysed and triangulated several sources of data in order to better understand the nature of the occurring errors and their associated factors. The Maintenance Error Decision Aid (MEDA) questionnaire was administered to RBAF technicians, and Quality Assurance (QA) reports were collected and analysed in a manner consistent with the MEDA framework. Technicians were also interviewed to identify their perceptions of the factors contributing to errors, and their insight into how the current reporting system could be improved.

The type of error most commonly reported in this research was “aircraft/equipment errors, and “organisational factors” was nominated as the most common contributing factor. Both of these were reported in lower frequencies by technicians than by QA investigators. QA investigators’ experience probably helped in correctly identifying and classifying the various categories of error and contributing factors, while technicians may have treated some errors as negligible (and thus failed to report them), or may have lacked the experience or expertise to classify the errors as specifically. The technicians’

responses highlighted the importance of: proactively detecting errors; communication and the use of procedures; and pre-planning of tasks (in order to reduce maintenance errors).

Based on the findings of our research project, we have developed a tool (The Tool for Error Reduction and Management (TERM)) which can be used as part of the accident reporting and investigation process; to assist in understanding systematic patterns within a large set of events; and to identify strengths, weaknesses, and opportunities for improvement within the maintenance organisation.

There is no doubt that implementing the proposed tool in military aviation maintenance poses significant challenges, but from the RBAF organisational perspective, there are numerous benefits that will be gained by implementing it, most notably the reduction and improved management of maintenance errors.

Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1

Understanding, Identifying, and Managing Maintenance Errors in The Royal Bahraini Air Force (RBAF)

1.1 Rationale for the Research Project

The Royal Bahraini Air Force (RBAF) is continuously pursuing means to develop and improve the quality of the maintenance activities; however, in recent years the RBAF has experienced a series of accidents/incidents that prompted the RBAF management to investigate the underlying factors behind the sudden surge of accidents/incidents. Based on the researcher's experience as an Aircraft Maintenance Officer, two underlying factors led to the decision to undertake this study to attempt to understand and reduce the onset of maintenance human errors. First, there has been a Headquarter demand for continuing safe air operations during both maritime and combat situations following concerns over recent maintenance related accidents/incidents. Second, the workload of maintenance technicians is increasing due to factors such as: increased aircraft utilization; increased maintenance requirements for continuing airworthiness of older aircraft; increased requirements for new technical knowledge and skills to maintain new technology and new aircraft; the shortage of qualified maintenance technicians; and pressure from RBAF Headquarters that demands maintenance organizations to increase their efficiency and effectiveness while maintaining a high level of safety.

1.2 Aims of the Research Project

The primary objective of the study is to develop a tool to improve understanding, identification and management of errors/failures in military aviation maintenance. In order to achieve this objective the research project will attempt to fulfil the following aims:

1) Understand the nature of maintenance errors across RBAF fighter and helicopter bases;

2) Contrast errors and their underlying factors from the existing accident reporting and investigation system with those identified through the Maintenance Error Decision Aid (MEDA) and interviews conducted with RBAF technicians;

3) Identify the role and nature of organisational failures in maintenance error within RBAF; and

4) Evaluate the existing RBAF reporting and investigation system and develop an improved tool for identifying and managing maintenance errors within the Air Force.

To achieve these aims three studies were conducted. In Study (1), 41 technicians were asked to complete the Maintenance Error Decision Aid (MEDA) results form in order to share their experience concerning errors that they committed or witnessed during their career in the RBAF. In Study (2), 88 accident/incident investigation reports were reviewed and analysed. This analysis determined the types of maintenance errors that were committed by the technicians, and the contributing factors that led to these errors. In Studies (3) and (3a), we explored technicians‘ perceptions relating to the types of maintenance errors that they experienced or witnessed in the RBAF and the contributing factors that led to these errors as well as their perceptions regarding the current reporting system. Data was collected by structured interviews with RBAF technicians. The most appropriate manner to collect qualitative data was by adopting the grounded theory approach. This analysis was used to determine the types of maintenance errors and the contributing factors that led to these accidents/incidents. These errors and contributing factors were then mapped to MEDA categories; to facilitate consistent comparison of data across studies (1), (2), and (3). Figure 1.1 illustrates the aims, methods and the intended outcome of this project.

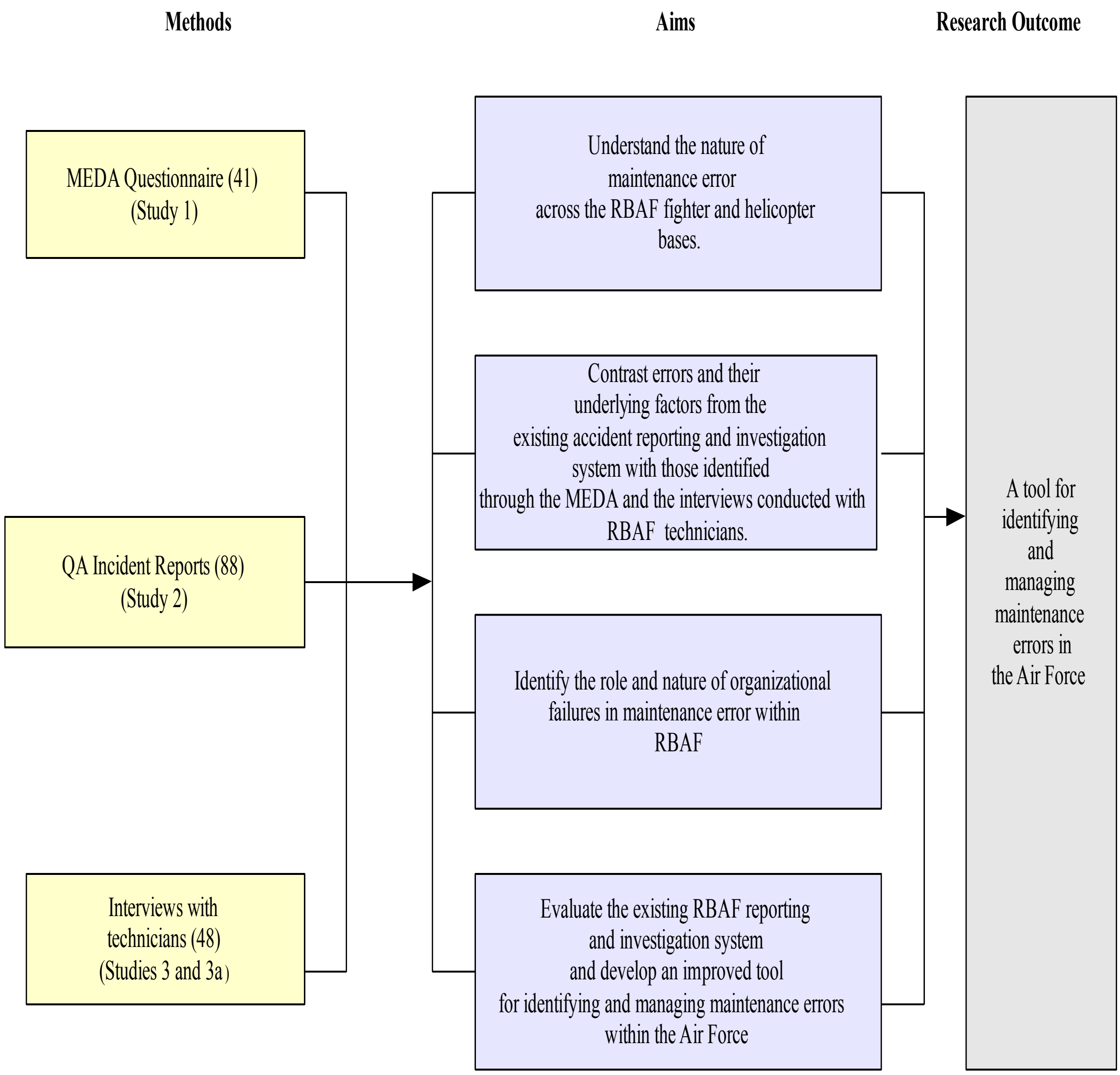

Figure 1.1: A conceptual diagram illustrating the aims, methods, and the intended outcome of this research project.

1.3 Anticipated Benefits

Several studies have been developed to identify, analyse, and reduce errors in the civil aviation industry, but there is little available literature about errors/failures in the military sector. It is anticipated that several benefits will be gained, not only for the RBAF, but for all of the maintenance units serving in the Bahrain Defence Force (BDF). These benefits will include:

- Demonstration of a systematic approach to human factors assessment of aircraft maintenance within the RBAF and ultimately the other BDF maintenance units;

- Overall improvement in safety and reliability, and consequent reduction in the risk associated with the maintenance activities;

- Increased potential for aircraft maintenance technicians, engineers and management to correctly identify and rectify latent errors within their maintenance organisations;

- Increased potential for aircraft maintenance technicians and engineers to correctly priorities defects for future attention or immediate correction;

- Reduced potential for aircraft maintenance technicians to introduce defects into the system during maintenance activities; and

- Development of a proactive tool for the reduction and management of maintenance errors.

1.4 Scope

The maintenance activities that will be studied include:

- Flight line maintenance, encompassing those minimal inspections and servicing carried out on the aircraft, engine, and support equipment prior to a flight and within a limited time period. These inspections include a review of incoming defects (in order to decide whether to rectify the defect immediately or defer it to a more convenient time); and

- Scheduled maintenance, encompassing more detailed inspections, servicing activities of a preventative nature, and rectification of more substantial deferred defects; and major maintenance activities on aircraft parts, engines, and support equipment (such as major phase or periodic inspections, scheduled and unscheduled removals and installations of parts and components).

Due to the fact that this research project was conducted in a military environment, no reference can be made to the types of weapon systems, location of military bases or detailed demographics of the technicians participating in this research project. The researcher gained access to these data by virtue of employment by RBAF.

Chapter 2

Literature Review

2.1 Introduction

The main aim of this research is to develop a tool to better identify, understand, and manage errors/failures and their underlying factors in the military aviation domain. In achieving this aim, this research project will identify the roles of individuals and organizational failures in maintenance errors; contrast errors and their underlying factors within the existing accident reporting and investigation system with those identified through the Maintenance Error Decision Aid (MEDA) and the interviews conducted with technicians in the Royal Bahraini Air Force (RBAF); evaluate the existing reporting and investigation system; and propose a refined reporting and investigation system.

As a starting point, we conducted a literature review on topics relate to these aims, including risk management, human error-related research that has been conducted in different domains, human error in maintenance, reporting systems, error management, and organizational and safety cultures. The literature review was based on a survey of human factors and ergonomics text books, relevant scientific journals, and relevant internet sources. The results of the literature review are presented in the following sections.

Aviation safety is the most important in both civil and military aviation. The reviewed literature suggests that accidents caused by the aviation maintenance have increased year after year. For example in China, the aviation accident rate from 1949 to 1989 is 7.9%, however, the rate becomes 16.7% from 1989 to 1996, furthermore, 25% from 1996 to 2005 (Yanqing & Xueyan, 2010). According to the statistical data of aviation accidents all over the world, it is known that 20 to 30% of engine failures, 80% of flight cancellations were related to aviation maintenance (General Administration of Civil Administration of China (CAAC), 2003; & Zhiqin & Fan, 2006). Therefore, it is necessary to carry safety risk management in the process of aviation maintenance in order to improve the safety level in aviation maintenance. Risk management introduces the idea that the likelihood of an event happening can be reduced, or its consequences minimised. In aviation, the term ―risk management" is frequently used in the context of decision-making about how to handle situations, which affect aviation safety. Effective risk management seeks to maximise the benefits of a risk (usually a reduction in time or cost) while minimising the risk itself (Transport Canada, 2010).

2.2 Risk management

Although there is no one accepted definition for Risk Management (RM), the Australian/New Zealand Standard on Risk Management (AS/NZS ISO 31000:2009), which became now an International Standard, defines RM as the ―coordinated activities to direct and control an organization with regards to risk." Risk arises because organizational objectives are pursued against an uncertain background (Cooper, 1995). An organization may set its objectives, but to achieve these objectives the organization often has to contend with internal and external factors and influences that it may not control and which may generate uncertainty and thus risk (Cooper, 1995).

The purpose of RM is to improve organizational performance by systematically identifying and assessing risk, and by developing strategies to reduce or avoid risks and to maximize opportunities (Chapman & Ward, 1997). In order for a risk management program to be successful, it needs to be integrated into the various business functions within the organization (AS/NZS ISO 31000, 2009). The advantages of RM are, for example, encourage proactive rather than reactive management, identify and treat risk through the organization, and improve incident management and prevention (AS/NZS ISO 31000, 2009)

The RM process is a continuous activity that involves: 1) the identification of risks using both historical and current information about risk (Merna & Al-Thani, 2008) such as incident reports and interviews with individuals who can affect, or be affected, by a decision or an activity (AS/NZS ISO 31000, 2009); 2) the development of an understanding of each risk, its consequences, and the likelihood of these consequences; 3) the evaluation of risks and risk interactions to assess the range of possible outcomes; and 4) the improvement of existing controls or the development and implementation of new controls (Cooper, 1995). For this process to be effective, the organization needs to integrate RM within the organization‘s policies and organizational structure to implement, sustain, and improve the RM process. This integration is termed the RM framework (Cooper, 1995). The framework ensures that information about risks derived from the RM process is adequately reported and used as a basis for decision making at all relevant organizational levels (AS/NZS ISO 31000, 2009). The relationship between the principles, the framework, and the process of risk management is shown in figure 2.1.

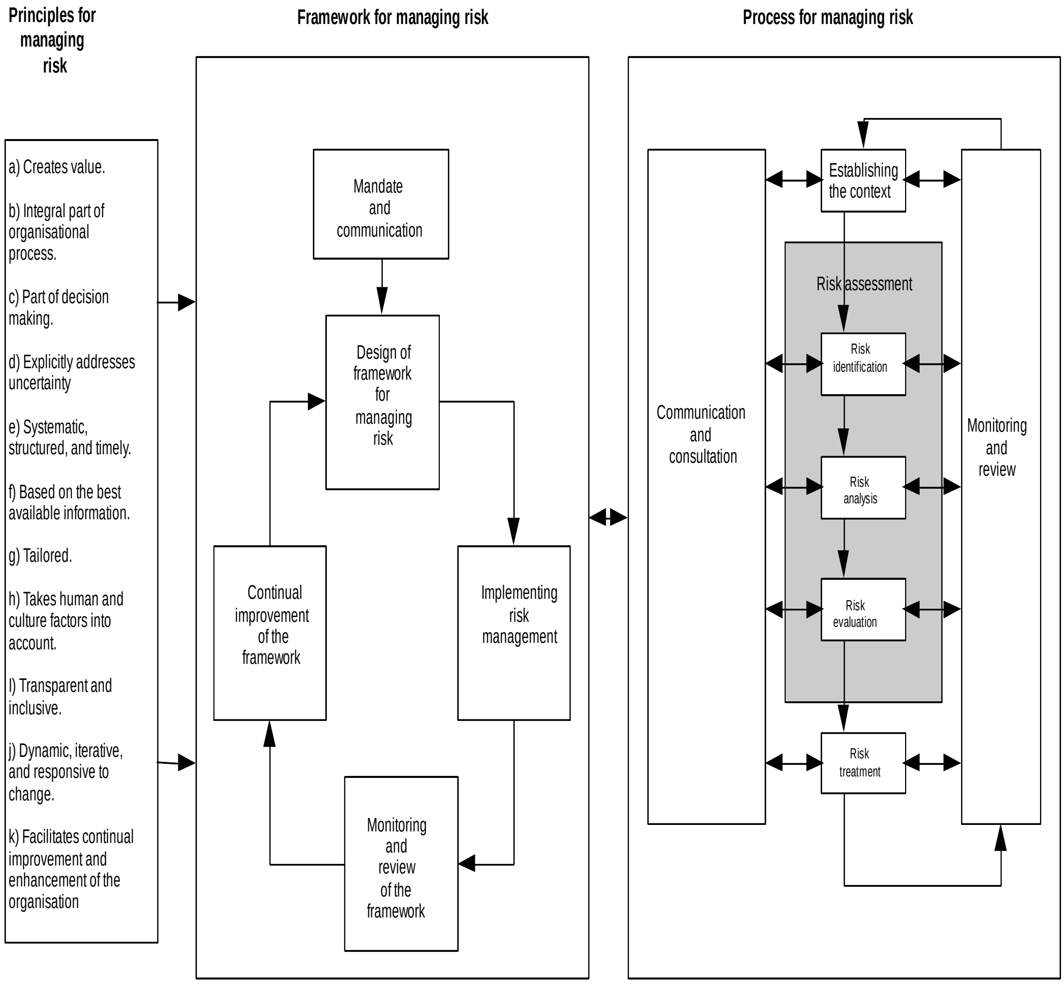

Figure 2.1: The relationship between the risk management principles, framework and process (adapted from the AS/NZS ISO 31000, 2009).

Aviation is one of the leading industries in risk management (Wilf-Miron, Lewenhoff, Benyamini, & Aviram; 2003). Aviation risks are commonly divided into financial risk (e.g. aircraft acquisition cost and fuel prices); strategic risk; operational risk (e.g. technical problems with aircraft and related equipment arising from improper or inadequate maintenance or repair, and human factors); and hazardous risk (e.g. severe weather conditions and aircraft accidents) (Flight Safety Information, 2005). The weakest link in the man-machine environment interface in aviation still remains the human being (Taneja, 2002). Human error has been implicated in a variety of occupational accidents including 70-80% of those in civil and military aviation (Wiegmann & Shappell, 2001a; O'Hare, Wiggins, Batt, & Morrison, 1994; & Yacavone, 1993). The following section will review the concept of human error proposed in the literature.

2.3 Human Error

Human error has consistently been identified as at least a contributory factor in a proportion of accidents and incidents in various domains. For example, recent research indicates that, within the rail transport domain, human error was identified as a contributory cause of almost half of all collisions occurring on UK Network Rail between 2002 and 2003 (Lawton and Ward, 2005). Within the health care domain, the US Institute of Medicine estimates that between 44,000 and 88,000 people die each year as a result of medical errors (Helmreich, 2000). Within the road transport domain, it has been estimated that inappropriate human actions are involved in as much as 95% of road traffic crashes (Rumar, 1995; cited in Aberg & Rimmo, 1999). Research also indicates that, within the aviation domain, human or pilot error is the source of up to 70% of incidents occurring in the commercial aviation domain (Boeing Airplane Safety Engineering (BASE) 1997; cited in McFadden & Towell, 1999). Additionally, human error has been found to be a contributing factor to a number of high casualty catastrophes such as the three mile island, Chernobyl and Bhopal nuclear power disaster, and the Kings Cross station fire disaster. Consequently, human error has received considerable attention from the relevant academic and research communities and has been investigated across a wide range of domains, including rail (Lawton & Ward, 2005), nuclear power and petro-chemical reprocessing (Kirwan, 1992a, 1992b, 1998a, 1998b, and 1996), air traffic control (Shorrock and Kirwan, 2002), road transport (Reason, Manstead, Stradling, Baxter and Campbell, 1990). In the aviation sector, both civil and the military organisations have paid considerable attention to human errors (Shappell & Wiegmann, 2000; Marshall, Stanton, Young, Salmon, Harris, Demagalski, Waldmann & Dekker, 2003) despite the differences in aims and operations between these types of organisations. Unlike civil aviation missions, military missions involve low-level flights close to the surface during which airspeed and altitude are adapted to the contours of the ground surface in order to avoid enemy detection (Falconner & Todd, 2007). Military missions also involve high-G force manoeuvring to evade enemy aircraft and missiles (Shappell & Wiegmann, 2004). In addition, military organisations tend to be less homogeneous than civil operations. Throughout military aviation, there are great variations in the type of aircraft (e.g. fighters, bombers, cargo planes, helicopters, and even tilt-rotors) and levels of automation (very little to fully glass cockpit) (O'Connor, Hahn & Nullmeyer, (2010).

According to the literature, human error has been variously defined. A universally accepted definition of human error does not yet exist. A brief summary of the more prominent definitions offered in the literature is presented next.

Rasmussen (1987; cited in Fuller, 1990) suggests that human error represents a mismatch between the demands of an operational system and what the human operator does. Rasmussen, Duncan & Leplat (1987) define human error as an act that is counterproductive with respect to the person‘s intentions or goals. Sanders and Moray (1991) suggest that a generally accepted definition of error is an act that has been done which was either not intended by the actor; not desired by a set of rules or an external observer; or that led the task or system outside of its acceptable limits. Hollnagle (1993) labels human error as ‗erroneous actions‘ and defines them as ―actions which fail to produce the expected result and which therefore lead to an unwanted consequence". Reason (1990) defines human error as ―A generic term to encompass all occasions in which a planned sequence of mental or physical activities fail to achieve their intended outcome, and when these failures cannot be attributed to the intervention of some chance agency." Based on the reviewed literature concerning the definition of human error, we can conclude that human error can be defined as any mental or physical activity, or failure to perform an activity, that leads to an unintended or unaccepted outcome.

According to Kirwan (1998a) there are three major components to an error:

- External Error Mode (EEM), which refers to the external manifestation of the error, or the form that the error takes in the world (e.g. pressed wrong button or failed to check display reading).

- Performance Shaping Factors (PSF) (e.g. environmental conditions, inadequate training, time pressure, fatigue etc).

- Psychological Error Mechanisms (PEM), which refers to the internal manifestation of error or how the actor failed psychologically (e.g. memory failure).

Past research has led to the identification and classification of different error types within the general category of human error, and various error classification schemes or taxonomies have been proposed. In the following section, an overview of the different classifications of error types proposed in the literature is presented.

2.4 Error Classification

Error classification is used to identify and classify the different types of error that humans make. The basic level of error classification is a distinction between errors of omission and errors of commission (Wickens et al, 1998). Errors of omission are those instances where an operator fails to act at all, such as failing or forgetting to perform a particular action that is necessary for the particular circumstances they are facing (Swain & Guttman, 1983). Errors of commission, on the other hand, are those instances where an actor performs an action either incorrectly or at the wrong time (Swain & Guttman, 1983), such as pressing the wrong button, or pressing a button too early or too late.

The most common system for the classification for errors involves the differentiation between errors committed in the planning of actions, and errors committed in the execution of actions (Thomas & Petrilli, 2004). The term ‗mistake' is used to describe the errors that occur in the planning of actions and involves errors where the plan for specific action is deficient or fundamentally flawed. In this instance, an operator might execute a plan of action flawlessly, but not achieve the desired outcome due to an inherent problem with the plan of action itself. As Reason (1990) suggests, mistakes frequently occur through the failures of higher-order cognitive processes involved in judging the available information, setting objectives, and deciding on the means to achieve a desired outcome. This type of error relates directly to Rasmussen‘s (1986) knowledge-based behaviours, which involve conscious reasoning during problem-solving activities. Accordingly, these errors are frequently referred to as knowledge-based mistakes.

However, mistakes are also frequently observed with respect to less conscious or deliberate planning processes. Termed rule-based mistakes, these forms of error involve the incorrect initiation of actions in response to existing behavioural routines. Frequently, rule-based mistakes involve an automatic response to misdiagnosed problem, or the automatic misdiagnosis of a situation. Rule-based mistakes occur through the interference of biases or quasi-automatic intervention of more familiar rules, and can occur in relation to both the identification of a situation and the selection of an action (Rizzo, Ferrante, & Bagnara, 1995).

Similarly, two broad types of error can be categorized at the execution stage. Firstly, slips involve unintentional actions or active failures in the execution of a plan. In these situations, the intended action is appropriate, but due to low level attentional failures in highly practiced and automatic behaviours, incorrect action is executed (Norman, 1981).

For instance, simple errors in psychomotor performance such as moving a lever forward instead of backward typify slips.

Secondly, lapses are defined as errors that occur as a result of memory failures, and most frequently involve forgetting a procedural step or planned action. For instance, a task, or individual task step, is omitted through a failure in memory processes. Again, it has been suggested that attentional failures, or diversion of attention through distraction, are important mechanisms in the production of lapses (Rizzo, Ferrante, & Bagnara, 1995).

Norman (1981) differentiated between slips and mistakes. Whilst slips reside in the observable actions committed by operators, mistakes reside in the unobservable plans and intentions that are formed by an operator. A mistake is therefore categorized as an inappropriate intention or wrong decision followed by the correct execution of the required action (Norman, 1981). Therefore mistakes originate at the planning level, rather than the execution level, can also be termed planning failures (Reason, 1990).For example, a mistake would be when a driver accelerates when the appropriate action would have been to decelerate or slow down.

Another category of errors is violations. Violations are categorized as any deliberate or erroneous behaviour that deviates from accepted procedures, standards, and rules (Reason, 1997). Violations can be either deliberate or erroneous (Reason, 1997). Deliberate violations occur when an individual deliberately deviates from a set rule or procedure. For example, a driver who is deliberately exceeding the speed limit is committing a deliberate violation. Erroneous or unintentional violations, however, occur when an individual unintentionally deviates from a set of rules or procedures. For example, a driver who is unintentionally exceeding the speed limit (either not comprehending his own vehicle‘s speed and/or not comprehending the current speed limit) is committing an erroneous or unintentional violation.

Various taxonomies of error have been proposed in order to aid the classification or identification of different error types in error analysis. According to Swain & Guttmann (1983), errors are classified into three forms as shown in table 2.1.

Table (2.1): Classification of external error modes as outlined in Swain & Guttmann (1983).

Error type	Description
Error of Omission	Acts which are not carried out.
Error of Commission	Acts that were carried out inadequately, in the wrong sequence, too early or too late, to either too small or too great an extent (or degree), or in the wrong direction (orientation).
Extraneous error	Wrong (unwanted) acts were performed.

Error classification enables safety critical issues to be highlighted and error trends to be identified (Shorrock & Kirwan, 2002). A number of different approaches, theories and models of human error have been proposed. An overview of the human error approaches and models are presented in the literature is provided in the next section.

2.5 Theoretical Approaches to Human Error

According to Dekker (2002), there are two different approaches to human error, the person approach and the system approach. In the person approach, human error is treated as the cause of most accidents. The systems in which people work are assumed to be safe, and the main threat to system safety is the lack of reliability of humans. Progress in safety can be achieved by protecting systems from human unreliability through automation, training, discipline, selection, and proceduralisation (Dekker, 2002). According to system approach however, human error is treated as a symptom of problems within the system. Safety is not inherent within systems, and human error is linked to the tools used, tasks performed, and operating environment (Reason & Hobbs, 2003). In the following sections, an overview of the two approaches is presented, and selected human error models developed from each approach are discussed.

2.5.1 The Person Approach to Human Error

The person approach to human error represent the traditional approach and focuses on the unsafe acts, such as error and procedural violations, that operators make at the sharp end (i.e. the part of the system where human operators perform the activity required for productive tasks e.g. control room operations, flight deck, nurses, technicians etc) of system operation (Reason, 2000). In this approach, errors are seen to emerge from psychological factors such as aberrant mental processes, including forgetfulness, inattention, poor motivation, carelessness, negligence, and recklessness (Reason, 2000). Person-based research typically attempts to identify the nature and frequency of errors within complex systems, the ultimate aim being to propose operator-focused strategies and countermeasures designed to reduce variability in human behaviour. Person-based models of human error include, for example, Rasmussen et al (1981) skill-based, rule-based, and knowledge-based (SRK) Model, and the Generic Error Modelling System (GEMS) (Reason, 1990). A brief summary of these models is presented below.

2.5.1.1 The Skill, Rule, Knowledge –Based (SRK) Model

The SRK model comprises the hierarchical 'step-ladder' process which Rasmussen (1983) believes is associated with actions and decision-making. This model considers that behavior may be classified into three levels: skill-, rule-, and knowledge-based behavior (Rasmussen, 1983). Each of the levels within the SRK framework defines a different level of cognitive control or human action (Vicente, 1999). Skill-based behavior occurs in routine situations that require highly practiced and automatic behavior, and where the operator has only a small amount of conscious control (Kirwan, 1994). According to Vicente (1999), skill-based behavior consists of smooth, automated, and highly integrated patterns of action that are performed without conscious attention.

The second level of behavior, the Rule-based level, occurs when the situation deviates from the normal; but can be dealt with by the operator applying rules that are either stored in memory or are readily available as in the case of emergency procedures

(Kirwan, 1994). According to Vicente (1999), rule-based behavior consists of stored rules derived from procedures, experience, instructions, or previous problem solving activities. Errors at this level of behavior are typically mistakes associated with the misclassification of situations leading to the application of inappropriate rules or the incorrect recall of procedures (Reason, 1990)

The third level of behavior is Knowledge-based behavior, which typically occurs in non-routine situations (i.e. emergency scenarios) where the operator has no known rules to apply and has to use problem solving skills and knowledge of the system characteristics and mechanics in order to achieve task performance (Kirwan, 1994). According to Vicente (1999) knowledge-based behavior consists of deliberate, serial, search based on an explicit representation of the goal and a mental model of the functional properties of the environment. Further, knowledge-based behavior is slow and effortful as it requires conscious, focused attention (Vicente, 1999). Errors at the knowledge-based level of behavior are typically mistakes arising from resource limitations and incomplete or incorrect knowledge (Reason, 1990). The SRK Model is presented in figure 2.2.

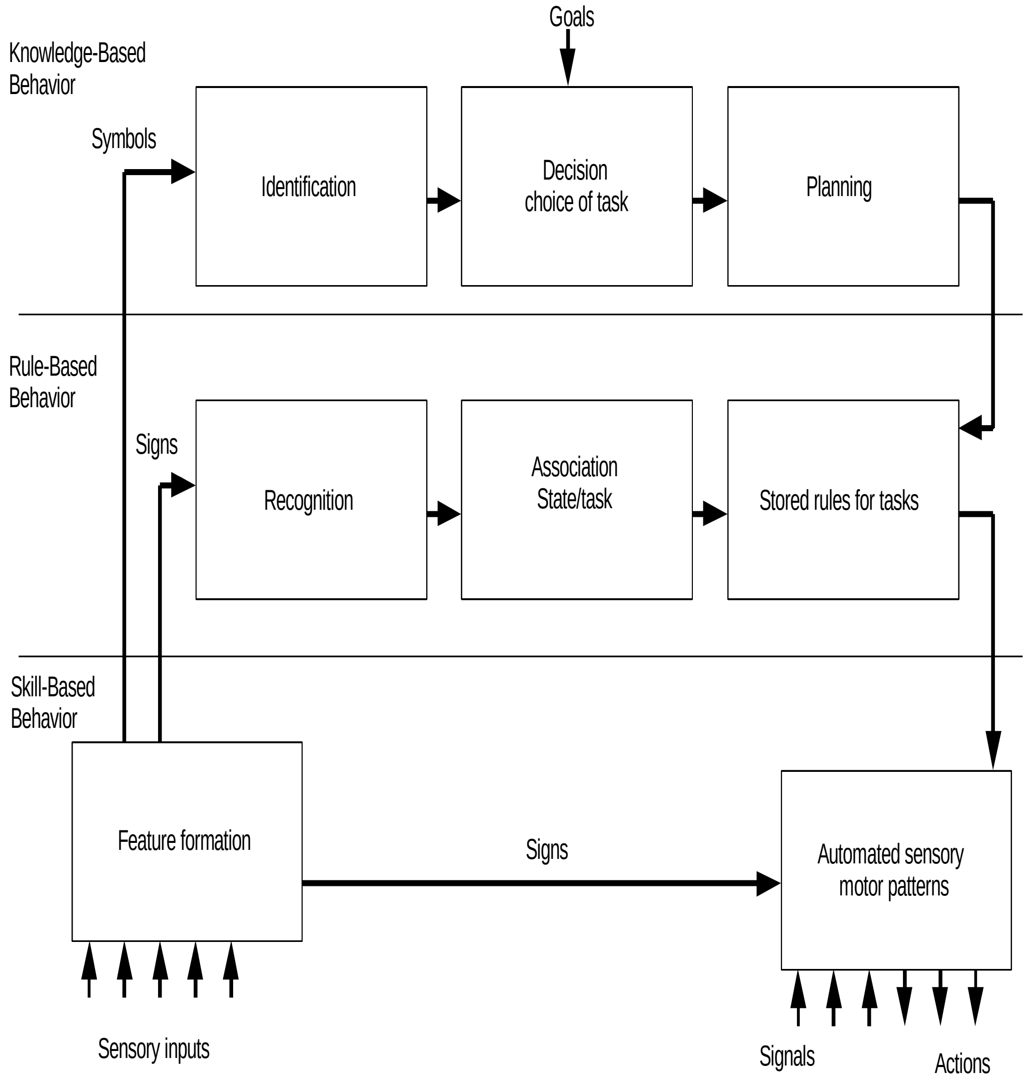

Figure 2.2: Levels of performance; Skill-based, Rule-based, and Knowledge-based behavior (adapted from Rasmussen et al, 1981).

Since the 1980s, Rasmussen‘s widely-used Skill-Rule-Knowledge (SRK) model (Rasmussen 1982, 1983) has become the ‗Industry Standard‘ among error models in a wide variety of settings (Sanderson and Harwood, 1988). Despite its widespread application, the practical value of the SRK model has been questioned (Dougherty, 1990). According to Harwood and Sanderson (1986) and Sanderson and Harwood (1988), some of the criticisms of the SRK model has come from those who see it as a psychological model, rather than a model of the interaction of a person and a task. As

Harwood and Sanderson (1986) point out, the SRK model falls short of the requirements for a scientific model, not least because it is unfalsifiable. Yet in his early writing, Rasmussen made it clear that the SRK was not intended to be a psychological model (Sanderson and Harwood, 1988).

Harwood and Sanderson (1986), and Glendon (1993) have noted that despite the simplicity of the SRK model, it also possesses a looseness that makes is difficult to apply consistently. One reason for this looseness is that the model supposes that cognitive control varies along a continuum. While prototypical examples of actions may fit easily into one of the three levels (Skill, Rule, Knowledge), there will be other occasions where actions cannot be so easily classified (Harwood and Sanderson, 1986; & Glendon, 1993).

A further complication of the SRK model is that, as Rasmussen (1982) and Kirwan (1994) note, a person‘s task performance may involve more than one level of control at once. In particular, automatic or skill-based routines may continue to control behaviour, even when higher level processing becomes necessary. A person engaged in knowledge or rule-based problem solving, for example, could still be engaged in actions under skill-based control.

Despite its limitations, however, the SRK model has provided a common terminology for many human factors practitioners and is currently one of the few tools that enable the task/person interaction to be described in terms which give insight into the cognitive demands of the task (Hobbs and Williamson, 2002).

Based upon the SRK model, Reason (1987 & 1990) developed GEMS for identifying the origins of the different error types from the slips, lapses, mistakes, and violations classification scheme described previously in this chapter. A brief summary of GEMS is presented next.

2.5.1.2 The Generic Error Modelling System (GEMS)

The Generic Error Modelling System (GEMS) was developed through the investigation of human behaviour during catastrophic breakdowns and incidents in nuclear power stations (Barber, 1999). According to GEMS, there are two basic error categories: skill-based slips and lapses (which occur prior to the identification of a problem) at one level, and knowledge-based and rule-based mistakes (arise once a problem is identified) at the other level (Kirwan, 1994). Slips can be categorised as those error in which the intention or plan was correct but the execution of the required action was incorrect (e.g. inadvertently operating the wrong push button) and lapses involve a failure to perform an intended action or forgetting the next action required in a particular sequence (e.g. forgetting to turn off the lights when departing his/her car, even though they fully intended to do so) can be considered unintentional; whereas mistakes (e.g. operating the wrong push button instead of the desired push button) could be thought of as an error of judgment or risk perception, and in either case results in an error of intention. The GEMS model is presented in figure 2.3.

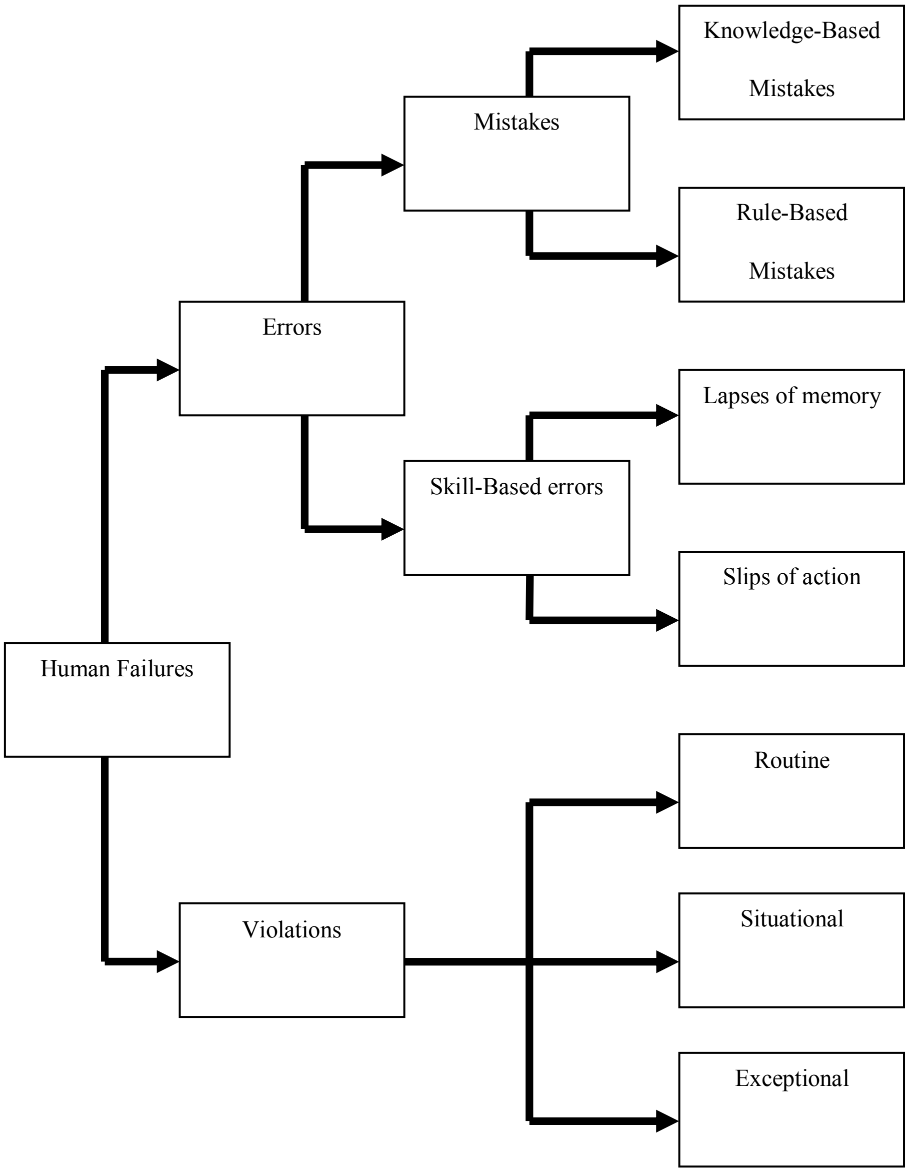

Figure 2.3: The Generic Error Modelling System (GEMS) (adapted from Reason 1990).

The GEMS model assumes that routine performance is controlled by stored patterns of behaviour, and that the operator reacts to programmed behavioural sequences combined with attentional progress checks designed to establish whether actions are running according to plan, and also whether the current plan is adequate to achieve the desired outcome (Reason, 1990). According to GEMS, when confronted with a problem, the operator initially searches for solutions at the rule-based level. If a solution at this level cannot be found, then the operator moves to the knowledge-based level for a solution. Thus, the GEMS proposes that the rule-based problem solving will always be attempted first (Reason, 1990). If successful (the rule-based cycle may be repeated several times until a solution is derived) the operator then returns to the skill-based level of behaviour. The operator only switches to the knowledge-based level upon realization that none of the rule-based solution is appropriate or adequate for the problem in question. Once a solution is identified at the knowledge-based level, a new set of skill-based routines is required. According to Reason (1990), this involves borrowing routines from activities via rapid switch between the skill-based and rule-based levels. This continues until routine performance is resumed.

The model gives guidance on the types of error shaping factors which are likely to apply to the above categories of error, such as mind-set, overconfidence, an incomplete mental models, etc. According to Brostoff & Sasse (2001), however, this guidance is quite limited and relies, ultimately on the insight and expertise of the individuals who apply this model within a particular organization. Another criticism of the GEMS model is that it needs to determine not only what the types of error that exist (e.g. error of omission, such as failing to respond to an alarm), but also what the internal human malfunctions would be (e.g. detection failure), and the underlying factors of human malfunctions (e.g. failing to realize the situation has deviated from routine) (Kirwan, 1994).

Both the SRK (Rasmussen, 1982 &1983) and the GEMS (Reason, 1990) are examples of person-based models that attempt to classify human error according to the level of cognitive control which was guiding behaviour at the time of the error. The person approach is heavily criticized for its contribution to individualistic blame culture within organizations (Reason, 1997 & 2000); and that the resultant error countermeasures (e.g. poster campaigns, new procedures, disciplinary actions, threat of litigation, retraining, blaming and shaming) (Reason, 2000) are focused specifically upon human behaviour, rather than the inadequate conditions in the wider system (Salmon, Lenne, Stanton, Jenkins, and Walker; 2010).

2.5.2 The System Approach to Human Error

The other approach to human error is the system approach. This approach treats error as a system failure, rather than an individual operator's failure (Reason, 1990; and Rasmussen, 1997). Unlike the person approach, human error is no longer seen as the primary cause of accidents, rather it is considered as a consequence of latent failures created by decisions and actions at all levels of the organization (e.g. management, and operators) (Salmon, Lenne, Stanton, Jenkins, and Walker; 2010). The system approach has received increased attention in recent years, and is currently being adopted as an approach to error and error management in various domains such as road transport (Stanton & Salmon, 2009), healthcare (Reason, 2008), nuclear process control, and aviation (Salmon, Regan, & Johnston, 2005). According to Salmon, Regan, and Johnston (2005) there are a number of advantages associated with the system approach to error, namely: it considers the latent conditions throughout the system that contribute to the errors made by operators; it removes the apportioning of potential blame to individual operators within the system; it recognizes the fallible nature of humans and accepts that errors will occur without making them the focus; it promotes the development of error tolerance within the system; and it promotes the developments of appropriate countermeasures that are designed to treat both the latent failures within the system and the active failures made by the operator.

Latent failures are those conditions residing throughout the system that may contribute to the breach of system defences. Examples of latent failures within a system include poor design, inadequate supervision, manufacturing defects, maintenance failures, inadequate training, and inappropriate or ill-defined procedures (Salmon, Regan, & Johnston; 2005). According to Reason (1997) latent failures are present in all systems, and are typically the result of senior-level decisions made by designers, manufacturers, and organizational managers. These failures may lie dormant for a significant period of time without any adverse effect before they combine with local conditions and active failures to cause an accident (Reason, 1997). Active failures, on the other hand, represent those errors that are committed by human operators that have an immediate impact on system safety. Active failures take a variety of forms such as slips, lapses, mistakes, and procedural violations (Reason, 1990). According to Reason (2000) active failures have a direct and usually short lived impact on the integrity of the defences. At Chernobyl, for example, the operator wrongly violated plant procedures and switched off successive safety systems, thus creating the immediate trigger for the catastrophic explosion in the core of the reactor.

Although various system-based models exist (Leveson, 2004; O'Hare, 2000; and Rasmussen, 1997), the system-based model of human error and causation (Reason, 1990) or the 'Swiss Cheese Model' as it is better known (Salmon, Regan, & Johnston, 2005) is probably the most influential and widely recognized. It focuses on the interaction between latent failures and unsafe acts and their contribution to organizational accidents (Salmon, Lenne, Stanton, Jenkins, and Walker, 2010)

2.5.2.1The Swiss Cheese Model

Reason (1990) describes four levels of human failure, each influencing the next. An adaptation of the Swiss cheese model is presented in figure 2.4. Working backwards in time from the accident, the first level depicts those *unsafe acts* (active failures) of operators that ultimately led to the accident. This level is where most accident investigators have focused their efforts and consequently, where most contributing factors are uncovered. After all, it is typically the actions or inactions of operators that are directly linked to the accident. The second level that Reason describes in his model is the preconditions for unsafe acts. In this level two major subdivisions are identified, substandard conditions of operators and the substandard practices they undertake. The third level of human failure is the unsafe supervision. In this level, four categories were included: inadequate supervision, planned inappropriate operations, failure to correct a known problem, and supervisory violations (Shappell & Wiegmann, 2000b). The last level of failure modes is the organizational influences. In this level, fallible decisions of upper management directly affect supervisory practices, as well as the conditions and actions of operators. These organizational errors often go unnoticed by safety professionals, due in large to the lack of a clear framework from which to investigate them. The most latent failures related to this level are resource management, organizational climate, and operational processes (Shappell & Wiegmann, 2000b).

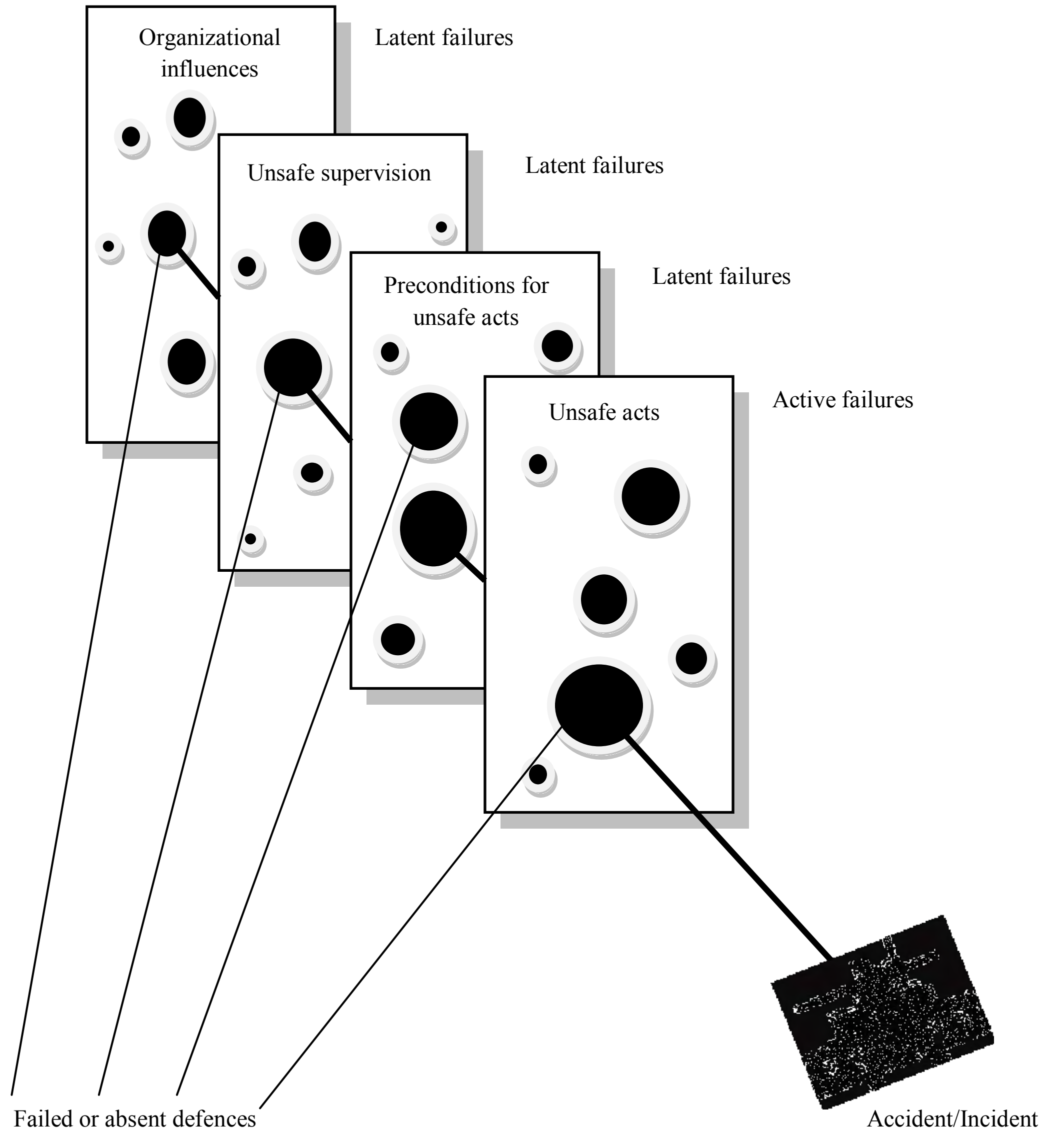

Figure 2.4: Reason's "Swiss Cheese" Model of human error that illustrates an event involving the complete penetration of the system's defences, barriers, and safeguards (adapted from Reason, 1990).

As mentioned earlier, Reason has illustrated how organization-related defences and latent conditions affect safety using the analogy of slices of Swiss cheese that are lined up against each other. The cheese slices represent organizational-related defences against the hazards of unsafe acts, while unforeseen deficiencies within the system (such as managerial decisions, line managers‘ actions, and unsafe acts) resemble holes in the Swiss cheese. If the Swiss cheese slices were placed one against the other, the holes will unlikely to line up in sequence. Organizational-related defences, portrayed as portions of the cheese, would block an error from penetrating. However, should the deficiencies (holes) line up uniquely, an active error could breach the system, an unsafe act would not be prevented from affecting the system, and an accident or incident could result (Strauch, 2004).

Reason‘s distinction between the active operational errors and the latent organizational conditions effectively makes human error a contributory factor in 100% of accidents/incidents (Young, Shorrock, and Faulkner, 2005). Reason asserts that these latent conditions are the true causes of disasters (typically the operator merely inherits a defective system) and active errors are seen as the consequences, rather than the causes of the accident/incident chain.

Despite the model's appeal it does have a number of distinct flaws. Firstly, the model has been criticised for the tenacious search for latent conditions leading to the accident/incident. Whilst the importance of analysing human factors throughout the accident/incident sequence is not in question, the dogmatic and rigid adherence on identifying the latent conditions could and should be challenged in cases where active failures have played a major roll (Young, Shorrock, Faulkner, 2005). Reason himself was the first to challenge the use of the Swiss Cheese Model on two occasions, once when he warned that –the pendulum may have swung too far in our present attempts to track down possible errors and their contributing factors that are widely separated in both time and place from the events themselves” (Reason, 1997); and the second when he argued that remote factors are –out of the control of system managers, and mostly intractable” (Reason, 2003 a & b). Secondly, the model lacks a clear definition of different latent failures residing at each of the levels within the model and also lacks a taxonomy in the identification of the errors and violations involved in accident/incident scenarios (Salmon, Lenne, Stanton, Jenkins, and Walker; 2010). According to Wiegmann & Shappell (2003) this has led to difficulties in applying the model in real world. Finally, the model is descriptive rather than analytical (Salmon, Lenne, Stanton, Jenkins, and Walker; 2010).

The Swiss cheese model remains the dominant model of human error within the literature (Salmon, Lenne, Stanton, Jenkins, and Walker; 2010), although other system-based models of error have been proposed. For example, the Bow-tie model (developed by Shell to meet the requirements for risk assessment while integrating the understanding of how accidents happen derived from the Swiss cheese model) (van der Graaf, Milne, and Primrose; 1996).

2.5.2.2 The Bow-Tie Model

The Bow-tie model is a structured approach, used for the probabilistic assessment of risks of industrial accidents (Jacinto & Silva, 2009) in which causes of hazards are linked directly to the possible consequences in a single model (Federal Aviation

Administration (FAA), 2004). Basically, the model can be considered as an approach that has both proactive and reactive elements and that systematically works through the hazard and its management. Indeed, all the causes are clearly depicted in the Bow-tie diagram, as shown in the figure 2.5.

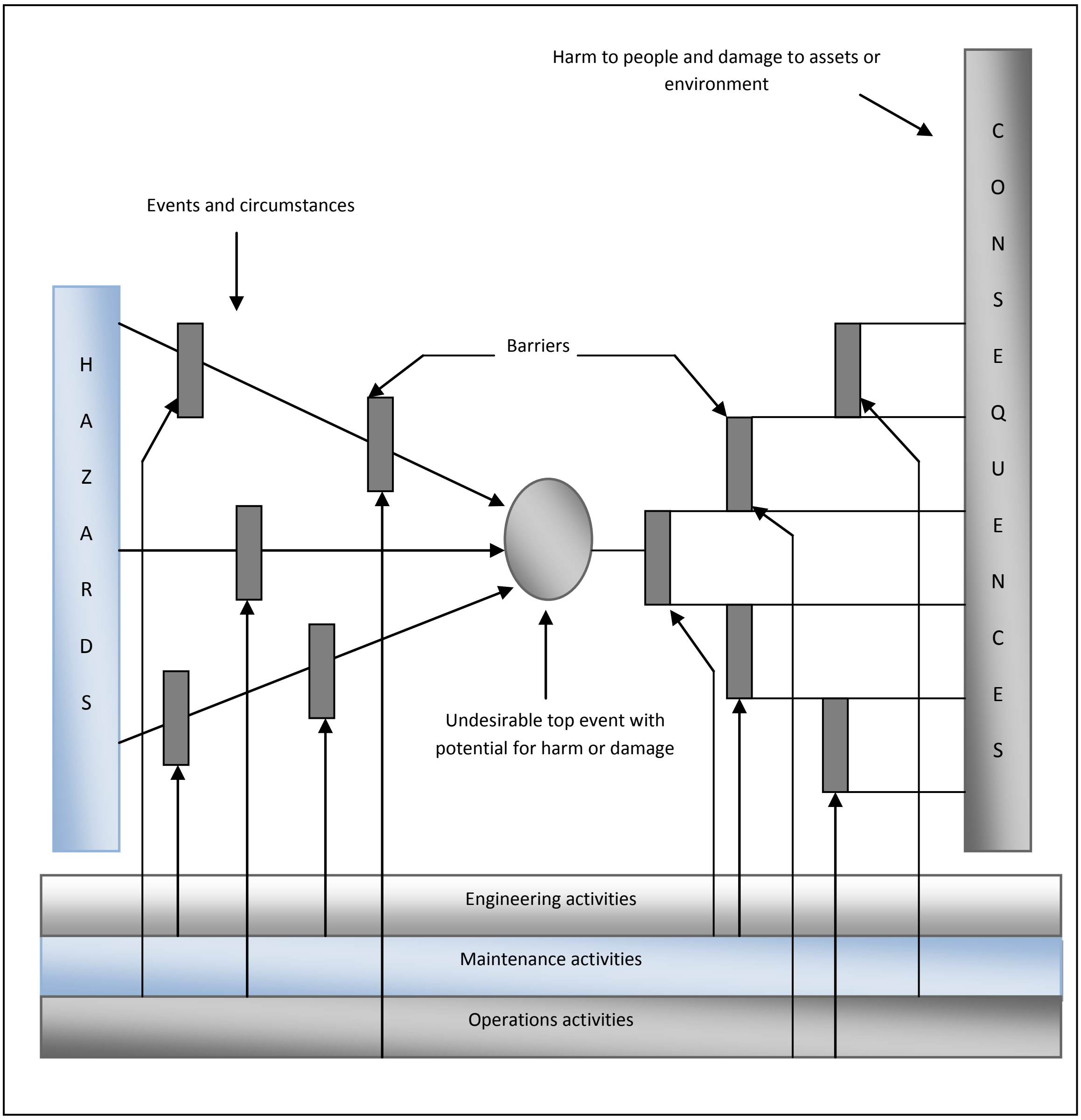

Figure 2.5: The Bow-Tie Model (adapted from Hudson & Guchelaar, 2003)

The left-hand side includes a list of potential hazards leading to an undesirable event, through different pathways, to specific ‗top event' or accident type, whilst the right-hand side includes the different consequences of such event (Hudson & Guchelaar, 2003). The left-hand side can be viewed as a fault tree in which the different branches identify the possible causes of the ‗top event' (i.e. the possible links between the hazard and the accident type) (Jacinto & Silva, 2009). The right-hand side, on the other hand, uses the event tree analysis philosophy to identify the possible consequences (Jacinto & Silva, 2009). This analysis is used to model the system state and worst credible effect of a hazard, taking into account mitigations that could be incorporated to break an accident sequence in the event the hazard occurs (FAA, 2004). As shown in figure (2.5), the critical concepts in the bow-tie model are ‗hazards', ‗top events', and ―consequences" with barriers interposed to ensure that hazards are not allowed the chance to turn into consequences (Hudson & Guchelaar, 2003). The ‗top event' is a specific undesirable type of event with significant potential for undesirable consequences, linking the potential sequence between hazard and consequences. The ‗top event' is inserted within the sequence of barriers similar to the Swiss cheese model, providing a specific event, that can be used by Probabilistic Risk Assessment (PRA), while stressing the barriers that can be interpolated to either prevent ‗top events' from happening or, after the event had occurred, ameliorating the consequences. Each barrier relies on one or more activities, engineering or operations, to ensure the barrier presence and effectiveness. Barriers can be hard, such as designs that make failure less likely, or soft, such as procedures and individual competence (Hudson & Guchelaar, 2003).

An example of a top event in aviation is spillage of a toxic /hazardous substance. The barriers to prevent the toxic/hazardous substance might be chemical handling procedures, and container transport procedures. Recovery measures might be neutralising the toxic /hazardous substance, Personal Protective Equipment (PPE), emergency evacuation procedures, and water spray. Failure to barriers could lead to the toxic /hazardous substance spillage in this case; the failure of the recovery measures could lead to severe consequences such as serious injuries or human lives.

Models such as the ―Bow-Tie" are based on three assumptions: the system under investigation allows analytic reduction, i.e. it can be decomposed into separately functioning components, without affecting the analysis results of the functioning of the overall system; the components or events in the system are not subject to feedback loops or other non-linear interactions; and the interactions between components in the system are simple enough to be considered separate from the behaviour of the system as a whole (Leveson, 2002). These assumptions could be a limitation of the Bow-Tie model; because in practice these assumptions do not hold for many of the (socio-technical) systems (van Meer, 2010). Socio-technical theory implies that human operators and social institutions are integral parts of the technical system, and that the attainment of organizational objectives are not met by the optimisation of the technical system by itself, but by the joint optimisation of both the technical and the social aspects (Trist & Bamforth, 1951; cited in Qureshi, 2008).

Another limitation of the bow-tie model is that, because of its probabilistic feature, it is less likely applicable or viable in individual organizations, in which the historic accident information is not enough to derive data for probabilistic assessments (Jacinto and Silva, 2009). This is because the quantification of the bow-tie diagram is a complex task: it not only requires reliable data on the frequency of all events, but the failure probabilities of the barriers need to be known as well. This type of assessment also calls for the involvement of highly specialised individuals from different areas of expertise (Jacinto & Silva, 2009). For all these reasons, it is unlikely that individual organizations will be able to apply the bow-tie model utilizing the quantitative feature. Despite this limitation, the model constitutes an attractive basis to support quantitative analysis (Jacinto & Silva, 2009).This is because the Bow-Tie Model provides simple diagrammatic representation of the risk scenarios; the Model displays the causal pathways, outcomes and controls in a manner that emphasise the linkages between them, showing the relative importance of the risk controls and helping to identify vulnerable pathways. In addition to identifying the internal organisational interfaces, the Bow-Tie Model helps show the interfaces with external agencies and where these agencies impact the specific organisation utilising the Bow-tie Model for the assessment of their organisational risks.

Both Hollnagel (1993) and Dekker (2002) studied human error and human contribution to accidents. One view, recently dubbed ‗the old view‘‘ (AMA, 1998; Reason, 2000), sees human error as a cause of failure. The other view, called ‗the new view,‘‘ sees human error not as a cause, but as a symptom of failure (AMA, 1998; Hoffman & Woods, 2000; Rasmussen & Batstone, 1989; Reason, 2000; Woods, Johannesen, Cook, & Sarter, 1994). In the new view, human error is systematically connected to features of people, tools, tasks, and operating environment. Progress on safety comes from understanding and influencing these connections (Dekker, 2002).

The old view (The Person Approach) models (e.g., SRK and GEMS) have a high analytic capability, but are not very good at converting field data to useful and practical tools for prediction of possible erroneous actions. The analytic capability derives mainly from the large number of general statements relating to "error" tendencies that are typically part of such models. The validity of predictions based on these models is, however, unclear (Marsden & Hollnagel, 1996). Experience shows that actions frequently fail when they should be well within the user's performance capability. Conversely, it is easy to document instances where user performance has been quite accurate for tasks where the model would predict failure (Neisser, 1982).

The new view (The System Approach) models, on the other hand, provide a better approach for characterising the interactions between information technology and users (Dekker, 2003). These models are particularly strong in their technical content because they are based on viable and well articulated descriptions of human action rather than of covert mental processes. Moreover, the emphasis on the contextual determination of human behaviour is clearly better as opposed to past experience and prior knowledge. The new view also affords a comparatively high level of predictive capability in a model that can be converted into practical tools for investigation of erroneous actions (Marsden & Hollnagel, 1996).

The purpose of studying human error is not to find out where people went wrong. It is to find out why their assessments and actions made sense to them at the time. It is not to say what people failed to do. It is to understand why they did what they did, by probing the systematic, lawful connections between their assessments and actions, and the tools, tasks and environment that surrounded them (Dekker, 2003).

Many studies have identified human errors contributing to accidents/incidents in domains such as nuclear power, chemical processing, rail, and aviation (Cacciabue, 2005); (Shorrock & Kirwan, 1999); (Huang & Zhang, 1998); (Kirwan, 1997b); and (Reason, 1990). In the following section an attempt will be made to identify the nature of maintenance error in the aviation domain.

2.6 Human Error in Aviation Maintenance

Human error in aviation accidents/incidents have been widely investigated over the last two decades. One cause of fatal accidents is human error in aviation maintenance. For the purpose of studying human error in aviation, maintenance error is defined as the action or inaction of an aircraft maintenance technician or inspector that leads to an unexpected aircraft discrepancy (physical degradation or failure) (Graeber and Marx, 1993). In 2003 the International Air Transport Association (IATA) reported that maintenance errors initiated the accident chain in 26% of 92 accidents (Hackworth et al., 2007). Maintenance errors – usually latent failures that have a delayed effect (Lind, 2008; and Reason, 1990) – are responsible for an estimated 20 – 30% of engine and aircraft equipment in-flight shutdowns (Hackworth et al., 2007). Maintenance errors may lead to flight cancellations, delays in aircraft availability, engine-shutdowns during flight, maintenance rework, damage to aircraft or equipment, and injury to maintenance personnel.

According to the literature, different types of maintenance errors exist in aviation maintenance. For example, the United Kingdom Civil Aviation Authority (UK CAA) conducted a study to analyse the maintenance error related data captured and stored under the requirements of the Mandatory Occurrence Reporting (MOR) scheme, with the objective of identifying common causes or factors, addressing these causes and factors, and thereby reducing the associated safety risks (UK CAA, 2009). A review of the 3284 MOR data set categorized maintenance errors into:

- Maintenance control errors (An error attributed to an ineffective maintenance control system such as configuration control, task scheduling, and incorrect or conflicting airworthiness data);

- Incomplete maintenance (An error where the prescribed maintenance activity is prematurely terminated such as not tightening pipes or screws at the end of a task or omitting wire locking); and

- Incorrect maintenance action (An error where maintenance procedures were completed but did not achieve its aim through the actions or omissions of the technician such as cross connections, damage to components, and non-adherence to documentation) (UK CAA, 2009).

In 1998, the Australian Transport Safety Bureau (ATSB) distributed a safety survey to licensed Aircraft Maintenance Engineers (LAMEs) in Australia. The survey was designed to identify safety issues in maintenance, with particular emphases on human factors (Hobbs & Williamson, 1998). Of the 4600 surveys distributed, 1359 were returned, representing a response rate of 29%. 610 respondents used the survey to report a safety occurrence. The most common outcomes for airline related maintenance occurrences were systems operated unsafely (for example, the activation of systems such as flaps and landing gears when it was not safe to do so, either because personnel or equipment were in the vicinity, or the system was not properly prepared for activation); towing events (a safety occurrence which occurred while an aircraft was under tow such as damage to towing vehicle or aircraft contacts a stationary structure or equipment); and incomplete installation (for example, a connection may have been left finger tight rather than correctly tightened) (Hobbs & Williamson, 1998). On the other hand, the most common outcomes of non-airline occurrences were incorrect assembly or orientation (for example, a hydraulic pump was installed or assembled incorrectly); incomplete installation; and technicians contacting hazards which caused, or had the potential to cause injury such as electric shocks, falls and exposure to aircraft fluids or other chemicals) (Hobbs & Williamson, 1998).

In1994-1995 a field test was conducted by Boeing with nine maintenance organizations (eight airlines and one repair station) (Boeing, 1995). The purpose of this field test was to evaluate the usefulness of the Maintenance Error Decision Aid (MEDA) to maintenance organizations. According to this field test, the types of errors that led to the investigated operational events included: improper installation (26 errors), improper fault isolation/inspection/testing (11 errors), improper servicing (9 errors), improper/incomplete repair (3 errors), errors leading to Foreign Object Damage (FOD) (2 errors), errors leading to personal injury (1 error), and other errors (17 errors). Of the 17 errors, 8 were related to that caused by ground damage (Rankin, 2000).

To reduce human errors and improve human performance, the effects of Performance Shaping Factors (PSFs) or contributing factors (during the maintenance tasks) need to be identified. Many studies have noted that PSFs affect the occurrence of human error (Kirwan, 1998a; Kirwan. 1998b). Swain and Guttman (1983) developed situational variables for PSFs using expert opinions and by considering the state and importance of various factors that determine performance. They defined three major types of PSFs: external PSFs, including situational characteristics, job and task instructions, and task and equipment characteristics; internal PSFs, including previous training, personality, intelligence, motivation, attitude, gender differences, and physical conditions of the person; and stressor PSFs. Stressor PSFs may include psychological stressors that directly affect mental stress (e.g., death or illness in the family, task speed, duration of stress, high risk, and distractions); and physiological stressors that directly affect physical stress (e.g., fatigue, poor physical condition, temperature extremes, radiation, vibration, and disruption rhythm.) (Rankin, Hibit, Allen & Sargent; 2000).

In aviation maintenance tasks, PSFs also encapsulate most of the contributors to human error (Boring and Blackman, 2007; Broberg and Kolaczkowski, 2007; and Saurin et al., 2008). Endsley and Robertson (2000) investigated factors related to situation awareness in aviation maintenance teams at a major airline. Based on this investigation, they recommended a training program to improve situation awareness in aircraft maintenance at both the individual and the team levels. Some studies have linked mental workload to human performance (O'Neal and Bishop, 2010; DiDomenico and Nussbaum, 2005; and Xie and Salvendy, 2000). The European Joint Aviation Authority (JAA) showed that error rates may increase when the technicians experience overload (when the technician is overworked). This is a particular feature of some maintenance areas such as line maintenance (e.g. aircraft towing, pre-flight inspections, post flight inspections, servicing, removal and installation of components etc.) and base maintenance (e.g. phase inspections, assembly and disassembly of components, calibration etc.) in military bases.(JAA a & b, 2000; RBAF 66-1, 2000).

2.6.1 Human Error in Military Aviation Maintenance

Assessing the cause of the accident is central to preventing them, or reducing their likelihood in the future. Many factors may contribute to aviation accidents. Human error, mechanical failures, weather, and maintenance problems are some of the factors that can by themselves, or in conjunction, cause aviation accidents/incidents. The Defence Science Board (DSB) – the US Department of Defence (DoD) premiere body of scientific and technical advisor- found in 1997 that human performance was a contributing factor in over 70% of all Class A accidents (An accident is categorized as Class A if: the total cost of damage to government and other property is $1 million or more; a DoD aircraft is destroyed; or an injury and/or occupational illness results in a fatality or permanent total disability) (DSB, 1997). As the following table suggests, human error (at least for the U.S Navy and Marine Corps) may have had an even stronger influence on aviation accidents in the time period 1997-2001(Bolkcom, 2002a).

Table (2.2): US Navy/US Marine Corp Class A Accidents Contributing Factors (Fiscal Years 1997-2001) (adapted from Bolkcom, 2002).

Factor	Number of events	Rate	Percentage
Human Error	114	1.52	86
Supervisory	91	1.21	69
Aircrew	88	1.17	67
Material Failures	51	0.68	39
Maintenance	18	0.24	14
Facilities	13	0.17	10

According to the US DoD, human performance appears to affect all four military services more or less equally. The General Accounting Office (GAO) found that "during fiscal years (FY) 1994-1995, human error was a factor in 71% of Air Force accidents, 76% of Army accidents, 74% of US Navy/US Marine Corp accidents (GAO, 1997).

The U.S Coast Guard (USCG) detailed some of the factors that lead to maintenance related accidents. In 2001, for example, 89% of Coast Guard accidents involved incomplete, improperly followed, inappropriate or unavailable procedures. 55% of accidents involved inattention, complacency, or lack of awareness. 25% of accidents involved incomplete checklists and poor communication. Workload, feeling rushed or having lack of resources was mentioned in almost 40% of the Coast Guard accidents. Inexperience, lack of training, and inappropriate staffing were also factors in 40% of the accidents in 2001 (USCG, 2001).

Assessing accident data may provide some tentative observations regarding military aviation safety. It would also be useful to compare safety and accident rates between military units such as those in the United States (US) and that of foreign military units. Unfortunately, such comparisons are difficult to make. Foreign governments do not always make safety and accident information publically available. When they do, information often not reported in ways that foster comparison. For example, often a total number of accidents are provided but not flight hours or maintenance man hours. Alternatively, accidents are reported, but severity classifications are not included, or are not comparable to US accident classifications (Bolkcom, 2002a). The most valid safety comparisons that can be made with US air forces are likely with the air forces and maintenance units of other industrialized countries (e.g. NATO Countries, Australia, and Canada). These countries tend to fly the same aircraft as the US, and they have the resources to train personnel and maintain equipment at comparable levels. It is generally recognized that US accident rates are superior to those found in less industrialized countries, and at least comparable to those of other industrialized countries (Bolkcom, 2002b).

For the RBAF, reviewing the US DoD safety database may be, in many ways, more helpful than reviewing civil safety databases. The Royal Bahraini Air Force (RBAF) flies many of the same types of aircraft as the DoD fighter and helicopter aircraft and under conditions that may be similar to the US combat and training conditions. Also because the RBAF trains with and is closely associated with the US Air Force, the RBAF may share some of the US military aviation culture and operating procedures. For these reasons we predict that our research will reveal similarities between the data collected from the RBAF and those reviewed in the literature.

The literature also indicates that there is a large body of information on the different types of errors that are committed in complex, socio-technical systems (e.g., nuclear power plants, healthcare, aviation, etc.), the frequency with which these errors are made, and the consequences of the different types of errors (Hobbs, 2008; Reason, 1990; & Norman 1981). This information is typically used to develop countermeasures designed to reduce future error occurrences. Despite these countermeasures, the literature also indicates that individuals, regardless of skill, experience, and training continue to make error during task performance and that these errors continue to impact system safety in complex socio-technical systems (Reason & Hobbs, 2006). Consequently, further measures are required to reduce, mitigate and manage human error in such domains. So called error management programs are employed for this purpose in safety-critical systems and use formal methods to develop deeper understanding of the nature of, and contributing factors surrounding, error occurrences in a particular system (Salmon, Regan, & Johnston; 2005). The ultimate goals of such programs are, through a variety of means, the reduction, eradication, and management or mitigation of errors and their consequences within the system in question (Reason & Hobbs, 2006). In our research project, data would be collected (from several sources in the RBAF) and analysed to identify the most prominent types of errors and their associated factors. Based on the findings of our research project we would develop a tool that has the potential to reduce and manage maintenance errors and the factors leading to these errors.

2.7 Human Error Management

Error Management (EM) is defined as “the understanding of the nature and the context of error, changing the conditions that induce error, determining the behaviours that prevent and mitigate error, and training personnel in their use” (Helmreich, 2000). EM has two components: error prevention and error containment (Reason, 2005). While error prevention strategies include the identification and reduction/elimination of errors, user-friendly equipment, training, briefings and de-briefings; error containment involves the use of strategies designed to limit the consequences of those errors that do occur. These strategies may include, for example, the reduction of error vulnerability of task and/or task elements; the determination, assessment, and elimination of error-producing factors within the workplace; the identification of organizational contributing factors that create error within the individual, team, task, and workplace; and enhancing error detection (Reason, 1997).

Despite the widespread implementation of EM programs in different domains, Reason (1997) suggests that the implementation of principled and comprehensive error management programs is very rare. Reason (1997) also suggests that most error management efforts are reactive in nature, focus upon active failures and on individuals who committed errors, and rely heavily on disciplinary sanctions. Instead, Reason (1997) suggests that an effective error management program should be proactive and focuses on latent conditions residing in the system, and focuses on the organizational and environmental contributing factors.

EM programs employ a variety of different approaches, methodologies, and techniques to address human error. The literature review indicated that there are several techniques related to error management in complex systems. For example, Reason (1997) cites a wide selection of EM related techniques, including training, procedures, rules and regulations, Total Quality Management (TQM), human error identification, and Crew Resource Management (CRM). The type of EM approach employed depends on the domain, system, and organization involved (Salmon, Regan, & Johnston; 2005). Normally a mixture of approaches are used, but Reason (2005) points out, that there is no single best approach to error management and the mixture of practices, techniques, and measures should be determined on the basis of the culture in a particular organization. Error management techniques are required for each of the different components within a particular system including the person, the team, the task, the workplace, the organization, and the system itself (Reason, 2005). The following sections present an overview of selected error management approaches used in the domain of aviation maintenance.

2.7.1 Accident/Incident Investigation

In recent years, several investigation systems have been developed specifically for aviation maintenance. One of these systems is the Boeing's Maintenance Error Decision Aid (MEDA). MEDA is an aviation maintenance error investigation technique developed by Boeing in collaboration with the Federal Aviation Administration (FAA) and Galaxy Scientific Corporation (Reason, 1997). The MEDA approach is used to identify the contributory factors involved in maintenance error accidents/incidents and to aid the development of countermeasures designed to reduce maintenance error occurrences (Hobbs, 2008). The MEDA approach comprises of five phases (Appendix A). Phase one is used to gather general information regarding the accident/incident under analysis, including the airline and aircraft involved in the occurrence, type of maintenance (line or base maintenance), and the time and date of the occurrence. Phase two is used to describe the nature of the event under analysis. For example, operations process event (flight delay, engine in-flight shutdown, diversion, etc.), aircraft damage event, personal injury event, etc. Phase three involves the identification of the nature of maintenance errors/failures involved in the occurrence under analysis. The following major categories are used: installation failure; servicing failure; repair failure; fault isolation/test/inspection failure; foreign object damage (FOD); airplane/equipment damage; personal injury; and other types of errors/failures. Phase four involves identifying the factors that contributed to the accident/incident under analysis. In order to facilitate this, the analyst is provided with a contributing factors checklist. This checklist is then completed for each of the errors/failures identified in phase three of the MEDA results form. The contributing factors include information (e.g., work cards, maintenance manual, service bulletins, etc); equipment or tools (e.g., unsafe, not available, inappropriate for the task, etc); aircraft design and configuration and parts (e.g., inaccessible, not used, not available, etc.); job or task (e.g., repetitive/monotonous, new task, confusing, etc); technical knowledge and skills (e.g., task knowledge, task planning, English language proficiency, etc); individual performance (e.g., memory lapse, time pressure, personal events, etc); environment and facilities (e.g., lighting, heat, hazardous or toxic substances, etc); organizational environment (e.g., quality of support from technical organizations, not enough staff, organizational policies, etc); supervision (e.g., planning and organization of tasks, prioritization of work, amount of supervision, etc); and communication (e.g., between technicians, between shifts, between flight crew and maintenance, etc.).

The final phase of the MEDA approach identifies the strategies required to prevent future occurrences. This phase comprises of two stages; the first stage involves determining whether or not there were any procedures, processes, and policies already in existence that should have prevented the accident/incident from occurring in the first place, whereas the second stage is used to identify the corrective actions or measures that should be taken to prevent the recurrence of the accident/incident (Rankin, Hibit, Allen, & Sargent; 2000).

According to Boeing and the United States Air Transport Association (ATA) members (1995), benefits from MEDA implementation include revised and improved maintenance and airline work procedures, reductions in aircraft damage through improved towing procedures, improved line maintenance work load planning and a reduction in on-the-job accidents/incidents (Boeing/ATA, 1995).

Another accident/incident investigation approach is the Aircraft Dispatch and Maintenance Safety System (ADAMS). This approach was developed in Europe by a consortium of maintenance organizations and researchers to study the nature and extent of human factors in aircraft maintenance (Hobbs, 2008; and Van Avermaete and Hakkeling-Mesland, 2001). The ADAMS project can be considered the first major research effort within Europe studying maintenance human factors (Van Avermaete and Hakkeling-Mesland, 2001). In the first phase of the ADAMS project, the team investigated issues like procedural compliance, organizational aspects, and the role of modern technology. A comprehensive taxonomy was developed to identify the potential contributory factors to an accident. In the second phase the project focused on some potential improvements to aircraft maintenance in the civil aviation domain (Van Avermaete and Hakkeling-Mesland, 2001). Based on this project an error reporting form was developed and a curriculum for maintenance human factors training was specified (Van Avermaete and Hakkeling-Mesland, 2001). In common with MEDA, the Aircraft Dispatch and Maintenance Safety system (ADAMS) include a large list of consequence, maintenance error, and contributing factor options (Ghobbar, Boutahri & Curran, 2009). ADAMS provides even more options of contributing factors than MEDA in all sections. In addition, ADAMS has separate sections for coding the so called internal errors. Internal errors describe how the technician's performance failed to achieve the desired outcome (Ghobbar, Boutahri & Curran, 2009). Internal errors can better enable the consideration of measures to reduce or mitigate errors, because the internal cause of the error can be analysed (Shorrock, 2002; and McDonald, 2001). Examples of internal error in the ADAMS Form are memory failure (leaving a rag in the fuel tank), rule based error (not checking the position of the flap lever before pushing in a cockpit circuit breaker that provided electrical power to a hydraulic pump), or knowledge based error (misinterpreting the maintenance manual and installing a part upside down). The ADAMS system provides the investigator with a choice of approximately 100 contributing factors covering the task, the work environment, the organization, and the technician‘s physical and mental condition (Russell, Bacchi, Perassi & Cromie; 1998).

In addition to the MEDA and the ADAMS approaches, military organizations have also developed accident/incident investigation systems to be used in the military domain. For example, the Human Factors Analysis and Classification System (HFACS) was developed by the Naval Safety Centre to analyse human errors contributing to Naval Aviation accidents (Wiegmann and Shappell, 2003). The HFACS incorporates feature of Heinrich‘s ―Domino Theory" (Heinrich, Petersen, & Roos, 1980) and Edwards‘s ―SHEL Model" (Hawkin, 1993) as well as Reason‘s ―Generic Error Modelling System (GEMS)" (Schmidt, Lawson, & Figlock, 1998).The HFACS framework is presented in figure 2.6.

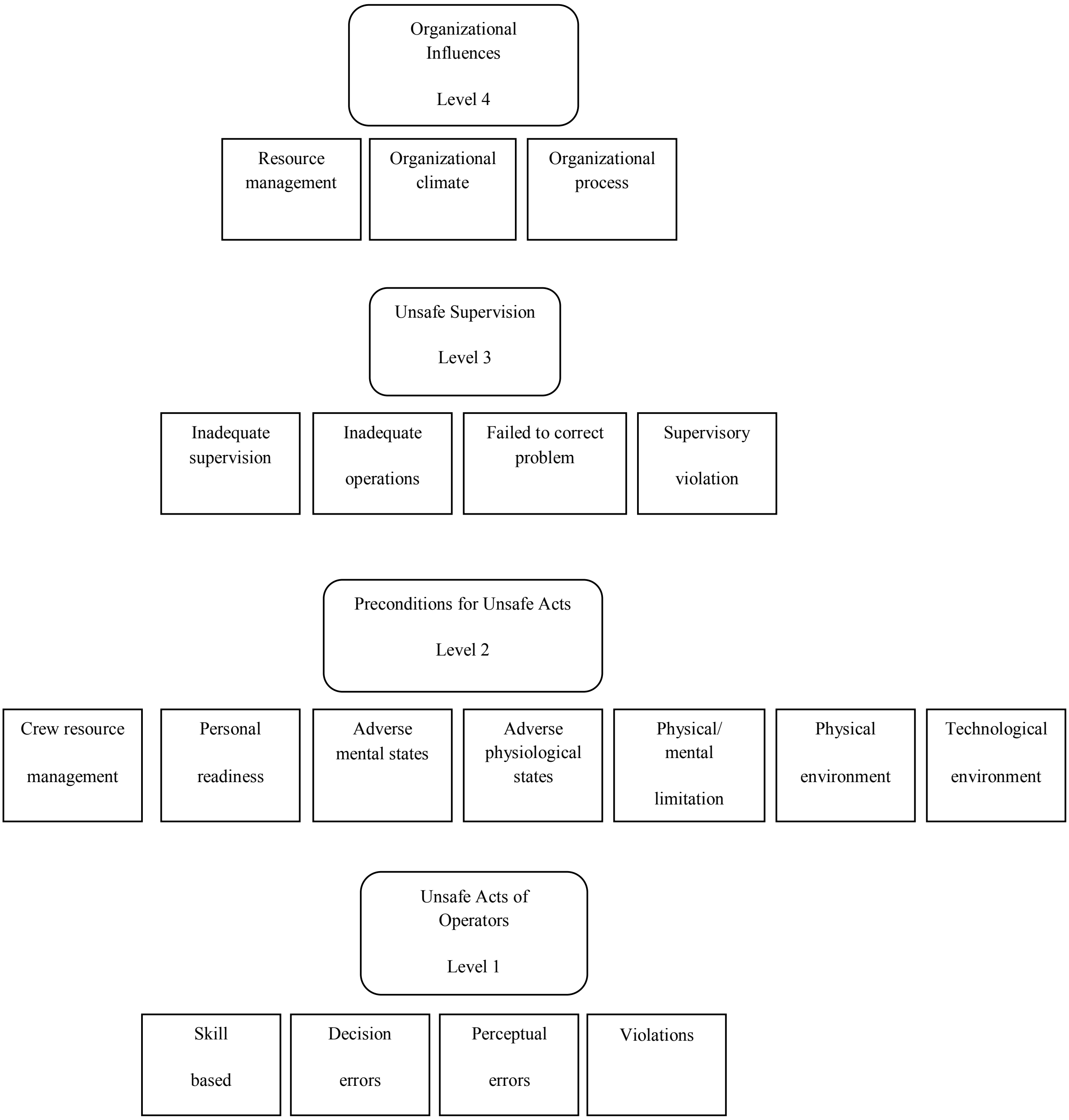

Figure 2.6: Human Factors Analysis and Classification System (HFACS) operational framework (adapted from Wiegmann & Shappell, 2003)

Historically, HFACS has been used mostly to analyse data available from existing accident/incident investigations. However, HFACS was designed to also guide accident/incident investigations to support collection of human factors-related information in the first place (Reinach & Viale, 2005). Some United States federal agencies such as the Coast Guard and the Department of Defence (DoD) have used the HFACS to support accident/incident investigation as well as analysis (Wiegmann & Shappell, 2003). An addition to the HFACS framework, termed ―Maintenance Extension” (ME), consists of four error categories: Management Conditions (latent failures), Maintainer Conditions (latent failures), Working Conditions (latent failures), and Maintainer Acts (active failures) (Schmidt, Lawson, & Figlock, 1998). As shown in table (2.3), the three maintenance error orders reflect a shift from a molar to a micro perspective (Schmidt & Figlock, 1998). Table (2.3) also provides an example for each error order (Schmidt, Lawson, & Figlock, 1998).

Table (2.3): Error categories, orders, and examples of the Human Factors Analysis & Classification System-Maintenance Extension (HFACS-ME) (adapted from Schmidt & Figlock, 1998).

First Order	Second Order	Third Order	Examples
Management conditions	Organizational	Inappropriate processes	A manual omits a step calling for an O-ring to be installed.
		Inadequate documentation	A publication does not specify torque requirements.
		Inadequate design	A component layout that prohibits direct viewing during inspection.
		Inadequate resources	Shortage of tools leads to using what is

			immediately available.
	Supervisory	Inadequate supervision	A commander does not ensure that personnel require protective gear.
		Inappropriate operations	A main rotor head change is performed in a high wind condition despite risk.
		Uncorrected problem	A supervisor does not correct cutting corners in a procedure.
		Supervisory misconduct	A supervisor orders personnel to wash an aircraft without training.
Maintainer conditions	Medical	Adverse mental state	A technician who has marital problems and cannot focus on his work.
		Adverse physical state	A technician who worked for extended hours straight and suffers from fatigue.
	Crew coordination	Inadequate communication	A technician who tows an aircraft into another due to poor hand signals.
		Inadequate assertiveness	A technician who signs off an inspection due to perceived pressure.
	Readiness	Training/Preparation	A technician who is working on an aircraft skipped the requisite On-the-Job (OJT) evaluation.
		Certification/Qualification	A technician who engages in a procedure he is not qualified to

			perform.
		Infringement	A technician who is intoxicated on the job.
Working conditions	Environment	Inadequate lighting	A technician who is working at night does not see a tool he left behind.
		Unsafe weather/Exposure	A technician who is securing an aircraft in high wind conditions fails to secure the main and tail rotors.
	Equipment	Damaged/Unserviced	A technician who is using a defective test set does not pre-check it before use.
		Unavailable/Inappropriate	A technician who works on a landing gear without a jack because all in use.
	Workplace	Confining	A technician who is working in a hanger bay cannot properly position a maintenance stand.
		Obstructed	A technician who is spotting an aircraft with his view obscured by cloud.
Maintainer acts	Error	Attention/Memory	A technician who is familiar with a procedure may reverse steps in a sequence.
		Knowledge/Rule based	A technician who inflates an aircraft tyre to a pressure required for a different type of aircraft.
		Skill/Technique based	A technician who roughly handles a delicate engine valve

			causing damage.
	Violation	Routine	A technician who engages in rule bending that is condoned by management.
		Infraction	A technician who strays from accepted procedures to save time.
		Exceptional	A technician due to perceived pressure omits an inspection and signs off the task.
		Flagrant	A technician who wilfully breaks rules disregarding the consequences.

The HFACS-ME was effective in capturing the nature of and relationships among latent failures and active failures present in Naval Aviation Class A accidents (Schmidt, Schmorrow, & Hardee; 1998). The major accidents analysed were primarily flight related accidents/incidents, meaning that many imposed in-flight maintenance conditions on aircrew. Subsequent analysis of Naval Aviation major and minor incidents and injuries (Schmidt, Figlock, & Teeters; 1999) demonstrated the ability of HFACS-ME to capture factors leading to maintenance errors (Schmidt, Lawson & Figlock, 1998).

In a study sponsored by KLM Engineering and Maintenance and conducted by Ghobbar, Boutahri, & Curran (2009), the MEDA, ADAMS, and the HFACS-ME were evaluated to determine the most suitable taxonomy to be used for their research project. Based on this evaluation the HFACS-ME was considered impractical for the investigation of maintenance errors. This is because maintenance errors and consequences cannot be coded in the taxonomy resulting in an incomplete view of the occurrence. Also the terms used in the taxonomy were considered too academic for the practical maintenance environment (Ghobbar, Boutahri, & Curran; 2009). The ADAMS taxonomy, on the other hand, was considered very comprehensive due to its level of details and the multiple sections incorporated in the investigation form that an investigator needs to complete in order to investigate an event. Moreover, the number of the investigation form pages (16 pages compared to the MEDA‘s five pages) was considered impractical and frustrating in situations where occurrence details were lacking. Also, its enormous level of details makes reliable coding often impossible (Ghobbar, Boutahri, & Curran; 2009). Another disadvantage of the ADAMS taxonomy is that it is far less widely used in the industry than MEDA and HFACS-ME (Ghobbar, Boutahri, & Curran; 2009), which makes sharing investigation results with other maintenance organizations more difficult. According to Ghobbar, Boutahri, & Curran (2009), the evaluation of the three taxonomies revealed that MEDA was the preferred taxonomy to be used for their research for the following reasons: MEDA is widely used throughout the aircraft maintenance industry; it is user friendly for the investigation of maintenance errors; its logical structure and good balance between detail and flexibility were all characteristics that were much appreciated by the investigators; the compactness of the MEDA structure made implementing the taxonomy easy and coding options can be easily found (Ghobbar, Boutahri, & Curran; 2009).

The principal objective of accident/incident investigation is to prevent reoccurrence, reduce risk and advance health and safety performance (De Landre, Gibb & Walters;

2006). The use of established investigation methodologies and approaches guides the investigation team in following a structured and logical path during the course of an investigation. Investigation methodologies provide guidance in gathering investigation data and a framework for organising and analysing accident/incident data (De Landre, Gibb & Walters; 2006). Investigation approaches (such as MEDA, ADAMS and HFACS-ME) not only identify how an accident/incident occurred, but also identify why it occurred. Most importantly, corrective actions and key learning lessons arise from the investigation data aimed at preventing similar accidents/incidents from occurring again.

In a complex socio-technical system, such as civil aviation maintenance, our understanding of accidents/incidents is constrained by the quality of the data gathered and the experience and training of the analysts who analyse the data (Grabowski et al., 2009). Military aviation maintenance is no different, and there are various issues surrounding the data available, and its collection, storage and analysis. Some data collection (e.g. accident/incident reporting) systems are not currently based on existing theoretical frameworks that take human error or other human factors issues into consideration (Grabowski et al., 2009). This prevents a more in-depth understanding of the contributing factors underlying accidents/incidents, and their complex interactions.

2.7.2 Accident/Incident Reporting Systems

Accident/Incident reporting systems were first introduced in the aviation domain (Salmon, Regan, & Johnston; 2005). Probably the most well known accident/incident reporting system is the Aviation Safety Reporting System (ASRS) used by the U.S Federal Aviation Administration (FAA) and the National Aeronautics and Space

Administration (NASA). Most reporting systems around the world have two characteristics in common: first, reporting systems gather data principally about human error, and second, they guarantee the confidentiality of the reporter (European Transport Safety Council-ETSC-, 1996). In this section, we will describe and evaluate some of the accident/incident reporting systems such as the ASRS and its counterparts in the United Kingdom and Australia. These systems were developed with the mission of improving aspects of their home countries‘ national aerospace systems (Beaubien & Baker, 2002).

In the USA, the Aviation Safety Reporting System (ASRS) is managed by NASA Ames Research Centre and enables air traffic controllers, dispatcher, pilots, cabin crew personnel, and technicians to voluntarily and confidentially report a safety accident/incident without punitive action (Rosenkrans, 2008). Accidents/incidents are reported via ASRS report forms. Once the form is submitted, ASRS forms are analysed by at least two aviation safety analysts (Salmon, Regan, & Johnston; 2005). Initially, any aviation hazards are identified from the report. Once these hazards are identified, an alerting message is sent to the appropriate aviation authority. Next, the reports are classified in terms of the accident/incidents‘ underlying factors. The reports and associated findings are then added to the ASRS database (Salmon, Regan, & Johnston; 2005). According the ASRS website (http://asrs.arc.nasa.gov), feedback, in the form of periodic bulletins and newsletters , database search requests, quick-turnaround data analysis, and other products, is provided to air carriers, researchers, and government agencies so that they can investigate allegations of unsafe practices and take appropriate corrective actions (NASA, 1999).

According to Beaubien & Baker (2002) a major strength of ASRS is that the reporting form contains a section for describing a second aircraft (if relevant) that was involved in the event. A second strength is that ASRS explicitly inquires about the chain of events. Specifically, the reporters are asked to describe how the event occurred, what factors contributed to the event, and what corrective actions were taken (Beaubien & Baker, 2002). Despite the strengths of ASRS scheme, according to Beaubien & Baker (2002), all the human factors-related information in an ASRS report is stored as text. A more convenient and effective way of collecting such information might be to include ―reason codes" which the reporter could select via menus or check-in- box items (Beaubien & Baker, 2002). This information could supplement the information provided in the narrative. The ―reason codes" not only would help standardise the data collection process, but it could also serve as a validity check for assessing the analysts' diagnosis (Beaubien & Baker, 2002). Another limitation of the ASRS scheme is that since the reports rely on self-report, the accuracy of the data is subject to the accuracy of the reporters' perceptions and memory for the events (FAA, 1998).

Another accident/incident reporting system is the United Kingdom (UK) Confidential Human Factors Incident Reporting Program (CHIRP). CHIRP was formed in 1982 as a result of a joint initiative between the Chief Scientific Officer of the Civil Aviation Authority (CAA), the Chief Medical Officer of the CAA, and the Commandant of the Royal Air Force Institute of Aviation Medicine (IAM) (CHIRP, 2008). The program was based on the Aviation Safety Reporting System (ASRS) that had been formed in the US under the management of NASA (Salmon, Regan & Johnston; 2005). The CHIRP organization was initially formed as a research project within the IAM which continued to provide management for the program until 1994. In 1986, following representation from several professional bodies, CHIRP was expanded to include the processing and analysis of reports from air traffic control officers. In 1994, following the formation of the Defence Research Agency (DRA) as a Fund Agency, several of the IAM functions were transferred to the DRA. As part of this process, management responsibility for CHIRP was transferred to DRA/Centre for Human Sciences where it remained until 1995 (CHIRP, 2008). Following a comprehensive independent review by the Guild of the Air Pilot and Navigators (GAPAN) in 1996, the program was restructured to enable it to make a more effective contribution to the resolution of important safety related issues in the UK air transport industry (Tait & O'Neil, 2002). Following the restructuring of the program, the program was extended to incorporate licensed engineers, approved maintenance organizations and cabin crew (CHIRP, 2008). In its present form, CHIRP is maintained by the CHIRP Charitable Trust, an independent organization that is funded by the UK CAA and the UK air transport industry (Tait & O'Neil, 2002).

CHIRP is a voluntary, confidential, non-punitive incident reporting system that was established to identify and resolve a wide range of safety-related issues in the UK air transport industry. Incident reports may be submitted by general aviation pilots, commercial airline pilots, cabin crew, air traffic controllers, engineers and maintenance staff. These reports are de-identified by CHIRP staff and analysed for trends (Beaubien & Baker, 2002). De-identified data is submitted on regular basis to the CAA's Safety Investigation and Data Department (CHIRP, 2008). Further de-identification (for instance of time and place, company, reporter's gender) is usually undertaken before publication in "FEEDBACK" newsletter or making data available to other agencies (CHIRP, 2008; and Beaubien & Baker, 2002). Each ―FEEDBACK” newsletter features summary statistics, de-identified accident/incident reports on selected topics of interest, suggestions for avoiding reoccurrences, and references to relevant CAA regulations including new report forms (Beaubien &Baker, 2002). These newsletters are sent four times a year directly to all commercially licensed pilots, air traffic controllers and maintenance engineers (CHIRP, 2008).

A major strength of CHIRP is the inclusion of a comprehensive glossary that is used in classifying CHIRP incident reports. A standardized glossary is essential when coding textual data, especially when multiple coders are used (Creswell, 1994). A second strength is that CHIRP, like the ASRS, does not limit itself to collecting accident/incident reports from only one functional group. In theory, this could allow the CHIRP staff analyzing the reports to identify multi-faceted perspectives to individual accidents/incidents by linking pilots' reports with technician or ATC reports for the same accident/incident (Beaubien & Baker, 2002). This could be achieved, for example, by sorting reports by their date, time and location of the occurrence. Furthermore, CHIRP frequently provides users of the program specific feedback regarding common human factors problems and suggested solutions. Despite the strengths of the CHIRP, the program has a number of limitations: like the ASRS, virtually all of the human factors-related data is located exclusively in text format; CHIRP does not provide a formal mechanism for specifying the chain of events; and CHIRP does not formally request information on contributing factors, how the problem was discovered, and how the event was corrected (Beaubien & Baker, 2002).

In 1984, the Australian Bureau of Air Safety Investigation (BASI) represented by the Human Performance and Investigation Research Group conducted a feasibility study for possible introduction of a confidential aviation reporting system scheme. The outcome of the feasibility study would supplement the mandatory accident and incident reporting program that had been running in Australia since 1947 (Sullivan, 2001). In 1987 the feasibility study evolved into an implementation study that was released in a report in 1988.

The Confidential Aviation Incident Reporting (CAIR) program was introduced in 1988, initially for technical flight crew only due to resources constraints, but was extended to Air Traffic Control (ACT) in 1999 followed shortly thereafter by the inclusion of maintenance/ground handling personnel, flight attendants, and passengers (Sullivan, 2001). Like the ASRS and the CHIRP, CAIR is a voluntary, confidential, and non-punitive accident/incident reporting system that was established to proactively identify safety-related deficiencies and suggest appropriate corrective actions. However, CAIR's focus is not on individual events, but on systems, procedures, and equipment (Beaubien & Baker, 2002). All reports are de-identified and analyzed by BASI analysts for system-level issues. However, BASI analysts do not use the terms "primary cause" or "contributing cause." Rather, all analysis results are presented as "findings" and "significant factors" (Lee, 2001). This is because BASI analysts consider all air safety occurrences to be a complex interaction of many factors. Similarly, BASI does not distinguish between accidents and incidents. They are all classified as "safety occurrences" (Lee, 2001).

CAIR uses a generic reporting form that can be completed by pilots, ATC personnel, cabin crew, maintenance technicians and passengers (Beaubien & Baker, 2002). In many ways, the CAIR incident reporting system is identical to ASRS and CHIRP; it contains a series of fields that describe the conditions (e. g., type of flight, phase of flight, weather, etc.) that immediately preceded the event. Space is also provided for a text narrative (Beaubien & Baker, 2002).

A major strength of CAIR scheme is its holistic approach to air safety investigations. By not distinguishing between "primary" and "contributing" causes, BASI analysts are better able to engage in system-level thinking. At the same time, by not making such distinction, all contributing factors, even the most trivial, may artificially receive equal weight. As a result, this practice may both hinder and help the search for causal trends (Beaubien & Baker, 2002).

Annex 13 (Aircraft Accident and Incident Investigation) of the International Civil Aviation Organization (ICAO) recommends that States should establish a voluntary incident reporting scheme that supplements mandatory accident/incident reporting (ICAO, 2004). From 1988 Australia met this recommendation through the CAIR scheme. However, CAIR was based on an administrative guarantee of confidentiality only (ICAO, 2007). In Annex 13, the ICAO also requires supplementary reporting schemes to be non-punitive with a system of protection for the sources of submitted information (ICAO, 2004). In response to this requirement, Australia introduced the Air Navigation (Confidential Reporting) Regulations 2006 (ANCR Regulations). These regulations create the REPCON scheme (short for Report Confidentially) (ICAO, 2007). REPCON provides a scheme for the confidential reporting of aviation safety concerns. Its aim is to identify and counter unsafe procedures, practices or conditions in order to prevent or lessen the likelihood of aviation accidents and incidents (ICAO, 2007). The NCR Regulations allow the Australian Safety Bureau (ATSB) to achieve this objective through issuing information briefs and alert bulletins. Information from a brief or an alert can be used by the industry to exchange operational practices, or can be used by the regulator to make changes in the regulatory system or introduce additional education campaigns or surveillance (ICAO, 2007). REPCON is distinguished from CAIR through its legislative guarantee of confidentiality and protection from punitive use for the information contained in a REPCON report (ICAO, 2007).

According to the European Transport Safety Council (ETSC), if an accident/incident reporting system (whether mandatory or voluntary) is to be effective, the maximum use must be made of information received, and the target population of reporters must also realise that their contribution are being effectively utilised (ETSC, 1996). Such effective utilisation will be achieved only if those who are capable of implementing change (i.e. regulatory authorities) have a comfortable relationship with the scheme and have a positive attitude towards using the information to bring about changes to organisational culture, equipment, procedures, and training (ETSC, 1996). Experience has shown that an effective reporting system employs most of the following characteristics (Perezgonzalez & McDonald 2005; the European Aviation Safety Agency (EASA), 2004; and Wells & Rodrigues, 2003):

1) Perceived as being non-punitive;

2) Managed by an organisation other than that responsible for the enforcement of aviation regulation;

3) Reporting forms should be readily available, simple to compile, with adequate space for descriptive narrative, and should encourage suggestions on how to improve the situation or prevent recurrence of the event;

4) Collects and analysis accident/incident data;

5) Assesses and extracts accident/incident data;

6) Evaluates all relevant information relating to accidents/ incidents;

7) Identifies adverse trends;

8) Identifies corrective actions taken, or to be taken, in order to address deficiencies;

9) Incorporates a method of circulating the information related to those accidents/incidents as necessary;

10) Allows for further investigation of those incidents whose causal factors are not known;

11) Helps in the construction of safety recommendations;

12) Helps in the implementation of suitable corrective actions; and

13) Helps in monitoring and assessing the effectiveness of corrective actions in addressing the reported conditions.

Sheehy and Chapman (1997) noted over fifteen years ago that a major limitation of many safety systems in the coal industry was that they recorded injury data treating the incident as an isolated event, as opposed to an interaction of work related processes (Sheehy & Chapman, 1997). These authors argued that for a safety system to contribute to the development of preventative strategies, recorded data must have a process focus.

Only when a safety system contains information concerning the work related factors surrounding injury and non-injury incidents will it be possible to contextually analyse processes related to those incidents (Brown & Kirk, 2004). Therefore, in order to develop an effective reporting system, data obtained from the accident models discussed previously should be collected for subsequent trend analysis.

In a survey conducted by Jacinto and Aspinwall (2004) to analyse the reporting and registration system, currently being used in the European Union for occupational accidents, it was found that a common feature was that all countries have official notification forms for the reporting of accidents at work. The main purpose of the system in all the European Countries is that they use their systems for the development of accident preventive policies, or the planning of inspection activities, or both. However, four countries (Belgium, France, Germany, and Italy) also use the system for financial purposes (Jacinto & Aspinwall, 2004).

Several agencies have information systems to manage and report accidents/incident and improve safety, for example, the National Transportation Safety Board (NTSB) of the United States of America, and the Australian Transport Safety Bureau (ATSB), and of course the previously mentioned the European Aviation Safety Agency (EASA). Table (2.4) shows a summary of the type of information managed by the information systems in both the NTSB and the ATSB.

Table (2.4): A summary of the type of information managed by the NTSB and the ATSB information systems.

NTSB information system	ATSB information system (Aviation, Rail, and Maritime)
1) Provides a database query screen which gives the user options to select a date range of an accident/incident, city, state, and country where the accident/incident has occurred, type and model of aircraft, type of operation, investigation type (accident or incident), and whether the flight was scheduled or unscheduled. 2) Based on the selections, the system shows a screen with a list of accident/incident reports with an option of a full text report or a summary report. 3) Gives the user the option to view general interest reports or view reports for other modes of transportation, pipeline, and hazardous materials. In the aviation mode of transportation, the system gives an option to select from the most recent accidents, old accidents, studies, and accident statistics; while in the *other* modes of transportation, pipeline, and hazardous	1) Provides accidents/incidents listed by occurrence number, and information about the status of the report (final, preliminary, etc.), occurrence date, report release date, location of the accident/incident, State, title of the report, occurrence category (accident, collision, derailment, grounding, fire, etc.), and injury level (fatal, minor, none, etc.). 2) Provides an option for selecting a preliminary, a final, or an active report types. 3) Includes a Confidential Report Form which can be completed and sent on-line or off-line. 4) Includes a Self-Report Form which can be completed and sent on-

NTSB information system	ATSB information system (Aviation, Rail, and Maritime)
materials, it provides the option to select from accidents and studies only. Accidents/incidents are listed by the title of the report, NTSB report number and National Technical Information System (NTIS) report number; with an option of a full text report, a summary report or a PDF document. 4) Provides revisions and recommendations from the NTSB.	line or off-line. 5) Includes a confidential reporting scheme (REPCON) for aviation to report matters such as unsafe scheduling or rostering of crew, crew or aircraft operator bypassing safety procedures, or non-compliance with rules or procedures. 6) Provides recommendations from the ATSB.

Accident/incident reporting systems provide an important means of learning from errors/failure in many safety-critical applications. For instance, British Airways operate their confidential BASIS reporting system (http://www.basishelp.com). The NASA Safety Reporting System gathers accident information from diverse operations (http://www.hg.nasa.gov/office/codeq/narsindx.htm). These systems share many common problems. For example, it can be difficult to elicit information about events when individuals are concerned that this might initiate disciplinary action. Similarly, once accidents have been reported, there are few guarantees that different investigators will identify similar contributing factors for similar accidents/incidents (Johnson, 2002). Military accident/incident reporting systems face a number of additional problems. For example, the command structure can make it difficult to sustain promises of confidential, blame-free reporting. This is a significant barrier because other systems have identified such assurances as a prerequisite for the development of trust in any reporting system (Johnson, 2002). Such concerns can have an important impact on the range of human factors issues that are elicited by military reporting systems (US Army, 1998).

Much can be gained from studying the diverse accidents/incidents that are elicited by military reporting systems. As we shall see in Studies 1, 2, 3, and 3a, many of the accidents/incidents that have occurred in the Royal Bahraini Air Force (RBAF) reveal the limited support that the existing reporting system provide for the investigation of these complex, multi-party incidents.

2.7.2.1 The Royal Bahraini Air Force (RBAF) Accident/Incident Reporting System

Currently in the RBAF, accidents/incidents are initially reported verbally by technicians or written in the aircraft log book by the pilot, in both cases, Maintenance Control receives notification about these accident/incidents. Maintenance Control then notifies the Quality Assurance (QA) section that performs a preliminary investigation and notifies the Maintenance Commander. Based on the preliminary QA investigation, the Maintenance Commander issues instructions to perform a more detailed incident investigation, which includes an interview with the individual who reported the event and requires a final report with investigation findings and recommendations. This process is described in the following functional diagram shown in figure 2.7.

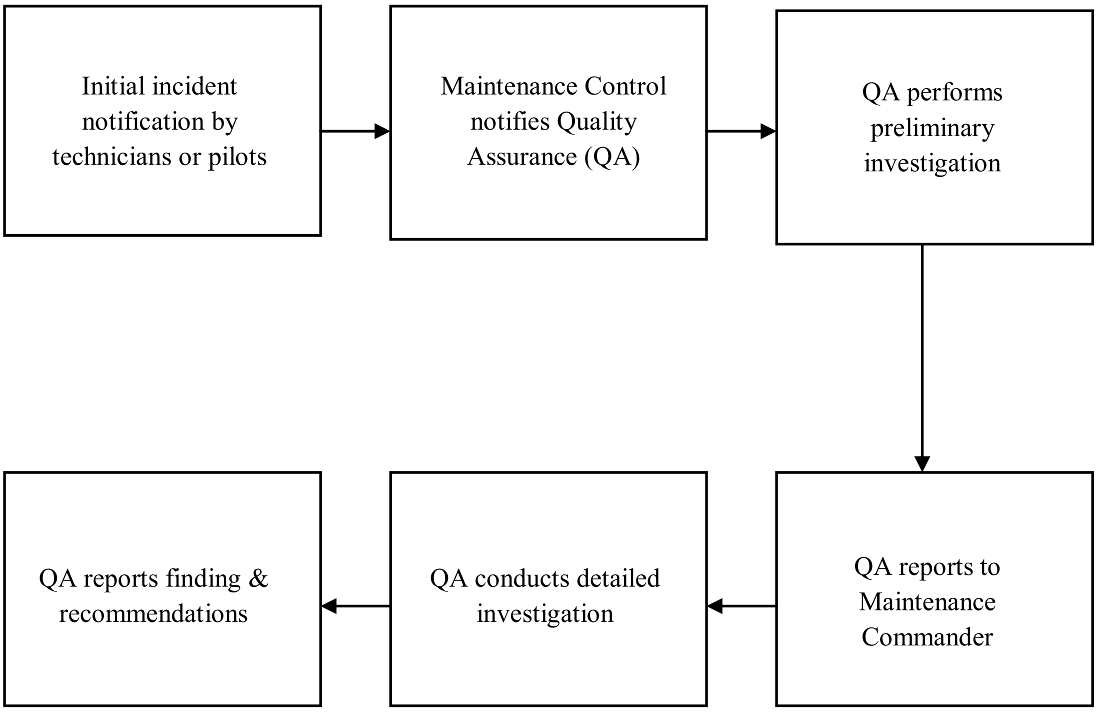

Figure 2.7: The functional diagram for the accident/incident reporting and investigation in the RBAF.

Given the ubiquity of errors, the key to safety is their effective reporting and management. In the previous paragraphs we described and evaluated various error management approaches such as accident/incident investigation and accident/incident reporting. Another error management approach is training.

2.7.3 Error Management Training

Error management training, also known as Crew Resource Management (CRM) (Helmreich, Merritt, & Wilhelm, 1999), represents a major change in training, which had previously dealt with only the technical aspects of flying (Helmreich, 2000). Originally developed and applied within the aviation domain, CRM training is used to enhance the collaboration between, and performance of, flight crewmembers. CRM is formally defined as "using all available resources (such as information, equipment, and people) to achieve safe and efficient flight operations" (Lauber, 1984). Salas, Prince, Bowers, Stout, Oser, & Cannon-Bowers (1999) define CRM as "a set of teamwork competencies that allow the crew to cope with the situational demands that would overwhelm any individual crew member." CRM considers human performance limiters (such as fatigue and stress) and the nature of human error. CRM also defines behaviors that are countermeasures to error, such as leadership, briefings, monitoring and cross checking, decision making, etc. Crew Resource Management is now required for flight crews worldwide, and data supports its effectiveness in changing attitudes and behaviors and enhancing safety (Helmereich & Wilheim, 1991).

Error management training is based upon the assumptions that human operators are fallible and error is an inevitable feature of cockpit performance, and involves the use of strategies designed to highlight the limits associated with human performance and to aid the management of error as they arise (Helmreich, Wilhelm, Klinect, & Merritt, 2001). CRM error management training programs aim to provide the following defenses against errors: avoiding the error by preparation, planning, and briefing; trapping the error by checking, inquiry, advocacy, and vigilance; and mitigating the consequences of the error by developing decision-making strategies, task prioritization and checklist management (Salmon, Regan, & Johnston; 2005).

The catalyst for the development of CRM was the United Airline (UAL) Flight 173 DC-8 accident. According to the NTSB, the aircraft was approaching Portland (USA); the flight crew noticed a problem with the landing gear. The pilots kept flying while trying to resolve the problem, thus diverting their attention from the task of monitoring other critical systems. Eventually, they ran out of fuel and crashed short of the runway, killing 10 people (NTSB, 1978). This accident resulted in UAL initiating the CRM training. The UAL CRM concentrated on improving communication among pilots and other crew members on the flight deck. This program eventually evolved into Crew Resource Management, which also pertains to utilizing resources outside the cockpit. This training is sometimes called Command/Leadership/Resource Management (CLR) (Wiener, Kanki, & Helmreich; 1993).

Just as CRM grew from a reaction to a tragic event, another key accident led to the development of another error management training program. This program is termed the Maintenance Resource Management (MRM) training. According to the NTSB, Aloha Airlines Flight 243 suffered a near –catastrophic failure (NTSB, 1989). Eighteen feet of fuselage skin ripped off the aircraft at an altitude of 24,000 feet, forcing an emergency landing. Following this accident, the FAA issued an Airworthiness Directive (AD) requiring a close visual inspection of 1300 rivets on B-737 aircraft (Boeing AD, 1993). The Aloha B-737 involved in this accident had been inspected by two technicians, one with 22 years of experience, and the other, the chief inspector, with 33 years of experience. Neither found any cracks in their inspection. However, post-accident analysis determined there were over 240 cracks in the skin of this aircraft (NTSB, 1989). The ensuing investigation identified many human factors-related problems leading to the failed inspections. These findings focused attention onto maintenance as a potential accident contributing factor, and led to the development of MRM (Robertson, 1997).

Maintenance Resource Management (MRM) and Crew Resource Management (CRM) share many of the basic issues of communication and team coordination and an interest in evaluating resulting attitudes and behaviours that relate to those issues (Fotos, 1991). But MRM differs from CRM in a variety of important aspects. For example, target audience in MRM is more diverse than CRM and includes Aircraft Maintenance Technicians (AMTs), support personnel (such as ground support equipment personnel, engine technicians, and avionics technicians), and management: MRM goals include the reliability of technical operations processes and occupational safety as well as airworthy aircraft (Taylor, 2000). The most important difference between MRM and CRM is that MRM programs have a wide variety of objective performance data available to test its outcomes. From its inception, MRM was intended to impact maintenance error rates; and it was created to improve human reliability in measurable terms. CRM is popularly assessed in terms of accidents prevented, while MRM can be more readily assessed in terms of performance achieved (Taylor, 2000).

CRM and MRM have spread to other carriers in the US commercial aviation industry and to various sectors of US military aviation (Taylor, 2000). For example, in 2002, The US Coast Guard identified that maintenance error is involved in one of five Coast Guard aviation accidents/incidents (Naval Safety Centre, 2002). In an effort to reduce those maintenance error induced accidents/incidents, the Coast Guard created a Human Factors in Maintenance (HFIM) program. Drawing on data from the FAA, NASA, NTSB, and commercial airline sources, the Coast Guard finally implemented a US Navy-developed variant of MRM. In 2005, the Air National Guard (ANG) Aviation

Safety Division made the MRM program available to the ANG units across 54 US states and territories. In 2006, following a series of maintenance related accidents/incidents in the United States Air Force (USAF), the Defence Safety Oversight Council (DSOC) of the US Department of Defence (DoD) recognized the accident/incident prevention value of the MRM program by partially funding a variant of the ANG MRM for training throughout the USAF (Slocum & Vaughan, 2008). This became known as the Air Force Maintenance Resource Management (AF-MRM) and is now widely used in the USAF (Slocum & Vaughan, 2008). The main objectives of the AF-MRM program include recognizing and identifying human factors elements; understanding human errors and contributing factors; identifying the chain of events in an accident/incident; developing safety nets; developing effective communications; and being aware of individuals' differences and behavioural styles (MCCHORD AFB, 2008).

Maintenance Resource Management is also used to change the “culture of an organization by establishing a pervasive, positive attitude towards safety” (Sian, Robertson, & Watson, 1998). Such attitudes, if positively reinforced, can lead to changed behavior and better performance. When poor organizational culture is coupled with a low level of management commitment to change the system, the result is ineffective, and sometimes unsafe, performance. Many organizations find that solving communication and coordination problems requires changes in management, organization, and the organizational culture (Robertson, 1997).

2.8 Organisational Culture

Recognising their potential for catastrophic consequences, high-risk organizations are characterised by their demand for high reliability and categorised according to complexity, interdependencies and proximity to hazard (Aase & Nybo, 2002). Examples of high-risk organizations include nuclear power plants, transportation systems (air, maritime, rail, etc.), chemical processing plants, power distribution centres, multinational manufacturing, offshore installations and large construction projects. HROs are expected to handle demanding technologies under hazardous conditions without major accidents (Van Dyke, 2006).

Catastrophic failures, such as the loss of an aircraft, define the boundaries between our civilisation and its technological legacy (Batteau, 2001). Although rare among HROs, when accidents occur, organizational, managerial and human factors, rather than purely technical failures, are usually identified as the prime causes. By their very nature, these factors touch on cultural issues (Van Dyke, 2006).

Widespread studies of organizational culture were triggered in the early 1980s by four popular books (Ouchi, 1981; Pascale & Athos, 1981; Deal & Kennedy, 1982; and Peters & Waterman, 1982). Over time, senior managers realized that the cultures of organizations define limits, explain both success and failure, and point to opportunity (Stricoff, 2005a). The first type of these cultures to be identified was organizational culture, accepted by many to be *a collection of beliefs, expectations, symbols and values learned and shared by a corporation's members and succeeding generations of its employees* (Smircich, 1983). According to Frontiera (2010), Organisational culture is often described as the values that hold an organisation together. Additional definitions emphasise cognitive aspects of culture, such as “meanings” and “understandings” (Martin, 2002). The maintenance of the dominating organizational culture within any organisation, therefore, is supported by ongoing analyses of organisational systems, goal-directed behaviours, attitudes and performance outcomes (Fry & Killing, 1989). However, due to a general lack of information on how culture works, or how it can be shaped, changed or otherwise managed in practise (Furnham & Gunter, 1993), there is no consistent definition of what an organizational culture might be (Williams et al., 1989).

Williams et al. (1989) take issue with the notion that organisational culture reflects shared behaviours, beliefs, attitudes and values. They argue that not all organisational members respond in the same way in any given situation, although there may be a tendency for them to adopt similar styles of dress, modes of conduct, and perceptions of how the organisation does, or should, function. Beliefs, attitudes and values about the organisation, its function or purpose can vary from division to division, department to department, workgroup to workgroup, and from individual to individual. Thus, although an organisation may possess a dominating ‘cultural theme’, there are likely to be a number of variations in the way in which the theme is expressed throughout the organisation (Williams, 1991; Hamden-Turner, 1990; and Furnham & Gunter, 1993). For example, one department may put safety before production, whereas another department may put production before safety. In the former, risk assessments might always be conducted prior to starting every job, while in the latter, people circumvent all the safety rules and procedures to ensure the completion of a maintenance task. It follows, therefore, that several different sub-cultures will emerge from, or form around, functional groups, hierarchical levels and organisational roles, with very few behaviours, beliefs, attitudes or values being commonly shared by the whole of the organisation's membership. In turn, these sub-cultures may either be in alignment, or at odds, with the dominating ‗cultural‘ theme. This is not surprising given that organisations are ―dynamic, multi-faceted human systems that operate in dynamic environments in which what exactly suits at one time and one place cannot be generalised into a detailed universal truth" (Dawson, 1996). Pidgeon (1998) argues that, differing sub-cultures actually serve a useful function, as they are a valuable resource for dealing with collective ignorance determined by systemic uncertainty because they provide a diversity of perspectives and interpretation of emerging safety problems.

Unless safety is the dominating characteristic of an organisation‘s culture, which arguably it should be in high risk industries, safety culture can be viewed as that sub-component of the organisational culture which alludes to individual and organisational features influencing health and safety (Douglas,Wiegmann, Zhang, Von Thaden, Sharma, & Mitchell, 2002). The prevailing organisational culture therefore will exert a considerable influence on safety. For instance, organisations that genuinely strive to achieve a quality culture by involving all employees in each step of the process will probably have a greater impact on building a positive safety culture. (Dominic, 2001) The importance of safety as a performance criterion is likely to be accepted by all and may well be integrated into every aspect of the organisational processes. Therefore, a good safety culture is believed to positively impact upon an organisation‘s quality, reliability, competitiveness, and profitability (Dominic, 2001).

2.9 Safety Culture

When incidents occur in the workplace, it is important to understand what factors (human, technical, organizational) may have contributed to the outcome in order to avoid similar incidents in the future (Matrix Safety Systems, 2009). Through developing an understanding of why and how incidents occur, appropriate methods for incident prevention can be developed. Recent years have witnessed a growing concern over the issue of safety culture within aviation and other complex, high-risk industries. Numerous definitions of safety culture have abounded in the safety literature. Reviews of the literature have revealed several diverse definitions of the concept (Wiegmann, Zhang, & von Thaden, 2001). Most definitions originate from articles that have focused on safety culture in industries in various domains (e.g., mineral industry, off shore oil & gas, and aviation). Examples of definitions of safety culture include:

Safety culture refers to the formal safety issues in the company dealing with perceptions of management, supervision, management systems, and perceptions of the organization (Minerals Council of Australia, 1999).

Safety culture refers to expectations that people will act to preserve and enhance safety, take personal responsibility for safety, and be rewarded consistently with these values (Carroll, 1998).

Safety culture refers to entrenched attitudes and opinions that a group of people share with respect to safety (Flin, Mearns, Gordon, & Fleming (1998).

Safety culture is a group of individuals guided in their behaviour by their joint belief in the importance of safety, and their shared understanding that every member willingly upholds the group's safety norms and will support other members to that common end (Helmreich & Merritt, 1998).

The safety culture of an organisation is the product of individual and group values, attitudes, perceptions, competencies, and patterns of behaviour that determine the commitment to, and the style and proficiency of, and organisation's health and safety management (Lee, 1996).

Nonetheless, there does appear to be several commonalities among these various definitions regardless of the particular industry being considered. The commonalities among the various definitions of safety culture regardless of the particular industry (Douglas, Wiegmann, Zhang, Von Thaden Sharma & Mitchell, 2002; and Reason and Hobbs, 2003) are listed below. Safety Culture:

1. Is defined at the group level or higher, and refers to the shared values among all the group or organization members;

2. Is concerned with formal safety issues in an organization, and closely related to, but not restricted to, the management and supervisory systems;

3. Emphasises the contribution from everyone at every level of an organization;

4. Is usually reflected in the contingency between rewards system and safety performance and an organisation‘s willingness to develop and learn from errors and accidents;

5. Is relatively enduring, stable, and resistant to change;

6. Continuously drives the organisation towards the goal of maximum attainable safety regardless of commercial pressures or who is occupying the senior management position;

7. Reminds the organisation‘s members to respect operational hazards, and to expect that people and equipment will fail;

8. Creates an atmosphere of trust in which people are willing to confess their errors and near misses; and

9. Both reactive and proactive measures are used to guide continuous and wide-reaching system improvements rather than mere local fixes.

Pidgeon and O'Leary (1994) and Reason (1990) have warned of the influence that safety culture has on accidents. Hidden (1989), in his investigation into the Clapham Junction rail disaster, found that British Rail's safety culture was a significant contributor to that accident. Furthermore, the serious procedural errors evident in the Chernobyl nuclear disaster were interpreted as direct evidence of a poor safety culture at the plant (Organization for Economic Cooperation and Development (OECD), 1987). Such research suggests that factors such as management involvement and support, open communication between all levels of staff, and continuous efforts to maintain safety awareness are important determinants associated with reducing unsafe behaviours (Edkins & Pollock, 1997).

US airlines (Taylor, 2000) and US military organizations (Slocum & Vaughan, 2008; and Serving history, 2010) have implemented error management programs. Many of these airlines and organizations are finding that trust in open communication still requires attention which is leading to an increased interest in communication training for maintenance. The combination of systems for error identification and improved communication require a cultural change (Taylor, 2000). Programs such as voluntary error reporting and MEDA might be the platform for improved technical information for safety improvement in the future (Taylor, 2000).

Aircraft as well as inspection and maintenance equipment, are becoming more complex. As the RBAF fleet ages, and members of maintenance personnel diminish, maintenance workload is increasing. These pressures exacerbate the likelihood of human error in the military aviation maintenance. These errors have various effects on the aviation system in the RBAF; from inconsequential slips, to those which affect the fleet‘s efficiency and reliability, to those which ultimately result in an accident/incident. In recognition of this, our research project aims to:

1) Understand the nature of maintenance error incidents across RBAF fighter and helicopter bases;

2) Contrast errors and their underlying factors from the existing accident reporting and investigation system with those identified through the Maintenance Error Decision Aid (MEDA) and interviews conducted with RBAF technicians;

3) Identify the role and nature of organizational failures in maintenance errors within the RBAF; and

4) Evaluate the existing RBAF reporting and investigation system and develop an improved tool for identifying and managing maintenance errors within the Air Force.

In the next chapter we will report on a study (Study 1) conducted in the Royal Bahraini Air Force (RBAF) to apply and evaluate the MEDA framework. Although the MEDA framework has been implemented in the civil airline industry, however, MEDA has never been applied and evaluated in the military aviation maintenance domain.

Chapter 3

Study 1

Applying the Maintenance Error Decision Aid (MEDA) Framework in The Royal Bahraini Air Force (RBAF)

3.1 Introduction

Maintenance errors cost operators of commercial airlines millions of dollars each year in lost revenue and repeat-repairs, as well as presenting potential safety concerns. Aviation industry studies indicate that as many as 20 per cent of all in-flight engine shutdowns and up to 50 per cent of all engine-related flight delays and cancellations can be traced to maintenance error (Boeing/Air Transport Association members (ATA), 1995).

The ultimate goal of maintenance organisations is to minimise the rate of accidents/incidents in the future. Therefore, there is a need to develop databases to track data about the root causes of accidents/incidents, solutions implemented and the effectiveness of these solutions (Perezgonzalez, McDonald, Smith; 2005). The types of data that are collected by maintenance organisations can be classified into two categories: performance data and error investigation data.

Performance data are all the data that help understand where resources have been spent and what losses have been incurred. In military settings, these losses may occur due to damage to aircraft during ground movement, job-related injuries (i.e. injuries that were caused during the performance of a maintenance task), weapon systems being released in an unworthy state, and events that affect the safety of a weapon system and/or personnel. Performance data that is available in most aviation maintenance organisations will include ground-damage data, frequency of lost-time injuries, repeat repair data and logbook error data (Patankar & Taylor, 2004).

Error investigation data helps us to understand the root causes and the factors which contribute to them. The error-investigation process tends to resemble a network, rather than the single linear chain that is more common in flight-related investigations (Patankar & Taylor, 2004). This network places the maintenance error in the centre, with threads of causal relations radiating out in various directions. Typically, an error investigation is triggered by self-disclosure by the mechanic, voluntary disclosure by the maintenance organisation, a regulatory violation cited by a certified inspector or by an accident/incident (Patankar and Taylor, 2004).

In aviation maintenance, management and technicians are confronted with what appear to be multiple, sometimes contradictory, goals. Such goals include the reduction of maintenance costs, minimising maintenance task complexity, reducing error-provoking situations, and developing methods to investigate maintenance errors. The first goal that management needs to deal with is the reduction of maintenance costs. Minimising maintenance costs means balancing minimum staffing levels while still adhering to the mandated workload, without risking the safety of aircraft or disrupting flight schedules (Kappor, Dharwada, Iyengar, Greenstein and Gramopadhye, 2004). Minimising costs means that technicians have to be sensitive to the efficiency (speed) and effectiveness (accuracy) of their performance (Kappor, Dharwada, Iyengar, Greenstein, and

Gramopadhye, 2004). The second goal that management and technicians have to struggle with is the complexity of maintenance tasks. Maintenance tasks are complicated because of the wide variety of aircraft defects being reported in both older aircraft and newer aircraft. Scheduled repairs account for only 30% of all maintenance in older aircraft, compared to 60 – 80% in the younger fleet, which is attributed to an increase in the number of age-related defects (Federal Aviation Administration (FAA), 1991). Thus, a more intensive inspection program is required for older aircraft. The introduction of newer aircraft, however, will not substantially reduce the maintenance workload, because new airframe composites create an additional set of problems, further complicating maintenance and inspection practices. The task of aircraft maintenance becomes increasingly demanding as more experienced inspectors and mechanics retire, to be replaced by a much younger and less experienced work force. Not only do the new inspectors lack the knowledge and skills of more experienced inspectors, but they are also not trained to work on as wide a variety of aircraft (Kappor, Dharwada, Iyengar, Greenstein and Gramopadhye, 2004). Thirdly, the stress produced by the conflicting demands of cost effectiveness and the complexity of meeting the demands of newer technologies can itself result in maintenance errors. This has been supported and documented through task analyses of commercial maintenance and inspection activities (Drury, Prabhu and Gramopadhy, 1990). Aircraft maintenance is a complex activity requiring above-average coordination, communication and co-operation between inspectors, maintenance personnel, supervisors and various other sub-systems in order to be effective and efficient (FAA, 1991 and 1993). Thus, it is clear that there exists potential for errors, and it is only through devising strategies that identify where they are likely to occur that we can eventually determine problem areas and develop interventions that will minimise their impact (Kappor, Dharwada, Iyengar, Greenstein, and Gramopadhye, 2004).

In order to minimise maintenance errors, the aviation maintenance industry has invested significant effort in developing methodologies for investigating them. The literature covering human error is rich, having its foundations in early studies which analysed human error made by pilots (Fitts and Jones, 1947), human error investigations following the Three Mile Island accident, as well as recent research in human reliability and development of error taxonomies (Norman, 1981; Rasmussen, 1982; Reason, 1990; Rouse and Rouse, 1983; and Swain and Guttman, 1983). An example of such taxonomies is the Maintenance Error Decision Aid (MEDA) which was developed for identifying and investigating errors in aviation maintenance (Rankin, Hibit, Allen and Sargent, 2000).

3.1.1 Maintenance Error Decision Aid (MEDA)

The MEDA was developed by Boeing, along with representatives from British Airways, Continental Airlines, United Airlines, the International Association of Mechanics and the U.S. FAA. Its purpose is the investigation, analysis and identification of maintenance errors at airlines (Boeing/ATA, 1995).

An event must occur in order for a MEDA investigation to be started. At this point the maintenance individual whose performance has caused the event will complete the MEDA results form. The MEDA investigation requires that this individual be interviewed. This interview may determine that other individuals or functions within the maintenance organisation contributed to the event (e.g. if stores did not have the needed part and supplied the technician with an incorrect substitute part), so follow-up interviews may be needed. The data collected from the results form (concerning the investigation process and its outcomes) is then made available (via the organisation's accident/incident information system) to all individuals affected by the improvement process (to learn and benefit from). These individuals include senior management, supervisors and all other technicians in the maintenance organisation. The main aspect of the tool is the MEDA results form (Rankin, Hibit, Allen & Sargent, 2000). The results form consists of five sections (as shown in Appendix A): section 1 contains general information (e.g. aircraft identification information, engine type and dates of the error and of the error investigation); section 2 contains event information (e.g. flight delays, flight cancellations, in-flight engine shutdowns, aircraft damage and injury to maintenance technicians); section 3 lists information about the types of maintenance errors (e.g. improper installation, improper servicing, improper fault isolation/testing, actions leading to Foreign Object Damage (FOD) and actions causing personal injury); section 4 lists information about the types of contributing factors and sub-factors ; section 5 outlines information about error prevention strategies (e.g. existing procedures, processes and/or policies which are intended to prevent the particular accident/incident, but did not) and individuals' comments; and finally section 6 provides a summary of contributing factors, errors and the events.

It is particularly important to note that section 5 requires the individual to list the existing procedures, processes and policies in the maintenance organisation which were intended to prevent the error. A second sub-section provides space for the individual to list recommendations for event prevention strategies. (Rankin, Hibit, Allen and Sargent, 2000).

Violations were excluded from the MEDA framework (Rankin and Allen, 1996, 1997; Allen and Rankin, 1995). The aim is to encourage technicians to help in identifying the causal factors of an event, without fearing the consequences of making an error or a violation.

3.1.2 The MEDA Process

The MEDA process was developed based on the philosophy that maintenance errors result from a series of related contributing factors. These factors are viewed as being largely under management control and, therefore, changeable (Rankin, Hibit, Allen, & Sargent, 2000; Drury and Woodcock, 2002). It has been estimated that about 80% of contributing factors could be controlled by management, whereas about 20% of errors could not be corrected, because the contributing factors are either unique or are specific to the technician involved (Rankin and Allen, 1997). Management is thought to have the greatest likelihood of reducing these contributing factors by organising, planning and providing appropriate supervision of tasks. The MEDA process concentrates on identifying the organisational processes and procedures relevant to the error. Although it is necessary to determine who made the error, the MEDA results form does not require the name of the technician in question to be included (Rankin, Hibit, Allen, & Sargent, 2000). The MEDA process is outlined in figure 3.1 (below).

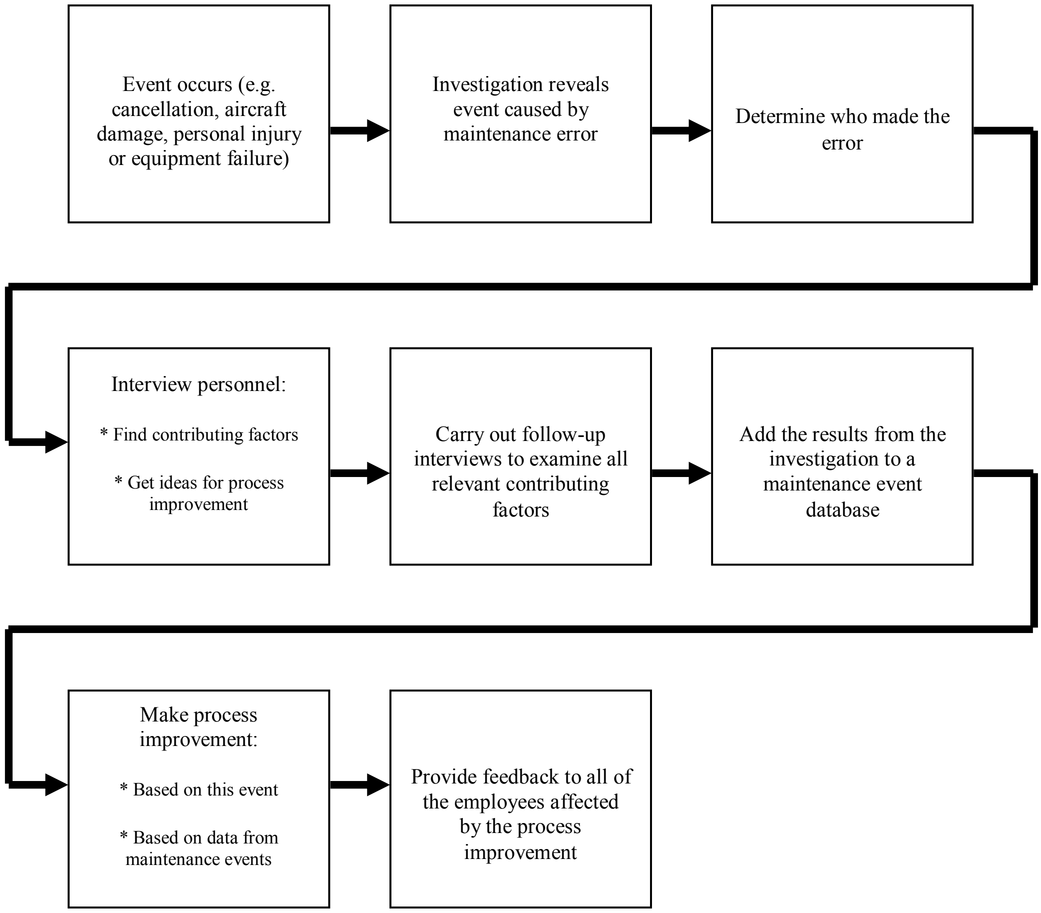

Figure 3.1: The MEDA investigation process as used in the civilian airline industries (adapted from Boeing/ATA, (1995)).

3.1.3 Benefits of MEDA

About 60 operators have already implemented some or all of the MEDA process. According to Boeing Commercial Airplane Group, participating operators such as United Airlines, Aerolinea De Colombia, BF Goodrich and Hong Kong Aircraft Engineering Company have reported several benefits. Reported benefits include:

a) A 16 per cent reduction in mechanical delays.

b) Revised and improved maintenance procedures.

c) A reduction in aeroplane damage through improved towing and headset procedures.

d) Changes in the disciplinary culture of operators (blaming the process, rather than the person).

e) Elimination of an engine-servicing error through the purchase a filter-removal tool that had not previously been available in the shop where the service was being conducted.

f) Improvements in line-maintenance workload planning.

g) A program to reduce on-the-job accidents and injuries based on the MEDA results form and investigation methods.

The Royal Bahraini Air Force (RBAF) is continuously pursuing means to develop and improve the quality of its maintenance activities. In recent years, however, the RBAF has experienced a series of accidents and incidents that prompted the RBAF management to investigate the underlying factors. Two main factors led to the decision to undertake this study and attempt to reduce the onset of human maintenance errors: higher demands from headquarters and increased maintenance workload. Increased demands for improvements in maintenance were issued from HQ following concerns over the aforementioned spate of maintenance-related accidents and incidents. The increase in maintenance workload was due to five factors: a) increased aircraft utilisation; b) increased maintenance requirements for continuing airworthiness of older aircraft; c) increased technical knowledge and skill requirements in order to maintain new technology and new aircraft; d) shortage of qualified maintenance technicians; and e) pressure from RBAF HQ on maintenance organisations to increase their efficiency and effectiveness while maintaining a high level of safety.

The aim of this study is to identify the types of maintenance errors (and their contributing factors) experienced by the technicians of the Royal Bahraini Air Force (RBAF) using the MEDA framework. The secondary aim was to assess the appropriateness of MEDA for the military context as opposed to civilian aviation where it was developed. The data from this study will then be compared with other sources of data from further studies to better understand maintenance error at the RBAF and lead to the development of an improved error identification and management tool.

3.2 Methodology

MEDA is a framework used to investigate events caused by maintenance technicians and/or inspectors performances (FAA, 2008). MEDA is also used to identify maintenance errors and their associated contributing factors (Hobbs, 2008; and Rankin, Hibit, Allen, and Sargent, 2000). In this study, MEDA was used as an error identification tool. This usage allowed us to investigate the main aim of this study: identifying maintenance errors and the factors leading to these errors.

The main investigative tool used was the MEDA results form, which formed the basis for the study. The results forms were completed by the technicians whose performance has lead to an error. The investigator requested to meet with maintenance technicians from the flight-line and engine-maintenance groups. These technicians were randomly selected by the maintenance commanding officer from three different airbases (175 from the helicopter bases and 300 from the fighter base). The investigator (verbally) provided the participants with all the information needed to aid them with the completion of the Results form.

The participants were instructed to report about one event only. Because the participants were from different air bases and trades, the events discussed may not be the same. The participants were asked not to write down their names, service numbers or any information that might identify them directly or indirectly. To minimize the possibility of coercion, the investigator made available a sealed box (in their work places), envelopes and a stack of 300 MEDA Forms. Ninety minutes was allowed for the technicians to complete the results form. A few technicians needed more time to complete the results form, so 10 more minutes were allowed. After all the results forms had been collected, we had an opportunity to meet with some of the participants and conduct informal discussions about the importance of the MEDA study, the reasons for not following maintenance procedures, ―Training" as a contributing factor, and the effectiveness of the strategies adopted by the RBAF. These discussions were brief and the participants voluntarily elected to participate in them.

Due to the fact that this study was conducted in a military environment, no reference can be made to the types of weapon systems, location of military bases or demographics of the technicians participating in this study.

3.3 Results

A total of 149 forms were picked up by the technicians. Only 41 forms were completed (23 forms from the helicopter bases and 18 forms from the fighter base). 101 forms were rejected because they were either not completed, or only the ―General Information" portion was completed, or the technicians who completed the forms were not from the flight line or engine maintenance. This constitutes a participation rate of 27.5%.

This study (Study 1) identified several types of errors and contributing factors, however, only the top five types of errors and contributing factors will be reported to facilitate consistent comparison between Study (1) and Studies (2) and (3) which will be reported in the following chapters.

The top five types of maintenance errors (as outlined in figure (3.2)), are: installation errors; aircraft/equipment errors; servicing errors; fault isolation/test/inspection errors; and errors leading to personal injury.

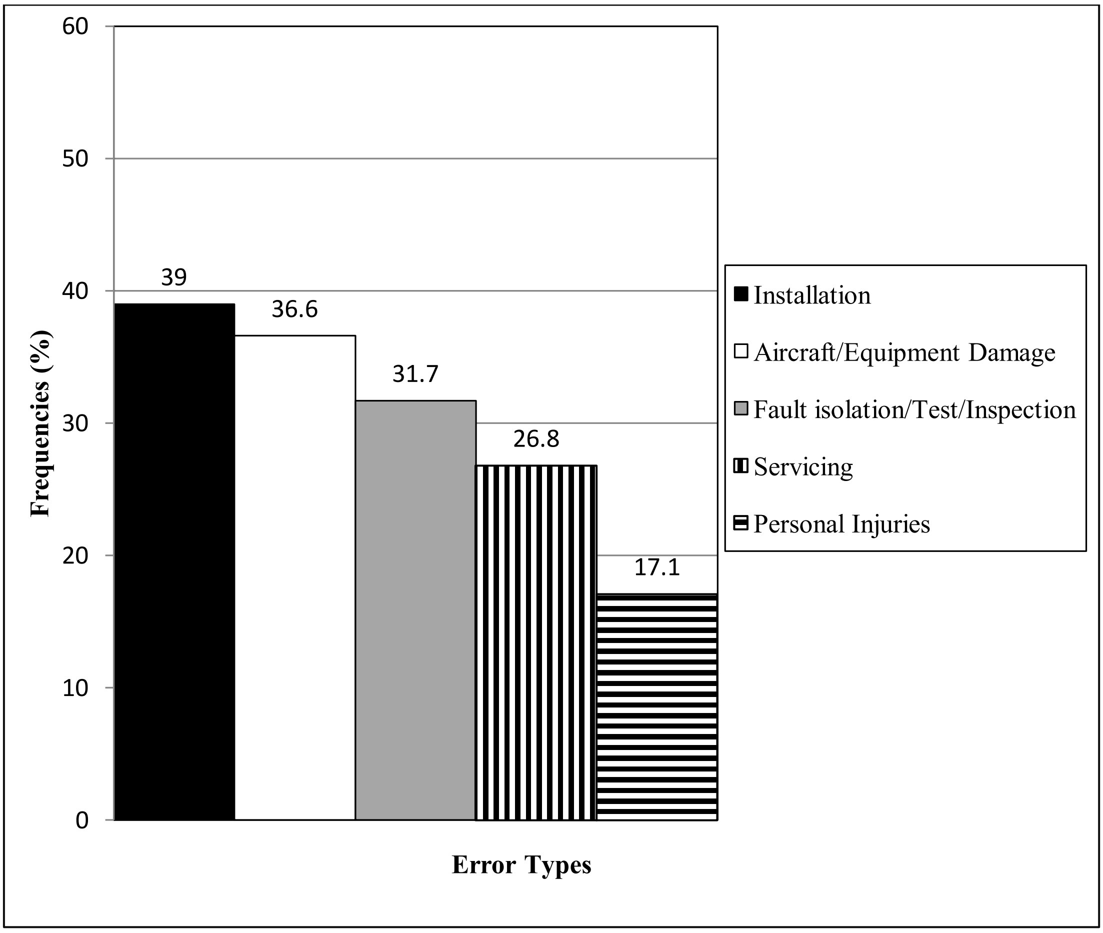

Figure 3.2: The frequencies of the top five types of maintenance errors nominated by RBAF flight-line and engine technicians using the MEDA framework.

According to the MEDA survey, the top five contributing factors the led to the errors mentioned above include: organizational factors, individual factors, leadership/supervision factors, information factors and job/task factors. These factors are presented in figure 3.3.

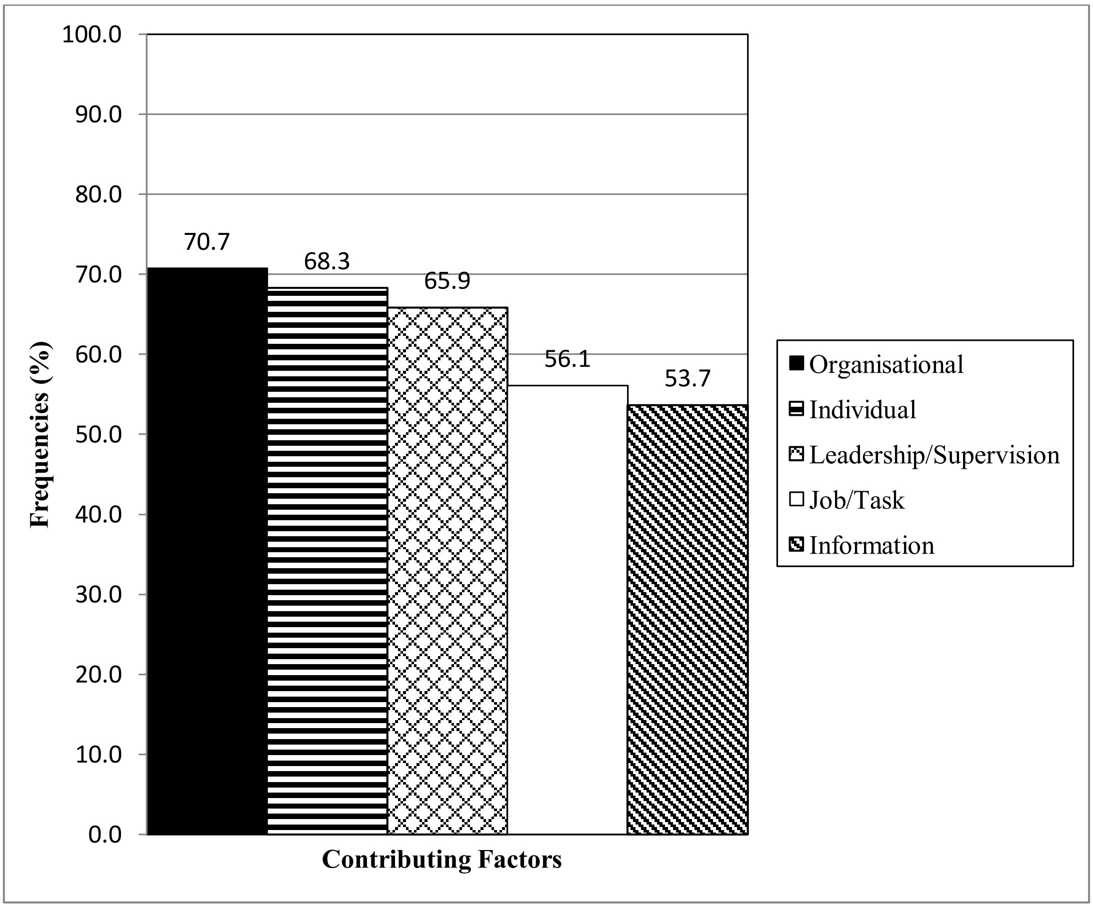

Figure 3.3: The frequencies of the top five contributing factors leading to maintenance error as nominated by RBAF flight-line and engine technicians using the MEDA framework.

3.4 Discussion

3.4.1 Maintenance Errors

The study used the Maintenance Error Decision Aid (MEDA) results form to investigate the factors that contributed to each particular error. The purpose of using the MEDA results form is to engage the technicians who participated in the adverse event, in order to identify the contributing factors. The use of MEDA enabled the capture of data covering both maintenance errors and the factors contributing to these errors. In the following sub-sections we will discuss each type of error in turn.

3.4.1.1 Installation Errors

The most frequently nominated type of error is installation error. Technicians who nominated this type of error (39%) stated during the informal discussions that they did not install a required part, improperly installed the part, or damaged the part during installation. The technicians reported that they committed these errors because they did not use the maintenance manuals. These manuals were not available, not current, or ambiguous.

3.4.1.2 Aircraft/Equipment Errors

The second most frequently nominated type of error is aircraft/equipment damage error (36.6%). The types of equipment that most often get damaged are towing trucks, towing bars, towing wheels and ground support equipment. The damage to these types of equipment is possibly caused by the high usage of the equipment during aircraft towing and servicing operations (on a daily basis), making the exposure and risk higher. The damage to aircraft is probably caused by the fact that equipment has to be attached to the aircraft during towing or servicing. The movement of either the aircraft or the equipment may result in damage to the aircraft itself or other aircraft or equipment in the vicinity.

3.4.1.3 Servicing Errors

This type of error was nominated by (26.8%) of the technicians as one of the top five types of errors experienced in the RBAF. This error involved improper servicing (too much or too little servicing fluid was used) or required servicing was not carried out. The technicians stated (in section 5 of the MEDA results form) that the cause of this error was the malfunction of the gauge, and the lack of current Maintenance Operating Instructions (MOIs).

3.4.1.4 Fault Isolation/Test/Inspection Errors

The technicians also nominated fault isolation/test/inspection error as one of the top five types of errors (31.7%) that are experienced in the RBAF. According to the MEDA results forms, the individuals who committed this error did not discover the defect during an inspection, or did not undertake a required inspection or a functional check because it was not documented in the maintenance manual.

3.4.1.5 Errors Leading to "Personal Injuries"

Another type of error nominated by the technicians surveyed in this study is the error leading to personal injury (17.1%). Due to the nature of maintenance work, where technicians work on top of aircraft and in an environment where oil and fuel are frequently used, errors leading to slips, falls and contact with hazardous material frequently occur. Injuries from the exposure to these errors are most frequently reported by technicians. These errors resulted from improper equipment design, lack of communication between technicians, and not following manufacturer‘s safety instructions.

According to the survey, the above errors were caused by several contributing factors, as outlined in Appendix (B), only the top five contributing factors will be discussed in the following section. Each of the identified contributing factors will be discussed in turn.

3.4.2 Contributing Factors

3.4.2.1 Organisational, Information, and Job/Task Factors

In this section the “Organisational” factor, the “Information” factor and the “Job/Task” factor will be discussed as a group. These factors may involve the use of procedures and information (such as work cards, maintenance manuals, service bulletins, etc). The common denominator between these three categories is that technicians frequently failed to follow the procedures or use the information required to perform the task.

As shown in Appendix (B), the most nominated sub-factors in these categories are “work process/procedures not followed”, “information not used”, and tasks are “repetitive/monotonous”, respectively. Studies on maintenance work show that technicians perform maintenance actions without following the procedures described in the technical manuals. For example, Hobbs and Williamson (2000) stated that 60% of aircraft maintenance personnel reported continuation of an unfamiliar task, even when not sure they were performing it correctly. McDonald et al. (2000) reported that 34% of routine maintenance tasks are performed in ways different from those outlined in the maintenance procedures. During informal discussions with respondents in this study, they stated that inaccurate, inaccessible and impractical information were some of the reasons for not following maintenance procedures. Other reasons reported by technicians for not following instructions or procedures were operational constraints (such as meeting scheduled mission time) and that following procedures is time consuming.

Participants reported in section 5 of the MEDA results form that in instances of performing repetitive tasks (such as the same towing team repeatedly towing aircraft), that they felt so accustomed to the procedures such that they did not need to use the manual or job cards.

This study identified a need for improvements in procedures, policies, and standards. In order to minimise accidents/incidents in the RBAF, management needs to introduce changes to management and organisational processes and policies (such as those that govern work shift assignment, planning and scheduling of tasks, and changes to aircraft configuration for missions). Technical procedures, policies and standards (including local operating practices, instructions and guidelines) require revisions to be clear, accurate and unambiguous. Any inaccuracies, ambiguities or missing information needs to be recorded and reported to the manufacturers of the equipment or part (Civil aviation authority, 2002).

3.4.2.2 Individual Factors

In MEDA, adverse mental, physical and individual limitations were covered under several sub-factors, such as peer pressure, complacency, personal fatigue, physical health, time constraints, work-place distraction/interruption, personal events, memory lapses and body size/strength. The study identified that the most frequently reported sub-factor in this category in the RBAF was ―time constraints”, which was nominated by 43.9% of the participants. Time constraints are an individual factor in the sense that participants stated in the results form (section 5) that maintenance control and management would schedule maintenance tasks and inspections close to the end of shifts, and would then direct technicians to complete these tasks by the end of that shift, or stay behind until the completion of assigned tasks. This was not appreciated by most technicians. This lack of planning and improper scheduling results in technicians taking shortcuts in following the requirements outlined by maintenance manuals and job cards and hence increases the likelihood of error.

3.4.2.3 Leadership/Supervision Factors

The study identified leadership/supervision as one of the major contributing factors to maintenance errors. In the MEDA framework, this factor refers to planning and organisation of tasks, task delegation and assignment, prioritization of work, unrealistic attitude/expectations and amount of supervision. 46.34% of the technicians who participated in this study nominated ―inadequate amount of supervision” as a sub-factor contributing to a particular error. Several of the participants voiced their dissatisfaction with the degree of supervision they received. This dissatisfaction was documented in section 5 of the MEDA results form, where the technicians were asked to briefly summarise the event and point out the leading contributing factor (s).

In the military environment, supervisors have well-defined roles and responsibilities. They provide training, operational guidance, oversight and operational leadership (Wiegmann, Shappell, Cristina, and Pape; 2000). Due to heavy work-load and shortage of personnel, supervisors in the RBAF may be overwhelmed with the duties of their positions to the point where they struggle to fulfil all the roles and responsibilities that these positions require. They appear to concentrate on tasks and responsibilities that they believe are more prone to errors or which they consider as higher priorities. Technicians outside of these areas will often feel isolated, as the tasks associated with day-to-day maintenance operations invariably increase. Therefore, supervisors may need to be reminded that supervision is an active process that may need to be modified according to the situation. It requires physical proximity, continuous attention and the capacity to intervene when injury hazards are imminent (Saluja et al., 2004).

From informal discussions, the majority of the technicians who participated in this survey stated that ―maintenance policies and procedures”, ―work cards”, ―maintenance manuals” and ―maintenance operations instructions (MOIs)” were the strategies adopted by the RBAF to prevent maintenance errors. These strategies were not effective in preventing maintenance errors because the technicians were under tremendous time pressure and operational constraints (organisation and recruitment problems, equipment availability, peer pressure, etc.). These factors caused the technicians to push aircraft and engines to the flight line as quickly as possible, in order to avoid delays in the maintenance and operational schedules.

3.4.3 Evaluation of MEDA

Overall, this study indicated that MEDA addresses several types of errors, contributing factors and sub-factors leading to accidents/incidents in military aviation, despite the fact that it was developed for the civil aviation sector. This is due to the detailed nature of the MEDA results. Nevertheless, this degree of detail might lead to confusion among technicians who use the tool. For example, in the current MEDA, the term ―work process/procedures not followed" was listed as a sub-factor under ―Organisational Factors" and the term ―not used" was listed under the ―Information" factor. Both terms denote the same meaning; work process/procedures can also be considered as information that the technician uses to perform a certain task. Similarly, the term ―work process/procedures not documented" listed as a sub-factor under "Organizational Factors" and the term ―unavailable/inaccessible" which was listed as a sub-factor under "Information" factor also denote the same meaning. This terminology may lead technicians to record accident/incident contributing factors in either or both listings, which might produce duplicate or inaccurate entries in the results form. To overcome this issue, the terms ―not followed" and ―not used" might be merged under the ―Information" contributing factor. Likewise, the terms ―unavailable/inaccessible" and ―not documented" could be merged under the ―Information" contributing factor as ―unavailable/inaccessible/not documented." Although these changes are minor, they may improve the technicians' understanding and improve the consistency of MEDA results.

In the current MEDA version, there is no section in the results form directly addressing training as a contributing factor. Training usually yields universal knowledge and skills required to perform tasks or operate complex systems. The results form does list “knowledge” and “skills” as contributing factors, but it does not identify whether the deficiency in knowledge or skills is due to inadequate training, or whether the degraded skills are due to a lack of formal, practical, or supervisory training. Shortages in the training provided by the organisation are more likely to increase deficiencies in technicians‘ performance (Strauch, 2002). In section 5 of the MEDA results form, 9.8% of the technicians commented that some of the events were caused by lack of training, while several other technicians indicated (during informal discussions) that lack of training was a contributing factor for an event. Participants in this study did indicate in their responses that there was a problem with supervision, but they were not able to identify, for example, whether it was a lack of supervisory training or simply inadequate supervision. Hence, there is a need to include training as a contributing factor in the MEDA results form or as a sub-factor in several factors.

According to those participants (43.9%) who stated that "time constraints" was one of the sub-factors (listed in the individual factors category) that lead to maintenance errors; Maintenance Control (MC) may have mis-scheduled tasks, reducing the time allocated to perform those tasks, thus not allowing the technicians to follow the requirements of maintenance directives. Because this sub-factor was caused by an agency in the maintenance organisation, it might be appropriate to list “time constraints” as an “Organisational” factor rather than an “Individual” factor or to specify what is meant by "time constraints" in each contributing factor (i.e. more specific information such as a definition of time constraints or an example for each factor or sub-factor).

Finally, MEDA is developed in paper form, which makes it very difficult to document all the types of errors, contributing factors, sub-factors, findings, recommendations and corrective actions for trend analysis. A computer-based version of an accident/incident analysis tool would automatically record all the data, making possible a more comprehensive analysis and more accurate predictions of current and future accident/incidents.

3.4.4 Study Limitations

Three main limitations of the study itself were identified. First, judgments concerning errors and contributing factors were made on the basis of information provided by survey respondents in response to a results form. It is very likely that the information gathered has been affected by biases in reporting and recall. Respondents may have been unaware of the circumstances surrounding specific occurrences, or may have filtered or elaborated their responses on the basis of preconceived ideas. In addition, all technicians were responding in relation to different events. Had they all been relating to the same event, or had a set of events been supplied to them, and then they were asked to complete a MEDA results form for each of the events, a different set of factors could have been identified and greater consistency achieved. One way to overcome this limitation is by using multiple data sources (triangulation). Triangulation has the potential of reducing biases and exposing unique differences or meaningful information that may have remained undiscovered with the use of one approach or data collection technique (Thurmond, 2001).

Additionally, in its existing format and the current RBAF culture, MEDA may not be useful to meet the requirements of immediate identification and analysis of maintenance errors and failures in the military environment. The nature of maintenance operations in the military is that weapon system maintenance, inspections and repairs must be performed in the shortest duration possible, in order to meet operational and training demands. Performing the MEDA investigation in the manner outlined in the MEDA process (discussed earlier) is time consuming.

Finally, the small number of participants (41) suggests that the language barrier was a limitation and a contributing factor to the low response rate. Providing small pieces of information (like the few words describing a MEDA category) may lead to misinterpretation by technicians who speak English as a second language. This is supported by Feldmann and Stammer (1987), who suggest that “the more clues the learners are able to pick up, because of the natural redundancy of a text, the better they will accomplish the task”. Giving further context to the categories may have assisted in understanding. In addition, the large number of contributing factors available to choose from (76) might have led to confusion or reduced motivation to complete the results form, or make the task seem overly complex. The fundamental function of communication (verbal or written) is to deliver a message from one human being to another. In almost every aspect of aviation work, communication also fulfils a secondary role as an enabler (or tool) that makes it possible to accomplish a piece of work (Kanki and Smith, 2001). Among many variables, standard phraseology influences communication between individuals in an aircraft maintenance organisation (Fegyveresi, 1997). The use of standard phrases familiar to the technicians might aid communication, i.e. MEDA may need to be tailored to each organizational and cultural context in which it is used in order to get more reliable and useful results.

3.5 Conclusion and Future Direction

Despite the limitations identified with the application of MEDA in the military setting, and the limitations of the study itself, our results suggest that an investigation process based on the ―contributing factor" concept can work in the military as well as in the commercial airline industry. Our results also suggest that (in the military aviation maintenance domain) there are several factors contribute to errors, rather than one (which is the technician) and that is 'new' from a military perspective. This study can be used as the basis for the development of a tool in the military sector designed to understand, identify and reduce maintenance errors and their factors.

The aim of this chapter (Study 1) was to apply the Maintenance Error Decision Aid (MEDA) in the Royal Bahraini Air Force, in order to understand and identify the types of errors occurring (and their contributing factors) across the fighter and helicopter maintenance organisations. Due to the need to use multiple data sources, Study 2 will review actual past accident/incident investigation reports from the various RBAF helicopter and fighter bases. The aim of Study (2) is to identify the types of errors, the contributing factors that led to these errors and the level of involvement of the organisation and the technicians themselves in these errors. The results of Study 2 will then be compared with those obtained from Study (1). In the following chapters, the results of these studies and Study (3) (interviews with RBAF technicians) will be compared, in order to determine the dominant types of errors and factors contributing to them, and an attempt will be made to develop a tool that will be useful in managing these errors.

Chapter 4

Study 2

Review of the Royal Bahraini Air Force (RBAF) Accident/Incident Reports

4.1 Introduction

Error investigation data helps us to understand maintenance errors, the root causes of these errors and the contributing factors leading to them (Patankar & Taylor, 2004). This data can be collected through the use of questionnaires, interviews, observation techniques, analysis of past accident and incident reports, and/or simulation.

To date, little research has been conducted to examine human error contributing to aviation maintenance incidents and accidents in the Royal Bahraini Air Force (RBAF). In the previous chapter (Study 1), we described how MEDA questionnaires were used to collect data about past accident/incidents in the RBAF. These questionnaires identified technicians‘ perceptions of the types of maintenance errors that they were involved in or heard about from other technicians, and the contributing factors that led to these errors. The aim of Study (1) was to assess the usefulness of the MEDA taxonomy in the military environment and to identify the types of maintenance errors and contributing factors experienced by technicians in the RBAF.

For this chapter (Study 2), actual accident/incident investigation reports were used to collect error data. These reports were written by qualified Quality Assurance (QA) personnel who investigated the accident/incident. These reports were then analyzed by us in a manner consistent with the MEDA framework.

To understand maintenance errors and their contributing factors within the RBAF, it is important that we understand how these errors and contributing factors were reported and investigated. The following paragraphs provide a brief background of the RBAF accident/incident reporting and investigation process, the entities performing these investigations, and the document used to report investigation findings.

4.1.1 Background Information about Accident/Incident Investigations in the RBAF

4.1.1.1 Reporting and Investigating Aircraft Accidents/Incidents

Aircraft accident/incident reporting and investigation in the RBAF may be conducted by a Safety Investigation Board (SIB), a tailored SIB, or a single Investigating Officer (IO). The term ―Investigating Officer" can includes Non-Commissioned Officers (NCOs) who are appointed to investigate mishaps.

An SIB is normally required for all aircraft accidents/incidents involving a destroyed aircraft or a fatality. SIBs are normally composed of a current pilot who is qualified in flying aircraft similar to the type of aircraft involved in the accident/incident; a fully qualified maintenance officer, civilian equivalent, or senior NCO with at least two years maintenance experience on a similar type of aircraft as the aircraft involved in the event (if available); an Air Force flight surgeon or physician qualified in aerospace medicine; an Air Traffic Control (ATC) officer (or senior NCO, if air traffic control is known or suspected to have been a factor in the mishap); and a Weather Officer, if weather is known or suspected to have been a factor in the mishap.

A tailored SIB may be convened for aircraft events that do not involve a fatality or a destroyed aircraft (this investigation board is rarely used by the RBAF). A tailored SIB consists of only those SIB members the convening authority believes are needed to adequately investigate the event and prepare the necessary reports.

An IO may be used when the investigation is deemed to be technically complex. Regardless of the complexity of the investigation, IOs are required to prepare a formal accident/incident investigation report. A single investigator may require additional technical assistance from persons otherwise qualified as SIB members, but these persons are not generally involved in preparing the final report.

The IO for weapons-system events must be a graduate of a Flight Safety Officer/NCO Course or an Aircraft Accident Investigation Course. An IO must also meet Air Force defined experience criteria. Current or previous qualification in the weapons system involved in the accident/incident is desirable. The responsibility for investigation of less severe aircraft maintenance events is assigned to the Quality Assurance (QA) personnel and therefore a QA inspector acts as an IO.

Generally, QA inspectors are selected from the major trades in the maintenance organisation (e.g. engine, avionics, flight controls, armament, radar, etc.) At a minimum, QA personnel must have worked for at least six months in their specialization before being selected as a QA inspector, and should be assigned to QA for a minimum of 24 months to ensure program continuity.

4.1.1.2 Quality Assurance (QA) Personnel

The combined efforts of maintenance officers, QA personnel and technicians are necessary to ensure high quality maintenance and equipment reliability. Maintenance officers are responsible for the safety of flight, safety of equipment operation, the quality of maintenance, and the management of resources under their command. QA personnel are not an extension of the work-force and are not tasked to perform production inspections as part of their day-to-day activities. QA serves as the primary technical advisory agency in the maintenance organisation, assisting maintenance supervisors at all levels to resolve quality problems.

The evaluation and analysis of deficiencies and failures is a key function of QA, a process which highlights and identifies the underlying causes of poor quality in the maintenance effort. By identifying the causal factors of quality problems and recommending corrective actions to technicians and supervisors, QA can significantly improve the quality of maintenance within the maintenance complex.

Each maintenance organization in the RBAF (i.e. helicopter maintenance and fighter maintenance) has an independent QA section.QA personnel in these sections are answerable to the Maintenance Commander (through the QA Section Officer). QA personnel are expected to perform the duties and responsibilities prescribed in the RBAF Maintenance Management Policies‘ Manual (66-1). These responsibilities and duties are outlined below.

- Investigate aircraft, engine, and support equipment accidents/incidents and other events related to maintenance production and inspection activities.

- Evaluate unit maintenance management procedures, including locally developed forms, publications, Operational Instructions (OIs), checklists etc. for accuracy, intent, and necessity.

- Review all new and revised technical data and TCTOs for completeness, accuracy and applicability. Inform applicable maintenance shops of changes and advise maintenance management on any problems discovered during this review.

- Assist the Planning, Scheduling & Documentation section (PS&D) and the Munitions Flight section with the Time Change Technical Order (TCTO) program.

- Manage and evaluate programs such as the Foreign Object Damage (FOD) prevention program, weight and balance program, end-of-runway inspections, ramp-inspection program, Quality Verification Inspections (QVIs), cannibalisation program (which is the removal of a serviceable component or part from an unserviceable aircraft, engine, or equipment to install it on another), hot refueling procedures etc.; assign a Technical Order Distribution Office (TODO) manager to ensure Technical Orders (TOs) are managed in accordance with the applicable Air Force policies.

- Implement and administer the Maintenance Standardisation and Evaluation Program (MSEP).

According to the RBAF 66-1 manual, QA inspectors investigate all weapons system accidents/incidents (minor and major) and other maintenance-related deficiencies and errors. As part of this investigation process, the QA investigator conducts an interview with the technician involved in the accident/incident, in order to collect all the necessary information pertaining to the event. Once the investigation process is completed, the QA investigator is responsible for submitting an accident/incident report to the Maintenance Commander.

4.1.1.3 Accident/Incident Reports

The accident/incident report is a classified document that may not be disclosed outside of the RBAF. These reports contain both factual information relating to the accident/incident and the investigator‘s analysis and conclusions. The factual summary portion of an accident/incident report explains how the accident/incident occurred. The narrative portion of the report explains why it happened, in the opinion of the investigator. The narrative portion of the report includes a brief synopsis or narrative of the accident/incident, investigation, analysis, findings, causes, and recommendations.

The QA section (in each maintenance organization) controls and manages all hard copies of the report until the Maintenance Commander is briefed on the results of the investigation. Upon approval for release, the QA section will control the distribution of the report to the concerned maintenance sections. Appendix (C) outlines the type of information recorded in the maintenance accident/incident investigation reports which will be reviewed in this study.

The aim of this study is to identify the types of maintenance errors that are occurring, the contributing factors that led to these errors, and the level of involvement of both the organisation and the technicians in these errors, using the QA investigation report data. In the following chapters, the results of these studies will be compared to determine the most dominant types of errors and contributing factors, and to assist in developing a tool to identify and manage these errors.

4.2 Methodology

A total of 116 accident/incident investigation reports were collected from the QA sections located in the RBAF helicopter and fighter bases. These reports were written by qualified QA personnel who were involved in accident investigation. The investigation reports covered a date range between 2001 and 2006 for the fighter aircraft, and 1996 and 2006 for the helicopters. The reports contained information about accidents/incidents with safety and work-quality outcomes, and provided an opportunity to compare the level of technician error and organizational involvement in each accident/incident. We used the Maintenance Error Decision Aid (MEDA) framework as a means of identifying the maintenance errors experienced by the technicians, the types of contributing factors and the management and technician involvement in the events. We then analysed these investigation reports in detail to identify the types of errors that preceded each accident/incident, and the contributing factors associated with the circumstances surrounding each accident/incident. Each type of error and contributing factor was then mapped to a unique category using the MEDA framework. This framework was used to facilitate consistent comparison of data across studies. Twenty-eight reports were rejected because they did not relate to flight line and engine maintenance activities. The remaining eighty-eight investigation reports were written by two different investigator groups. Seventy-two investigation reports were written by fourteen qualified QA investigators from the helicopter bases, while sixteen investigation reports were written by eight qualified QA investigators from the fighter base. This means that each QA investigator from the helicopter bases wrote an average of five accident/incident investigation reports, while each QA investigator from the fighter base wrote an average of two accident/incident investigation reports.

For the purposes of systematic comparison of the results across studies, only the top five types of maintenance errors and contributing factors reported by QA investigators will be discussed.

4.3 Results

4.3.1 Maintenance Errors

All eighty-eight events included at least one type of maintenance error. Figure (4.1) shows the various types of errors that have been experienced in the helicopter and the fighter bases. The top five types of maintenance errors were identified as: (Aircraft/Equipment Errors, Fault isolation/Test/Inspection Errors, Installation Errors, errors leading to Personal Injury, errors leading to Foreign Object Damage (FOD), and Servicing Errors). Because QA investigators equally reported FOD and ―Servicing" errors, therefore, they were both included in the graph.

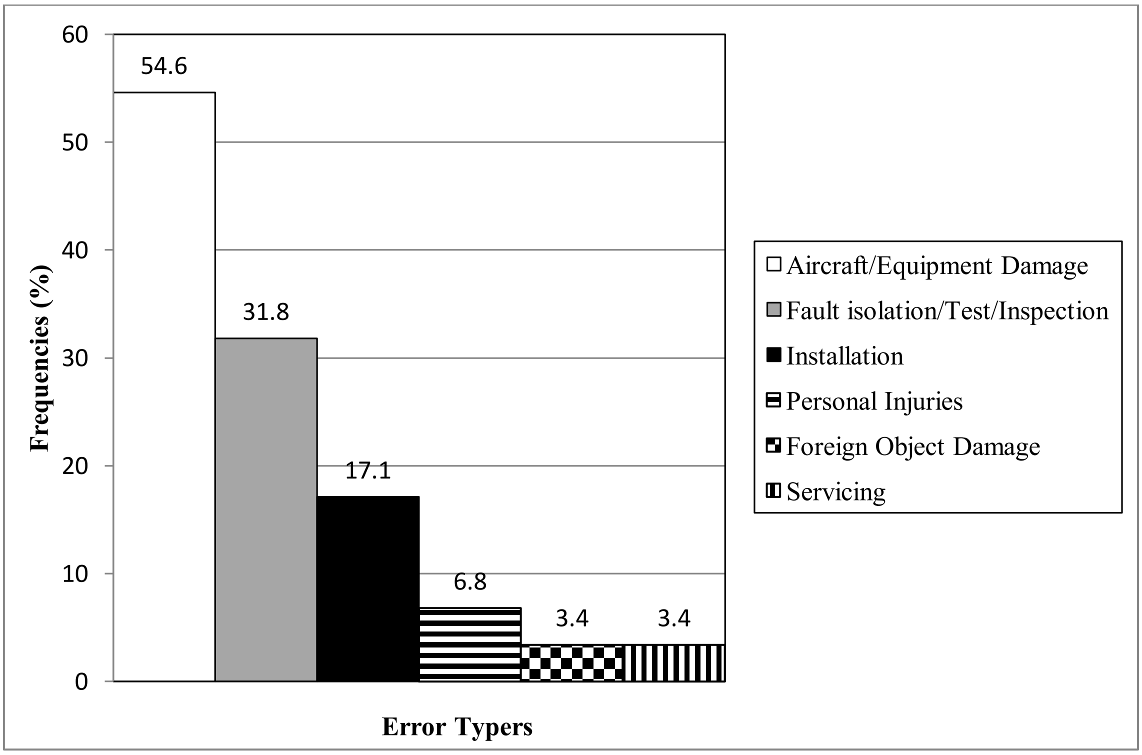

Figure 4.1: The frequencies of the top five types of maintenance errors reported in RBAF QA investigation reports.

4.3.2 Contributing Factors

In this study, organisational factors contributed to all but one of the reported events, and many events were associated with multiple organisational and individual factors. The various factors contributing to accidents/incidents are outlined in figure 4.2.

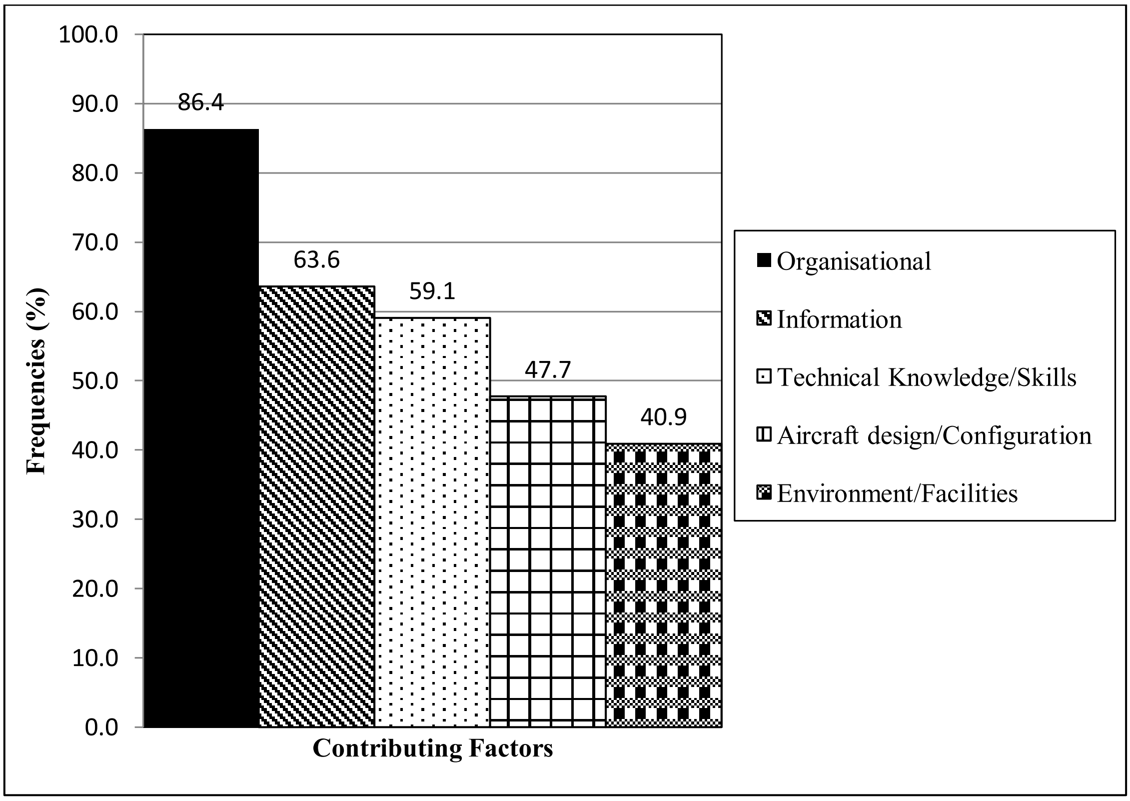

Figure 4.2: The frequencies of the top five contributing factors leading to maintenance errors reported in RBAF QA investigation reports.

Appendix (D) shows the main contributing factors and sub-factors that led to the event, and the percentage of reports that reported these factors. It is clear that the majority of these factors are under the management of the maintenance organisation (e.g.

organisational policies, equipment and parts unavailable, maintenance and repairs of maintenance facilities not accomplished by the maintenance organisation, ineffective communication between maintenance organization and manufacturer, inadequate training etc.).

4.4 Discussion

4.4.1 Maintenance Errors

The same types of maintenance errors nominated by technicians in Study (1) were also reported by Quality Assurance (QA) investigators in Study (2), with the exception of errors leading to Foreign Object Damage (FOD), which were not nominated by the technicians. A comparative rundown of the results in each error category follows.

As shown in Figure 4.1, ―Aircraft/Equipment Damage" error was the most frequently reported type of error in Study (2) (54.6%) while in Study (1) only 36.6% of the technicians nominated this type of error. Usually, this type of error results in damage to the aircraft or the equipment used by the technician during maintenance activity. This damage cannot be repaired without the use organisational resources (spare parts, special tools, etc.). Therefore, the technicians have to report this damage to QA, who would then launch an investigation, after which the aircraft or equipment can be repaired. For this reason, we believe, that ―Aircraft/Equipment Damage" is more represented in the QA investigation reports than in the technicians' responses in Study (1).

Furthermore, “Installation” errors were frequently identified by technicians (39%) in Study (1), while only 17.1% of the QA investigation reports mentioned “Installation” errors as one of the error types in Study (2). Similarly, the “Servicing” error was one of the errors that were reported in both Studies (1) & (2). In Study (1), this type of error was nominated by 26.8% of the technicians, while in Study (2) it was reported in only 3.4% of QA investigation reports.

The findings of studies (1) and (2) suggest that “Installation,” and “Servicing,” errors were more frequently reported by technicians (Study 1) than by QA investigators (Study 2). A possible explanation for these findings is that technicians, a team mate or their supervisors may have detected the “Installation” and “Servicing” errors and been able to rectify them without reporting them to QA or to maintenance management, and thus it does not become an incident on which QA have to investigate and write an investigation report. Such errors might be of the type that were easy to detect by visual inspection only (conducted by a team mate or a supervisor); and can be rectified by installing the missing part (such as bolts, nuts, gaskets, O-rings etc) or adjusting the level of the fluid (adding or draining some fluid) in the component or equipment being serviced as part of the main assigned task. Whereas, in Study (2), QA might have reported these types of errors following an emergency landing call by a pilot (high visibility incident) due to low oil or hydraulic fluid warning indicator or technicians‘ failure to service an aircraft/equipment which necessitates a full investigation and reporting of this event.

In addition, in Study (1), errors leading to personal injuries were nominated by 17.1% of the technicians. According to those technicians, these errors resulted in slips, falls, and technicians contacting hazardous and toxic materials. The technicians in Study (1) stated that these errors occurred because technicians did not follow safety and manufacturers‘ guidelines, lack of communication between technicians, and improper equipment design. In Study (2), similar findings were observed, however at a much lower frequency (6.8%). It is speculated that technicians only report severe injuries that they sustain. Less severe and minor injuries were treated and managed without being reported. However, comparing the findings of studies (1) & (2) with those that would be obtained from Study (3) might shed more light on the reasons behind the disparity in the findings between Studies (1) & (2).

Moreover, the error leading to ―Foreign Object Damage (FOD)" was only highlighted in QA investigation reports (3.4%) (Errors leading to FOD were not among the five types of errors frequently nominated by technicians in Study (1)). In Study (2), this type of error was reported following three separate events which involved the ingestion of foreign matter (such as fasteners, adhesive material or cleaning cloths) into the engine intake. The rectification of this type of error can only be accomplished by removing the engine from the aircraft, disassembling it to remove the foreign matter and then repairing any defective parts. This task cannot be undertaken without the knowledge of maintenance management. Therefore, technicians must notify QA about this event, and QA must then report to management for further instructions.

Finally, in both studies (1) and (2), “Fault isolation/Test/Inspection” errors were almost equally reported by technicians and QA investigators (31.7% and 31.8% respectively). In the QA reports, this type of error might have resulted in serious events such as the loss of an expensive item during flight, an emergency landing, or a system malfunction that was reported by pilots. Commanders at all levels in the air force demand to be kept informed about such events (in the RBAF, these events are known as high-visibility events). Therefore, both technicians and QA investigators are required to report these events.

Neither study provided information about why technicians often fail to report errors to management. In the next chapter (Study 3), responses from interviewed technicians might provide insight into the reasons that discourage technicians from reporting maintenance errors.

4.4.2 Contributing Factors

The most unexpected result (from a military perspective) which emerged from the RBAF accident/incident investigation report review was the large number of “Organisational factors” reported by QA investigators as contributing to errors (as shown in Figure 4.2). Though not necessarily unexpected according to human factors theory, this was unexpected in military contexts due to the aforementioned tendency to think that accidents have individual factors at their cause (see Appendix D). All but one event was associated with at least one organisational factor, suggesting that on the whole, accidents/incidents in the RBAF are the result of latent failures and system deficiencies that only become noticeable when they combine with other factors (Reason, 1990). These factors were the contributing factors in 76 events which were documented in the reports we reviewed in this study. This result is contrary to the usual practice in the RBAF, but is consistent with what would be expected by human factors theory. By contrast, Study 1 technicians nominated “Organisational factors” in only 29 events (each technician was describing only one event). In both studies “Not following work process/procedures” was the most commonly reported sub-factor in this category. “Work process/procedures” may include, but not limited to, scheduling, assigning tasks at the beginning of the shift, shift turnover, design and access to work instructions cards, inspection processes, and work schedules. This sub-factor was reported by 37.5% of the QA investigators and nominated by 36.6% of the technicians.

One interesting finding was that QA investigators reported “Organisational policies” (a sub-factor from the Organisational factors category) as a major cause for a series of events that led to a number of “Aircraft/Equipment Damage” errors. In these instances, QA investigators reported that the aggressive emergency landing training program (in addition to other sub-factors that will be discussed later in this section) contributed to the frequent cracking of helicopter skid tubes (the landing gear for this type of aircraft). This finding is interesting because technicians in the RBAF rarely dispute the management policies relating to pilot training programs.

Our findings of studies 1 and 2 relating to “Organisational factors” reinforce the QA investigators and technicians‘ perceptions that there are opportunities for reducing human error. The primary target for error reduction is to minimize the effects of organizational factors that promote/permit maintenance errors.

The work environment, including easy access to documentation, access to special tools, and access to safety equipment ought to make compliance with safety and maintenance regulations easy. Human nature is to find the quickest and easiest way to complete the job. Therefore, the RBAF should strive to amend the current processes and procedures in such a way that makes the technicians‘ tasks easier and safer.

The other contributing factor that was reported by both the technicians in Study (1) and documented in the QA investigation reports (Study 2) was the ―Information" factor. In Study (1), 22 technicians (53.7%) nominated ―Information" as a contributing factor for the event they were discussing; in Study (2), 56 QA reports (63.6%) identified ―Information" as a contributing factor. The most common sub-factor in the ―Information" category was ―Information not used‘‘. In Study (1), 43.9% of the technicians stated that information was not used, while in Study (2), 61.4% of the reports suggested that information was not used when technicians performed maintenance tasks. The failure to make use of information may be due to three main reasons. Firstly, it is possible that there is a conflict between maintenance manuals and other maintenance instructions, that the information was unreliable, unavailable or not understandable. Secondly, management may not have provided access to the information. Finally, the weapon system‘s manufacturer may not have distributed the information (Technical Orders/Service Bulletins) in a timely manner.

In this case, it is not surprising that both the technicians and the QA personnel reported the same sub-factor (Information not used). Technicians use information documented in maintenance manuals and other related technical documents on a regular basis and they have first-hand knowledge of deficiencies pertaining to technical information. At the same time, QA personnel have detailed knowledge about the availability and accuracy of technical manuals, service bulletins, and other technical information. This is because QA personnel are responsible for the management, review, and evaluation of all applicable technical documents, forms, and operational instructions (locally introduced instructions). Moreover, they need to ensure that these publications are applicable, valid, and accurate for use in the RBAF maintenance organisation. Based on this knowledge, technicians and QA investigators acknowledge that procedures can only be effective if they are used. Procedures that are perceived as being wrong, inaccurate, or impractical would rarely be relied upon in practice. Some procedures seem to be written in a way that makes them easy to write rather than easy to follow. In addition, updates in procedure may not effectively be brought to the attention of maintenance staff, creating the risk that staff might be following out-of-date procedures. For maintenance management to reduce the effects of a lack of information or, inefficiency in information transfer, maintenance policies and procedures need to be reviewed regularly to ensure applicability, validity, and accuracy.

The next three contributing factors identified in by QA investigator and documented in their investigation reports were ―Technical knowledge/Skills”, ―Aircraft design/Configuration”, and ―Environment/Facilities” factors. The majority of these contributing factors were reported by QA personnel from the helicopter bases.

According to the results obtained from the responses of technicians in Study (1), these factors were not among the most frequently nominated contributing factors that led to maintenance errors. However, more in sight might be gained when comparing the findings of this study with those of Study (3) in the next chapter.

Regarding the “Technical Knowledge/Skills” factor, 47.7% of the reports suggested that “Skills” was the leading sub-factor that contributed to errors. According to these reports, technicians‘ handling skills during the towing of aircraft from and to the maintenance hangers contributed to the frequent cracking of helicopter skid tubes (the other contributing sub-factor, mentioned earlier, was “Organizational policies”). Possibly, QA investigators have access to this information as a result of the frequent Quality Verification Inspections (QVI) that QA inspectors conduct on technicians. These regular inspections, probably, led QA personnel to be aware of the level of proficiency with which technicians were towing the aircraft.

In terms of “Aircraft Design/Configuration”, 29.6% of QA investigators reported that “Material deficiency” of the Aircraft/Equipment was a significant sub-factor. One possible reason that this sub-factor was reported by QA investigators (but not reported by technicians) is that QA investigators (as part of their investigation process) might have had access to Non-Destructive Testing (NDI) laboratory reports, which might have concluded that material deficiency is one of the possible reasons for skid tube cracks.

The leading sub-factor in the “Environment/Facilities” category was the “Maintenance/repair of facilities”, reported in 27.3% of the reports. These reports suggested that uneven ramp areas, slopes which were too high at the entrances of the hangers were also possible reasons for the frequent damage caused to helicopters‘ skid tubes. The investigation reports also suggested that the cleanliness of runways, taxi-ways and aircraft parking areas were a major area of concern that led to damage to aircraft tires and engines. QA personnel might have obtained this knowledge from the regular inspections that they conduct on the facility as part of the ramp inspection program that they are responsible for.

This data demonstrates that several contributing factors lead to maintenance errors in aviation. Safety hazards also frequently went unnoticed by maintenance management and supervisors, highlighting a need for close monitoring of technicians, resources, and procedures.

Analysis of QA reports of incidents was instructive, but also gave some conflicting information when compared to the MEDA questionnaires completed by technicians in Study (1). This highlights the importance of comparing multiple sources of data when establishing strategies to identify and manage maintenance errors. Study (3) will report on yet another source of data relevant to the identification of maintenance errors and the contributing factors leading to these errors. These multiple sources of data will assist in developing a comprehensive error identification, reporting and management tool.

4.4.3 Study Limitations

Accident/incident reports are of fundamental importance for the collection of data pertaining to the analysis of individual errors (and their contributing factors) and the determination of means to prevent these errors and the associated factors from recurring, however, due to the limited number of accident/incident reports collected for this study, there might be some errors and factors which were not explored. There are three major problems exist, in the RBAF, for the generation of accident/incident reports relating to maintenance error data:

- Human errors which do not lead to severe injuries to personnel or serious damage to aircraft or equipment are unlikely to be reported.

- A human error which is recovered almost immediately, especially when recovered by the person who committed the error, his supervisor, or a teammate, is unlikely to be reported.

- The current RBAF reporting and investigation system seldom documents information on the root causes of events, such as inadequate procedures, poor working environment, ambiguous information feedback to the technician, etc. Normally, only the consequences or observable manifestation of the error (External Error Mode (EEM)) are reported, such as “inspection panel left open following a pre-flight check.”

If these types of errors and contributing factors were not reported, then the data collected from the RBAF investigation reports would be incomplete and of limited use for error data analysis (based on the number of reported events).

An alternative approach to overcome this limitation would be to collect data from multiple sources (triangulation) such as questionnaire, interviews, etc. This approach was adopted in our research project.

Triangulation involves the use of different sources of data/information (Guion, 2002). There are three rationales frequently given for using triangulation. The first is completeness, which recognizes that following McGrath (1982), any single research method chosen will have inherent flaws, and the choice of that method will limit the conclusions that can be drawn. It is therefore essential to obtain corroborating evidence from a variety of sources. Such sources complement each other, providing richness or detail that would be unavailable from one source alone. The second rationale is contingency, which is driven by the need for insights into how and why a particular data source is chosen (Jack & Raturi, 2006). For example, qualitative data is often used when a phenomenon is very complex or poorly understood (such as the understanding of human error in aviation maintenance). The third rationale for triangulation is confirmation. Triangulation should improve the ability of researchers to draw conclusions from their studies and might result in a more robust and generalisable set of findings (Knafl & Breitmayer, 1989). Traditional criteria like reliability and validity are replaced by the level of symmetry between the different sources of data used (Jack & Raturi, 2006). By using a variety of data sources, the researcher hopes to overcome the intrinsic biases arising from single method, single-observer, and single theory-studies (Jack & Raturi, 2006).

Another limitation of this study is that the accident/incident investigation reports were written by Quality Assurance (QA) investigators who did not receive human factors training; hence the reports might have not explored all the errors and factors relating to human factor issues that led to the events.

The literature suggests that maintenance errors have been assuming greater prominence over the past several years as operational failure modes are gradually reduced, and now constitute a major threat to the continuing reduction in accident rates (Ma, Richards, Sarac & Drury, 2001). Within the aircraft maintenance industry, the most common responses to this threat have been human factor training programs, such as Maintenance Resource Management (MRM) (Taylor, 2000). MRM is used by many major commercial airlines to train its employees in aspects of human factors (e.g. improved communication and awareness, recognition of norms and safeguards to reduce error) (Ma, Richards, Sarac & Drury, 2001). The MRM program attempts to change the way technicians and others (e.g., QA investigators) approach their jobs by promoting greater understanding of the human factors considerations underlying human work and error causation (Ma, Richards, Sarac & Drury, 2001).

According to the literature, Drury, Ma & Woodcock (2002) conducted a study to measure the effects of job aid intervention (e.g., accident investigation tools such as MEDA) on participants‘ ability to discover causal factors in accident investigation. Most of the participants in their study had previous training in both human factors and accident investigation (e.g., MEDA). According to Drury, Ma & Woodcock (2002), their study showed that job aids (MEDA) made the investigators relatively more aware of potential contributing factors of importance and that training in human factors does help the depth of accident investigation (Drury, Ma & Woodcock, 2002).

As we stated in the methodology section of this study, each error type and contributing factor documented in the investigation reports were mapped to a unique MEDA category using the MEDA framework. Due to the large number of contributing factors that MEDA identifies, the MEDA framework might lead to confusion among technicians who use the tool, and might give misleading or incomplete analysis of the contributing factors. However the MEDA results form and the MEDA users' guide do give consistent definitions of error types and contributing factors being investigated, and because MEDA has been used successfully in many airline maintenance organizations, MEDA does have some degree of validity. In addition, because MEDA was developed by human factors practitioners in aviation maintenance it also has content validity (Drury, Ma & Woodcock, 2002).

4.5 Conclusion

As military aircraft maintenance is rarely the focus of psychological research, military aviation technicians are often unaware of the human factors that affect their daily maintenance tasks. The objective of this study was to provide information regarding human errors in military aircraft maintenance, to identify the factors that influence human errors as well as the individual and organisational influences that lead to these errors. For these purposes, data was collected by assessing accident/incident investigation reports collected from the Royal Bahraini Air Force (RBAF). The information found assisted in reaching an understanding of which human factors exist in the RBAF maintenance organisation (and thus have the potential to cause human errors). The results of this study are consistent with the findings of other researchers and investigators who have pointed out that error is caused by multiple contributing factors (Reason, 1990, 1997). As these researchers assert, many errors result from interacting causes, including organisational, social, and individual factors. The present accident/incident report review was useful in identifying the factors involved in the maintenance errors within the RBAF. It is hoped that this identification would lead to a greater awareness of the existence of these factors and that it may thus help to reduce human error. Specific ―human factors” training could help to eliminate the impact that these factors have on military aircraft technicians and ultimately improve error management.

Chapter 5

Study 3

Assessing the Maintenance Technicians' Understanding about the Factors Influencing Maintenance Errors

5.1 Introduction

Over the last decade various human factors studies in maintenance-related issues have been initiated by airworthiness agencies, manufacturers, and the aircraft maintenance industry. The objective of these studies has been to identify research issues and to promote and conduct both basic and applied research related to human factors in aircraft maintenance (Anand, Gramopadhye, and Drury, 2000). In Study (1), Study (2) and in this study, similar initiatives have been made to identify the types of maintenance errors, the contributing factors that led to these errors, and the level of organization and technicians' involvement into these errors.

In studies (1) and (2) data were collected through the MEDA questionnaires and previous accident/incident investigation reports respectively; while in Study (3), data were collected by interviewing technicians from the flight line maintenance and the engine maintenance activities. These qualitative interviews aim to identify the types of errors that the interviewees have experienced or witnessed (during the time of their recruitment in the Royal Bahraini Air Force (RBAF)), the contributing factors that led to these errors, and to explore the technician's perceptions and observations about the effectiveness of the current reporting and investigation system in reporting, identifying, and analysing accidents/incidents in the RBAF. The perceptions and observations of technicians about the effectiveness of the current reporting and investigation system will be discussed in the next chapter (Study 3a). Based on the findings of studies (1), (2), (3), and (3a) we will attempt to develop a tool to identify, reduce, and manage these errors and their associated contributing factors.

We used a triangulation approach to obtain the depth of data required to explore knowledge, attitudes, and behaviour of the technicians involved in the three studies. Triangulation of data is recommended in qualitative research for several reasons. First, triangulation enhances the trustworthiness of analysis by providing a more inclusive and complete narrative (Kidder and Fine, 1987; Mason, 1994). The collection and analysis of data from several sources is likely to include information that might not be available if only one source of data were utilised. Secondly, triangulation reduces the bias and limitations of any individual method of data collection by compensating with the strengths of another method (Lincoln and Guba, 1985).

The use of multiple methods for data collection leading to the same findings can strengthens the validity of the interpretation of the data and adds richness and new perspectives to the data collection process (Fielding and Fielding, 1986; and Brannon, 1992). Moreover, the use of both qualitative and quantitative methods of inquiry may lead to confirmation of the argument either through divergence (when multiple methods lead to the similar results); or in the case of dissonant results, such multiple methods may open pathways to new theories and areas of further exploration and research (Perlesz and Lindsay, 2003).

In studies (1) and (2) we used quantitative research to quantify data and generalise results from a sample of technicians to measure the incidence of various views and opinion of the studied sample; while in Study (3), we used qualitative research to gain an understanding of underlying reasons and motivations, to provide insights into the setting of problems, generating ideas, and to uncover prevalent trends in thoughts and opinions of technicians.

Qualitative research is a method of inquiry appropriated in many different academic disciplines, traditionally in the social sciences (Denzin & Lincoln, 2005). There are many approaches in use to conduct qualitative research, and much depends on the nature of the research in question. If the interview questions are open-ended and exploratory, a grounded theory approach might work best (Ash & Guappone, 2007).

5.1.1 The Basic Ideas of the Grounded Theory

Grounded theory, described in Glaser and Strauss (1976), is a data analysis approach that is largely data driven and aims at producing a theory that describes interesting relationships between situations, events, and activities called –phenomena” which are reflected in the data by abstract concepts. The term –grounded” indicates that this theory will contain only statements which are derived from actual observations, documents, or the words of interviewees (Salinger, Plonka, & Prechelt, 2008; and Strauss, 1987).

Strauss and Corbin (1990) suggest three methods for coding when employing grounded theory based data analysis; Open coding, axial coding and selective coding. Open coding is the part of the analysis concerned with identifying, naming, categorizing and describing phenomena found in the text part of the analytic process. Open coding is used to identify the general categories such as institutions, work activities, social relations, social outcomes, etc. Axial coding is the process of relating codes to each other. To simplify this process, grounded theorists emphasise casual relationships, and fit information into a basic frame of generic relationships. The basic frame consists of the following elements as shown in table 5.1 below.

Table (5.1): Elements of a basic frame of generic relationships.

Elements	Description
Phenomenon	This is the outcome of interest.
Causal conditions	These are the events or variables that lead to the occurrence or development of the phenomenon. It is a set of causes and their properties.
Context	The specific locations (values) of background variables. A set of conditions influencing the action/strategy.
Intervening conditions	Identify context with moderating variables and intervening conditions with mediating variables.
Action strategies	The purposeful, goal-oriented activities that researchers perform in response to the phenomenon and intervening

	conditions.
Consequences	The consequences of the action strategies.

Finally, selective coding is the process of integrating and refining the theory. During selective coding the researcher looks selectively for cases that illustrate themes. These themes: identify a story line using the concepts and analytical relations already disclosed; identify a core category, its characteristics, and dimensions; and recognise categories, identify categories to fill the gaps and relate categories to each other (Mikkelsen, 2005).

The aim of this study is to identify the types of maintenance errors that the interviewees in the RBAF have experienced or witnessed and the contributing factors that led to these errors. In addition, we will explore the level of organisational involvement into these errors and factors.

5.2 Methodology

Due to the nature and sensitivity of information relating to human factor issues in the RBAF maintenance environment, no reference can be made to the type of the weapon system, location of the military bases, or the demographics of the technicians participating in this study.

Qualitative research commonly uses purposive sampling, a method in which participants who are best suited to provide a full description of the research topic are selected. To identify important patterns that cut across different settings (Patton, 1990; & Kuzel, 1992), flight line and engine maintenance technicians from the fighter and helicopter bases were sought. To gain insight into the factors that contribute to maintenance errors and the perceptions of the maintenance technicians, fully structured interviews were conducted. A fully structured interview has predetermined questions with fixed wording, usually in a pre-set order and uses an open - question format (Robson, 2002). The interviews typically lasted for 35 – 55 minutes. Interviews were arranged by an administrative member of the Air Force maintenance organisation.

The questions used in this study comprised of two parts. The first part consisted of 35 questions dealing with what happened in an event (that the individual technician has experienced or heard about), how the event happened, and how the technician detected and recovered from the error. This set of questions were developed by Neelam Naikar and Alyson Sanders from the Defence Science and Technology Organization (DSTO), Australia (Naikar & Saunders, 2003); and modified for the purpose of this study. The questions used in these interviews are listed in Appendix (E). The second part contained 13 questions dealing with information about the current reporting system, information such as reports management, report review, the types of information recorded in the report, how this information were used, tracking of corrective actions, etc. This set of questions will be discussed in Study (3a).

To minimize the possibility of coercion, the investigator provided the Officer(s)-in-Charge of the technicians with the necessary information sheet(s) and requested them to invite the technicians to participate in the interview. The Officer(s)-in-Charge advised the potential participants that participation was voluntary. The names of technicians who have agreed to participate were then provided to the investigator.

48 maintenance technicians from the flight line and engine maintenance branches from the helicopter (24) and fighter aircraft (24) bases agreed to participate in this study. A meeting was conducted with the potential participants to brief them on the purpose of the study, and how it would be conducted. A tape recorder was used to record the participants‘ responses to the questions that were directed to them. Names of the participants were not recorded. Once the interviews were completed, interview transcripts were made by the researcher for review and analysis.

To facilitate a systematic comparison between the results studies (1), (2), and this study (Study 3) only the top five types of maintenance errors and the top five contributing factors identified by technicians and QA investigators will be presented.

For initial analysis, we conducted multiple readings of the transcripts to identify prominent themes. These transcripts were then reviewed by the researcher to interpret and to further refine themes driven by the participants‘ own words and phrases. Through this process a template of themes and open codes were constructed as shown in figure 5.1.

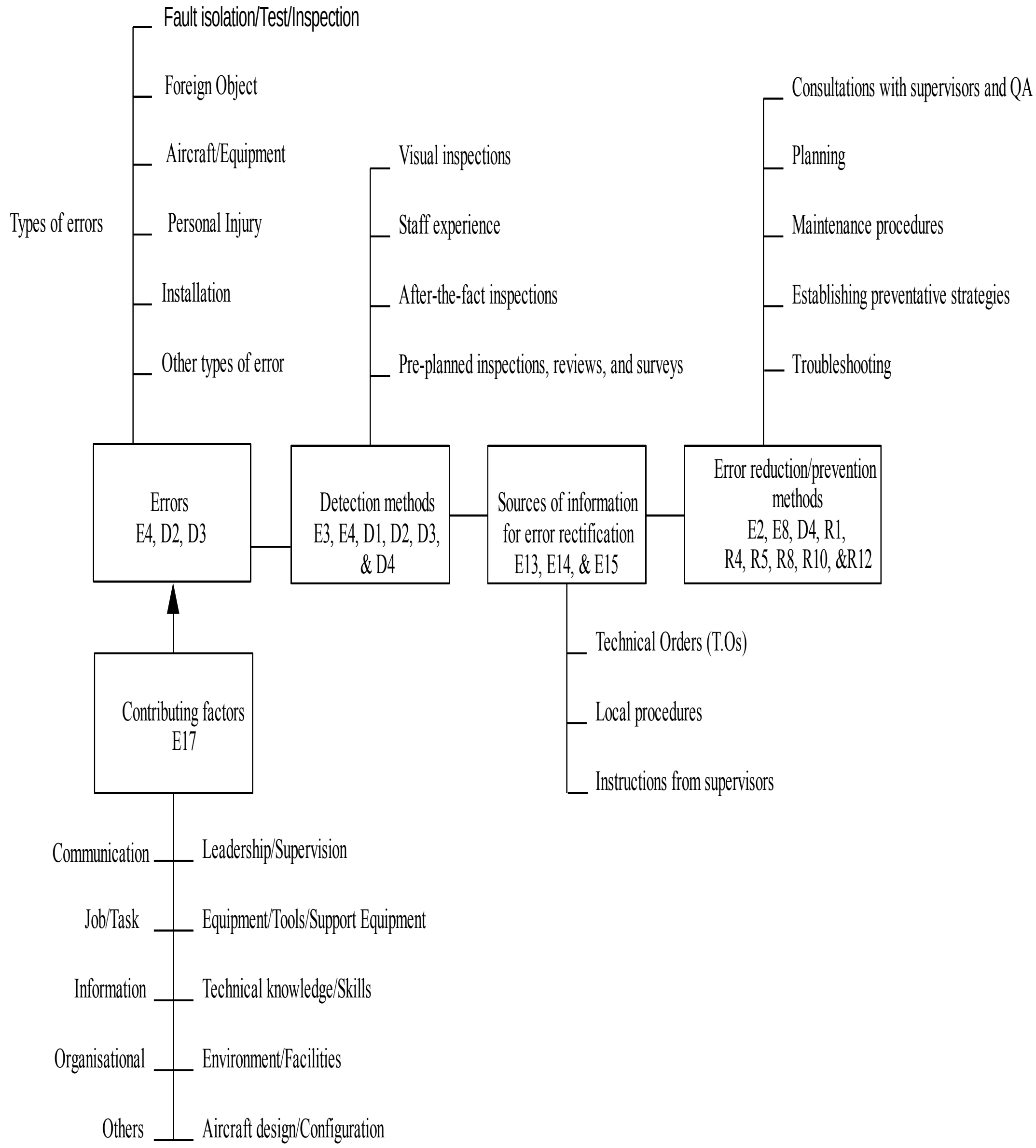

Figure 5.1: Themes and codes emerging from qualitative analysis of interview transcript.

The codes E2, D4, E17 etc. refer to interview questions that we used during the interviews. These questions prompted the generation of the themes shown in figure 5.1 above. For instance, the code (E2) refers to question (Q4) which asks the technician ―Can you tell me what happened?" (Referring to the event); the code (D4) refers to question (Q23) which states ―Could you have detected the error earlier? and if so how?”; the code (E17) refers to question (Q19) which states ―Where there any contributing factors?”, If so, what are they?” and so on.

5.3 Results

All 48 interviewees discussed one event only (each relating to a different event). Of the 48 technician interviewed, 11 did not experience or hear of any maintenance errors in the RBAF because they were new recruits, but they were included because they either have full or partial knowledge about the current RBAF reporting system, with the exception of one who had no idea at all about the RBAF reporting and investigation system, but has some idea about other reporting systems. Therefore, it was decided to include these technicians in the study to assess their perception and provide some insight into the reasons for not reporting errors and the features that should be available in an effective reporting system.

Technicians‘ descriptions of the events that they experienced (or heard about) revealed five major themes. These themes are: types of maintenance errors; contributing factors; detection methods; rectification methods; and methods of recovery and prevention as shown in figure 5.1 above.

5.3.1 Maintenance Errors

The top five types of maintenance errors identified by the interviewees were (aircraft/equipment errors, fault isolation/test/inspection errors, errors that led to personal injury, errors that led to foreign object damage and Installation errors). Figure 5.2 shows a graphical representation of these errors. Most of the technicians reported at least one type of error (other technicians reported more than one type of error). The most dominant type of error was the aircraft/equipment damage error.

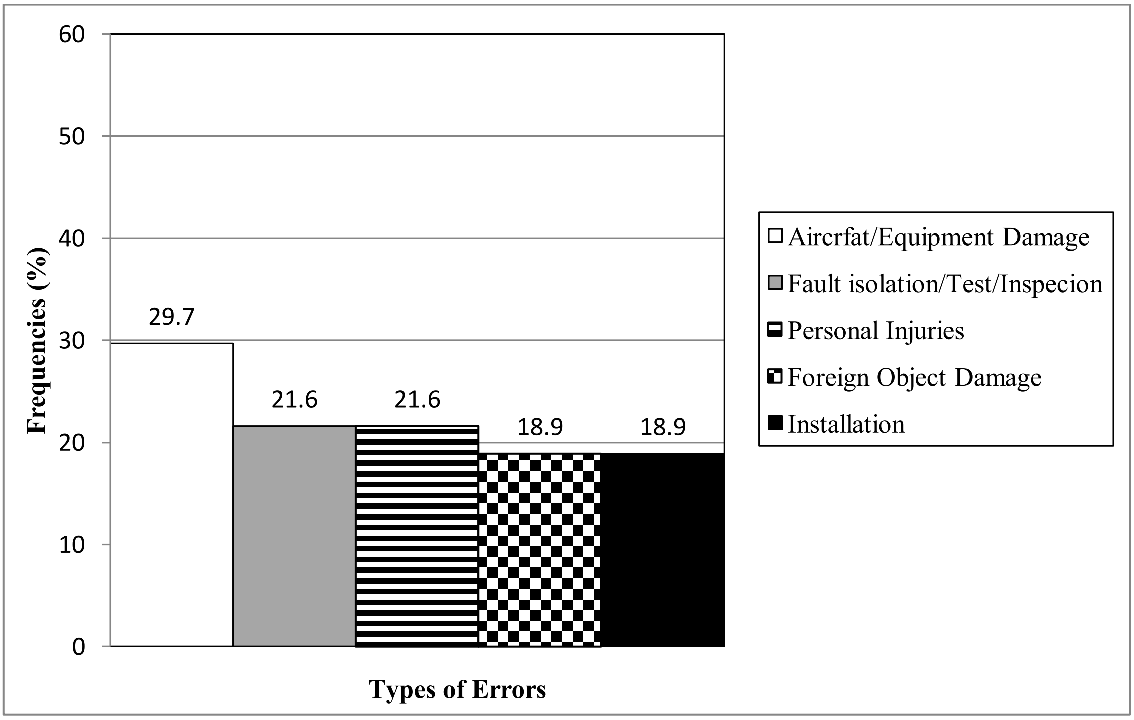

Figure 5.2: The frequencies of the top five types of maintenance errors mentioned by RBAF flight-line and engine maintenance technicians during the interviews.

29.73% of the participants in this study indicated that the most dominant type of error was Aircraft/Equipment Damage errors. Examples of such types of errors include unserviceable engine mount rail being used to mount a serviceable engine, a towing tug crashing into a parked air conditioning unit due to defective transmission, and a towing tug crashing into a parked aircraft due to defective hand brake.

21.6% of the interviewees reported that they have encountered or witnessed personal injury types of errors. These errors involved technicians falling from the top of an aircraft, mechanics slipping on the hanger floor and a crew chief gets his hand rolled over by an aircraft tire while performing an engine run.

Another 21.6% of the interviewed technicians stated that they experienced a Fault isolation/Test/Inspection type of error. Examples of these types of errors include an incident were a crew-chief failed to inspect the aircraft tire for correct air pressure; where a supervisor failed to perform a follow-on inspection on the particle separator of the engine, or where an engine shop technician failed to test the engine-wash trolley for proper functioning.

Some technicians indicated that they have experienced errors involving foreign objects. 18.9% of the participants reported that they have either made or witnessed this type of error. Examples of these types of errors include: forgetting to remove a cleaning rag from the inside of an engine; and an incident where fasteners fall inside an engine or an aircraft control system.

Finally, another 18.9% of the interviewees stated that they either committed an installation error or witnessed or heard about such an error. These errors include installing a wrong bolt, installing a gasket in the wrong orientation, and failure to install a landing gear safety pin prior to performing a landing gear retraction test.

5.3.2 Contributing Factors

According to the interviewees, several contributing factors led to the different types of errors encountered by the technicians. The top five contributing factors are outlined in figure 5.3.

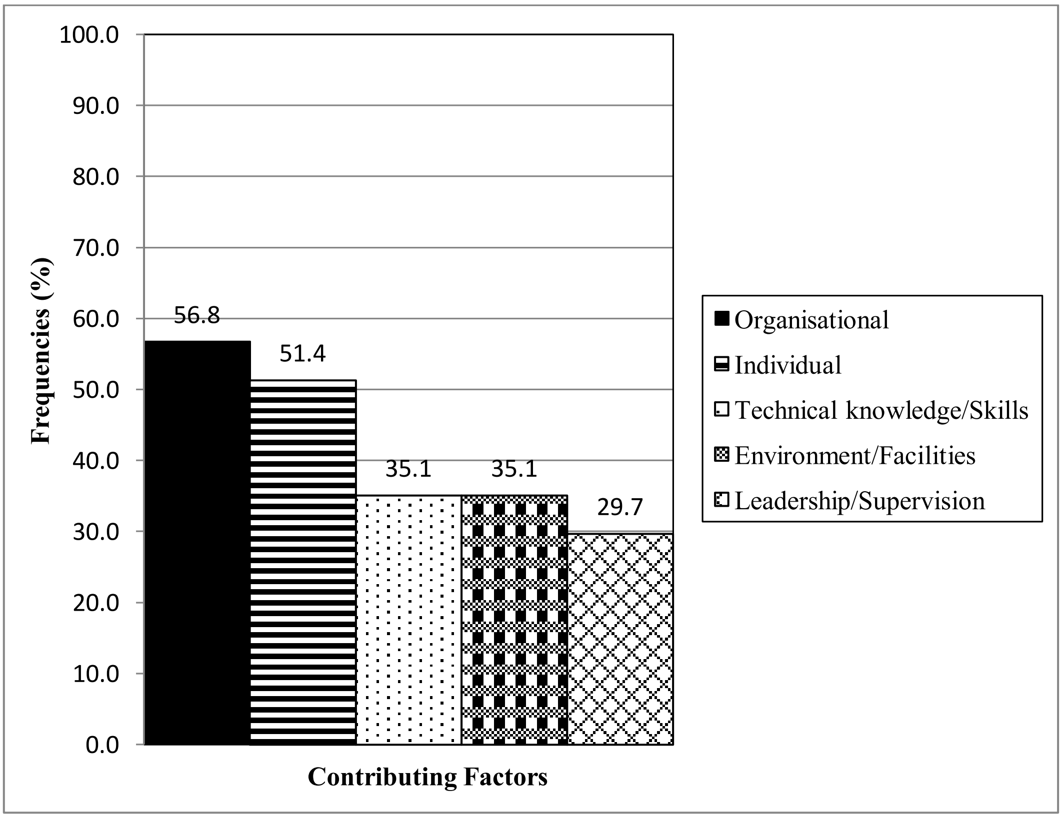

Figure 5.3: The frequencies of the top five contributing factors leading to maintenance errors mentioned by RBAF flight-line and engine technicians during the interviews.

The interviews with the maintenance crew indicated that organizational factors were the most frequently occurring factors that led to the events. The typical problems were perceived to be related to lack of manpower, safety procedures were not followed, lack of or unclear organisational policies, and work group normal practices. For instance, one supervisor stated that safety precautions/procedures not being followed because of management/organisational failures; this is evident from the statement he made during the interview relating to an error committed by one of his technicians:

> *My assessment was that safety precautions were not followed.... the technician did not wear the proper safety shoe...maintenance management did not provide the safety shoe in the first place.* (H40)

The codes that follow participants' responses represent the base in which the technician was assigned to, and the technicians' last two digits of his service number, this code was used to maintain anonymity. Codes that are preceded with the letter (H) signify that the technician was assigned to a helicopter base, while codes that are preceded by the letter (F) indicates that the technician was assigned to the fighter base. For example, the code (F42) signifies that the technician is from the fighter base and his service number is XXX42.

Participants also suggested that individual factors also played a role in leading to the events that they have experienced or witnessed. These factors were related to time constraints (time pressure) from maintenance control staff to complete the assigned tasks in less than agreed upon time frames; work place distractions from the shop officer, the pilot or a team member; and memory lapses.

The interviewees also pointed out that there are other factors that led to the events; these factors include the lack of technical knowledge/skills, environment/facilities, and leadership/supervision. The majority of interviewees who reported technical knowledge/skills and leadership/supervision factors were from the helicopter bases, with the exception of the environment/facilities factor that was reported by more technicians from the fighter base than from the helicopter bases.

Figure 5.3 represents only the top five contributing factors that the interviewed technicians experienced or witnessed. Appendix (F) lists all the contributing factors and the percentages of technicians who stated that the top five factors have contributed to the events that they experienced or witnessed.

5.3.3 Error Detection Methods

According to the interviews, errors were detected by four methods. The most frequently reported method of error detection was –pre-planned inspections”. 91.6% of the technicians (from both the fighter base and the helicopter bases) reported this method as an effective means for error detection. These pre-planned inspections might include regular reviews of maintenance documents and publications for currency, accuracy and validity. The pre-planned inspections might also include regular surveys of maintenance facilities and equipment to ensure proper maintenance and repair actions have been undertaken.

The next most reported error detection method was “after-the-fact investigations” conducted by QA investigators. 66.7% of the technicians reported that this method was used to detect errors that they either committed or witnessed while working in the RBAF.

Few technicians (14.6%) stated that errors were detected by visual inspections performed by themselves, a supervisor or a QA inspector. These inspections were either documented in the existing Technical Orders/Service Bulletins (TOs/SBs) or special maintenance instructions communicated to maintenance management by the manufacturer.

In contrast to the relatively high percentage of technicians who reported that “after-the-fact investigation” was one of the error detection methods, error detection by QA/Supervisor‘s experience was only reported by 2.1% of the technicians. This method was utilised when there was no other means of error detection documented in the relevant maintenance manual and investigators or supervisors mainly relied on their experience. Table (5.2) outlines the error detection methods that interviewees used to detect maintenance errors.

Table (5.2): Methods of error detection identified by technicians.

Methods of error detection	Percentage of interviewees mentioning this item (N=48)
1- Pre-planned inspections, reviews, and surveys.	91.6
2- After-the-fact investigation.	66.7
3- Visual inspection.	14.6
4- Experience of a supervisor/QA personnel.	2.1

5.3.4 Sources of Information for Error Rectification

One of the themes that were identified by the technicians interviewed in this study was the sources of information the technicians referred to for the rectification of errors. Table (5.3) summarises technicians' responses pertaining to the sources of information that might be available for the rectification of maintenance errors.

Table (5.3): The sources of information that technicians and supervisors used to rectify errors.

Sources of information for error rectification	Percentage of interviewees mentioning this item (N= 48)
Local procedures	47.9
Manufacturer's procedures/publications	41.7
Instructions from supervisors	29.2

"Local procedures" were the most frequently referred to by technicians (47.9%) to deal with failures that led to personal injuries and aircraft and equipment damage. According to the interviewees, these procedures were: reporting the error to QA, and conducting a

QA investigation. This is evident from some of the responses that were collected from the interviews.

I called for assistance from the supervisor… then called the QA… and then QA performed the investigation. (H14)

I went to the accident site, informed my section officer, and contacted QA to proceed with their investigation. (F59)

Apparently, some of the technicians did not know the exact procedures for dealing with events involving failures that lead to injuries or weapon system damage, but they knew that QA is the activity that should be contacted following such events. The following responses support this interpretation.

I called the Officer-in-charge and the QA personnel and told them about what happened, but I do not know if there is a standard procedure to deal with such an event. I worked from intuition. (H73)

QA had the procedures to deal with such events. (F42)

The other source of information available for technicians to rectify errors was the technical manuals and job cards. These publications were provided by the weapon system manufacturer to the users of the weapon system in order to maintain and repair systems‘ malfunctions. 41.7% of the interviewees stated that technicians and supervisors used manufacture‘s procedures documented in the relevant Technical Orders (T.Os) to rectify the errors that they encountered or witnessed. Some of the technicians‘ responses are listed.

I told the supervisor about what happened, he told me to order a replacement bolt, he went to check the location of the task to make sure that there was no other damage sustained. When the bolt was delivered from supply, I made sure that it is the correct bolt by checking the part number, ***then I installed it as directed in the T.O*** *, but this time by applying the exact torque value only (using the torque wrench).* (F99)

I called my supervisor and told him what happened and ***he carried out the action as directed in the maintenance manual.*** (H95)

Carry out the task (on both aircraft) ***as specified by the T.O***. (F47

The least reported source of information available for technicians to rectify maintenance errors is ―instructions from supervisors”. Only 29.2% of the technicians reported that their supervisors provided them with information on how to rectify the error they made when they were performing a maintenance task.

5.3.5 Error Reduction/Prevention

The final theme that was identified by this study was the “error reduction/prevention methods” used or suggested by the participants. Table (5.4) outlines the methods used by technicians and supervisors to reduce/prevent the various types of errors.

Technicians reported that planning was an effective method for error reduction/prevention. Had they planned the task earlier, the error might have been avoided. The majority of these technicians (47.9%) stated that they did not have a plan available for conducting the task nor for dealing with the event. When these technicians were asked “What was your plan for dealing with this event?” they responded that they corrected the error in accordance with instructions from the supervisor, the shop officer, or QA.

Perform the task as instructed by the supervisor or the QA if there is no procedures are available. (H30)

Performing the task as instructed by the officer... (H64)

Table (5.4): Methods used by technicians and supervisors in the RBAF to reduce/prevent errors.

Error reduction/prevention methods	Percentage of technicians who reported this method (N=48)
Planning	
Plan not available	47.9
Plan is available	35.4
Other repair centre planned and executed the task	6.3
Standard procedures	
Procedures available	64.6
Procedures not available	12.5
Procedures available in other repair centre‘s manuals	4.2
Consultation with:	
Supervisors	47.9
QA Personnel	22.9

35.4% of the interviewed technicians stated that they had a plan to perform the task as directed in the relevant maintenance manual, but they did not develop a plan for dealing with the event because the QA department has already developed that plan. Most of the events which have been reported by these technicians involved failures that led to personal injuries and/or weapon system damage. For such events the QA department has pre-planned procedures for the evacuation, treatment of personnel or the repair of damaged weapon systems, and the investigation of these events.

The next most commonly reported method of error reduction/prevention by technicians in the RBAF was using standard procedures. 64.6% of the technicians stated that errors might have been reduced/prevented by following the standard maintenance procedures. They also stated that, initially, task standard procedures were not complied with as required by the technicians, but after the occurrence of the error, the technicians had to perform the task again. This time the standard procedures were followed as required.

We were performing the requirements of some of the Time Compliance Technical Orders (TCTO) on one of the engines. We completed the tasks and closed the engine up… we did not record the serial numbers of the parts that we installed and this is one of the requirements, so we had to open the engine again and record the serial numbers. We did not comply with the TCTO as required. (F73)

Only 12.5% of the technicians indicated that standard procedures were not used because they were not available, had these procedures been available, these errors might have been prevented.

All the steps were verbal among the technicians and the inspector. *It was the inspector who should take a look at the intake of the engine before the inlet particle separator was installed...****The current procedures were modified to add the inspection step to the particle separator inspection list before closing the inlet cowling.*** (H17)

4.2% of the interviewed technicians stated that they committed the error because task procedures were not documented in the shop‘s Technical Orders (T. Os) they were documented in the T. O(s) of another shop. The following statement by one of the technicians serves as an example to demonstrate the situation.

... I was only following the supervisor's orders…and ***the manual I was using (the electrical shop manual) did not contain the correct information (torque values on the bolts), this information was available in the engine shop manual.*** (H10)

The technicians‘ statements cited above suggest that standard maintenance procedures were important sources for the reduction/prevention of maintenance errors. The lack of these procedures (unavailability) and time pressure were some of the reason for not complying with these procedures. Evidence indicates that maintenance personnel often fail to comply with procedure (CAP 716). According to The United Kingdom Civil Aviation Authority (CAA), some of the issues which lead to non-compliance with procedures are poorly written procedures, unavailability of appropriate maintenance procedures or tooling, time pressure, etc. (JAA JAR 145). One of the reasons for procedural non-compliance identified in a European study (ADAMS, 1999) is that there are better or quicker methods for conducting a task. Some of these methods may be safe; others may not. Therefore, it is important to determine and document the best procedures, and to establish a situation whereby the best, quickest, and safest method for performing a task is to follow the established procedures, abolishing the need to work around procedures in order to accomplish the task.

70.9% of the technicians interviewed in this study consulted with their supervisors, QA, or both to obtain information on how to deal with the error. 47.9% of these technicians stated that supervisors provided guidance and assistance on how to deal with and reduce the possibility of committing similar errors. This assistance was in the form of instructions: to notify QA personnel about an error and the need to perform a detailed investigation (due to the severity of the damage); to perform a follow-up inspection to assess the situation and conduct corrective actions; or to provide instructions to the technicians on how to conduct a maintenance task in accordance with manufacturer‗s publications. This guidance from supervisors provides a learning experience that might reduce/prevent similar errors in the future.

I called my supervisor and told him what happened and he carried out the action as directed in the maintenance manual. (H95)

... Consulted with the supervisor about the correct way of installing the seal... (F42)

Some of the technicians (22.9%) stated that they would consult with a QA for guidance and instructions when they commit an error. Other technicians stated that they would deal with the event as instructed by the supervisor or the QA in the absence of standard procedures.

I will consult QA for guidelines and instructions. (H30)

Performing the task as instructed by the supervisor. (F99)

When the interviewees were asked ―Is there anything you could have done to prevent the event from occurring, if so, what?" they suggested several strategies that maintenance management could implement to reduce and possibly may prevent the reoccurrence of these errors. Some of these strategies are listed in table 5.5.The following are some of the technicians' statements regarding the safety strategies that can be implemented.

…Implement the policy of not putting the power 'ON' if the aircraft is inside the hanger…(H30)

Allow enough time to perform the task. (H91)

…The organization should have provided the safety shoes… (H40)

Table (5.5): Possible strategies that could be implemented by maintenance management to reduce/prevent the on-sit of future maintenance errors.

Other error reduction/prevention Strategies	Percentage of technicians who reported these strategies (N=48)
Review maintenance policies and procedures regularly for applicability (Including safety precautions).	37.5
Review availability and serviceability of tools, equipment, and parts.	10.5
Proper planning and scheduling of tasks by maintenance control.	10.5
Review technicians' needs (such as safety wear requirements, rest periods, moral boosting etc).	8.4
Review technician's training needs.	8.4
Review manning requirements.	4.2
Adherence to scheduled task durations.	4.2
Review facilities maintenance requirements.	2.1
Perform required facility maintenance and repairs.	2.1

The interviews revealed that technicians from all the bases in the RBAF perform unscheduled aircraft and engine repairs and scheduled preventative maintenance on aircraft and engines. In addition, these technicians also perform maintenance related tasks around the clock in case of an urgent repair; as well as security functions such as guarding the maintenance facilities. In practice this may lead the technician to working alone and some errors may be committed without being reported which is a challenge for accident/incident reporting.

5.4 Discussion

5.4.1 Maintenance Errors

Comparison of the results of studies (1), (2), and Study (3) revealed some interesting results relating to the types of maintenance errors in the RBAF. The three studies indicated that similar types of maintenance errors were identified and reported in studies (1), (2), and (3). For example “aircraft/equipment” errors, “fault isolation/test/inspection” errors, errors leading to “personal injury” and “installation” errors were reported in studies (1), (2), and (3). However, with regards to “servicing errors” and errors leading to “foreign object damage (FOD)” the results of theses three studies differed. For instance, “servicing errors” were identified in Study (1) and Study (2) only and not in Study (3), while errors leading to FOD were reported in studies (2) and (3), but not in Study (1). In the following section we will attempt to offer possible explanations for the findings of these studies.

5.4.1.1 Aircraft/Equipment Errors

In Study (3), aircraft/equipment error was the most reported type of error, similar to studies (1) and (2) (S1: 36.6%, S2: 54.6% and S3: 29.7%). This type of error resulted in damage to the weapon system. In order to repair the damaged aircraft or equipment parts and special tools must be supplied. These parts and special tools can not be issued without the knowledge of maintenance management. Therefore technicians have to report “aircraft/equipment” errors to QA to investigate the event, and then QA investigators have to report the findings of the investigation to management (in compliance with the requirements of the RBAF 66-1 manual). Once the QA investigation is completed, the aircraft, engine, or equipment may be repaired. For this reason we believe that ―aircraft/equipment” errors were more represented in the QA investigation reports than in studies (1) and (3). The possible reasons for the lower percentages in studies (1) and (3) are: in Study (1), technicians, probably, did not report all of the errors that were committed to QA because some of the errors might be negligible or did not require tools or major parts to repair the aircraft/equipment; while in Study (3), because the MEDA framework was not utilised, some participants in this study may had difficulties in classifying the error that they experienced as an ―aircraft/equipment” error, and hence were not reported. This possibility is supported by findings of a study conducted by Drury, Ma, & Woodcock (2002) to measure the effectiveness of MEDA as an incident investigation aid. According to Drury, Ma, & Woodcock (2002), investigation aids, such as MEDA, encourage logical thinking, e.g. the classification of the event and errors, and would support the investigation process.

5.4.1.2 Fault Isolation/Test/Inspection Errors

As in studies (1) and (2), the ―fault isolation/test/inspection” error was one of the top five types of errors reported by technicians in Study (3) (S1: 31.7%, S2: 31.8%, S3: 21.6%). However, lower percentages were recorded for this error in Study (3), possibly because 11 of the interviewed technicians did not experience or hear of any maintenance errors in the RBAF because they were new recruits. According to the technicians who participated in Study (3), ―fault isolation/test/inspection” errors had to be reported because it resulted in: the cancellation of a mission, an emergency landing, or a system malfunction that was reported by a pilot to the Air Wing Commander. The findings of studies (1) and (2) relating to ―fault isolation/test/inspection” errors suggest that this type of error is actually reported by technicians and QA in the RBAF; had more experienced technicians participated in this study, different results might have been obtained.

5.4.1.3 Installation Errors

Installation errors were mentioned in this study by18.9% of the technicians (in studies 1 and 2, they were nominated by 39.0% of the technicians and reported by 17.1% of the QA investigators respectively). These results suggest (contrary to the requirement of the current procedures) that a considerable number of installation errors were committed but were not reported to QA or maintenance management, especially if no damage was sustained to the weapon system. Another reason might be that installation errors were detected and corrected by the technician involved in the event, a team mate, or a supervisor and were not reported to QA. This is evident from the responses of the technicians who participated in this study.

> *After the event the engine was brought back to the shop, further inspection was conducted and was found that the seal was installed backwards. Sheet metal was called to help in removing the seal (it was damaged during removal). We ordered a replacement, and was installed correctly in accordance with the T.O.* (F42)

…when he (the technician) *tightened the bolts he over torqued them and one bolt was broken…a small piece of the bolt was protruding from the casing, so I removed it and installed another bolt.* (H77)

The results of studies (2) and (3) appear to be similar, and support the idea that ―installation” errors do occur in RBAF maintenance organisations. Interestingly, the results of studies (1) and (3), relating to ―installation” errors, also support the claim that we made in Study (2) which we argued that there were significant errors committed by technicians in the RBAF without being reported to QA. For this reason, we believe, that ―installation” errors were nominated by technicians in Study (1) more frequently than in studies (2) and (3). This is evident from the responses cited above and the percentage of technicians who nominated ―installation” errors in Study (1) (39.0%).

5.4.1.4 Errors Leading to "Personal Injuries"

Errors that led to personal injury were among the most nominated errors in this study (21.6%). This type of error was also reported in Study (2) but at much lower percentages (6.8%). In Study (1), 17.1% of the participants nominated the errors that led to personal injury.

In Study (3), the participants described some of the events that involved errors which led to personal injury, for instance:

The technician climbed the first step of the maintenance stand and as he was stepping on the second step his foot slipped and fallen on the hanger floor ***and had a head injury and the wound was bleeding***. (H40)

As I was carrying the Mechanical Engine Control (MEC) unit to place it on the trolly, I slipped (there was oil and fuel dripping from the MEC on the floor), apparently I stepped on some oil or fuel and slipped (at that time I was still carrying the MEC in my hand). My hand and the MEC struck the hanger floor ***causing a sever injury to my finger (my finger separated from my hand), so I was rushed to the base clinic. In the clinic they cleaned my hand and put my finger in a plastic bag filled with ice and I was rushed to the hospital***.(F42)

We were running an aircraft on the trim pad, and then the crew chief told the technician to remove the chokes, as he was removing the chokes the wheels rolled over the technician's fingers... ***I thought he was seriously injured, but luckily he was not...the technician continued the task following treatment.*** (F67)

In Study (2), we speculated that technicians in the RBAF only reported severe injuries that they sustained; less severe and minor injuries were treated without being reported to QA for investigation. The above cited examples of technicians‘ responses may provide some support for this claim. Furthermore, it is possible that because technicians in Study (1) did not receive training to use MEDA results forms to analyse the events that they experienced, it is possible that they did not recognise what constitute an error leading to –personal injury” or any error for this matter. For these reasons, we believe, there are differences between the results of studies (1), (2), and (3) relating to errors leading to –personal injuries”.

5.4.1.5 Errors Leading to “Foreign Object Damage (FOD)”

Errors that led to foreign object damage were among the most nominated errors in this study (18.9%). These types of errors were also reported in Study (2) but at much lower percentages (3.4%). In Study (1), errors that led to foreign object damage were not included as one of the top five errors.

In Study (3), the participants provide statements describing events that involved errors leading to FOD, for example:

I was performing a phase inspection on the main rotor head as I was removing the pitch change link bolt to check the condition of the bearing, the bolt fill from my hand inside the aircraft...then we opened the main drive shaft cowling and we found it there ***(no damage was sustained),*** *so the bolt was removed, installed the main drive shaft cowling, and installed the bolt in the pitch link and torqued it as specified in the T.O.* (H71)

I was holding the pilot's helmet bag in my hand, and the same time I was holding the aircraft ladder with my both hands to install it on the aircraft to allow the pilot to climb *down the aircraft ...The engine was turned Off, but the inlet guide vanes were still rotating and there was a light gust of wind blowing in the direction of the aircraft nose. As I was installing the aircraft ladder the bag was sucked from my hand by the engine into the inlet guide vanes, but luckily it was not sucked into the engine**...but minor damage was sustained to the inlet guide vanes**.* (F63)

In Study (2), errors leading to FOD were reported following events that caused severe engine damage that required the repair/replacement of effected parts. In Study (3), technician also reported errors leading to FOD, however, based on the descriptions provided by the participants, it appears that some of the FOD errors were not reported to QA because minor or no damage was sustained to aircraft or engines. Another reason for the difference between the results of studies (2) and (3) is that technicians in Study (3) might have detected the error by themselves, their supervisor, or a teammate and recovered from the error without being reported to QA. These reasons might justify the low number of events reported to QA in Study (2) relating to errors leading to FOD.

5.4.2 Contributing Factors

According to studies (1), (2), and this study several contributing factors led to the different types of errors. Table (5.6) provides a comparison of the results identified by these studies regarding the types of contributing factors.

Table (5.6): A comparison of the findings of studies 1, 2, and 3 regarding the contributing factors that led to maintenance errors.

Types of Contributing Factors	Frequencies (%)		
	Study 1 (MEDA)	Study 2 (QA Investigation Reports)	Study 3 (Interviews)
Organizational Factors	70.7	86.4	56.8
Individual Factors	68.3		51.4
Technical knowledge/Skills		59.1	35.1
Environment/Facilities		40.9	35.1
Leadership/Supervision	65.9		29.7
Information Factors	53.7	63.6	
Aircraft design/Configuration		47.7	
Job/Task Factors	56.1		

5.4.2.1 Organisational Factors

The findings of the three studies revealed that technicians (in studies 1 and 3) and QA investigators (Study 2) acknowledge that “organisational factors” were the most dominant contributing factors that led to maintenance errors in the RBAF, and that RBAF management should focus on this factor to reduce or minimise the reoccurrence of similar errors. Despite the agreement between the results of the three studies, the studies differ in terms of the frequencies with which “organisational factors” were reported. As shown in table 6, QA investigators reported the highest frequency of occurrence (86.4%). QA investigators in the RBAF are the most qualified and experienced technicians in their trades. This experience, we believe, aided the QA investigators in correctly identifying and classifying the various factors that contributed to errors. On the other hand, technicians in Study (1) (some of them are also highly experienced and qualified in their trades) reported lower frequencies because they might have misinterpreted or did not recognise the different types of factors listed in the MEDA results form (an inherent limitation of the MEDA framework that we discussed in Study 1). Whereas in Study (3), we believe that the frequency with which ―organisational factors” were reported was lower than the frequencies in studies (1) and (2) is due to the less experienced technicians who participated in this study (11 technicians). 11 technicians represent 22.9% of the total technicians participated in Study (3) (48); not considering these technicians, effected the results (pertaining to types of errors and contributing factors) of this study. As shown in table 5.6 above, the results of Study (3) are the lowest compared to those of studies (1) and (2), which suggest that had the 11 technicians been more experienced, higher frequencies might have been reported. This explanation applies not only to ―organisational Factors”, but it might also apply to the different types of errors and contributing factors reported in this study.

In studies (1) and (2), technicians and QA investigators reported that not following ―work processes/procedures” was the leading sub-factor (in organisational factors category) for committing maintenance errors; whereas in this study ―not enough staff” was identified by technicians as the leading sub-factor. One possible reason for the difference in results might be that at the time of the events a number of the skilled technicians were either retired or reassigned to other departments in the Air Force and were replaced with semi-skilled recruits or trainees. This is evident from the statements of the participants in this study.

One of the crew chiefs **assigned a new technician to prepare an aircraft for flight**. *The pilots completed their pre-flight inspection and started the engines …At this time the new technician completed the task of the crew chief to check the oil levels in the engine and the Reduction Gear Box (RGB).* (H05)

…he (the technician) *knew he should do the assigned task first, but his shop officer directed him to assist the dock maintenance team first, because the aircraft is required soon and* **the dock maintenance has a shortage of manpower**. (H64)

Maintenance Control reported that an aircraft has a fuel leak, so my supervisor told me to check the aircraft, take the corrective action and come back and inform him to do the inspection on the action I took. So I went to check what was the problem, I took the aircraft log book, made a write-up, went to the aircraft, I followed the correct procedures, but I went to the wrong aircraft. At that time I had a fever and I was not feeling well, I told the supervisor about that, but he told me **he has nobody else to do that task**, *all of the technicians were engaged in other tasks (a shortage of technicians).* (F47)

Adequate actions required to prevent an accident can only be ensured by the availability of skilled and qualified technicians, this can be achieved through appropriate education, training, experience and systematic measures for maintenance of proficiency. The comments cited above emphasise the essential role of skilled and qualified people in preventing accidents or handling them correctly if they do occur.

5.4.2.2 Individual Factors

In this study ―individual factors" were among the top five contributing factors nominated by technicians. In Study (1), ―individual factors" were also among the top five factors that were mentioned by the technicians. Technicians in both studies identified ―time constraints" as the leading sub-factor (in the individual factors category) that led to maintenance errors (S1: 43.9% and S3: 20.8%). Participants in studies (1) and (3) agree that ―time constraints" are one of the sub-factors that contribute to maintenance errors. Therefore, technicians in this study suggested that maintenance management in the RBAF might introduce certain measures to review planning and scheduling of maintenance tasks in the maintenance organization. In Study (2), ―individual factors" were not one of the top five factors reported by QA investigators, therefore was not mentioned here.

The following are some of the technicians‘ statements regarding the measures that might be incorporated to reduce the likelihood of errors relating to ―time constraints."

Exercise proper planning and scheduling of tasks. (F42)

Plan the task in advance…better training for maintenance control personnel…proper planning and scheduling of tasks. (F67)

…effective coordination between maintenance control, dock chief, and crew chief…exercise proper planning and scheduling of tasks. (F08)

Time constraint has been shown to influence decision making in several ways. Reviews of the literature suggest that time constraint often results in poorer task performance and that it could cause shifts between the cognitive strategies used in judgement and decision-making situations (Edland & Svenson, 1993; and Maule & Hockey, 1993). For this reason technician in this study proposed certain strategies that might reduce the effects of ―Time constraint”.

5.4.2.3 Leadership/Supervision Factors

Similar to Study (1), this study identified ―leadership/supervision” as one of the top five contributing factors leading to errors. In these studies, inadequate ―amount of supervision” was a major sub-factor that led to maintenance errors (46.3% and 12.5% respectively). In Study (1), technicians were dissatisfied with the amount of supervision they received from their supervisors; this dissatisfaction was documented in section (5) of the MEDA results form. Technicians in Study (3) were also not satisfied with the amount of supervision they received. This dissatisfaction was caused by the unavailability of the supervisors to correct known deficiencies in documents, processes, procedures or inappropriate or unsafe actions. As in Study (1), these supervisors might have attended to responsibilities or tasks which have higher priority or that were more prone to errors as some of the technicians' statements suggest.

My assessment of the event was that the technician forgot the piece of rag inside the particle separator, and ***no supervisor checked after the completion of the task****…* ***all it needed was more supervision*** *of the trainee performing the task…****the supervisor was occupied doing another task on a different aircraft****.* (H17)

My assessment is that I did not use the correct tool to perform the task (the supervisor gave me a normal spanner), I was not applying the required torque value (this value was not mentioned in the electrical shop manual, it was only mentioned in the engine shop manual), and ***the supervisor was not available for assistance, he was working on another aircraft****. So I think it was not my fault, it is probably the supervisor's fault.* (H10)

5.4.2.4 Technical Knowledge/Skills

The ―technical knowledge/skills" factor was reported as one of the contributing factors that led to errors in both studies (2) and (3). The leading sub-factor in both studies was the lack of technicians' ―skills" in performing the assigned task (47.7% and 22.9% respectively). It is no surprise that QA investigators (Study 2) are aware of ―skills" as a contributing factor to accidents/incidents, because part of their responsibilities as QA personnel is to conduct Quality Verification Inspections (QVI) on a random sample of technicians at regular intervals (RBAF 66-1). However, it is quite surprising that some technicians in studies (1) and (3) did not report “skills” as a factor for the errors that they committed; this is because “skills” (or the lack of “skills”) directly affect their performance in the RBAF. It is possible that these technicians did not report “skills” because of fear of retribution by the maintenance organisation (an organisation that adopts a blame culture, like any other military organisation). These technicians might be punished for directing blame towards the maintenance organisation for not providing the required training, and they might also be punished for not acquiring the required skills to perform the assigned tasks. We believe that these reasons may justify the differences between the results of studies (1), (2), and (3).

5.4.2.5 Information Factors

In studies (1) and (2) the “information factor” was reported by technicians and QA investigators (53.7% and 63.6% respectively) among the top five factors for committing errors. The leading sub-factor in both studies was “information not used” (43.9% and 61.4% respectively). “Information” includes work cards, maintenance manual procedures, maintenance service bulletins or engineering orders, and other manufacturer supplied or internal sources. It might be that QA investigators reported a higher frequency for “information not used” because they conducted interviews with errant technicians, and also they were aware of the existing deficiencies in the available maintenance publications. Technicians in Study (3) use information documented in maintenance publications on a regular basis (similar to technicians in Study 1), but only

4.6% of those interviewed technicians suggested ―maintenance procedures were not followed" among the top five factors contributing to errors. It is possible that because technicians in Study (3) were not using a questionnaire or reporting tool, the role of ―information" in contributing to errors was not apparent to them or reported as a factor.

5.4.2.6 Environment/Facilities Factors

In both Study (2) and this study the ―environment/facilities" was among the top five contributing factors. In Study (3), excessive ―heat" was the most frequently reported by technicians as a sub-factor leading to errors (14.6%). Jenkins (2005) stated that heat exhaustion can cause industrial incidents such as machinery mishaps, elevation fall and mistakes in handling hazardous materials leading to dizziness, fatigue and confusion set in by heat. Technicians in the RBAF work in an environment similar to that experienced by mechanics in the manufacturing industries. Therefore, it is not surprising that technicians in Study (3) reported the ―heat" sub-factor as one of the leading sub-factors for errors, because they have to combat this factor on a day-to-day basis. However, in Study (2), QA investigators reported the lack of ―maintenance/repair" of facilities as the most commonly reported sub-factor in the ―environment/facilities" category (27.3%); whereas ―heat" was only reported in 4.6% of the QA investigation reports. Governed by the RBAF 66-1 Regulations, QA personnel are required to perform duties and responsibilities that focus on engineering and technical issues; therefore, from a QA personnel perspective, focusing on defective equipment such as an air-conditioning unit or an improperly ventilated work shop, appears to be more important than some of the environmental issues that technicians are exposed to such as working under extreme heat conditions. In Study (1), on the other hand, 34.2% of the technicians nominated

―heat” as the leading sub-factor in the ―environment/facilities” factors category. The results of studies (1), (2), and (3) demonstrate that QA investigators and technicians focus on issues which are more related to their trades and perceived to be more important to improve the technicians‘ performance. These different perspectives might be the reason behind the difference in results between the three studies relating to ―environmental/facilities factors”.

5.4.2.7 Aircraft Design/Configuration Factors

The ―aircraft design/configuration” factor was not included as one of the top five contributing factors in Study (1) and Study (3); however, in Study (2), 47.7% of the QA investigators reported that ―aircraft design/configuration” as a leading factor for causing errors. The leading sub-factor reported by these investigators was lack of ―maintenance/repair” of facilities (27.3%). Normally, during the accident investigation process, QA investigators focus their attention on issues of engineering and technical nature, and that is probably why only QA investigators reported this factor.

5.4.2.8 Job/Task Factors

Job/task factors were included as one of the top five contributing factors in Study (1) only. The most commonly nominated sub-factor in this category was that tasks were ―repetitive/monotonous”. Participants in Study (1) reported in section (5) of the MEDA results form that there were instances that they did not follow the procedures prescribed in the related maintenance manuals or job cards. Although ―repetitive/monotonous” and “work process/procedures not followed” are two separate sub-factors, it is possible that these two sub-factors are related; that is, when technicians perform repetitive tasks, maintenance procedures were not followed. This is because the technicians felt too accustomed to these tasks that they did not need to follow task procedures.

Probably, because of lack of specifications or examples relating to the several reported sub-factors under the “job/task factors” and “organizational factors”, technicians (in Study 1) were confused as how or where they categorize these sub-factors. Possibly, for this reason, we believe that the majority of participants in Study (1) nominated “repetitive/monotonous” as a leading sub-factor while technicians in Study (3) and QA investigators reported other factors such as “not following maintenance procedures” (because they did not have the MEDA results form as a guide).

5.4.3 Error Detection, Sources of Information for Error Rectification, and Error Reduction/Prevention

The findings suggest that the majority of the technicians in this study detected errors after the event had occurred, rectified errors by referring to procedures and their supervisors, and that they could not recover from the error earlier because they did not develop a plan to perform the task in the first place. The following sections will discuss the methods used by technicians to detect errors, the sources of information used to rectify the detected errors, and the strategies used (or should be used) to reduce/prevent error reoccurrence in the RBAF.

5.4.3.1 After-the-Fact Detection

Study (3) revealed that 66.7% of the errors were detected by QA investigators after the event had occurred, and the most common factor that led to these errors was not following maintenance procedures. This factor was also reported by technicians and QA investigators in studies (1) and (2). Together, these finding highlights the potential role of QA experience in error detection, and that error detection forms a significant weakness in error management strategies during routine maintenance tasks. These strategies were identified by the participants in Study (1) which included maintenance manuals, job cards, service bulletins, etc.

After-the-fact detection might suggest that technicians misunderstood the situation they were confronted with. Kontogiannis and Malakis (2007) suggest that self-monitoring is important for the improving understanding of situations in complex systems. Self-monitoring can also play an important role in assessing task progress during the implementation of a plan. Inadequate self-monitoring can give rise to omissions, failure to detect problems caused by previous efforts, forgetting steps that have been interrupted or deferred, and failure to detect individual errors or errors of others.

Mentally rehearsing a series of steps that may be carried out later under time pressure is a good strategy for preventing slips (Blavier et al. 2005). Mentally rehearsing tasks can also work for error detection since intentions leave a stronger trace in memory during this process or tasks can establish connections with environmental cues. Interruptions and high workload can divert attention from the course of action and may result in omissions or delays in performing tasks. Reminders can help operators detect omissions particularly in cases where tasks are independent from each other (Kontogiannis and Malakis, 2007). Finally, anticipation is useful in making preparation for when and how to detect errors, prevent them from occurring, as well as recover from them. Mental rehearsal might be an effective approach to recover from errors. In aviation, it is a common practice that pilots mentally rehearse a series of actions that may have to implement in future under time pressure or may need to respond to future unexpected events (i.e., ―touch and go” in landing).

Further analysis of the findings of this study revealed other methods are available for error detection. For example, monitoring and cross checking of supervisors and other team members. In this study, 14.6% of the participants suggested that inspections by their supervisors and other team members had helped them in detecting an error. These findings provide evidence that the inter-monitoring function is a core component for successful error detection.

5.4.3.2 Sources of Information for Error Rectification

Analysis of the data collected for this study highlighted three sources of information for error rectification: local procedures, manufacturers‘ procedures, and instructions from a supervisor. 47.9% of the participants in this study referred to local procedures when they were involved in errors that led to personal injury or equipment damage. For engineering and technical issues participants referred to manufacturers‘ publication such as manuals and other related documents (41.7%). This finding highlights the importance of local and manufacturers' procedures for the rectification of errors, and provides a clear message to management to make every effort to ensure the availability and clarity of all maintenance documents.

Some participants referred to their supervisors for instructions to correct an error (29.2%). According to the statements of participants in Study (3), some technicians were new recruits and have little experience in how to deal with maintenance errors. This finding highlights the role of supervision in effective error rectification, and identifies an essential component of the command role in error rectification.

5.4.3.3 Error Reduction/Prevention

As illustrated in table 4, participants in this study identified three means of error reduction/prevention. The majority of the participants stated that they would consult with a QA investigator or their supervisor to prevent an error. 64.6% of the participants stated that the availability of standard procedures enabled them to reduce/prevent errors; while 47.9% of the technicians stated that lack of task planning has led them to commit errors. These findings highlight the role of communication, work procedures, and task pre-planning for effective error reduction/prevention.

5.4.4 Study Limitations

As discussed in this study a qualitative methodology was the type we focused on when we conducted the interviews. This method uses smaller samples than in quantitative methods, seeing each individual as a unique being. It is often difficult to draw definitive conclusions from the findings or at least generalise them to larger groups (Wimmer and Dominick, 1997).

Our interviews were closed or structured interviews, in which each person was given the same questions (Wimmer and Dominick, 1997). Their responses may have been influenced by feelings of embarrassment, inadequacy, lack of knowledge on the topic, nervousness, confusion or social desirability. To overcome this limitation, the data collected from the interview approach was complemented by collecting data from the MEDA results forms that were completed by technicians in Study (1), and by reviewing past RBAF accident/incident investigation reports whicht we collected for Study (2). Data from these three sources combined may enhance the validity and reliability of the data collected.

Despite of the limitations of this approach, in general, there are obviously advantages for using the structured interview method. The information is easily quantifiable and allows the responses to be compared. Structured interviews allow questioning to be guided as desired and can clarify points that need to be made clearer more easily. This approach may also tempt the participants to provide very elaborate answers in an attempt to aid in achieving the purpose of the study.

5.5 Conclusion

This study improved our understanding of how actions and decisions (at higher managerial levels in the RBAF) result in errors in aircraft and engine maintenance production lines. The study illustrated that a maintenance error investigation process based on the contributing factor concept may work in the military aviation maintenance. The results of this study, as well as of studies (1) and (2), indicate that deficiencies in the technical/physical environment and organizational policies and procedures were major factors that compromised safety. The participants showed willingness to combat accidents; this was demonstrated by coming forward and sharing their experiences in the RBAF. The findings of this study also suggest that technicians generally managed safety by means of control and passive prevention. A different perspective that addresses the environmental, organizational, social, and technical factors is necessary for effective safety management. In the context of the RBAF, a proactive error management system which is designed to measure and reduce the adverse impact of latent failures might be the answer. Proactive systems work in part by asking people to judge how frequently each of a number of factors such as staffing, supervision, procedures, and communication impact adversely on a specific aspect of their work. The findings of this study also suggest that some changes need to be made to the current accident/incident reporting and investigation system. Moreover, the findings of this study suggest some cultural changes focused on changing the system rather than blaming the individual may be necessary in the RBAF before an effective reporting system can work optimally. An effective reporting system is a necessary and integral part of the overall feedback system within an organization, and plays a critical role in the management of safety. Conducting the accident/incident investigation and making corrective actions might be relatively easy to do once an effective process has been put in place. The findings of this study, as well as the findings of studies (1) and (2), will be used to develop a tool (which will be discussed in more details in the next chapter) that may serve not only to reduce maintenance errors, but also to foster a culture that, by moving away from blaming the individual, encourages reporting. Although no such system currently exists in the RBAF, much can be learnt from industries that have already embraced this approach.

Chapter 6

Study 3a

Assessing the Maintenance Technicians' Perceptions and Understanding about the Current Royal Bahraini Air Force (RBAF) Reporting System

6.1 Introduction

In Study (3), the grounded theory approach was used to seek the perceptions of the maintenance technicians to identify the issues that relate to the current RBAF reporting system. Data was collected by interviewing 48 technicians from helicopter and fighter bases. The interview questions used in Study (3) dealt with the event, how it happened, the errors and contributing factors involved, how the technician detected and recovered from these errors and contributing factors. The second part of the interview, reported here in Study (3a), contains 13 questions (labelled Q40 to Q52 in Appendix G) dealing with information about the current reporting system. This includes information such as report management, report review, the types of information recorded in the report, how this information was used, tracking of corrective actions etc.

The aim of this study is to evaluate the existing RBAF reporting and investigation system. A further aim of this study is to develop an improved tool for identifying and managing maintenance errors within the Air Force.

6.2 Methodology

The methodology used to collect data was the same as Study (3), with the same participants. The questions and statements used in the interviews covered six themes. These themes include:

- RBAF processes regarding how accident/incident reports were tracked, reviewed, and managed;
- How accident/incident information were used and by whom;
- The capabilities, limitations, and whether there is a need to improve of the current reporting system;
- Whether or not the participants know what is meant by –Self-reporting”;
- The reasons for not reporting occurrences; and
- The important features that might be available in an effective reporting system.

Full details of technicians‘ responses regarding the reporting system are shown in Appendix (G).

It is important to note that all the bases involved in this study follow a reporting and an investigation process identical to the one described in the Literature Review chapter; which means that all the participants will refer to the same reporting and investigation process.

6.3 Results and Discussion

Questions 41, 42, and 43

In the RBAF, corrective actions are normally performed by the maintenance shop to which the task was assigned to. Upon completion of the task, QA inspectors review the corrective action for completeness, accuracy and in accordance with the relevant maintenance manual. Once the maintenance work is completed, documents signed by both the technician and the supervisor, and QA reviewed the task, the entire document package is delivered to Maintenance Control for documentation in the weapon system records (RBAF 66-1).

In Study (2), the duties and responsibilities that QA personnel are expected to perform in accordance with the RBAF Maintenance Management Policies Manual (RBAF 66-1) were outlined. In the literature review chapter we described the process in which accidents/incidents are reported and investigated. Contrary to the policies documented in the RBAF 66-1 manual, the findings of this study suggest that there is neither an explicit process for reviewing investigation reports nor a process for tracking corrective actions and recommendations. In their response to Q41, 23 technicians (47.9%) stated that corrective actions were performed by technicians and reviewed by QA investigators for completeness and compliance in accordance with the relevant maintenance manual. 12 of the participating technicians (25%) stated that these corrective actions were only tracked by the shop supervisor/officer. Only 3 technicians (6.3%) stated corrective actions were performed by technicians, reviewed by QA investigators, and Maintenance Control documented these actions in the weapon system‘s records. Other technicians stated that reports were only tracked by QA or not tracked at all (6.3% and 2.1% respectively).

The literature suggests that in an adequate accident/incident reporting and investigation system, reports are reviewed by experts who understand the maintenance environment and who are trained to recognize underlying system causes; and that corrective actions should be planned, managed, and monitored by an independent department (Cohen MR, 2000; Connell, 2000; Cohen M, 2000; Gaynes et al., 2001; and Perezgonzalez, McDonald, and Smith, 2005). In this study, 22 of technicians (45.8%) responded to Q42 that these reports were reviewed by the shop supervisor/officer and QA personnel. 8 technicians (16.7%) stated that reports were reviewed by the QA department only or by the shop supervisor/officer only (8.3% each). Only one technician (2.1%) stated that management does not review investigation reports, hence no corrective actions are being taken. Current practices (as suggested by the responses of participants to Q42) indicate that the responsibilities of assessment, planning, management, and monitoring of corrective actions are being performed by the QA departments in the helicopter and fighter bases (who adopt a decentralized approach for reporting and investigating accidents/incidents). Moving to a centralized QA function (managed by RBAF HQ), instead of a distributed function, might ensure the effectiveness of corrective actions in re-installing the system to the intended safety level, prompt a new implementation plan; and ensure that corrective actions are undertaken efficiently, reliably and in a consistent manner.

As far as the management of accident/incident reports (Q43), 22 of the participants (45.8%) stated that these reports are kept with QA for review and follow-up of corrective actions and recommendations for implementation. Only 6 participants (12.5%) stated that reports are kept at either the shop supervisor/officer or the QA department.

Surprisingly, 37 technicians (77.1%) responded that they were unaware of issues relating to tracking of corrective actions, report review and report management processes (12.5%, 35.4%, and 29.2% respectively). It is possible that those technicians were not aware of the maintenance organization‘s policies and procedures due to improper dissemination of these policies by maintenance management, the commanding officer or the supervisor.

Questions 44 and 45

The participants were asked ―how and by whom this information was used?" (Q44); and ―what was done with this information?" (Q45). 26 technicians (54.2%) stated that accident/incident information was used by the QA department, to issue safety notices/letters and Maintenance Operating Instructions (MOIs) to maintenance shops. 10 technicians (20.8%) stated that some maintenance supervisors/officers conduct lectures and meetings with their shop technicians to discuss these investigation reports and extracts solutions to rectify or recover from errors experienced by other technicians. The majority of technicians (43.8%) responded that this information was mainly used to prevent similar events. Other technicians (27.1%) stated that these reports were also used to develop lessons learned from previous events. A few technicians reported that these reports were either used as a legal document for punishing the technician (14.6%) or not used at all (2.1%).

These results suggest that maintenance management (QA and shop officers/supervisors) were utilising these reports in a proper manner to foster knowledge and share experience among the technicians, however, this transfer of knowledge is not disseminated to every technician in the organisation. One of the fundamental barriers to disseminate error information is the lack of a safety culture in RBAF. An essential aspect of aviation maintenance is the need to accept that people, processes, and equipment (in a complex system such as aviation) will fail (Reason & Hobbs, 2003). Therefore, a safety culture is a culture where an organization promotes active awareness, where individuals are encouraged to speak up and identify conditions and practices that might lead to an incident, and where individuals are treated fairly. Another barrier to disseminating error information is that, even when individuals have the opportunity to speak up, they may not believe that their contribution to improve safety will make a difference to the system within which they work (Reason, 2004). Organisations often fail to show the benefits of sharing error information and to demonstrate how individuals can influence the organisational levels of risk or change the system. Another barrier is that the dissemination of knowledge is not sustained. An organisation may focus intensively on a problem for a short time but is distracted when new priorities emerge or staff transfer to other department or organisations. Organisations need to ensure that they set up knowledge and risk management systems for sharing lessons on an ongoing basis. More effort is required to disseminate error information to the rest of the Air Force; this can be achieved through group discussions with other technicians from different shops within the airbase, conducting seminars that can be attended by technicians from other bases within the air force, making available to technicians the analysis of previous investigation reports, and field observations of other organizations‘ efforts to combat maintenance errors.

Questions 46, 47 and 48

The technicians were then asked about the features of the current reporting system in the RBAF. 25 of the participants (52.1%) either agreed or strongly agreed with the statement that one of the drawbacks of the current reporting system is the lack of trend analysis of accident/incident data (Q46). In the case of the RBAF, trend analysis would be more effective if the RBAF Headquarters coordinated with maintenance organisations in the helicopters and fighter bases to collect and analyse error data. This coordination might compile a database more quickly than any airbase could do alone, possibly making the database more suitable for trend analysis, and disseminate accident/incident information to a larger number of technicians to enhance learning from previous events.

When the participants were asked for their opinion regarding the statement ―The current reporting system provides feedback to the initial notifier of the accident/incident" (Q47), 34 technicians (70.8%) stated that they either agreed or strongly agreed with this statement. Although most the participants responded positively to the statement, the current regulation does not require QA to notify the initial reporter about the findings and the recommendations, nor does the regulation specify the means of disseminating this information to other technicians. Feedback is important for maintaining technicians' motivation in the process, thereby ensuring future reporting of occurrences. This feedback also allows for a process of organisational learning, for example, by informing all personnel in the organisation about the reporting system and its management. According to Perezgonzalez, McDonald, and Smith; (2005), the European Aviation Safety Agency's Regulations Part-145.A.60 (b) requires that the occurrence reporting system includes a method of providing feedback to reportees. Therefore there is a need to provide feedback to RBAF technicians and this feedback should be mandated in the RBAF maintenance regulations. Furthermore, this regulation should identify the means of circulating this information and it should specify the type of information that should be circulated.

39 of the technicians (81.2%) pointed out that there is a need to improve the current reporting system (Q48) (35.4% agreed and 45.8% strongly agreed). The current regulations provided for the establishment of a reporting system, and provided a structure or a procedure in which maintenance organisations in various airbases can adopt. However, the current regulation does not specify, for example, the time within which reports have to be submitted, the minimum content required, or the organisations to which the report must be sent to for review, tracking of corrective actions, and for report management. To improve the current reporting system, RBAF Headquarters need to assess, manage, and improve the performance of the reporting system by comparing it with other effective systems across other organisations and industries and learn from their expertise.

Questions 49, 50 and 51

28 of the participants in this study (58.3%) had a fair understanding of what a ―Self-Reporting-System" is. This is not surprising, because some of the participants had either worked in organisations that had some sort of self-reporting programs, had taken the effort to read about reporting systems, or were trained in organisations that encourage self-reporting. However, it also seems that there is an overwhelming degree of mystery about the contents of a self-reporting program among the technicians in the RBAF

(41.7%). This is a great opportunity for the RBAF Headquarters to review the current policies and regulations pertaining to the reporting system (and other Air Force polices) and publicise these regulations through dissemination of success stories and frequent open discussions with technicians from various line and base maintenance within the RBAF.

There seems to be a high willingness to report maintenance errors within technicians in this study. Almost all of the participants (87.5%) stated that they either disagreed or strongly disagreed with the statement “I think I will be very reluctant to report an accident/incident in which I or someone that I know was involved” (Q50). Only 4 technicians (8.3%) agreed or strongly agreed with this statement. This willingness to report errors could be explained by the desire of the technicians to learn from previous events and attempt to reduce or eliminate such events.

It is important to mention, in any organisation there will be the perception by some individuals that it is in their best interest to keep any errors or potential errors to themselves for fear of litigation or recrimination. For example, in this study 38 of the technicians (79.2%) stated that one of the reasons for not reporting errors is “fear of punishment” (Q51). Without protection from prosecution or assurance of anonymity, it is possible that up to 85% of all safety deficiencies may not be reported (Nielsen, Carstense, & Rasmussen; 2006).

8 technicians (16.7%) stated that there are no reasons for not reporting an error; they “*will report an error regardless of outcome*.” Studies suggest that mechanics are willing

to report their errors (Patankar & Taylor, 2001). According to Harper and Helmreich (2003), one of the factors that influence an individual‛s willingness to report their own errors is the ability to affect change. This is due to the interpersonal trust between mechanics and managers which has been studied and extensively reported by Taylor and Christensen (1998) and Patankar and Taylor (2004). Based on these studies, interpersonal trust tends to be higher in smaller organisations and lower within larger organizations. Therefore, it is possible that technicians in the RBAF envisage that management will act on safety suggestions and take certain measures to reduce undesired outcomes.

Question 52

There is general agreement that an effective reporting system should include several important features (Cohen MR, 2000; Connell, 2000; Cohen M, 2000; and Gaynes et al., 2001). When we read the statement ―The important features that an effective reporting system should have are data collecting capability, tracking of recommendations and corrective actions, and on-line review capability for all concerned" (Q52); 45 of the participants either agreed or strongly agreed to this statement (20.8% agreed and 72.9% strongly agreed). The data collection capability is crucial to the development of a significant institutional database. The tracking of recommendations and corrective action capability provides assistance and training for field personnel on how to handle future similar events; maintains and updates records of outstanding actions to be performed; and provides for a database of alternative corrective actions should one corrective action fails. The on-line review capability provides a means for a larger number of technicians to learn from other technicians‛ experiences and manage their own errors. These capabilities demonstrate to the undecided technicians, maintenance management and staff the benefits of an improved reporting system (Spencer, 2000). Other important features of an effective reporting system are outlined in table 6.1 (Cohen MR, 2000; Connell, 2000; Cohen M, 2000; and Gaynes et al., 2001).

Table (6.1): Characteristics of an effective reporting system.

(Adopted from Cohen MR, 2000; Connell, 2000; Cohen M, 2000; and Gaynes et al., 2001).

Characteristic	Explanation
Non punitive	Reporters are free of fear of retaliation or punishment as a result of reporting.
Confidential	The identities of the reporter and the institution are not revealed.
Independent	The program is independent of any authority with the power to punish the reporter or the organization.
Expert analysis	Reports are evaluated by experts who understand the maintenance environment circumstances and who are trained to recognise underlying system causes.
Timely	Reports are analysed promptly, and recommendations are rapidly disseminated to those who need to know, especially when serious hazards are identified.
System-oriented	Recommendations focus on changes in system, processes, or products, rather than on individual performance.
Responsive	The agency that receives reports is capable of disseminating recommendations, and participating organisations agree to implement recommendations when possible.

6.3.1 Development of the "Tool for Error Reduction and Management (TERM)"

Studies (1), (2), and (3) demonstrated that there is seldom a single cause for error, but instead a series of contributing factors that lead to maintenance errors. Understanding how errors and their management interact to determine outcomes is critical to improving safety. Based on the results of studies (1), (2), and (3), there is a clear indication that there is a need to improve the current RBAF accident/incident reporting and investigation system. These improvements require a well-designed framework for recognising, reporting, analysing, and implementing corrective actions and recommendations to prevent future maintenance errors. This framework should also provide feedback to reportees and maintenance management. In our research project this framework is termed the ―Tool for Error Reduction and Management (TERM)."

6.3.1.1 Introduction to TERM

The TERM framework is a conceptual tool that assists in understanding the relationship between safety and technicians performing maintenance and inspection tasks in dynamic operational contexts. The tool is both descriptive and diagnostic. This tool is descriptive because it captures technicians' and system performance under normal conditions, resulting in a realistic description of outcomes. Additionally this tool is diagnostic because it identifies the complexities in the operational environment.

The TERM can be used in several ways. It can be used as an accident reporting and investigation tool and focus on a single event. TERM can be used to understand systematic patterns within a large set of events, as in the case with operational surveys and audits. TERM can also be used to identify strengths, weaknesses, and opportunities for improvement.

6.3.1.2 The Components of the TERM Framework

There are three basic components in the TERM framework. As shown in figure 6.1, these components are the proposed RBAF Reporting and Investigation System for front-line reporting and investigation (technicians and QA investigators), the proposed Information Analysis and Management System (IAMS) for more generic data analysis for trend over time and across organisations, and the Medium to Long-Term Action Plans. In the following sub-sections we will describe each individual component.

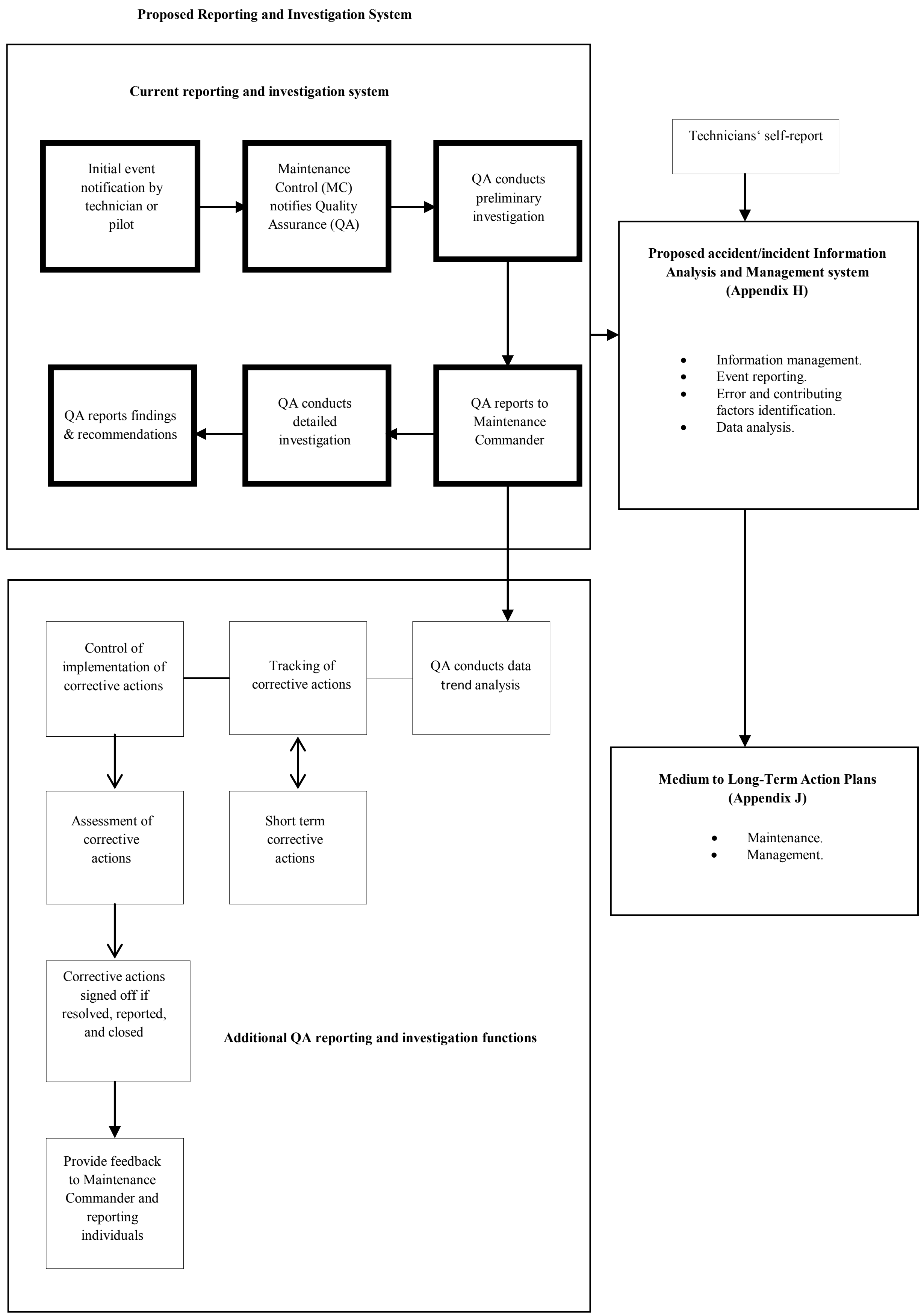

Figure 6.1: The proposed Tool for Error Reduction and Management (TERM).

6.3.1.2.1 The Proposed Reporting and Investigation System

The current reporting and investigation system comprises of six functions as shown in figure 6.1. The first function is the initial notification (to Maintenance Control) by a technician or a pilot that an event has occurred. Maintenance Control then notifies QA that an event has occurred and a preliminary investigation is required to determine the possible causes of this event. Once the preliminary investigation is concluded, a report is submitted by QA to the Maintenance Commander. This report contains the findings and recommendations of the investigating QA official. Based on these findings and recommendations, the Maintenance Commander determines whether a detailed investigation is required. If required, QA would conduct a through investigation and submit a final investigation report to the Maintenance Commander for further actions. In addition to the existing reporting and investigation process, our research highlighted seven additional QA functions for the reporting and investigation of errors and their contributing factors. These functions are shown in figure 6.1 above and are described in the following sub-sections.

6.3.1.2.1.1 Recognition of Errors

Due of lack of specifications of what issues to report in the current reporting and investigation system, technicians report only conditions of the aircraft, engine or component that have been found or suspected of having the potential to seriously compromise the airworthiness of the aircraft. The proposed reporting and investigation system deals with, and encourages, the reporting of all conditions to include those of a technical, human, ergonomic, organizational or environmental nature that could have the potential to compromise the airworthiness and safety of the aircraft, engine, or component.

A recognised error has only limited value, even to the person who recognised it, unless it is reported and properly analysed with appropriate actions taken to prevent its recurrence.

6.3.1.2.1.2 The Reporting Process in the RBAF

The current reporting process within the RBAF seems to be restricted in its scope regarding the reporting form or procedure. Based on the findings of Study (2), it seems that each airbase (helicopters and fighters) has its own unique accident/incident reporting form. Furthermore, maintenance management does not specify which information is pertinent, or the details of the information that should be included in the reporting form. The proposed reporting and investigation system establishes a detailed process for reporting and investigation, and it provides standard reporting forms for the purpose of organisation-wide data collection and analysis. These forms can either be completed electronically or in hard copy as shown in Appendix (H) and Appendix (I) respectively. The electronic form will be discussed in the next section when we will describe the proposed Information Analysis and Management System (IAMS). The electronic and the hard copy Forms basically contain information similar to the information outlined in the MEDA Form, however, we attempted to address some of the limitations pointed out in Study (1) such as form automation, and reducing the redundancy and ambiguity of the reporting form used in Study (1).

Once an error has been recognised and reported to the appropriate activities, it is necessary to carry out steps to ensure that the error does not reoccur. The next QA function in the proposed reporting and investigation system is conducting data trend analysis.

6.3.1.2.1.3 Trend Analysis

The objective of trend analysis is to determine what are the direct and the underlying factors that lead to errors or unsafe conditions and identify the required solutions. Trend analysis is conducted by trained QA analysts by reviewing current data and comparing them with previous data of similar events, and from this analysis short and long-term solutions are developed. Short-term solutions resolve direct causes, farther-reaching and more permanent solutions rectify root causes.

There are, however, a number of obstacles that limit trend analysis performance in the current reporting system. These obstacles include: lack of a tool or a framework to analyse errors; insufficient expertise to analyse errors; and dilution of relevant information due to lack of information transfer or lapsed time prior to incident investigation.

Although maintenance organisations in the helicopter and fighter bases can analyse trends, and report both these trends and their conclusions to the appropriate maintenance commander, however, the analysis would be more effective if the maintenance organisations implement the proposed tool. The reason for this increased effectiveness is that the reporting tool:

- Utilises a database that would compile error information more quickly than the current paper-based system;
- Incorporates a built-in analysis feature;
- Allows reportees to input event information in a faster and more reliable manner; and
- Disseminates error information to investigating parties and other authorised users of the system to facilitate learning.

6.3.1.2.1.4 Tracking and Control of Implementation of Corrective Actions

The tracking and control of implementation of corrective actions for addressing the safety hazards reported have been considered in the RBAF 66-1 regulations. The tracking and control of implementation of corrective actions is an important step in the evolution of the current reporting and investigation system. This step transforms the reporting system from a mere data collection system to an error management system responsible for improving safety.

The current reporting and investigation system is limited to identifying the solutions for an event based on the findings of the investigating Quality Assurance (QA) inspector. However, the authors suggest that the generation of multiple solutions from which one or several are selected for implementation enables investigators to better determine corrective actions that are both effective and practical. Generation of multiple solutions can be achieved through the utilisation of the tool that the authors are proposing. The proposed tool should be designed to contain information of past events that might be similar in circumstance to the one being investigated by a QA investigator. With this feature the investigator would possess the means to review multiple past solutions, by referring to a specialised drop-down menu, and consult with the actioning entity on the best possible action to resolve the situation in hand. It is important to mention here that, in this study, we are proposing the contents of the tool, as opposed to actually constructing the tool.

The current reporting and investigation system does not specify which activity plans, manages, and tracks corrective actions. The proposed tool assigns the planning and managing functions to the actioning entity, while tracking of corrective actions, control of implementation of overdue actions and feedback to the reporting activities is accomplished by the centralised QA department.

Corrective actions should be evaluated to assess the practicality of the solutions. It should be noted that selecting corrective actions based solely on risk reduction may not be practical. If solutions are unfavourable to management or technicians, future reporting and participation in the organisation‘s error management program may be adversely affected.

6.3.1.2.1.5 Assessment of Corrective Actions

Assessment of corrective actions is a function which is ignored by the current RBAF investigation and reporting process, yet it is critical for ensuring that the actions taken do correct the problem and/or might prevent the problem from reoccurring in the future. This assessment might be carried out by the QA section. This assessment should either ensure the effectiveness of the action taken in reinstalling the weapon system to the desired safety level or, alternatively propose a new implementation strategy.

6.3.1.2.1.6 Closure of Corrective Actions

Prior to closing an accident/incident report, the QA investigator would accomplish the following activities: update the investigation report if deviation from the intended action items were implemented; review/audit the corrective actions upon completion to ensure the implemented action fulfils it's intended purpose; and inform the reporter, and others when appropriate, that all actions that stemmed from the report were completed and the accident file is closed.

The closure of accident/incident files is the final step in the proposed accident/incident reporting and investigation process. This step occurs when all investigations have been completed, all corrective actions have been implemented and documented, and all remaining activities prior to closing an accident/incident reports are fulfilled. This step plays an important role in the information to be reported, and should aim towards the formal conclusion of the report, ensuring that all relevant information about the event is thoroughly documented (including the conditions that led to the event, the investigation results, the recommendations, the corrective actions and the reinstallation of the weapon system to a safe working level).

Having completed the data analysis, determined and assessed the corrective actions, and the accident/incident file has been closed it becomes prudent to inform the maintenance commander and the reporting activities for further actions and increased awareness respectively.

6.3.1.2.1.7 Feedback to the Maintenance Commander and Reporting Activities

According to the majority of the participants in Study (3a) (70.8%), the current reporting and investigation system provides feedback to the reportee and their commanding officers only; however, the proposed reporting and investigation system provides feedback to the individual(s) who reported the event, both on an individual as well as on a more general basis. This feedback is important for maintaining individuals‘ motivation in the process, thereby ensuring future reporting of occurrences. The feedback could be delivered by QA personnel who conducted the investigation by providing a written notification to the reportee(s) about the findings of the investigation, the corrective actions, the recommendations, and the implementation of the corrective actions.

The proposed system may also allow for a process of organisational learning, for example by informing all personnel in the organisation about the reporting process and its management. This process will be described in the next section where we discuss the proposed Information Analysis and Management System (IAMS).

6.3.1.2.2 The proposed Information Analysis and Management System (IAMS)

Similar to other information systems, the objective of the proposed Information Analysis and Management System (IAMS) is to capture, store, query, analyse, display, and report maintenance error data. Many of these systems have multiple methods to search or categorise the information. The proposed IAMS, however, incorporates an additional feature. This system incorporates an error taxonomy based on the Maintenance Error Decision Aid (the MEDA framework) which allows the maintenance and safety professionals to move beyond the ‗how' and ‗when' statistics of accidents to determine ‗why' the maintenance accident/incident happened and then prevent its reoccurrence. Another feature of the proposed system is that maintenance error data might be entered into the system by both the maintenance technicians involved in the performance of undesired outcomes and QA personnel investigating these outcomes. This data entry is performed electronically, which means that data entry is fast, easy, and significantly improved with almost immediate data validation and availability.

The IAMS is an on-line system that utilises preformatted screens for the input and output of data. The system will ideally have the capabilities to perform multiple tasks such as displaying basic accident/incident information pertaining to a unique aircraft tail number, a unique squadron or a unique type of aircraft or weapon system; reviewing existing preliminary/self reports and final accident/incident reports; the update of preliminary/self and final reports; and perform data trend analysis.

Security in the IAMS should be built in such a way that no user can access the system unless proper authorisation has been granted; however, it is beyond the scope of this study, and it is up to the RBAF HQ to decide on the most appropriate and feasible security measures to incorporate into the system if adapted.

The IAMS incorporates three modules as shown in Appendix (H). The Basic Information Module, the Accident/Incident Preliminary Report Module, and the Accident/Incident Final Report Module. These modules will be described in the following sub-sections.

6.3.1.2.2.1 The Basic Information Module

The users of the proposed IAMS can view four data options. The first option is the weapon system basic accident/incident data which contains data such as the date and time of the event, the type of weapon system, the name of the individual reporting the event, and brief description of the event. The second option is the aircraft incidents by tail number. This option provides a list of all the aircraft tail numbers involved in undesired events, the category of the event, event report number, date of the event, and a brief description of the event. The third option is the details of parts consumed, which provides information about the aircraft tail number, the Part Number of the part(s) replaced as a result of the event, the quantity of each replaced part, the cost of each part and the total cost of the parts replaced. The last option is the event cost details. This option provides information about the total cost of maintenance hours consumed in repairing the damage, the total cost of the parts, and the total maintenance man-hours and parts costs.

6.3.1.2.2.2 The Preliminary/Self Report Module

The information outlined in this module is based on the MEDA framework that we presented in Study (1). This information includes the types of maintenance errors that were involved during the event, the contributing factors that led to the error (organizational and individual factors), and the error prevention strategies that need to be implemented.

Based on the findings from studies (1), (2), (3), and this study and the suggestions from the participants in these studies, the proposed ―Technicians‘ Self-Report Form" was designed to improve on the MEDA results form that was used for collecting data for Study (1), for example, the grouping of several contributing factors and sub-factors into one resultant contributing factor. This grouping might reduce the confusion and ambiguity that could be faced when attempting to fill the original MEDA form. This grouping also reduces the number of sub-factors currently listed in the MEDA form which might lead to improved technicians‘ completion rates due to shorter reporting form.

Although we improved the proposed error reporting form, but technicians in the RBAF might still fear punishment if they do not submit the ―Self-Report" in a timely manner; this is because the military as an organisation rely on the threat of punishment as a principal means of attempting to ensure discipline, both during peace time and military campaigns (Adams, 2005). Rather than helping technicians to avoid or better manage conditions that are conducive to error, punishment actually conditions people not to get caught when errors occur. This is why punishment and learning are mutually exclusive activities. Dekker (2005) argues that organisations can either learn from an accident or punish the individual involved, but cannot do both at the same time.

In order to learn from failure, organisations need to accept that failure is a normal outcome of operations in dynamic, resource-constrained work environment. Effective learning is founded on continuous improvement. Amongst these improvements is to have a learning or a just culture that is part of the organisation‘s business culture (Reason & Hobbs, 2003), and not be seen as an explicit and overtly separate mechanism. This is where tools are useful in terms of guiding and shaping how an organisation behaves when an undesired event occurs (Drew, 2010).

In our proposed tool (TERM), the next module of the IAMS is the ―Final Report Module”. This module will be described next.

6.3.1.2.2.3 The Final Report Module

The final report would contain information about the time and date of the event, the type of weapon system that was involved in the event, the errors and contributing factors involved, and the total cost of the event. In addition to this information, the final report will also contain information about injuries sustained by the occupants of the weapon system, details of damage sustained to the weapon system, and details of weapon system inspection information. In case of fire, the final report might also include information regarding the cause of fire, and the types of fire extinguisher used. If the weapon system impacted terrain, the final report will also contain information about the ground impact details and survival aspects such as a map showing the distribution of weapon system structure, distance from primary impact point and whether or not survival equipment were used. Other important information such as organizational contribution to the event, the analysis of the event, the recommendations and findings of the investigating officials might also be included in the final report.

All of this information would be available to all users of the proposed IAMS. However, once the accident/incident investigation is completed, certain details about the personnel involved in the accident/incident would be deleted to maintain anonymity. Such details might include for example, the names, the service numbers and the organizations in which these individuals were recruited.

6.3.1.2.3 The Medium to Long-Term Action Plans

The objective of this component of the tool is to attempt to minimise future accidents/incident; educate managers, supervisors, and technicians in the maintenance complex; and to identify and correct deficiencies. This component employs human-in-the-loop to critically review evaluation and accident/incident reports from the IAMS. These reviews provide decision makers with the information they need to make decisions relating to aviation safety oversight and the assessment of the health of the system; these reviews also provide crucial feedback to the tool in order to allow the evaluation of the system to change and mature over time.

For an evaluation tool in military aviation safety oversight to be effective, many people and systems must interact. In particular, the users may be inspectors, their managers, as well as headquarters' staff officers and policy makers who require an overarching or broad view of the entire aviation safety system and how it is working on all levels (including staffing/budget requirements). The action plans were derived from the findings of studies (1), (2), (3) and the responses of technicians in this study. An example of medium to long-term action plans is outlined in Appendix (J).

6.3.2 Study Limitations

As mentioned in the method section of this study, data was collected for this study and Study (3) by conducting structured interviews, using the same interview questions, and with the same participants. The interviews were closed, in which each person was given the same questions (Wimmer and Dominick, 1997). We used a pre-arranged list of answers for the respondent to choose from. There is little freedom for flexibility, due to the fixed question order. For example, in question 52 which is relating to the important features of an effective reporting system, the participants had to select from 5 options (strongly disagree, disagree, neutral, agree or strongly agree). Had the participants were given a list of features or asked to list some of the features that they perceived to be important for the development of an effective reporting system, different results might have been obtained.

In addition, we designed the content of TERM based on human factors principles, civil aviation experiences outlined in the literature review, and responses provided by participants in our studies. TERM has not yet been developed into a working system (i.e. software design) and accordingly has not been tested. It is outside the scope of this project to design the software and fully evaluate TERM. Once the TERM framework is engineered, following our content design, further research and evaluation is necessary to determine TERM‘s long-term effectiveness in the understanding, identification, and management of maintenance errors in military aviation maintenance.

6.4 Conclusion

In summary, error management systems supported by valid data can provide a useful framework within which organisations focus efforts to enhance safety. –TERM” should prove to be a valuable tool for improving error understanding, identification, and management compared to the existing processes for accident/incident reporting and investigation in the RBAF. The content of TERM was designed based on the results of our research project specific to the RBAF, and the human factors principles on error classifications outlined in the literature review. Unlike the existing RBAF reporting and investigation system which recognises only one factor contributing to error (the technician), TERM identifies not only several contributing factors, but also the specific nature of each factor within the RBAF. This specificity would allow RBAF management to focus on each factor and establish means to reduce or eliminate the consequences of the error.

TERM improves on the existing reporting and investigation system by including the functions to track, control, and assess corrective actions. In addition to these functions, TERM incorporates an Information Analysis and Management System (IAMS). The IAMS provides capabilities for: QA investigators to perform trend analysis for the prediction and management of errors; technicians to contribute in the identification and management of errors by self-reporting without the fear of retribution; and managers to review accident/incident reports on-line to have first-hand knowledge of what is going on in their organisations.

Chapter 7

General Discussion and Summary of Data Findings

7.1 The Aim of the Research Project

In this research project we triangulated multiple data sources in order to measure RBAF technicians‘ perceptions about maintenance errors, contributing factors leading to these errors, and the effectiveness of the current RBAF reporting and investigation system. The data sources used were the MEDA framework (questionnaires), actual accident/incident investigation reports, and interviews with technicians who experienced or witnessed maintenance errors. The aims of the research project were to develop a tool to understand the nature of maintenance errors across RBAF fighter and helicopter bases; contrast errors and their underlying factors from the existing accident reporting and investigating system with those identified through the MEDA and the interviews conducted with RBAF technicians; identify the role and nature of organisational failures in maintenance errors within RBAF; and evaluate the existing RBAF reporting and investigation system and develop an improved tool for identifying and managing maintenance errors within the Air Force.

The analysis of data collected for this project demonstrated that maintenance errors in military aviation were caused by several contributing factors. This analysis also indicated that safety hazards and risks frequently went unnoticed by management and supervisors, highlighting a need for closer monitoring of technicians, resources, and procedures.

7.2 Summary of Data and Findings

In Study (1), the most commonly identified types of errors were “installation errors” (39.0%), “errors leading to aircraft/equipment damage” (36.6%), “fault isolation/test/inspection errors” (31.7%), “servicing errors” (26.8%), and “errors leading to personal injuries” (17.1%). Common installation errors include “not installing a part” (such as a fuel drain valve), “improperly installing a part”, or “incomplete installation”.

The most commonly identified contributing factor leading to errors in Study (1) was “organisational factors” which was involved in 70.7% of the reported events. This was followed by “individual” (68.3%), “leadership/supervision” (65.9%), “job/task” (56.1%), and “information” (53.7%) factors. Technicians in Study (1) most frequently identified “work process/procedures not followed” as the leading sub-factor (36.6%) in the “organisational factors” category.

In Study (2), QA investigation reports identified the same types of errors as those identified in Study (1) (with the addition of “errors leading to foreign object damage”). However, in Study (2), the most frequently reported type of error was the “error leading to aircraft or equipment damage” (54.6%), followed by “fault isolation/test/inspection errors” (31.8%), “installation errors” (17.1%), “errors leading to personal injuries” (6.8%), “servicing errors” and “errors leading to foreign object damage” (3.4% each). Examples of “errors leading to aircraft or equipment damage” include tools or equipment used improperly, defective tools or equipment used, or aircraft/equipment struck by another aircraft/equipment.

According to QA investigators, the leading factor that contributed to errors in Study (2) was –organisational factors”. The most commonly reported sub-factor in this category was –work process/procedures not followed” which was reported by 37.5% of the QA investigators. The other 4 factors reported by the QA investigators were –information” (56%), –technical knowledge/skills” (52%), –aircraft design/configuration” (42%), and –environment/facilities” (36%).

In Study (2), QA analysis of accidents/incidents was found to be instructive, but also provided some information (regarding the types of maintenance errors and the factors that led to these errors) which conflicted with the findings of studies (1) and (3). This highlights the importance of comparing multiple sources of data in order to obtain more reliable information that would help in the development of new strategies for identifying and managing maintenance errors and the factors leading to them.

In Study (3), data was collected by interviewing technicians from the helicopter and fighter bases. The type of error most commonly mentioned in Study (3) was the –error leading to aircraft or equipment damage” (29.7%), followed by –fault isolation/test/inspection errors” and –errors leading to personal injuries” (21.6% each), –errors leading to foreign object damage” (18.9%), and –installation errors” (18.9%).

According to the interviewed technicians, these errors were caused by several factors. The leading contributing factor cited was –organisational factors” (21%). The most commonly reported sub-factor in this category was –not enough staff”. The other four factors mentioned were –individual factors‘ (19%), –technical knowledge/skills”, –environment/facilities” (13% each), and –leadership/supervision” (11%).

It is unsurprising that the findings of our research, in terms of the types of errors and contributing factors which were cited, have been similar to the findings of previous studies (Raman et al., 1991; Hobbs and Williamson, 1995; Reason, 1990, 1997, & 2000; GAO, 1997; & USCG, 2001). However, our results do differ compared to military‘s usual methods of identifying maintenance errors and their causal factors. In the RBAF practice there is only one contributing factor and that factor is usually the technician.

In studies (1) and (3) (interviews with technicians) we found that technicians most often referred to local and/or manufacturer procedures to rectify or reduce the possibility of errors. Our studies suggest that procedures documented in technical publications were generally –not followed or used” because they were either unavailable or ambiguous. These findings demonstrate the importance of up-to-date, valid, and clear maintenance documents in the rectification and management of maintenance errors.

There appear to be some differences between the contributing factors nominated by the technicians in studies (1) and (3) and the factors reported by the QA investigators. A possible reason for these differences is that technicians focus their attention on the issues that affect their day-to-day performance, such as the resources available, the environment in which they work, their physical condition, and their well-being. QA investigator‘s (governed by the RBAF 66-1 regulations) focus on engineering and technical issues; therefore from QA investigators‘ perspective, it is more important to repair a defective air-conditioning unit, than it is to worry about whether the technician is performing the assigned task in a shaded location or a well-ventilated hanger.

7.2.1 Detection and Prevention of Errors

Technicians and QA investigators in studies (1) and (2) often reported that errors were detected after the event had occurred. These errors were detected by the responsible technicians themselves (after the recognition that something had gone wrong), by a team-mate, or by a QA investigator (following an accident/incident investigation). Similarly, the majority of technicians in Study (3) (66.7%) stated that the most frequently reported error-detection method was “after-the-fact investigations” undertaken by QA investigators. 14.6% of the participants in Study (3) stated that errors were detected through visual inspections by themselves, a teammate or a QA investigator. These inspections were performed in accordance to maintenance publications (maintenance manuals, service bulletins, or special maintenance instructions from the manufacturer of the weapon system). Only 2.1% of the technicians interviewed in Study (3) stated that QA and supervisors‘ experience played a significant role in detecting an error, occurring when no other means of error detection was available. 91.6% of the participants in Study (3) stated that “pre-planned inspections, reviews, and surveys” were effective means to detect and prevent future maintenance errors.

In Study (3a), the participants were asked about their perceptions of the current reporting and investigation system. The findings of this study suggest that:

- There is no explicit process for the review of accident investigation reports;
- There is no process for tracking corrective actions and recommendations;
- There is no process for the implementation and monitoring of corrective actions and recommendations;
- Accident investigation information/results are only disseminated to the errant technician and his supervisor/officer, depriving other technicians in the RBAF from learning from the experience of others;
- There is no standard accident/incident reporting form within the RBAF; and
- There is a need to improve the current reporting and investigation system.

7.3 Outcomes and Implications of the Research Project

The field of ―human factors” is concerned with the interaction between humans and systems or equipment. It‘s essential objective is to develop designs for equipment, procedures and the workplace that will facilitate effective, safe and efficient operation by a human or a group of humans (EUROCONTROL, 2010). The goal of human factors is to reduce errors by addressing how the human operator senses information, thinks, makes decisions, acts and behaves (Reason and Hobbs, 2003). Since human error is the largest causal factor in accidents (Hobbs, 2008), it is important for the aviation industry to devote special attention to solving human factors issues. Historically, human factors research focused almost exclusively on people and their behaviour (the ―person” view to human error) without placing this behaviour in the context in which it was performed (Reason, 1990; and Rasmussen, 1982 & 1983). In this view, errors were seen to emerge from psychological factors such as poor motivation, negligence, inattention, recklessness, etc. (Reason, 2000).

In the RBAF, this person-approach to human error still exists. During our review of the RBAF investigation reports (Study (2)), several reports incriminated technicians who committed errors without actually looking at the circumstances that led to those errors. For example, one of the reports stated that *“the technician did not follow the appropriate procedures for towing the aircraft inside the hanger”.* Based on our review of this particular report there were other contributing factors which were overlooked. For example, there were only two technicians conducting the towing task (according to the procedures a minimum of four technicians should undertake this task), there was no towing supervisor (the towing supervisor and another technician were towing another aircraft), the technician did not have a job guide (the job guide was with the towing supervisor who was teaching the other technician how to tow the other aircraft). This example illustrates the human error approach that the RBAF currently adopting.

The findings of this research project imply that a maintenance error investigation process based on the “contributing factors” concept can be beneficial in military aviation maintenance, just as it is in the commercial airline industry. Maintenance technicians do not make errors on purpose. Errors occur as a normal by-product of doing normal business (e.g. maintenance work on aircraft or equipment) under normal pressures of resource scarcity and competition (Dekker, 2005). Errors result from a series of contributing factors and many of these factors are under the control and management of the maintenance organisation. As the findings of studies (1), (2), and (3) suggest, the most commonly reported factor leading to maintenance errors was “organisational factors.” Traditionally, organisational factors generally revolve around three issues: operational processes, resource management, and organisational climate (Transport Canada, 2010).

The first issue, “operational process”, refers to formal processes (task load, time pressure, schedules, incentive systems, etc.), procedures (maintenance standards, documentation, instructions, etc.), and oversight within the organisation (organisational reviews, the establishment and use of safety programs and risk management). Sub-standard management and decisions can also have an indirect negative effect on operator performance (Wiegmann & Shappell, 2001).

“Resource management” refers to the management, allocation, and maintenance of resources, including human resource management (selection, staffing, and training), monetary safety budgets, and equipment design (ergonomic specifications) (Wiegmann & Shappell, 2001). In general, management decisions about how such resources should be managed centre around two objectives: the goal of safety and the goal of on-time, cost-effective operations. In times of prosperity, these goals can be balanced and satisfied easily. However, there may be times of financial hardship which demand a rebalancing of safety and cost-effectiveness (Transport Canada, 2010). During such times, safety and training are often the first areas to be cut.

Finally, ―organisational climate” refers to a broad class of organisational variables that influence technicians‘ performance (Transport Canada, 2010). These variables may include structure (as reflected in the chain of command), delegation of authority and responsibility, communication channels, formal accountability for actions, policies, and culture.

The findings of our research suggest that RBAF management needs to introduce changes to its operational processes and resource management strategies. The aim of these changes would be to ensure that procedures are readily available, current, and unambiguous, in order to facilitate proper implementation of tasks by technicians, and that resources (such as qualified technicians and supervisors and well-maintained equipment and facilities) are available and in sufficient quantities.

The findings of this research project also imply that changes need to be made to the current reporting and investigation system, in order that it properly, reflects the multiple causes of maintenance errors. Based on the reviewed ―human factors” principles, a key element of a human factors programme is a reporting system whereby hazards (or potential hazards) can be reported and investigated. The RBAF already have a reporting system for technical issues or discrepancies, but this system may need to be expanded, or additional functions incorporated, to allow for the reporting and investigating of human errors, ambiguities with procedures, mismatches between ―required” and actual practices, etc.

Once an error has been investigated and the contributing factors identified, a corrective action plan should be developed (Air Transport Association of America (ATA) Specification 113, 2002). This action plan is an important element of a continuous improvement process that both maintenance management and technicians should demand. A corrective action plan attempts to identify and correct deficiencies, minimise future events, and enhance organisational learning. This then becomes part of the error management system, so that corrective actions are focused on contributing factors which were identified during the reporting and investigation phases. It is essential that maintenance management give support for the error management system and other necessary changes (ATA Specification 113, 2002).

Another important step in the error-reduction process is to ensure that the work force benefits from the information generated by the error management system (Transport Canada, 2010). This is the only consistent way of effecting change. If maintenance technicians were made aware of the impact of corrective actions, they would be able to make adjustments to ensure long-term success.

The availability of results of special inspections, surveys, reviews, and the success or failure of a corrective action is of great value to a technician (ATA Specification 113, 2002). It is important to keep in mind the core idea of a human factor-based error management program, which ought to provide each technician with the essential tools and knowledge to accomplish a task correctly on the first attempt.

Organisational responsibility and accountability for the development of corrective actions should reside with the technical department concerned (ATA Specification 113, 2002). The findings of our research project imply that the current reporting and investigation system does not explicitly specify which entity is responsible for the planning, management, and tracking of corrective actions. What we are proposing is that planning and management of corrective actions should be assigned to the actioning entity, while monitoring and control of implementation of corrective actions and feedback (to maintenance management, involved work groups and to others in the maintenance organisation) should be moved to a centralised QA function (managed by RBAF HQ), as opposed to the decentralised approach currently in use by the helicopter and fighter bases. This change is more likely to ensure that corrective actions are undertaken effectively, efficiently, reliably and in a consistent manner.

A final implication of our results is that in order for the RBAF to have an effective reporting and investigating system it might be necessary for some cultural changes to be made, shifting the focus away from blaming the individual and towards changing the system. An effective reporting and investigation system depends on the willing participation of the workforce, particularly those individuals in direct contact with the hazards (such as maintenance supervisors and maintenance personnel). For the RBAF to have an effective reporting and investigation system it is desirable to establish a “reporting culture,” an organisational climate in which people are prepared to report their errors.

An effective reporting culture depends on how an organisation handles blame and punishment (Global Aviation Information Network (Gain), 2004). The literature suggests that only a small proportion of unsafe human acts are deliberate (e.g. recklessness, non-compliance, sabotage, etc.) and as such deserve sanctions of appropriate severity. A blanket amnesty on all unsafe acts would lack credibility in the eyes of the workforce and could be seen to oppose natural justice. A total ―no-blame” culture is therefore neither feasible nor desirable. What organisations need, according to Reason (1997), is an atmosphere of trust in which people are encouraged to provide essential safety-related information, but understand the difference between acceptable and unacceptable behaviour. This atmosphere is termed a ‗just culture”. A just culture is one which supports learning from unsafe acts (Reason and Hobbs, 2003). The first goal of any manager should be to improve safety and production. Any safety-related event, especially human or organisational errors, should be considered first as a valuable opportunity to improve operations through experience, feedback and lessons learnt.

The Tool for Error Reduction and Management (TERM) was developed based on the information which we collected from various data sources (MEDA questionnaires, RBAF accident/incident investigation reports and interviews with maintenance technicians) as well as human factors principles outlined in the literature. The development of TERM is a major advance for the RBAF; this is because it can assist in developing an approach which focuses on identifying the various factors which contribute to errors, rather than focusing on the individual technician involved. TERM also focuses on early identification of safety concerns and is more proactive than the existing error reporting and investigation system. The intent of TERM is to identify the nature of maintenance errors and the factors leading to these errors that are specific to the RBAF. By identifying these errors and factors, maintenance management can intervene in the chain of events which lead to accidents/incidents. TERM is a framework that adopts the –system approach”. This approach: recognises the fallible nature of technicians and accepts that errors will occur; promotes the development of error tolerance and countermeasures that are designed to treat latent and active failures within the system; and removes the apportioning of blame to individuals within the system. The Tool for Error Reduction and Management also incorporates features characterised as important by Perezgonzalez & McDonald (2005); the European Aviation Safety Agency (EASA) (2004); and Wells & Rodrigues (2003). These features include, for example: a reporting form that is readily available, simple to compile, which contains adequate space for descriptive narrative, and encourages suggestions on how to improve the situation or prevent a recurrence of the event; and monitoring and assessment of implementations for their effectiveness in addressing the reported conditions. We believe that, TERM would allow RBAF technicians and management to effectively manage the risk of maintenance errors in the helicopter and fighter bases.

7.3.1 Implementing the Tool for Error Reduction and Management (TERM) in the RBAF

The implementation of TERM requires revisiting and adjusting prevailing views of human error in the RBAF. Currently, maintenance management and QA investigators view human error as an undesirable and wrongful manifestation of human behaviour in which maintenance technicians purposely elect to engage. This research (and a considerable body of human factors literature) has provided a completely different perspective on aviation maintenance error. We have substantiated in practical terms a fundamental perspective on the concept of human cognition: that error is a normal component of human behaviour. Regardless of the quantity and quality of regulations the industry might promulgate, regardless of the technology it might design and the training technicians might receive, error will continue to be a factor in aviation maintenance environments because it is simply the inevitable downside of human cognition.

There is nothing inherently wrong with error itself (Maurino, 2010). The trouble with error in aviation lies with the negative consequences it may generate in an operational context. In this context, errors that are caught in a timely manner do not produce damaging effects and therefore, for practical purposes, do not exist. Countermeasures to error (such as accident/incident investigation, training etc.) should not be restricted to avoidance of error, but should be utilised to give more visibility to errors, so as to identify them before they produce damaging consequences: Errors are not avoidable, but they can be manageable. This is the purpose of ―error management".

Error management is the heart of TERM and reflects the argument presented above. Utilising TERM in the RBAF, flaws in technicians' performance and the ubiquity of error are taken for granted. Rather than focusing on improving technician, the objective becomes improving the environment within which technicians perform. However, implementing TERM in a military context faces one significant challenge. For the RBAF to successfully implement TERM, maintenance management needs to fully support and encourage technicians to self-report without fear of retribution, by adopting the concept of “just culture”. A just culture may take years to be fully established and regulations and financial allocations may have to be changed. However, the benefits to RBAF fully justify the establishment of a just culture and this is fundamental to the successful implementation of TERM.

7.4 Limitations of the Research Project

This research project has focused on understanding, identifying and managing maintenance errors in the RBAF. However, our results might have been adversely affected by limitations relating to: the MEDA framework and the sources from which data was collected. These limitations can be seen as fruitful avenues for future research under the same theme.

7.4.1 The MEDA Framework

The research indicated that the MEDA results form (developed by Boeing for the civilian aviation sector) addresses almost all of the types of errors, contributing factors and sub-factors which lead to accidents/incidents in military aviation. However, it is possible that the long list of contributing factors and sub-factors might have caused confusion to technicians who completed the results form. For example, in the current MEDA results form, the term “work process/procedures not followed” was listed as a sub-factor under the “organizational factors” and the term “not used” was listed under the “information” factor. Both terms (*work process/procedures not followed* and *not used*) denote the same meaning. Work process/procedures can also be considered as information that the technician used to perform certain tasks. Similarly, the term “work process/procedures not documented” and the term “unavailable/inaccessible” (listed under the “organisational factors” and “information factors” respectively) also denote the same meaning. This terminology might have led technicians to record accident/incident sub-factors in either or both listings which might have produced duplicate or inaccurate entries in the results form. To overcome this issue the “organizational” and the “information” factors (including their related sub-factors) might be merged into one category which might be termed “work process, procedures, and information.” This grouping of factors has been incorporated in the hard-copy and automated error reporting forms which are included as part of the proposed tool. This grouping might reduce the ambiguity (and hence confusion) that might face technicians attempting to fill out the MEDA form. This grouping also reduces the number of sub-factors currently listed in the MEDA results form which might lead to improved technician motivation to complete the proposed reporting form(s).

Additionally, the current MEDA version contains no clear section in the results form directly categorising “training” as a contributing factor. It also does not specify whether a technician‘s degraded skills resulted from lack of general technical knowledge or practical knowledge (on-the-job or hands-on training). This limitation might be overcome by including a specific “training” category or merging “training” with other related factors. In the proposed reporting forms (both the hard-copy and the automated), this limitation was addressed by creating a contributing factor termed “training/technical knowledge/skills and task”. In this new category we have included (based on the findings of the research project) two additional sub-factors: “amount and quality of technical training” and “amount and quality of on-the-job training.” The inclusion of these two sub-factors will serve two purposes: it will provide technicians with more specific information when they are selecting the appropriate factor which contributed to the error, and it will provide management with more information during the planning and budgeting of the organisation's training needs.

Finally, MEDA was developed in paper form, which makes it very difficult to document all of the types of errors, contributing factors, sub-factors, findings, recommendations, and corrective actions for trend analysis. A computer-based version of an accident/incident analysis tool can electronically record all the data, thus making possible a more comprehensive analysis and prediction of current and future accident/incidents. Our research findings and the review of civil aviation experiences with regard to the automation of reporting forms had led us to incorporate in our tool an electronic version of the MEDA form. The proposed reporting forms have been adapted from the best features in the existing MEDA results form. In addition, these forms include features that were suggested by the participants in our research and/or recommended by human factors literature.

In addition to the limitations inherent in the MEDA framework, that we have identified and attempted to overcome, there are several limitations related to the data sources that we collected for each specific study (the MEDA questionnaires, the review of RBAF investigation reports, and the interviews with technicians). These limitations are discussed next.

7.4.2 Sources of Data

In our research, we adopted a triangulation approach to collect data. According to Jack & Raturi (2006), this approach refers to a situation where the researcher combines (in one investigation) multiple observers, theoretical perspectives, sources of data, and methodologies. In this research, each data collection method (taken alone) was subject to certain limitations. In Study (1), for instance, judgments concerning errors and contributing factors were made on the basis of information provided by technicians in response to a results form. It is possible that the information gathered has been affected by biases in reporting and recall. Respondents may have been unaware of the circumstances surrounding the occurrences, or may have filtered or elaborated their responses on the basis of preconceived ideas.

All technicians involved in Study (1) were from different trades (flight line, sheet metal, hydraulic, engine etc.) and experienced different events (which might be a limitation, given the lack of consistency between events). That said, we believe this approach was useful for the following reasons: 1) it permitted technicians to identify types of errors and contributing factors that they had directly experienced in their work environment; 2) technicians might have experienced different errors with a different set of contributing factors; and 3) examining various different events might yield a greater variety of errors and contributing factors.

An alternative method (which could have been used to address this limitation), might have been to allow technicians to relate the same event, or providing them with a set of events and then instructing each technician to complete a MEDA results form for each of the events. This might lead to a different set of factors being identified and it is possible that greater consistency might be achieved. However, this approach also has its disadvantages: the supplied events may not relate to the specific trade or specialty of a particular technician and that technicians may have no response to those events, reducing the amount of data that could be collected and incorporated in our research; responding to events that do not relate to a technician‘s specific trade or specialty may not yield relevant (from personal experience) categories of errors and contributing factors; and having to respond to a larger set of events would be very time consuming. Therefore, we argue that the approach that we adapted (analysing different events, each described by a technician) yielded more actual accident/incident data for analysis, and allowed for the development of further-reaching improvement strategies.

In Study (2), the accident/incident investigation reports reviewed were written by Quality Assurance (QA) investigators who did not receive human factors training; hence they might have not included all the human factor issues involved in the events. Additionally, because QA investigators lack human factors training, it is possible that they only explored the active failures during their interrogations of the technicians involved in the events. This could have led the investigators to make assumptions about the factors which contributed to the event without them having the full picture.

In the RBAF, QA reports are the only relied upon data source relating to maintenance errors. QA reports are used to collect data on adverse events, errors, and contributing factors. These reports reflected QA‘s perspective on incident analysis. Incident analysis is a major step, which can reveal many issues with maintenance, operations and technicians‘ performance. QA investigation reports, according to our research findings, provided feedback into engineering and technical processes and into technicians‘ training (which has raised the safety levels). Coupled with accident investigation information, maintenance data extracted from these reports made it possible to refine maintenance operations to higher standards of efficiency, while at the same time reducing the risk of accidents. It was therefore crucial that we review these reports in order to understand and identify the types of errors occurring and the factors that led to these errors.

We adopted the ―structured interview” approach to interview the technicians for studies (3) and (3a). There are some limitations relating to the structured interview approach that might have affected the results of these studies. For example, the interviews were conducted using a pre-arranged list of answers for the respondent to choose from. Due to the lack of flexibility, (as discussed by Breakwell, Glynis, Hammond & Fife-Schaw; 1995) there was little room for the respondent to voice an opinion. In Study (3a), for example, the participants had to select from five options (strongly disagree, disagree, neutral, agree, and strongly agree) to identify the features of an effective reporting system. Had the participants been given a list of features or asked to list some of the features that they perceived to be important to develop an effective reporting system, different results might have been obtained. Moreover, the structured interview method relies on respondent willingness to give accurate and complete answers (Breakwell, Glynis, Hammond & Fife-Schaw; 1995). The technicians‘ responses may have been influenced by feelings of embarrassment, inadequacy, lack of knowledge on the topic, nervousness, confusion or social desirability. These are, however, inevitable problems that are encountered when the perceptions of participants are being sought.

According to Compton, Morrissey, & Nankervis (2009), structured interviews appear to be one of the most widely-used types of interviews. The main advantage of the structured interview is its consistency. All technicians were asked the same questions, treated in a similar fashion, and given an equal chance to respond to the questions. Furthermore, a structured interview is also time-efficient and therefore technicians were not taken away from their tasks for extended periods of time. In addition, for our interviews we used the –grounded theory approach” to analyse the responses of the participant. The grounded theory approach is a qualitative research method that uses a systematic set of procedures to develop an inductively derived grounded theory about a phenomenon (Strauss & Corbin, 1990). The primary objective of the grounded theory, then, is to expand upon an explanation of a phenomenon by identifying the important elements of the context and process of the study (Davidson, 2002). In other words, the goal of studies (3) and (3a) is to go from the general to the specific without losing sight of what makes the subject of a study unique.

7.5 Contribution to knowledge

In our research we claim to have added the following contribution to the field of human error in military aviation maintenance:

1) Development of a proactive risk management tool (TERM) that is in line with the principles of international risk management standards;

2) Development of the contents of an Information and Analysis Management System (IAMS) for the analysis and management of maintenance errors and their associated contributing factors in military aviation maintenance; and

3) Introduction of a new error-reporting form (based on the MEDA concept) for understanding, identification, and management of maintenance errors in military aviation.

7.6 Recommendations for the RBAF

Investigating accidents, identifying potential interventions, and issuing safety recommendations are central to any safety program. Ideally, safety recommendations when adopted by organisations will positively influence future operations in the field and thereby improve overall system safety (Wiegmann and Shappell, 2003). Based on the findings of this research project, the authors are offering the following recommendations for the RBAF commanders' consideration:

1) The use of the Tool for Error Reduction and Management (TERM) is recommended to make the investigation of maintenance errors more rigorous. Using the TERM model allows strategies which will mitigate human error to be identified and prioritised. This tool is appropriate for the study of aviation maintenance errors;

2) The RBAF works towards revising the current processes and procedures for aviation accident/incident reporting and investigation as suggested by this research project to include the TERM model. This inclusion would increase the usefulness of the current accident/incident reporting and investigating processes by standardising the reporting and investigation of maintenance errors and would aid investigators in assessing factors associated with maintenance errors;

3) The RBAF conducts regular surveys, reviews, and inspections relating to human resources, maintenance facilities, maintenance equipment, tools, and maintenance publications to ensure that holdings are appropriate, and that there are procedures in place to ensure that these resources are adequately maintained;

4) The RBAF introduces clear error-reporting policies in order to encourage technicians and supervisors to report accident/incidents related to human error. Such policies should outline in advance the consequences which would result when technicians report that they committed an error;

5) The RBAF considers the existence of an error-reporting policy as a positive safety indicator. Because reporting errors would enhance safety, reduce the consequences of errors and create a safety culture;

6) The RBAF considers shifting the culture of blaming the individual to a culture that recognises that there are multiple factors that lead to maintenance errors;

7) The RBAF evaluates and considers moving from a decentralised to a centralised QA function;

8) Maintenance organisations in the RBAF adapt the error-reporting form that we developed (based on the MEDA results form) to report and investigate maintenance errors;

9) The RBAF maintenance organisations ensure that maintenance personnel receive regular feedback on maintenance accident/incidents in order to learn from such events;

10) QA investigators, maintenance supervisors, and technicians undergo appropriate human factors training in areas such as coordination, communications, teamwork, and management of time-pressure. This type of training is the most commonly used intervention for maintenance human error. Indeed, such training is now mandated by the International Air Transport Association (IATA) and by the regulatory authorities in many countries;

11) Quality Assurance investigators and maintenance technicians are provided with MEDA training to assist them with the identification and analysis of maintenance errors; and

12) The authors finally recommend that the RBAF leads an effort to study error and contributing factor trends in the Bahrain Defence Force (BDF) generally by applying this model to other maintenance units.

7.7 Recommendations for Future Research

This research project has achieved its aims, but still more effort is recommended to enhance aviation maintenance safety. The authors consider the following areas as being eligible for further work:

1) Further research is required to evaluate the feasibility of standardising the practices of the proposed reporting and investigation system across BDF maintenance units;

2) Proactive thinking regarding the identification and management of maintenance error in the military domain should be further crystallised and disseminated within various military organisations worldwide, allowing them to learn from each other‘s expertise; and

3) Military error databases (similar to the ASRS, CHIRP, and CAIR) should be established in the military aviation sector. These databases would provide useful information regarding the most common types of errors and contributing factors experienced by other military organisations. These databases might also provide valuable insight leading to revolutionary techniques for the treatment and management of maintenance errors.

7.8 Conclusion

There is no denying that implementing the TERM in military aviation maintenance poses significant challenges, but progress has been achieved in tackling some of these challenges. For instance, early problems in defining and classifying maintenance error data obtained from the RBAF have been resolved by referring to human factors principles outlined in the literature. Also based on the literature, as well as the expertise of civilian airline industries, consensus has been developed regarding which data should be collected. From the RBAF organisational perspective, there is a need to consider using and integrating multiple data-collection methods (including incident investigation reports) for future analysis. This in turn will pose a challenge for future research, due to the differing formats of information contained in the current investigation reports from the helicopter and fighter bases. But the real challenge for the implementation of TERM will be overcoming the barrier presented by the existing culture of blaming technicians for the occurrence of errors. A continuous effort will have to be made over a sustained period before a just reporting culture is fully accepted by both maintenance personnel and management (whose ongoing support is essential).

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Appendix A

Maintenance Error Decision Aid (MEDA) Results Form (used to collect Study 1 data) (Adapted from Boeing's MEDA Results Form)

Section I – General Information

Reference no:...
Branch /Section / Shop :...
Type of maintenance (Circle) :
1. Line.......................If line, What type?.. .
2. Base.......................If Base, What type? ....
Airbase and Squadron: ....
Aircraft/Engine/Support Equipment type: ....Tail / Serial no.: ....
Date and Time of Event: / / ---:--- am pm

Section II - Event

Please write a brief description of the Event.
....
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....

Section III - Maintenance Errors

1. Installation Error ( ).
2. Foreign Object Damage Error ( ).
3. Servicing Error ( ).
4. Aircraft/Equipment Error ( ).
5. Repair Error ( ).
6. Personal Injury Error ( ).
7. Fault Isolation/Test/Inspection Error ( ).
8. Other Errors (explain) ....

Section IV - Contributing Factors Checklist

A. Information (For example, work cards, maintenance manuals, service bulletins, etc.)

---- 1. Not understandable.
---- 2. Update process is too long /complicated.
---- 3. Unavailable/inaccessible.
---- 4. Incorrectly modified manufacturer's TCTO/SB.
---- 5. Incorrect.
---- 6. Information not used.
---- 7. Too much /conflicting information.

B. Equipment/Tools/Safety Equipment.

---- 1. Unsafe.
---- 2. Cannot use in intended environment.
---- 3. Unreliable.
---- 4. No instructions.
---- 5. Layout of controls or display.
---- 6. Too complicated.
---- 7. Mis-calibrated.
---- 8. Incorrectly labeled
---- 9. Unavailable.
---- 10. Not used.
---- 11. In appropriate for the task.
---- 12. Incorrectly used.

C. Aircraft Design/Configuration/Parts.

---- 1. Complex.
---- 4. Parts incorrectly labeled.

---- 2. Parts unavailable. ---- 3. Inaccessible.	---- 5. Aircraft configuration variability. ---- 6. Easy to install incorrectly.
D. Job/Task.	
---- 1. Repetitive/monotonous. ---- 2. New task or task change.	---- 3. Complex/Confusing. ---- 4. Different from other similar tasks.
E. Technical knowledge/Skills.	
---- 1. Skills. ---- 2. Organization process knowledge. ---- 3. Task knowledge.	---- 4. Weapon system knowledge. ---- 5. Task planning.
F. Individual Factors.	
---- 1 Fatigue. ---- 2. Body size/Strength. ---- 3. Physical health (including hearing and sight). ---- 4. Personal event (for example family problems). ---- 5. Time constraints.	---- 6. Work place distraction. ---- 7. Peer pressure. ---- 8. Memory lapse. ---- 9. Complacency.
G. Environment/Facilities.	
---- 1. High noise levels. ---- 2.Vibrations. ---- 3. Hot. ---- 4.Cleanliness. ---- 5. Cold. ---- 6. Hazardous\Toxic substances. ---- 7. Humidity.	---- 8. Power sources. ---- 9. Rain. ---- 10. Inadequate ventilation. ---- 11. Lighting. ---- 12. Facility maintenance/Repairs. ---- 13. Wind.
H. Organizational Factors.	
---- 1. Quality of support from technical organizations. ---- 2. Corporate change/Restructuring. ---- 3. Work process/Procedures not documented. ---- 4. Work process/Procedures.	---- 5. Work process/Procedures not followed. ---- 6. Organisational policies. ---- 7. Work group normal practice. ---- 8. Not enough staff.
I. Leadership/Supervision.	
---- 1. Planning/Organization of tasks. ---- 2. Unrealistic attitude/Expectations. ---- 3. Prioritisation of work.	---- 4. Amount of supervision. ---- 5. Delegation/Assignment of task.
J. Communication.	
---- 1. Between departments. ---- 2. Between maintenance crew and lead. ---- 3. Between technicians.	---- 4. Between lead and management. ---- 5. Between shifts. ---- 6. Between flight crew and maintenance.
K. Other contributing factors (explain below).	
....	

Section V - Event Prevention Strategies

A. What current existing procedures, processes, and/or policies in your organisation are intended to prevent the incident, but did not?

( ) Maintenance Policies or processes. (specify)
....
....
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....
....

Required maintenance documentations.

( ) Maintenance manuals (specify)
....
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....
....

( ) Log books (specify)
....
....
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....
....
....

( ) Work cards (specify)
....
....
....
....
....
....

( ) Engineering documents (specify)
....
....
....
....
....

( ) Others (specify)
....
....
....
....
....
....

Supporting documentations.

( ) Service Bulletins (specify)
....
....
....
....
....

( ) Training materials (specify)
....
....
....
....
....
....

( ) Maintenance operation instructions (MOIs) (specify)
....
....
....
....
....
....

( ) Others (specify)
....
....
....
....
....
....

B. List recommendations for error prevention strategies.

Recommendation number	Contributing factor number

Section VI - Summary of Contributing Factors, Errors, and Event

Provide a brief description of the event.

....
....
....
....
....
....
....

Appendix B

Distribution of the contributing factors and sub-factors leading to accidents/incidents in the Royal Bahraini Air Force.

Main Contributing Factors	Number of participants who nominated this item is a factor leading to the accident/incident			Percentage of participants who nominated this sub-factor is leading to the accident/incident	
Leadership/Supervision	Helicopters	Fighters	Total	Sub-factor	Percentage
	15	12	27	Amount of Supervision	46.34
				Planning/organisation of tasks	24.39
				Unrealistic attitude/expectations	2.44
Organisational Factors	17	12	29	Work process/procedure not followed	36.59
				Not enough staff	29.27
				Quality of support from other organisations	7.32
				Lack of training	7.32
				Work pressure	2.44
Individual Factors	15	13	28	Time Constraints	43.90
				Fatigue	29.27
				Peer pressure	17.07
				Memory lapse	14.63
				Work place distraction	2.44
				Personal events	2.44
Information	14	8	22	Information not used	43.90
				Too much/conflicting information	4.88
				Instructions not adequate	2.44
				Information not understandable	2.44

				Incorrectly modified TCTO/SB	2.44
				Information not available	2.44
Technical Knowledge/Skills	10	1	11	Task knowledge	29.27
				Skills	14.63
				Task planning	14.63
				Weapon system knowledge	2.44
Equipment/Tools/Safety Equipment	11	7	18	Equipment/tools incorrectly used	21.95
				Unsafe	9.76
				Unreliable	4.88
				Not used	4.88
				Mis-calibrated	2.44
Job/Task	15	8	23	Repetitive/monotonous	34.15
				New task or change of task	12.2
				Complicated/confusing	9.76
Environment/Facilities	15	4	19	Heat	34.15
				Humidity	7.32
				Lighting	7.32
				Corrosive	4.88
				High noise level	2.44
				Cleanliness	2.44
				Inadequate ventilation	2.44
				Hazardous/Toxic	2.44
Communications	10	6	16	Communication between technicians	14.63
				Between maintenance crew and lead	12.2
				Between departments	7.32

				Between lead and management	2.44
				Between maintenance crew and management	2.44
				Between departments, technicians and shifts	2.44
Aircraft Design/Configuration	8	3	11	Complex and inaccessible	9.76
				Parts unavailable/not accessible	7.32
				Poor location of parts	4.88
				Easy to install incorrectly	2.44
				Weak material of part	2.44
Others	2	1	3	Hanger door not activated/deactivated	4.88
				Items in supply for extended period of time without inspection	2.44

Appendix C

The type of information recorded in a typical RBAF accident/incident investigation report

Report type, and mishap/event number.

FROM: (Originator)

TO:

SUBJECT:

1. Aircraft involved. Give the following details on each aircraft damaged or integrally involved in the mishap or event.

1.1 Aircraft / engine / Support Equipment mission-design-series (MDS) designator and type.

1.2 Aircraft / Engine / Support Equipment tail number, Engine or Support Equipment part no., serial number, and other unique identifiers.

1.3 Aircraft / Engine / Support Equipment Hours.

1.3.1 Engine / Support Equipment Time since Last inspection.

1.3.2 Engine / Support Equipment since last overhaul.

1.3.3 Engine / Support Equipment next due inspection.

1.4 Squadron.

1.5 Wing.

1.6 Base.

1.7 Maintenance activity at time of mishap or event.

2. Date and time of mishap/event. Date in format YYYYMMDD, 24-hour clock. State the local time zone.

3. Location. Provide location of event.

3.1. Base. Name of base or military property.

3.2. State and country of event.

4. Factual Summary. This section outlines a concise, chronological description of the facts and circumstances leading to the event

5. Narrative. This section contains information showing SIB or investigating officer‘s reasoning in reaching findings, causes, and recommendations. In all cases, the sequence through point of occurrence (or discovery) for all damage and injury should be continued until the event ends. Included also all the organizational and individual factors that mitigated damage or injury, features that did not work as designed, and features not incorporated into the design but that might have mitigated damage or injury.

6. Findings and causes.

6.1. Finding 1.

6.2. Finding 2, etc.

7. Recommendations.

7.1. Recommendation 1.

7.2. Recommendation 2, etc.

8. Damage to aircraft: Details of damage on each aircraft.

8.1 State whether aircraft is destroyed, repairable or undamaged. Briefly describe damage.

8.2 Briefly describe how repairs will be accomplished.

9. Personnel involved: Details on each person involved.

10. Damage and injury cost estimates: List costs in dollars. Include item title in front of cost figure.

10.1. Damage cost: Cost of damage to Air Force property, including labour and materiel.

10.2. Injury cost: Cost of injuries to Air Force personnel, including military and civilian.

10.3. Non-Air Force damage cost: Estimate of damage to non-Air Force property.

10.4. Total accident/incident cost:

Rank, Service number, and Name.

Unit.

E-mail address or telephone number.

Appendix D

The contributing factors, sub-factors and the percentage (frequencies) with which these factors and sub-factors were reported in the RBAF investigation reports.

Contributing factors	Number and %s of QA investigation reports that reported this contributing factor and sub-factor			
	Fighters (n)	Helicopters (n)	Total	% of reports
Leadership and supervision	**9**	**19**	**28**	
Planning / organization of tasks	2	5	7	7.95
Amount of supervision	4	9	13	14.77
Delegation / Assignment of tasks	5	5	10	11.36
Prioritisation of tasks	1	3	4	4.55
Organizational factors	**16**	**60**	**76**	
Not enough staff	6	10	16	18.18
Work processes / procedures not followed	12	21	33	37.50
Work processes / procedures not documented	0	2	2	2.27
Quality of support from other organizations	0	6	6	6.82
Work group normal practice	10	18	28	31.82
Corporate change / reconstruction	0	1	1	1.14
Organizational policies	0	31	31	35.23
Individual factors	**6**	**19**	**25**	
Memory lapse	0	6	6	6.82
Time constraints	5	7	12	13.64
Fatigue	0	1	1	1.14
Peer pressure	0	4	4	4.55
Work place distraction	0	6	6	6.82
Body size	1	0	1	1.14
Complacency	0	4	4	4.55
Information	**12**	**44**	**56**	

Information not used	10	44	54	61.36
Instruction not adequate	1	0	1	1.14
Information not understandable/unclear	1	1	2	2.27
TCTO / SB updates to long / not received	0	1	1	1.14
Too much / conflicting information	3	0	3	3.41
Information not available	1	1	2	2.27
Technical knowledge / Skills	**6**	**46**	**52**	
Task knowledge	5	7	12	13.64
Weapon system knowledge	1	5	6	6.82
Skills	4	38	42	47.73
Task planning	1	1	2	2.27
Equipment / Tools / Safety equipment	**2**	**18**	**20**	
Incorrectly used	1	2	3	3.41
Unsafe	0	1	1	1.14
Unreliable	0	1	1	1.14
Inappropriate for the task	0	4	4	4.55
Not used		6	6	6.82
Not available	1	5	6	6.82
Job / Task	**8**	**18**	**26**	
Repetitive / monotonous	8	9	17	19.32
Complex / confusing		2	2	2.27
New task or change of task	1	7	8	9.09
Different from other similar tasks		1	1	1.14
Environment / Facilities	**4**	**32**	**36**	
Hot / Cold	3	1	4	4.55
Cleanliness	0	1	1	1.14
Lighting	1	7	8	9.09
Maintenance and repair of facilities	0	24	24	27.27
Communications	**5**	**11**	**16**	
Maintenance crew and QA	0	1	1	1.14
Technicians	1	4	5	5.68
Maintenance crew and management / pilot	0	2	2	2.27
Departments	0	1	1	1.14

Departments, technicians, and shifts	1	0	1	1.14
Maintenance organization and manufacture	3	3	6	6.82
Aircraft design / configuration / parts	**3**	**39**	**42**	
Complex and inaccessible	1	4	5	5.68
Easy to install incorrectly	1	2	3	3.41
Equipment /Parts unavailable	1	3	4	4.55
Bad location of parts / Poor design	0	5	5	5.68
Configuration variability	0	4	4	4.55
Others- Material deficiency	0	26	26	29.55
Others	**1**	**6**	**7**	
Orientation of main rotor blades		1	1	1.14
Lack of training	1	3	4	4.55
Safety shoe not provided		1	1	1.14
Hanger door not activated / deactivated		1	1	1.14

Appendix E

Questions for interviewing maintenance technicians relating to error(s), error detection, and error recovery

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

1- What are your daily tasks?
Please answer using the scale above. 2- ----- Rules and instructions play a vital role in my work to minimize the onset of Accidents/Incidents.

Questions	Event(s)	Error Detection	Error Recovery
General questions	3- Have you ever been involved in, or knew someone who has been involved in, or heard about an Accident/Incident?	20- What did you see, hear, or smell that alerted you that something has gone wrong?	24- How did you respond to the event?
Specific questions: Observation	4- Can you tell me what happened?		
Diagnosis	5- What was your assessment of the event at that time?	21- What did you think had happened?	
	6- Did you find it difficult to understand what was going on?	22- Did you know what had gone wrong?	
Evaluation of options	7- What options, if any, did you consider?		25- Did you consider several options?
	8- Did you find it difficult to select / reject options? Why?		26- Why did you select/reject options?
Planning of task & resources	9- Did you have a plan to perform the task?		27- Did you develop a plan for dealing with the event?
	10- What was your plan?		28- What was your plan?
	11- Did you have any difficulty developing a plan?		29- Did you have any difficulty developing a plan for dealing with the event?
Planning & selection of procedures	12- Were there standard procedures for dealing with the event?		30- Did you use established procedures to recover from the error?
	13- If not, how did you work out what steps to take?		31- If not, how did you work out what steps to take?
	14- Did you have any difficulty formulating this procedure?		32- Did you have any difficulty formulating this procedure?

Questions	Event(s)	Error Detection	Error Recovery
Execution	**15- What actions did you carry out?**		**33- What actions did you carry out?**
	16- Did you have any difficulty carrying out these actions?		
Preventi1on	**17- Is there anything you could have done to prevent the event from occurring, if so, what?**	**23- Could you have detected the error earlier, and if so, how?**	**34- Could you have recovered more effectively from the error and, if so, how?**
	18- Why do you think the event occurred? **19- Where there any contributing factors, if so, what are they?**		**35- Could you have recovered from the contributing factors? How?**

Appendix F

A list of contributing factors and sub-factors (Frequencies (%)) mentioned by RBAF aircraft and engine technicians participated in Study (3).

Contributing factors	Number and %s of interviewees who nominated this contributing factor and sub-factor			
	Fighters (n)	Helicopters (n)	Total	%s of interviewees
Leadership and supervision	**4**	**7**	**11**	
Planning/organization of tasks	3	2	5	10.42
Amount of supervision	1	5	6	12.50
Organizational factors	**12**	**9**	**21**	
Not enough staff	11	8	19	21.59
Work processes/procedures not followed	1	3	4	4.55
Work group normal practice	3	0	3	3.41
Organizational policies	0	3	3	3.41
Individual factors	**8**	**11**	**19**	
Memory lapse	1	2	3	6.25
Time constraints	4	6	10	20.83
Fatigue	6	4	10	20.83
Peer pressure	0	2	2	4.17
Work place distraction	0	3	3	6.25
Information	**3**	**3**	**6**	
Information not used	2	3	5	10.42
Too much /conflicting information	1	0	1	2.08
Technical knowledge / Skills	**3**	**10**	**13**	
Task knowledge	0	5	5	10.42

Skills	3	8	11	22.92
Equipment/Tools/Safety equipment	**5**	**5**	**10**	
Incorrectly used	5	1	6	12.50
Unavailable	2	3	5	10.42
Defective	1	1	2	4.17
Inappropriate for the task	1	0	1	2.08
Not used	1	2	3	6.25
Job/Task	**1**	**2**	**3**	
New task or change of task	1	2	3	6.25
Repetitive/monotonous	0	1	1	2.08
Environment / Facilities	**8**	**5**	**13**	
Hot / Cold	4	3	7	14.58
Cleanliness	1	0	1	2.08
Lighting	1	2	3	6.25
Noise level	1	1	2	4.17
Wind	1	0	1	2.08
Storage area	1	0	1	2.08
Maintenance and repair of facilities	3	0	3	6.25
Communications	**3**	**3**	**6**	
Maintenance crew and lead	1	1	2	4.17
Technicians	1	2	3	6.25
Maintenance crew and management/pilot	1	0	1	2.08
Aircraft design/configuration/parts	**2**	**2**	**4**	
Complex and inaccessible	0	1	1	2.08
Bad location of parts/Poor design	1	1	2	4.17

Others- Material deficiency	1	0	1	2.08
Others	**7**	**3**	**10**	
Lack of training	3	3	6	12.50
Language problems	1	1	2	4.17
Selection of Maintenance Control staff	1	0	1	2.08
Trainees work alone	1	0	1	2.08
Promotion problems	1	0	1	2.08
Hanger door not activated/deactivated	1	0	1	2.08

Appendix G

Questions concerning the reporting system in the RBAF- Results

40- What do you know about the current reporting system in the RBAF?

Response	Helicopters	Fighters	Total
Full knowledge	8	7	**15**
Partial knowledge	13	14	**27**
Have no idea	3	3	**6**

41- How accidents/incidents corrective actions are tracked?

Response	Helicopters	Fighters	Total
Accomplished by shop, documented by M.C, and reviewed by QA.	2	1	**3**
Accomplished by shop and reviewed by QA.	14	9	**23**
Tracked by shop only (Officer and Supervisor).	2	10	**12**
Tracked by QA only.	2	1	**3**
Not tracked.	1	0	**1**
Have no idea.	3	3	**6**

42- What is the process for review of accident/incident reports?

Response	Helicopters	Fighters	Total
Shop Supervisor/Officer and QA review the report, assess corrective action & recommendations, implement corrective actions & recommendations and perform documentation.	12	10	**22**
QA reviews the report, assess corrective actions & recommendations, implement corrective actions & recommendations and perform documentation.	3	1	**4**
Shop Supervisor/Officer review the report, assess corrective actions & recommendations, implement corrective actions & recommendations and perform documentation.	1	3	**4**
No action is taken by management.	1	0	**1**
Have no idea	7	10	**17**

43- What is the process for managing these reports?

Response	Helicopters	Fighters	Total
Reports are kept at QA and shop Officer/Supervisor for review and follow-up of corrective actions & recommendations for implementation.	1	5	**6**
Report is kept at QA for review and follow-up of corrective actions & recommendations for implementation.	11	11	**22**
Report is kept in technician's file to justify his punishment as a legal document.	5	1	**6**
Have no idea.	7	7	**14**

44- How and by whom this information is used?

Response	Helicopters	Fighters	Total
Used to issue safety notices/letters and Maintenance Operating Instructions (MOIs) to maintenance shops by QA.	11	15	**26**
Used to be briefed in safety lectures and meetings for the technician's by the Shop Supervisor / Officer.	6	4	**10**
Justify the punishment of the technician by higher HQ.	5	1	**6**
Not used – Reports are filed only.	0	1	**1**
Have no idea.	2	3	**5**

45- What is done with this information?

Response	Helicopters	Fighters	Total
To prevents similar events.	10	11	**21**
Used as lessons learned.	5	8	**13**
Used as legal document for punishment.	6	1	**7**
Information not used.	1	0	**1**
Have no idea.	2	4	**6**

46- One of the drawbacks of the current accident/incident reporting system is the lack of trend analysis capability.

Strongly Disagree			Disagree			Neutral			Agree			Strongly Agree		
H	F	Total	H	F	Total	H	F	Total	H	F	Total	H	F	Total
0	0	**0**	6	3	**9**	7	7	**14**	10	12	**22**	1	2	**3**

47-The current reporting system provides feedback to the initial notifier of the accident/incident.

Strongly Disagree			Disagree			Neutral			Agree			Strongly Agree		
H	F	Total	H	F	Total	H	F	Total	H	F	Total	H	F	Total
1	0	**1**	5	4	**9**	2	2	**4**	14	13	**27**	2	5	**7**

48- There is a need to improve the accident/incident reporting system.

Strongly Disagree			Disagree			Neutral			Agree			Strongly Agree		
H	F	Total	H	F	Total	H	F	Total	H	F	Total	H	F	Total
1	1	**2**	5	1	**6**	1	0	**1**	10	7	**17**	7	15	**22**

49- Do you know what is meant by the self-reporting system?

Yes			No		
H	F	Total	H	F	Total
15	13	**28**	9	11	**20**

50- I think I will be very reluctant to report an accident/incident in which I or someone that I know was involved.

Strongly Disagree			Disagree			Neutral			Agree			Strongly Agree		
H	F	Total	H	F	Total	H	F	Total	H	F	Total	H	F	Total
11	10	**21**	9	12	**21**	2	0	**2**	0	1	**1**	2	1	**3**

51- What are the reasons that you would not report an Accident / Incident in which you or someone that you know were involved?

Response	Helicopters	Fighters	Total
No reason – Must report accidents / incidents.	6	2	**8**
Fear of punishment.	17	21	**38**
No learning from past Accidents / Incidents.	1	0	**1**
Shame.	0	1	**1**

52- The important features that an effective reporting system should have are data collecting capability, tracking of recommendations and corrective actions, and On-line review capability for all concerned.

Strongly Disagree			Disagree			Neutral			Agree			Strongly Agree		
H	F	Total	H	F	Total	H	F	Total	H	F	Total	H	F	Total
0	0	**0**	1	0	**1**	2	0	**2**	5	5	**10**	16	19	**35**

Appendix H

The Proposed RBAF Accident/Incident Information Analysis and Management System (IAMS).

Information Analysis and Management System

Menu Screen

Screen (SCR) Description

Basic Information Module

IBD – Incident Basic Data Screen

AIT – Aircraft Incident by Tail Number

PCD – Parts Consumed Details

ICD – Incident Cost Details

Incident Preliminary/Self Report Module

MET – Maintenance Error Types

Organizational and Individual Factors

WPI – Work process, Procedures, and Information

HEM – Hardware, Equipment, Tools and Manpower

WDC – Weapon System Design/Configuration/Parts

MLS – Maintenance Management, Leadership, Supervision

TTS – Training/Technical knowledge/Skills

ENF – Environment/Facilities

COM – Communication

IND - Individual Factors

Final Incident Report Module

INJ – Injuries and Aircraft Damage Details

AED – Aircraft & Engine Details

FRE – Fire Outbreak Details

WSO – Wreckage/Survival and Org. Cont.

ANL --Analysis and Recommendation

Mode: ….. SCR: … Squadron: ………….. Incident No.:…………...……………

Information Analysis and Management System

Incident Basic Data Screen

Mode: ..... Squadron: ………. Aircraft Tail No………….Incident No.:……...…………….

Incident Date:..../..../....　　　　Time:..................................

Aircraft Tail No....................................　　　　Aircraft Type:......................

Engine Part No.:....................................　　　　Engine Type:........................

Reported By:...

Service No.:...

Accident/Incident
Details:...
....
....
....

Preliminary Report exists: Enter ―Y" or ―N"

Mode: ..... SCR:...................... Squadron: ………. Incident No.:……...…………….

Information Analysis and Management System

Aircraft Incident by Tail Number Screen

Mode: ..... Squadron: ………. Aircraft Tail No………….Incident No.:……...…………….

Aircraft Tail No.	Category	Incident Report No.	Incident Date	Description
....	Major	....	..../..../....	....
....	Minor	....	..../..../....	....
....	Major	....	..../..../....	....
....	Major	....	..../..../....	....

Mode: ..... SCR:............................ Squadron: ………. Incident No.:……...…………….

Information Analysis and Management System

Parts Consumed Details Screen

Mode: ..... Squadron: ………. Tail No………….Incident No.:……..…………….

Aircraft Tail No.	Part NO./NSN	QTY	Unit Cost	Total Cost
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....

Mode: ..... SCR:.......................... Squadron: ………. Incident No.:……..…………….

Information Analysis and Management System

Accident/Incident Cost Details Screen

Mode: ..... Squadron: ………. Tail No………….Incident No.:……..…………….

Maintenance Cost:..

Part(s) Cost:...

Total Cost:...

Mode: ..... SCR:.......................... Squadron: ………. Incident No.:……..…………….

Information Analysis and Management System

Preliminary/Self Report

Maintenance Errors

Mode: ..... Squadron: ………. Tail No…………Incident No.:……...…………….

Select the type of maintenance error by entering ―X" of the applicable error type.

Installation Error ( )

Errors leading to Foreign Object Damage (FOD) ( )

Fault isolation/Test/Inspection Errors ( )

Servicing Errors ( )

Errors leading to Personal Injuries ( )

Aircraft/Equipment Errors ( )

Other Types of Errors ( )

Mode: ..... SCR:.......................... Squadron: ………. Incident No.:……...…………….

Information Analysis and Management System

Preliminary/Self Report

Organisational Factors

Mode: ..... Squadron: ………. Tail No…………Incident No.:……...…………….

Select the type of maintenance error by entering ―X" of the applicable sub-factor type.

Work process, Procedures, and Information.

Not used/Not followed ( )

Not understandable ( )

Incorrect ( )

Unreliable/Inaccessible ( )

Too much/Conflicting information ( )

Update process to long/complicated ( )

Incorrectly modified manufacturer's TCTOs/SBs ( )

Fatigue ( )

Mode: ..... SCR:.......................... Squadron: ………. Incident No.:……...…………….

Information Analysis and Management System

Preliminary/Self Report

Organisational Factors

Mode: ..... Squadron: ………. Tail No.…………Incident No.:……...…………….

Select the type of maintenance error by entering –X” of the applicable sub-factor type.

Resources (Hardware, Equipment, Tools, and Manpower).

Unsafe ( )	Too complicated ( )
Unreliable ( )	Incorrectly labelled ( )
Unavailable ( )	No instructions ( )
Inappropriate for the task ( )	Not used ( )
Cannot be used in intended environment ( )	Incorrectly used ( )
Mis-calibrated ( )	Not enough staff ( )

Mode: ..... SCR:.......................... Squadron: ………. Incident No.:……...…………….

Information Analysis and Management System

Preliminary/Self Report

Organisational Factors

Mode: ..... Squadron: ………. Tail No.…………Incident No.:……...…………….

Select the type of maintenance error by entering –X” of the applicable sub-factor type.

Aircraft, Engine, Equipment Design/Configuration/Parts.

Complex ( )	Parts incorrectly labelled ( )
Inaccessible ( )	Easy to install incorrectly ( )
Configuration variability ( )	Layout of controls ( )
Parts unavailable ( )	

Mode: ..... SCR:.......................... Squadron: ………. Incident No.:……...…………….

Information Analysis and Management System

Preliminary/Self Report

Organisational Factors

Mode: ..... Squadron: ………. Tail No…………Incident No.:……...…………….

Select the type of maintenance error by entering ―X" of the applicable sub-factor type.

Maintenance Management, Leadership, and Supervision.

Quality of support from other organizations ( )

Organizational change/Restructuring ( )

Work group normal practice ( )

Planning/organization of tasks ( )

Unrealistic attitudes/expectations ( )

Prioritization of work ( )

Delegation/assignment of tasks ( )

Amount of supervision ( )

Quality of supervision ( )

Time Constraints ( )

Mode: ..... SCR:.......................... Squadron: ………. Incident No.:……...…………….

Information Analysis and Management System

Preliminary/Self Report

Organisational Factors

Mode: ..... Squadron: ………. Tail No…………Incident No.:……...…………….

Select the type of maintenance error by entering ―X" of the applicable sub-factor type.

Training/Technical Knowledge/Skills.

Amount and Quality of technical training ( )

Amount and Quality of on-the-job training ( )

New task or task change ( )

Organizational processes knowledge ( )

Weapon system knowledge ( )

English Language Proficiency ( )

Task knowledge ( )

Skills ( )

Task is complex/confusing ( )

Task is repetitive/monotonous ( )

Different from other similar tasks ( )

Mode: ..... SCR:.......................... Squadron: ………. Incident No.:……...…………….

Information Analysis and Management System

Preliminary/Self Report

Organisational Factors

Mode: ..... Squadron: ………. Tail No…………Incident No.:……...…………….

Select the type of maintenance error by entering ―X” of the applicable sub-factor type.

Environment/Facilities.

High noise level ( )

Vibration ( )

Hot/Cold ( )

Cleanliness of workplace, ramp area, and runways ( )

Hazardous/Toxic substances ( )

Humidity ( )

Power sources ( )

Rain ( )

Inadequate ventilation ( )

Inadequate lighting in work area ( )

Wind ( )

Lack or inappropriate facility repair or maintenance ( )

Mode: ..... SCR:.......................... Squadron: ………. Incident No.:……...…………….

Information Analysis and Management System

Preliminary/Self Report

Organisational Factors

Mode: ..... Squadron: ………. Tail No…………Incident No.:……...…………….

Select the type of maintenance error by entering ―X” of the applicable sub-factor type.

Communication.

Between departments ( )

Between technicians and lead ( )

Between shifts ( )

Between flight crew and maintenance ( )

Between management and manufacturer ( )

Mode: ..... SCR:.......................... Squadron: ………. Incident No.:……...…………….

Information Analysis and Management System

Preliminary/Self Report

Individual Factors

Mode: ..... Squadron: ………. Tail No…………Incident No.:……...…………….

Select the type of maintenance error by entering ―X" of the applicable sub-factor type.

Individual Factors.

Body size/strength ( )	Memory lapse ( )
Physical health (including hearing and sight) ( )	Complacency ( )
Personal events (for example, family problems) ( )	Lack of awareness ( )
Work place distractions ( )	Lack of assertiveness ( )
Lack of communications between technicians ( )	Management pressure ( )

Mode: ..... SCR:......................... Squadron: ………. Incident No.:……...…………….

Information Analysis and Management System

Final Accident/Incident Report

Injuries and Aircraft Damage Details

Mode: ..... Squadron: ………. Tail No…………Incident No.:……..…………….

Injury to	**Fatal**	**Serious**	**Minor**	**Total**
Pilot	....	....	....	....
Student Pilot	....	....	....	....
Technician(s)	....	....	....	....
Trainees	....	....	....	....
Others	....	....	....	....
Grand Total	....	....	....	....

Aircraft Damage Details

Fuselage: ....

Wings: ....

Tail Unit: ....

Engines: ....

Landing Gear: ....

Mode: ..... SCR:.......................... Squadron: ………. Incident No.:……..…………….

Information Analysis and Management System

Final Accident/Incident Report

Aircraft and Engine Details

Mode: ..... Squadron: ………. Tail No.………….Incident No.:……...…………….

Aircraft Information

Total Flight Hours: .... **Hours since Last Overhaul:**..

Hours to next Overhaul:.. **Last Phase Inspection:** ....

Last Basic Post-Flight Inspection:.......... .... **Last Pre-Flight Inspection:** ....

Engine Information

Engine Part No.:.. **Total Engine Hours:** ....

Hours since Last Overhaul: .... **Hours to next Overhaul:** ....

Last Major Inspection:... **Last 50 Hour Inspection**:..

Last 25 Hour Inspection:.. **Last Engine Wash**:...

Mode: ..... SCR:.......................... Squadron: ………. Incident No.:……...…………….

Information Analysis and Management System

Final Accident/Incident Report

Fire Breakout Details

Mode: ..... Squadron: ………. Tail No………….Incident No.:……...…………….

Cause of Fire

Enter one of the following values:

1- Fuel.	2- Exhaust.	3- Brakes.	4- Hydraulic Fluid. ....
5- Engine(s).	6- Electrical.	7- Oil.	8- Others. ....

Extinguisher Details

Extinguisher used by technicians? .... (Enter ―Y” or ―N”)

Number of technicians injured: ....

AFFF Extinguisher

Enter one of the following symbols: ....

AA – Automatically Activated.
AM – Manually Activated.
AF – Activation Failed.

Portable Extinguisher

Type	Qty	Failed	Type	Qty	Failed
Water	....	....	Dry Chemical	....	....
Foam	....	....	CO2	....	....

Successfully Extinguished? ....(Enter ―Y” or ―N”)

Mode: ..... SCR:.......................... Squadron: ………. Incident No.:……...…………….

Information Analysis and Management System

Final Accident/Incident Report

Wreckage/Survival/Organisational Contribution

Mode: ..... Squadron: ………. Tail No…………Incident No.:……..…………….

Wreckage and Impact Details:

....
....
....
....

Survival Aspects:

....
....
....
....

Organisational Contribution:

Policies:..
....

Training:..
....

Facilities:...
....

Mode: ..... SCR:.......................... Squadron: ………. Incident No.:……..…………….

Information Analysis and Management System

Final Accident/Incident Report

Analysis, Findings, Recommendations, and Corrective Actions

Mode: ..... Squadron: ………. Tail No………….Incident No.:……...…………….

Analysis:

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Findings:

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Recommendations:

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Corrective Actions:

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Mode: ..... SCR:.......................... Squadron: ………. Incident No.:……...…………….

Appendix I

Proposed Technicians' Self-Report Form – Hard Copy.

Technician's Self Report Form
Name of technician and Service no. :.. Branch/Section/Shop:.. Type of maintenance: 1. Line... If line, What type? .... 2. Base... If Base, What type? .... Air Base and Squadron: .... Aircraft / Engine / Support Equipment type: ....Tail / Serial no.: .... Date and Time of event: / / ---:--- am pm
Event
Please write a brief description of the Event. ....
Type of Maintenance Error
Please select the maintenance error(s) that caused the event: ---1 Installation Error . ---2 Foreign Object Damage Error. ---3 Servicing Error . ---4 Aircraft/Engine/Equipment Error. ---5 Repair Error. ---6 Personal Injury Error. ---7 Fault Isolation/Test/Inspection Error. ---8 Other Errors (explain)……………………………….....
Contributing Factors' Checklist
Organizational Factors **1. Work process, procedures, and information.** ---1 Not used/Not followed. ---2 Not understandable. ---3 Incorrect. ---4 Unavailable/inaccessible/Not documented. ---5 Too much/conflicting/information. ---6 Update process too long/complicated. ---7 Incorrectly modified manufacturer's TCTOs/SBs. ---8 Fatigue. **2. Resources (Hardware, Equipment, tools, and manpower).** ---1 Unsafe. ---2 Unreliable. ---3 Unavailable. ---4 Mis-calibrated. ---5 Inappropriate for the task. ---6 Cannot use in intended environment. ---7 Too complicated. ---8 Incorrectly labeled. ---9 No instructions. ---10 Not used. ---11 Incorrectly used. ---12 Not enough staff. **3. Aircraft, Engine or Equipment Design/Configuration/Parts.** ---1 Complex. ---2 Inaccessible. ---3 Configuration variability. ---4 Parts unavailable. ---5 Parts incorrectly labeled. ---6 Easy to install incorrectly ---7. Layout of controls. **4. Maintenance management, leadership, and Supervision.** ---1 Quality of support from other organizations. ---2 Organizational change/restructuring. ---3 Work group normal practices. ---4 Planning/organization of tasks. ---5 Unrealistic attitude/expectations. ---6 Prioritization of work. ---7 Time constraints. ---8 Delegation/assignment of task. ---9 Amount of supervision. ---10 Quality of supervision

Technician's Self Report Form

5. Training/Technical knowledge/skills and task.

---1 Amount and quality of technical training.
---2 Amount and quality of On-the-Job training.
---3 English language proficiency.
---4 Organizational processes knowledge.
---5 Weapon system knowledge.
---6 Task knowledge.
---7 Skills.
---8 New task or task change.
---9 Task is complex/confusing.
---10 Different from other similar tasks.
---11 Task is repetitive/monotonous.

6. Environment/Facilities.

---1 High noise levels.
---2 Vibrations.
---3 Hot / Cold.
---4 Cleanliness of work place, ramp area, and runways.
---5 Hazardous/toxic substances.
---6 Humidity.
---7 Power sources.
---8 Rain.
---9 Inadequate ventilation.
---10 Inadequate lighting.
---11 Wind.
---12 Lack or inappropriate facility repair or maintenance.

7. Communication.

---1 Between departments.
---2 between technicians and lead.
---3 Between shifts.
---4 Between flight crew and maintenance.
---5 Between maintenance management and manufacturer.

Individual Factors

---- 1 Body size/strength.
---- 2 Physical health (including hearing and sight).
---- 3 Personal event (for example family problems).
---- 4 Work place distraction.
---- 5 Management pressure.
---- 6 Memory lapse.
---- 7 Complacency.
---- 8 Lack of awareness.
---- 9 Lack of communication between technicians.
---- 10 Lack of assertiveness.

Other contributing factors (explain below).

....
....

Error prevention strategies

Recommendation no.	Contributing Factor no.	

Appendix J

An example of Medium to Long-Term Action Plans

Objectives	Actions (Maintenance Organization level)	Frequency	Result of action plan 1. In progress. 2. Satisfactory. 3. Unsatisfactory 4. Seek an alternative action plan.
To develop and communicate the purpose, vision, and goals of the organization that focus on safety and quality of maintenance.	Conducting training, introducing rewards programs, and providing feedback to all maintenance personnel. Introducing an open reporting and developing tools to collect data. Conducting surveys, process reviews, and establishing crisis teams to review organizational performance. Implementing the findings of the investigation as appropriate.	On going	
To ensure the reliability, accessibility and quick dissemination of event information to technicians and departments.	Provide access to concerned individual to the database. Sharing lessons learnt to prevent similar occurrences through meetings and forums.		
To describe the organization's human resource requirements and plans based on the organization's strategic objectives and plans.	Review staffing levels, qualifications, and experiences. Manage and recognize technicians' performance through training and rewards. Deployment of personnel based on needs, recognition of system, and constant review of task complexities.	Annually	
To identify and review the organization‘s training needs to support its goals and objectives.	Identify personnel who need training, the content of necessary training, source of training, Alerting management to personnel‘s training needs. Developing an implementation plan, if necessary. Maintain proper record-keeping of training received.	Annually	
To analyse root causes, that prompts corrective actions, when a process fails to meet specified standards or	Review QA reports, to rectify findings and adopt QA recommendations, if applicable. Develop a systematic approach to act on the results of the various assessments conducted on key	On going	

targets.	processes. Develop committees / programs that track and performs follow-up on corrective actions.		
To evaluate and review maintenance documents and the documents of other related processes and procedures.	Perform inspections to ensure that technical manuals and service bulletins are applicable, contains a current log of pages and index, and contains an amendment record. Ensure that the Technical Order Distribution Office (TODO) personnel are sufficient and qualified to amend the organizational maintenance processes and procedures. Ensure that the TODO maintains a current register for Technical Manuals/Service Bulletin holders. Inform maintenance personnel of any changes to organizational processes and procedures. Implement areas for improvement identified through the reviews and surveys.	Annually On going On going When applicable	
To evaluate the Organization's standards for housekeeping and facilities maintenance and repair to meet the needs of safe, swift, and effective maintenance and operations.	Perform frequent inspections to determine facility condition (to include runways/taxiways, ramp areas, maintenance hangers, and shops) and identify maintenance and repair requirements. Advice Headquarters of findings of these inspections in order to take appropriate corrective actions.	Annually	
To review organization's workplaces and equipment maintenance requirements and availability based on the organization's strategic objectives and plans.	Review equipment levels, serviceability, repair and return schedules and capabilities Ensure that there are procedures for the storage, maintenance, control and calibration of tools and equipment in the workplace. Ensure that there are procedures to control tools and equipment that are borrowed or hired.	Quarterly	
To establish a systematic approach to act on the results of the various reviews and assessments conducted by maintenance activities.	Establishing committees and programs to track follow-up actions.	On going	
To understand the effects of fatigue on technician performance.	Establish guide lines for shift rosters. Provide management with recommended shift rosters. Inform technicians about the shift roster will in advance and restrict subsequent modifications to minimum.		
To understand the capabilities of the weapon system.	Provide access for all concerned technicians to these links and establish guide lines to use these links.		
To understand technicians' capabilities and limitations in terms of knowledge and	Review task assignments (mixing new technicians with experienced ones).	Quarterly	

experience.			
To understand team management errors to share the same awareness of what is happening or what has happened. To encourage technician involvement and commitment to teamwork and the achievement of the organization's goals and objectives.	Review maintenance teams‘ composition. Nominate team members to attend MRM. Disseminate benefits of working in teams. Encourage group discussions and communications.	On going	
To identify technicians‘ limitations, strengths, the effects of fatigue on performance, and human performance danger signs.	Introduction of Human Factors training to maintain operational integrity.	On going	
To understand why technicians violate good performance.	Encouraging technicians into compliance with safety regulations by displaying graphic posters and videos that highlight the grisly consequences of unsafe behaviour. Establish social controls (i.e. group discussions and group activities).		
To enhance mental readiness for the task (task imagination or mental rehearsal).	Introducing the technicians to mental rehearsal and preplanning techniques. These techniques include: 1) Positive imaginary - thinking about the task and imagine how things would look and feel before the actual job encounter. 2) Being prepared for problem -anticipation of problems and preparing effective measures to deal with them. 3) Mental readiness "Psyching yourself-up" to do good job, planning the procedural steps both in isolation and in consultation with colleagues. 4) Distraction control – anticipation of distractions and dealing with each one as it occurs. 5) Avoiding place-loosing (loosing or forgetting one's place in the sequence of the task steps) – the technician marks his position in the task (with a label, for example) at the time of being interrupted.		