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A RESILIENCE ENGINEERING APPROACH TO SAFETY EXCELLENCE IN THE MAINTENANCE OF OIL AND GAS ASSETS

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"All praise is due to Allah, the Almighty and the Most Gracious, the Most Merciful for providing me his guidance, help and blessings"

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List of Acronyms

AHRAP	As High Resilient As Possible
AIBN	Accident Investigation Board Norway
ALARP	As Low As Reasonably Practicable
ARP	Aspect Resilience Profile
ATA	Air Transport Association
ATSB	Australian Transport Safety Bureau
CFA	Confirmatory Factor analysis
CMMS	Computerised Maintenance Management System
ETA	Event Tree Analysis
ETTO	Efficiency Thoroughness Trade-Off
FMECA	Failure Mode Effects and Criticality Analysis
FRAM	Functional Resonance Analysis Method
FRP	Factor Resilience Profile
FTA	Fault Tree Analysis
HAZID	Hazard Identification
HAZOP	Hazard and Operability
HEP	Human Error Probability
HFACS-ME	Human Factors Analysis and Classification System Maintenance Extension
HRA	Human Reliability Analysis
HRO	High Reliability Organisation
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency
IAP	Institut Algérien du Pétrole
ICAO	International Civil Aviation Organisation
ISO/IEC	International Standard Organisation/ International Electro-technical Commission
KMO	Kaiser-Meyer Olkin
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MAH	Major Hazard Accident
MAL	MAturity Level
MARP	MAintenance Resilience Profile
MEDA	Maintenance Error Decision Aid
MEL	Maturity Excellence Level
MEQ	Maintenance Environment Questionnaire
MIT	Massachusetts Institute of Technology

MRM/TOQ	Maintenance Resource Management/Technical Operations
NAT	Normal Accident Theory
NPP	Nuclear Power Plants
OSHA	Occupational Safety and Health Administration
PCA	Principle Components Analysis
PHA	Preliminary Hazard Analysis
PRA	Probabilistic Risk Assessment
PSA	Probabilistic Safety Analysis
PSAEA	PSA-based event analysis
PSF	Performance Shaping Factors
QRA	Quantitative Risk Assessment
SCADA	Supervisory Control and Data Acquisition
SHELL	Software, Hardware, Environment, Liveware
SINTEF	Selskapet for INdustriellog TEknisk Forskning (The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology)
SPSS	Statistical Package for the Social Sciences
STAMP	Systems-Theoretic Accident Model and Processes model
STPA	STAMP-based Hazard Analysis
SWOT	Strengths Weaknesses Opportunities and Threats
TMI	Three-Mile Island

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To the memory of my parents that died without seeing their children becoming adults

To my beloved ZU and MEHDI

To Al HADJA

To my sisters and brothers

To all my family

Abstract

The established approach to safety management has failed to handle socio-technical systems that have become more complex. The main argument is this approach is based on assumptions that systems are protected against accidents by barriers (well-trained people, redundant mechanisms and safety devices, and procedures and safe systems of work). Complex systems, such as maintenance, are actually labour intensive; maintenance staff often works under pressure to finish tasks as rapidly as possible. They continuously adapt and make adjustments using available resources, time, knowledge, and competence to achieve success. Thus, they are accidents prone. Human factors inherent to maintenance accidents are most times difficult to identify. Research in this area in the oil and gas industry in maintenance management is limited in comparison to the aviation and nuclear sectors. Therefore, it has been suggested to overcome this lack by exploring the maintenance system and identifying appropriate methods and tools that lead a system to safety excellence. Resilience engineering (RE) approach has been found the suitable solution. Moreover, four system abilities (cornerstones of RE: ability to respond, to monitor, to anticipate, and to learn) have been identified to characterise the resilience of a system; if these abilities are known and increased, it will make the system As High Resilient As Possible (AHRAP). However, there is a need to bridge between RE theory and practice. Particularly, a tool that measures these abilities lacks in the oil and gas industry, specifically within the maintenance system.

In doing so, a framework based on a Gap Analysis (GA) was outlined. A tool, the MAintenance System Resilience Assessment Tool- MASRAT, was developed to assess current system resilience and identify strategies for improvement to achieve safety excellence. The maintenance system of SONATRACH was explored by the analysis of the system documentation and processes, interviews with maintenance staff, questionnaires, field observations, storytelling, and functional analysis. MASRAT has been validated by means of congruency and principal components analysis, PCA (content validity), and Cronbach's alpha (reliability). An expert panel testing was carried out to test its usability.

The exploration of the system came up with a snapshot of daily activities as well as a better understanding of the maintenance system. The study identified the most significant human factors (resources, time pressure, and supervision/coordination) and their probable impact on plant safety. The elements of the system were found tightly coupled, hence the system complex. Stories describing the continuous adaptations of people to achieve assigned objectives were collected. On the other hand, MASRAT was validated. All items were rated above 0.75 in congruency test. The results of PCA for the three selected factors confirmed the items may be clustered after extraction into four components which interpretation represents the four cornerstones of RE. The analysis showed MASRAT is reproducible. Cronbach's alpha results were found higher than what is required (0.7). MASRAT was found usable by maintenance expert panel. It was used to measure the maintenance department resilience. Strategies that may lead the system from current maturity level to excellence were identified. Eventually, recommendations were made to management to be implemented both at corporate and department levels. For the first time, the maintenance department resilience of petroleum assets was measured to fill in the gap between RE theory and practice. Besides, this can be of benefit to the petroleum industry by a better knowledge of the maintenance working environment and human factors impact on safety and by profiles determination and improvement strategies identification.

CHAPTER 1. INTRODUCTION

1.1. Background

The availability of personnel and equipment is extremely important to achieve production objectives. Maintenance activities are characterised by the nature of work, the types (corrective activities that are performed after the failures have occurred and preventive ones that are performed before a failure happens which could be respectively a trip in a pump or changing a bear), and their associated tasks and steps (preparation and work completion). Furthermore, the systems of work such as procedures and conditions of work, the places where the activities are performed as well as organisational aspects may have adverse effects on people's health and safety, the environment, and operation costs. Such activities are actually labour intensive and maintenance staff often works under pressure to finish tasks as rapidly as possible, and they sometimes lack the necessary knowledge to perform certain tasks as required (Ameziane et al., 2011). Thus, they are accidents prone.

The job, the organisation, and the individual are the three interacting aspects, called human factors that influence human behaviour at work and can affect health and safety as defined by HSE (2005). About 80 % (Reason, 1990) of industrial accidents are a result of human factors, a majority of which are maintenance related and occur mainly during the execution phase where corrective maintenance causes more accidents (Idhammar, 2004; Grusenmeyer, 2005; Giraud et al, 2008; Okoh and Haugen, 2014).

Two fundamental ways explain the human "contribution" to accident occurrences: first, it is seen either as a "human error", that is the "cause" of mishaps or as a symptom of a deeper problem within the organisation (Dekker, 2004); people at the bottom of the pile are generally blamed for such occurrences (Reason and Hobbs, 2004). Second, it is explained by a variability of the performance of the system (Hollnagel, 2004). Further details are given in Chapter 3, section 3.3.

Human factors inherent in maintenance related accidents are difficult to identify. Research in this area within the oil and gas industry in maintenance management is limited due to a lack of credible data (Ray et al, 2000; Burton et al., 2004; Grusenmeyer, 2005; Giraud et al., 2008; Kanki and Hobbs, 2008). Therefore, the need to explore the maintenance working environment and assess the inherent conditions of maintenance human factors is of great importance.

Accident causation models evolved from the simple linear (or sequential model, Heinrich's domino model), via complex linear (or epidemiological model, Reason's Swiss cheese model) to the non-linear (or systemic model) according to Hollnagel (2006). Traditional risk assessment techniques are good for technical failures in non-complex systems, but they fail to handle complex socio-technical systems (Hollnagel, 2010a; Leveson, 2011; Macchi, 2011). They may be used in combination with more powerful techniques such as systemic techniques that are based on resilience engineering precepts.

1.2. Resilience Engineering

Complex socio-technical systems are characterised by the unavailability of complete knowledge (Hollnagel, 2010a) which allows full system description due to continuous changing parameters (see section 3.4). In such systems, organisations are often working under pressure. Since the future is uncertain and unknown, organisations search to preventing negative outcomes (what can go wrong) to take place by early detection and correction as well as highlighting opportunities (what can go right) to take benefit from them. They face situations requiring the management of unexpected events. To achieve success, they must adapt their functioning and make correct adjustments. They have to rely on the capability of humans to make these adjustments that fill in the gap between "what should be done" and "what could be done" using available resources, time, knowledge, and competence. Actually, adjustments may lead to success or to increase of risks. The reliability of such systems is because "*people are flexible and adaptive, rather than because the systems have been perfectly thought out and designed*" (Hollnagel, 2010a p. 55). The performance of the system is, therefore, variable where the performance of the human part of the system is the main source of variability and this variability must be seen as an asset rather than a threat, something that is useful but also inevitable (Hollnagel, 2010a). Therefore, safety must be achieved by controlling performance variability rather than constraining it (Hollnagel, 2010b).

In resilience concepts and precepts book, Leveson defines resilience as "*the ability of systems to prevent or adapt to changing conditions in order to maintain (control over) a system property*" (Leveson et al., 2006 p. 95), where safety and risk are the property in question. For Leveson et al. (2006), safety is achieved when the system or organization avoids failures and losses, as well as responding appropriately after the fact, hence when the system is resilient. For Fairbanks et al (2014, p. 376) a system is "*resilient if it can adjust its functioning before, during, or following events (changes, disturbances, or opportunities) and thereby sustain* *required operations under both expected and unexpected conditions*". For Hollnagel (2010a), a resilient system is also safe.

The aim of Resilience Engineering (the approach that makes a system more resilient, see section 3.3 for more details) is not only to prevent things from going wrong, but also to ensure that things go right, that is to facilitate normal outcomes. In other words, enhancing the abilities that make things go right will reduce the possibility that they go wrong. Resilience engineering has been found the solution to complex socio-technical systems and safety must be managed by resilience engineering. Resilience engineering is a developing approach (Hollnagel et al., 2009). Therefore, there is a need to fill in the gap between theory and practice. This requires the development of tools to complement existing ones.

Currently, the well-known accident causation models which can be used as risk assessment methods as well, based on resilience engineering precepts and system theory, yet in development, are: the Systems-Theoretic Accident Model and Processes (STAMP) model (Leveson, 2004), and the Functional Resonance Analysis Method (FRAM), (Hollnagel, 2004). Instead of explaining accidents as a result of a break in a linear chain of events, they view accidents as a consequence of a failure to maintain safety constraints as performance changes (STAMP) or unexpected combinations of normal performance variability of the system that resonate to produce the undesirable events (FRAM).

1.2.1. The STAMP Model

The STAMP accident causation model as well as the corresponding risk assessment method STAMP-based Hazard Analysis (STPA) has been developed in Massachusetts Institute of Technology (MIT). STAMP has been mainly used in space and aviation industries. The underlying theoretical foundation of STAMP is a result of system and control theory rather than component reliability theory. It assumes that accidents occur when component failures, external disturbances, and/or dysfunctional interactions among systems or system components (including hardware, software, humans, and organizational components) are not adequately handled by the system design, the system operators, and management because of inadequate application of constraints at all levels of a socio-technical system (Hardy, 2011; Leveson, 2004; Dulac et al, 2005; Johnson and Halloway, 2003).

According to Alvarenga et al (2014), STAMP is a combination of two models namely Rasmussen and Svedung (2000) model and Forrester's model developed in 1961. The

Rasmussen and Svedung model is an application to risk management of Rasmussen model that was developed in 1997 to explain accident occurrences in complex socio-technical system. Actually, Rasmussen model is composed of several hierarchical control levels from legislators to operation staff through plant management (Qureshi, 2008). The Forrester model is based on concepts of process control system theory applied by Forrester in business dynamics involving economic processes (Alvarenga et al 2014). STAMP uses the mathematical model for system dynamics to describe the processes occurring in the structure of each level (Alvarenga et al 2014). Figure 1.1 shows the STAMP model as adapted by Leveson (2004).

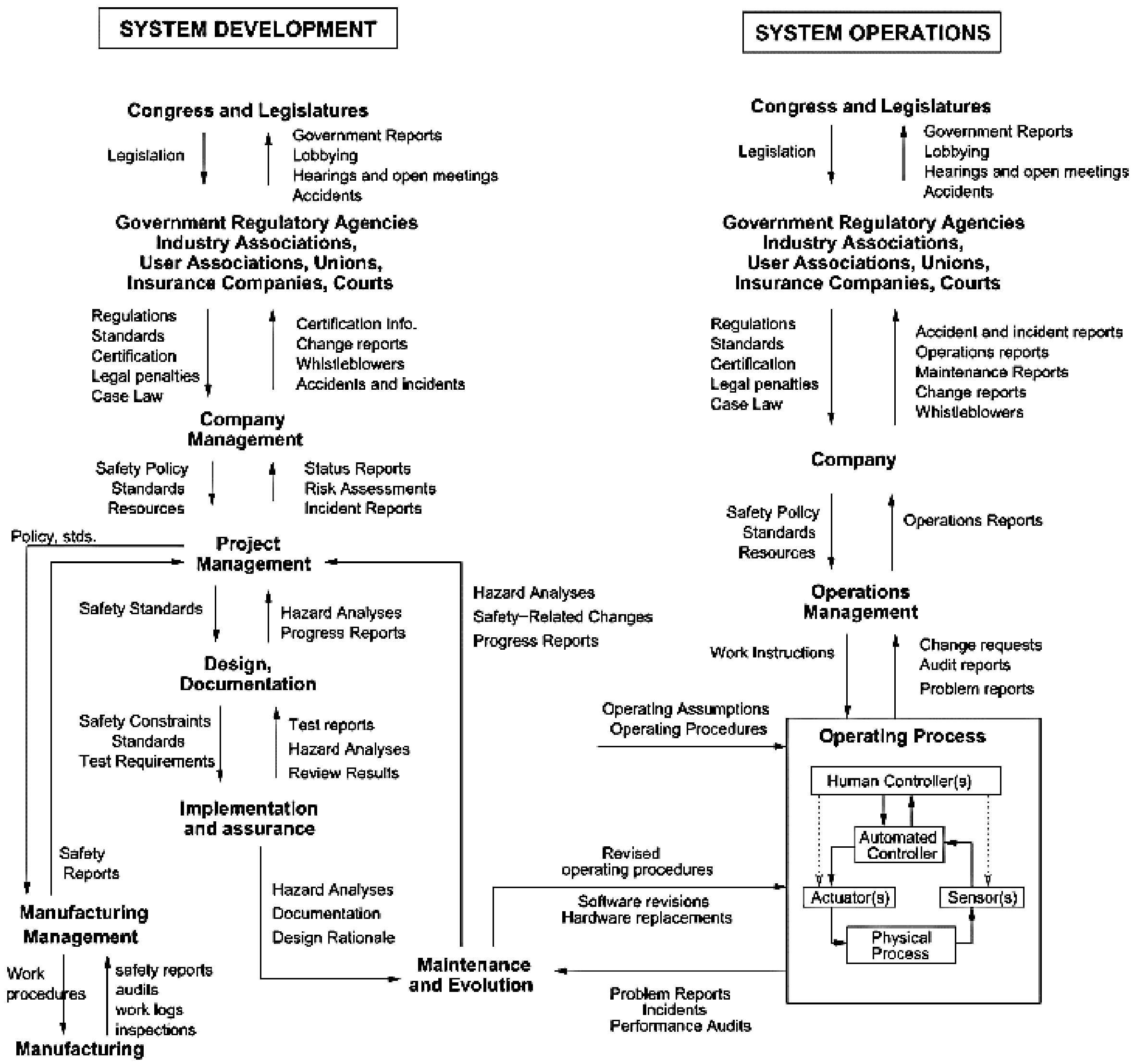

Figure 1-1 : General form of a model of socio-technical control (Leveson, 2004)

Systems are characterised by a dynamic balance state; accidents, therefore, stem from systems reaching imbalance –hazardous- state and inappropriate control (Leveson, 2004). For Leveson (2004), systems are viewed as hierarchical structures where each level imposes constraints on the activity of the level below it. Safety-related constraints specify those relationships among system variables that constitute the balanced state of the system (Leveson, 2004).

Basically, STAMP considers constraints instead of events to explain accident occurrences. Accidents may happen if constrains are not controlled or identified (Dulac and Leveson, 2004). STAMP treats safety as a control problem rather than a failure one (Ishimatsu et al, 2010). Control is not seen here as a coercion like in military system control, it is used rather to control the dynamic behaviour of a process. The need to control a system is emphasised by Bossel (2007) in terms of economic (costs of production), safety (safety instrumented systems), performance (production), and reliability (redundancy) controls. The STAMP model is built from three fundamental concepts that give rise to a classification of control flaws that can lead to accidents namely, constraints, hierarchical levels of control, and process models. Feedback loops of information and control maintain systems in a state of dynamic equilibrium. (Leveson, 2004)

This brief presentation of STAMP calls for some comments. In STAMP, based on systems theory and control theory, safety is viewed as a control problem (Hardy, 2011). According to this approach, there is a need to have controls that keep all constraints imposed. What matters here is how control is perceived with regard to the human part of the socio-technical system. The human performance is the most variable one in such systems. Control is performed by means of procedures, plans, a set of guidelines or instructions, a program, regulations, etc. All these means may play actually an important role to achieve safety; yet, do people react to the dynamic changes that exist within the system by complying to the letter with procedures, instructions, and so forth? They rather adapt their functioning to any situation in order to make the correct adjustments that allow achieving goals.

To achieve safety in industrial assets, all kinds of performance variability are constrained (rules, procedures, strict training, etc.) in order to avoid malfunctions or failures. This cannot be attained since systems are intractable (Hollnagel, 2010a). The solution lies within the human abilities to adapt and make correct adjustments as stated previously.

On the other hand, one can apply the control theory to a socio-technical system? Systems theory has been developed after World War II to face the increasing importance of system complexity particularly in the military domain. In such a theory, systems are viewed as interrelated elements that maintain a dynamic balance by means of feedback loops of control and information (Hardy, 2011). In control theory, the course of action is maintained by means of these feedback loops.

In STAMP, accidents are seen as a consequence of dysfunctional interactions between components rather than resulting from chain components failures events and safety is viewed as a control problem rather a failure one (Hardy, 2011). When a system is studied by means of STAMP model, dynamic simulation and modelling software are used such as Stella and Vensim (Hardy, 2011) to characterise the evolution of the studied system along time. According to Hardy (2011), the analyst must have a perfect knowledge of the elements that constitute the system as well as the interactions between its components. For Hardy (2011), the use of such software that are capable of representing the behaviour of a dynamically linear system, are extremely effective to analyse and predict a dynamic behaviour of a technical system which can be deterministic and predictable; a technical system has a bimodal functioning (success/failure) which can be predicted by means of reliability tools. As a result, STAMP is very suitable and adequate to risk assessing a system or analysing an accident for any technical system. However, this is not the case for socio-technical systems. When the human part of the system is taken into account to performing a quantitative analysis using this model, it might not be valid since software cannot predict the behaviour of a socio-technical system; software are based on linear differential equations but unfortunately the interactions of systems components are not linear in complex socio-technical systems. The same reproach is made to human reliability analysis. HRA tries to apply reliability theory that is suitable for technical systems but that is not valid for socio-technical ones. People have the ability to change the course of action of any situation.

1.2.2. The FRAM Method

The FRAM is a qualitative accident method as well as a risk assessment one that characterizes socio-technical systems by the functions they perform rather than by how they are structured (Hollnagel, 2012b). In FRAM method, performance variability of a system is seen as a source of successes as well as of failures. The main difference between the FRAM and STAMP lies within the fact that the FRAM uses a functional approach, whereas STAMP uses a structural one. The Functional Resonance Analysis Method, FRAM is an opportunity to explore how work is actually performed in the real world by studying how functions become coupled (Hollnagel, 2012b). In “FRAM: the functional resonance analysis method book”, Hollnagel (2012b) explained the principles underlying this method. It is focused on the fact that the FRAM addresses what is (or has been) actually performed and not what is (or was) assumed to be, leading to say that functions refer to activities rather than tasks. It has been particularly emphasised in the case of doing a risk assessment for instance, that describing tasks leads to speak about errors, violations, non-compliance with reference to work as imagined. On the other hand, if activities (work as performed) are described, performance variability is considered instead (see Chapter 3, section 3.3). According to Hollnagel (2012b), functions must be regarded as goals-means relations that is, a representation of means that are necessary to achieve goals. Functions may describe what a person or a group of people specifically does to achieve a specific goal, or what an organisation does, or what a technological system does itself or in interaction with humans (Hollnagel, 2012b). FRAM describes how functions may resonate and create hazards leading to an accident (Hollnagel 2004). The method can be used to analyse and predict any functional resonance. The FRAM was designed first as a model for accident modelling and complex system analysis (Hollnagel, 2004). It becomes over time an analysis method both prior to or following an accident and system monitoring as well.

According to Hollnagel (2010a), FRAM is based on four principles.

- First, the principle of equivalence of successes and failures: successes and failures are the result of organisations, groups and individuals' performance adaptations to cope with complexity.
- Second, the principle of approximate adjustments: complex socio-technical systems are by necessity underspecified and only partly predictable. System performance is adjusted to meet existing conditions; therefore, performance variability is both normal and necessary
- Third, the principle of emergence: variability of multiple functions may combine in unexpected ways, leading to disproportionately large consequences.
- Forth, the principle of functional resonance: the variability of a number of functions may resonate, so that the variability of some functions may exceed normal limits, the consequence of which may be an accident.

Hollnagel (2010a) outlined the steps of the method. After the definition of the purpose of modelling and describing the scenario to be analysed, step 1 consists of the identification of essential system functions and characterisation of each function by six basic parameters as shown in figure 1.2 (I: input; O: output; R: resources; P: preconditions; C: control; T: time). Step 2 characterizes the (context dependent) potential variability. Step 3 defines the functional resonance based on possible dependencies/couplings among functions and the potential for functional variability. By following the six parameters of step 2, the output of one function may be an input to another function, or produce a resource, etc. The combination of these links with the characterisation of the variability is then used to specify the different impacts. Step 4 identifies barriers for variability (damping factors). In addition to barriers, the FRAM specifies performance monitoring of variability through the development of performance indicators.

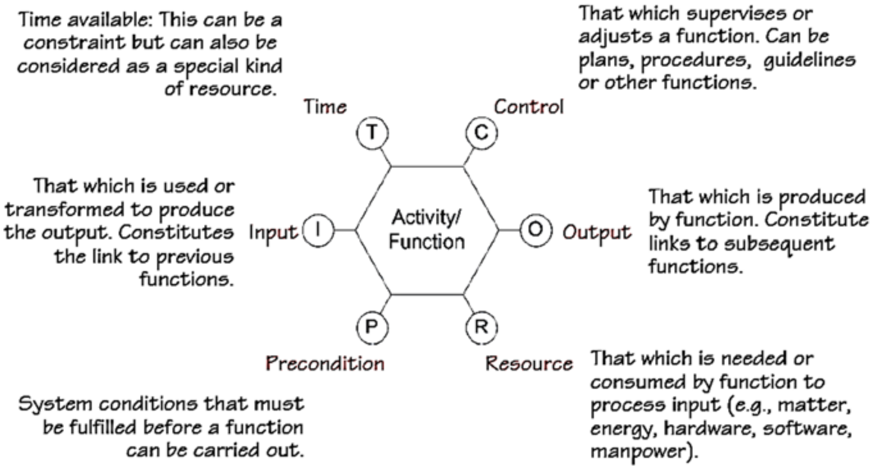

Figure 1-2 : The FRAM functional unit, module (Hollnagel, 2010a)

The FRAM is still under development, particularly the determination of the potential for variability by the development of a way to measure the variability of the performance.

1.2.3. The Four Cornerstones of Resilience Engineering

Four system abilities that make an organisation resilient have been identified. A resilient organisation is one that is able to increase these four abilities. This may be achieved by (1) monitoring the system’s environment as well as the surrounding environment, (2) responding properly to threats/opportunities, (3) anticipating any developments, and (4) learning from past experiences: these are the four cornerstones of resilience engineering (Hollnagel, 2009b) that need to be measured in order to know system’s resilience and increase it. A tool based on such precepts is therefore of great importance.

1.3. SONATRACH Overview

SONATRACH is an Algerian state-owned oil and gas producer and refiner. Its activities cover all branches of oil and gas industry that includes exploration, production, pipeline transportation of oil and gas, refining, petrochemical, gas liquefaction, polymers, and marketing of hydrocarbons as well as petroleum by-products. The company also stepped up investments in power generation, new and renewable energies, water desalination, and mining exploration and exploitation. With a turnover approximately $56.1 billion in 2010, it is ranked first company in Africa and twelfth in the world. It is also fourth world LNG exporter, third world LPG exporter and fifth World Natural gas exporter (SONATRACH, 2012).

In addition to its economic and social role, SONATRACH contributes in helping needy people and promoting scientific, cultural and sporting activities. It is also committed to reducing the negative impact of its activities on its employees and the neighbouring populations as well as on the environment particularly by reducing the emission of greenhouse effect gas and any other polluter in the Atmosphere.

SONATRACH facilities are old but many of them are being revamped. The maintenance system in place has been established first time in the 1970's. This system has never been evaluated. Furthermore, each branch of activity (upstream, downstream, and transportation) has acquired a computerised maintenance management system (CMMS) that is unfortunately underutilised and can be used only by the maintenance departments of the branch in question.

Maintenance personnel are motivated, but many of them are close to retirement. Factors such as lack or poor supervision/coordination, equipment issues, the absence of or unworkable procedures, and time pressure/fatigue, inadequate training characterise the system. In addition, the organisation culture is production driven. As can be seen, there are many opportunities that are worth exploring.

1.4. Research Problem and Rationale for the Study

After accidents such as the Three Mile Island in 1979, Bhopal in1984, Chernobyl in 1986, piper alpha in 1988, Toulouse in 2001, Skikda in 2004 and Houston in 2005, organisational and human factors have been highlighted as playing an important part in accident occurrences and new theories were born. The need to improve organisational culture has been emphasised.

Traditional risk assessment techniques such as FMECA, HAZOP, etc. (section 2.3) focus on a single initiating event, one event- "cause" of deviations. They are based on the system breakdown into meaningful elements, generally components or events and require a full description of the system that is not valid for socio-technical systems that have become more complex, intractable. They generally show limited examination of human and organisational contribution (Wells, 1997; Kletz, 1999; NASA, 2002a; NASA, 2002b; Hollnagel, 2010a; Leveson, 2011; Macchi, 2011). Human Reliability Analysis (HRA) was born to address these limitations by incorporating human factors. HRA was used as an extension of probabilistic safety assessment (PSA) where the impacts of human actions are taken into account (Hollnagel, 2005a). Dougherty (1990) critically analysed HRA methods and demonstrated they were not accurate. HRA applies the principles of technical components reliability to the failures of human actions by attempting to calculate the probability of "human error" (HEP). This is not valid; the concept of "human error" is discussed deeply in Chapter 3, section 3.3.

Because conventional accidents causation models and techniques for prevention of future undesirable events often fail to handle complex safety critical systems, more powerful techniques based on a systemic approach are needed to achieve excellence. Instead of focussing only on why accidents happen, it is worth orienting the work toward understanding also why things go right within systems. The solution lies within the use of non-linear methods/models based on systems theory and resilience engineering precepts. The FRAM method and STAMP model are examples of risk assessment and hazard identification techniques as well as accident investigation models that are used to find out what could be the combinations of conditions, events, and actions within the system that may lead to (or have led to) an undesired event and/or a successful one considering the performance of the system. Moreover, the FRAM method allows exploring any given system.

Since a resilient system is also safe, measuring system's resilience is, therefore, an important objective and developing a tool that performs this measurement is of great importance. However, there is a need to bridge between the theory of resilience engineering and the practice within the oil and gas industry. A more powerful tool is needed to address not only the daily activities but one that could be used as a continuous improvement management tool as well. Such a tool lacks in the oil and gas industry particularly in SONATRACH organisation, specifically within the maintenance system as maintenance activities have been shown to be accidents prone and that the maintenance working environment of oil and gas assets needs to be explored to overcome the lack of data as it has been highlighted in section 1.1.

As a result, the research questions are:

- "***What strategy can be developed to enable the optimisation of human factors in maintenance and achieve safety excellence?***"

- "***What can be the tool that may be used to implement such a strategy and lead the maintenance system of SONATRACH to achieve safety excellence*?"**

Once data are available, most significant human factors can be identified, resilience of the maintenance system assessed, and damping factors designed, implemented and maintained so that the system as a whole builds a culture of continuous improvement.

1.5. Aim and Objectives

1.5.1. Aim

The aim of this research work is to develop an approach based on resilience engineering to achieve safety excellence in maintenance within the Algerian National Oil and Gas Company.

1.5.2. Objectives

There are four objectives to achieve the aim of this research:

- Undertake an extended literature review of safety management, "human error" concept, accidents causation models, resilience engineering, impacts of maintenance activities in different industries, and human factors in the maintenance of complex socio-technical systems,
- Explore the maintenance working environment of SONATRACH by identifying the critical human factors and its characteristics
- Identify a strategy based on resilience engineering to achieve safety excellence in the maintenance system of SONATRACH
- Outline, test and validate a tool that measures the resilience of Oil and Gas maintenance systems

1.6. Thesis Layout

This Chapter has been devoted to introducing the research problem and the rationale for the current study. First, the maintenance working environment and the failure of traditional approaches to handling complex socio-technical systems and the potential of resilience engineering to tackle such systems were highlighted. Then, an overview of SONATRACH, the Algerian state-owned oil and gas producer and refiner and its maintenance system were presented.

This thesis is divided into three parts. The first part includes Chapters 2 and 3. It provides an extended literature review and theoretical background covering key important issues of this research work that have been tackled by some researchers. In Chapter 2, the different approaches to the management of safety are exposed. It covers the impact of maintenance activities on safety and the human factors in the maintenance of assets within high hazards industries as well. Chapter 3 addresses the concept of “human error” and the need for a proactive management of safety by resilience engineering. More specifically, it explores deeply the systemic approach to managing safety through resilience engineering. Eventually, a summary of the literature review outlines the missing aspects and the necessary improvements so that domains of interests of this research are delimited. The second part is about the research strategy. Chapter 4 tackles the development of the methodology, data collection and analysis. The third part includes Chapters 5 to 8. It is about the development, testing, and validation of the developed tool. Chapter 5 explores the maintenance system of oil and gas assets. Chapter 6 presents the development and validation of the Maintenance Resilience Assessment Tool, MASRAT. Chapter 7 deals with the expert panel testing of MASRAT. Chapter 8 summarises and reflects on the general findings. Finally, the main conclusions and recommendations are drawn from these findings.

CHAPTER 2. THE MANAGEMENT OF SAFETY

2.1. Introduction

The management of safety is receiving more importance than ever. Despite the huge efforts devoted to stopping accident occurrences by all sectors of industries, people continue to be hurt, even killed. This Chapter gives an overview of the management of safety with a particular focus on maintenance activities. Section 2.2 addresses the evolution of the approach to managing safety. First, some important definitions of the key words related to the aim of this thesis are given. Then, the traditional approach is introduced. A critical review of the conventional techniques of safety management and accident causation models is carried out and the limitations of such an approach are outlined. Afterwards, the organisational approach is introduced. Section 2.3 deals with the management of safety in the maintenance of industrial assets. The impacts of maintenance activities on plant safety are first addressed. This is followed by the human factors in the maintenance of assets. Section 2.4 highlights the limitations of the traditional approach to safety management.

2.2. The Conventional Safety Management Approach

2.2.1. Definitions

There is a growing concern within companies with regard to the management of safety since the latter is seen as the absence of ‘undesired events’, the accidents. There are actually three motivational factors to preventing accident occurrences: ethical/moral, financial, and legal factors. In the following, definitions of the most important concepts dealt with in this thesis including safety, safe, risk, human factors, systems, and maintenance are given.

2.2.1.1. Safety and Hazard

The origin of the words safety and safe (Merriam Webster) comes from the old French respectively sauveté and sauf (uninjured, unharmed), and from the Latin. salvus (uninjured, healthy). Hazard originates from French “hasard", from Spanish “azar”, and from Arabic “az-zahr” chance (Oxford dictionary). Danger is a situation and a hazard is anything that has the potential to cause harm. Harm is defined in Safety aspects—Guidelines for Their Inclusion in Standards by ISO guide (2012, p1) as “injury or damage to the health of people, or damage to property or the environment". For Leveson (2011, p467), safety is "freedom from accidents (loss events)". Hollnagel (2008a, p3) defined safety as "a state in which the risk of harm to persons or of property damage is reduced to, and maintained at or below, an acceptable level". In line with resilience engineering approach, a definition of safety is given at the end of this section.

2.2.1.2. Risk and Risk Management

Risk is traditionally defined by "the chance, high or low, that somebody could be harmed by hazards, together with an indication of how serious the harm could be" (HSE, 2014, p3). An equation combining the likelihood of the occurrence of harm and the severity of the consequences of that harm allow determining a certain risk level. A more general definition of risk is given by ISO (2009a). The standard defines risk as the effect of uncertainty on objectives where an effect is considered as a positive and/or negative deviation from what is expected. Tolerable risk is one that is accepted "in a given context based on the current values of society" (ISO guide, 2012, p.2). As it is known, hazards cannot be removed completely, the acceptability of risk should be therefore added in the definition of safety; hence, ISO guide (2012, p.1) defined safety as "freedom from unacceptable risk".

Leveson (1995) introduced factors that may affect the two components of risk called risk factors. Leveson (2011, p.467) defined risk factors as "factors leading to an accident, including both hazards and the conditions or states of the environment associated with that hazard leading to an accident". Examples of factors include the appearance of new hazards and the increasing complexity, exposure, energy, automation, centralization, scale, and pace of technological change. The components of risk are, therefore (figure 2.3): hazard level (hazard severity and hazard likelihood), hazard exposure, and the likelihood of hazard leading to an accident. For Leveson (2011, p.467), a risk level that is "a function of the hazard level combined with (1) the likelihood of the hazard leading to an accident and (2) hazard exposure or duration" is then calculated.

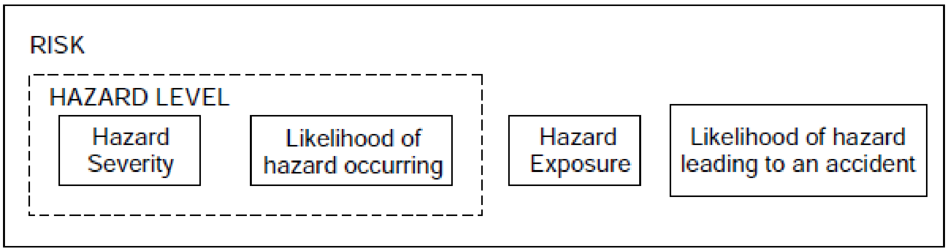

Figure 1-3: Components of risk (Leveson, 2011)

Most of the definitions of risks "involve the notion of an adverse outcome or a potential negative impact that arises from some present process or future event" (Hollnagel, 2008b, p.33). The problem lying within the traditional definition of risk given above is that it can be applied only for very simple cases where the probability and the severity of the outcomes are well known and easily estimated. In nowadays systems, it is quite impossible to know such values precisely.

The process of managing risk (ISO guide, 2012) consists of two major steps including (1) risk assessment (risk analysis and risk evaluation) and (2) risk reduction (figure 2.2). In other words, managing risks that is reducing risk to a tolerable level, is, therefore finding ways which allow avoiding such negative outcomes. Risk management is seen as "the coordinated activities to direct and control an organization with regard to risk" (ISO, 2009a, p4). The process of risk management is defined as "a systematic application of management policies, procedures and practices to the activities of communicating, consulting, establishing the context, and identifying, analysing, evaluating, treating, monitoring, and reviewing risk" (ISO, 2009a, p5). The process follows the framework given in figure 2.3.

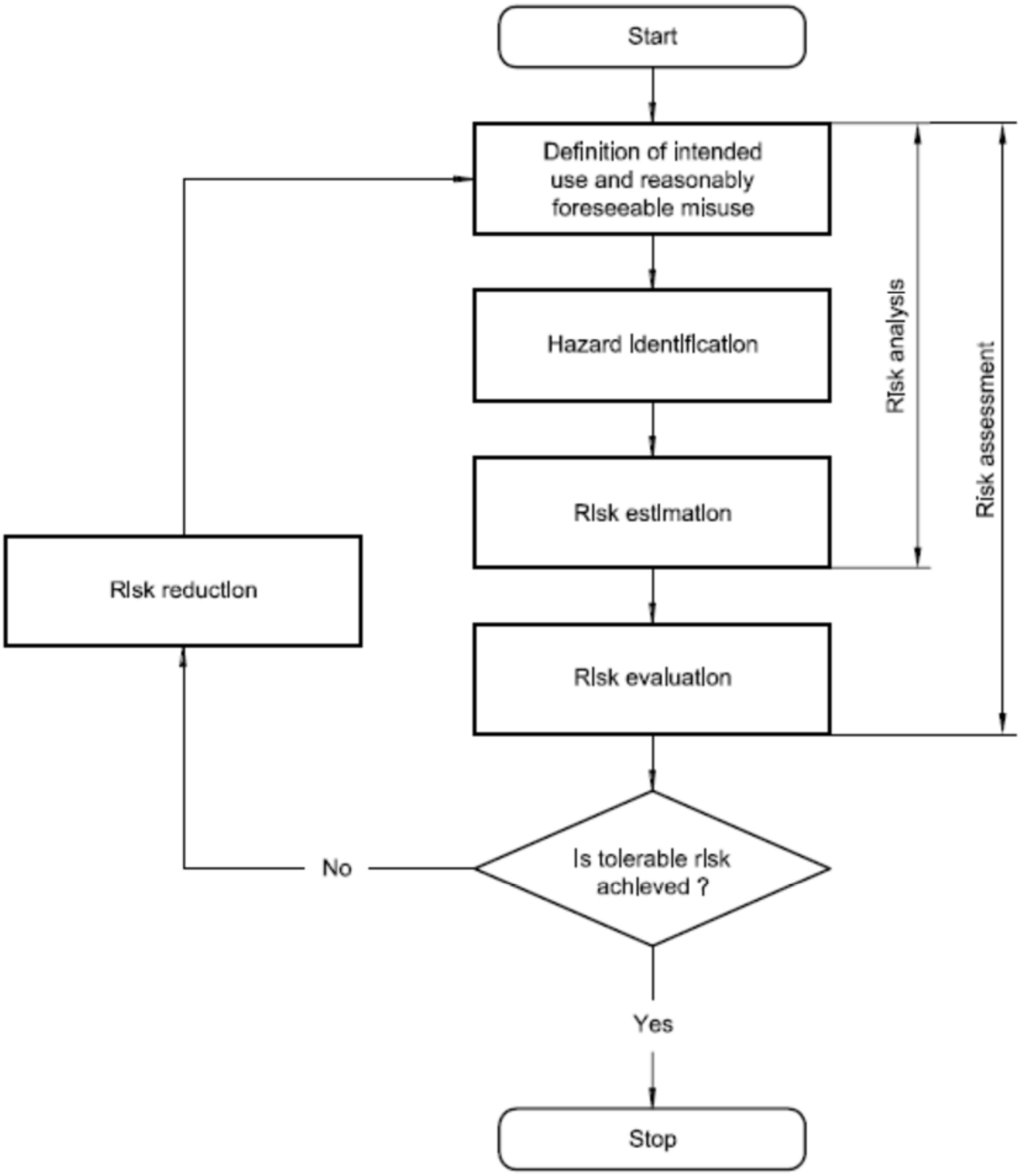

Figure 1-4: The iterative process of risk management (ISO guide, 2012)

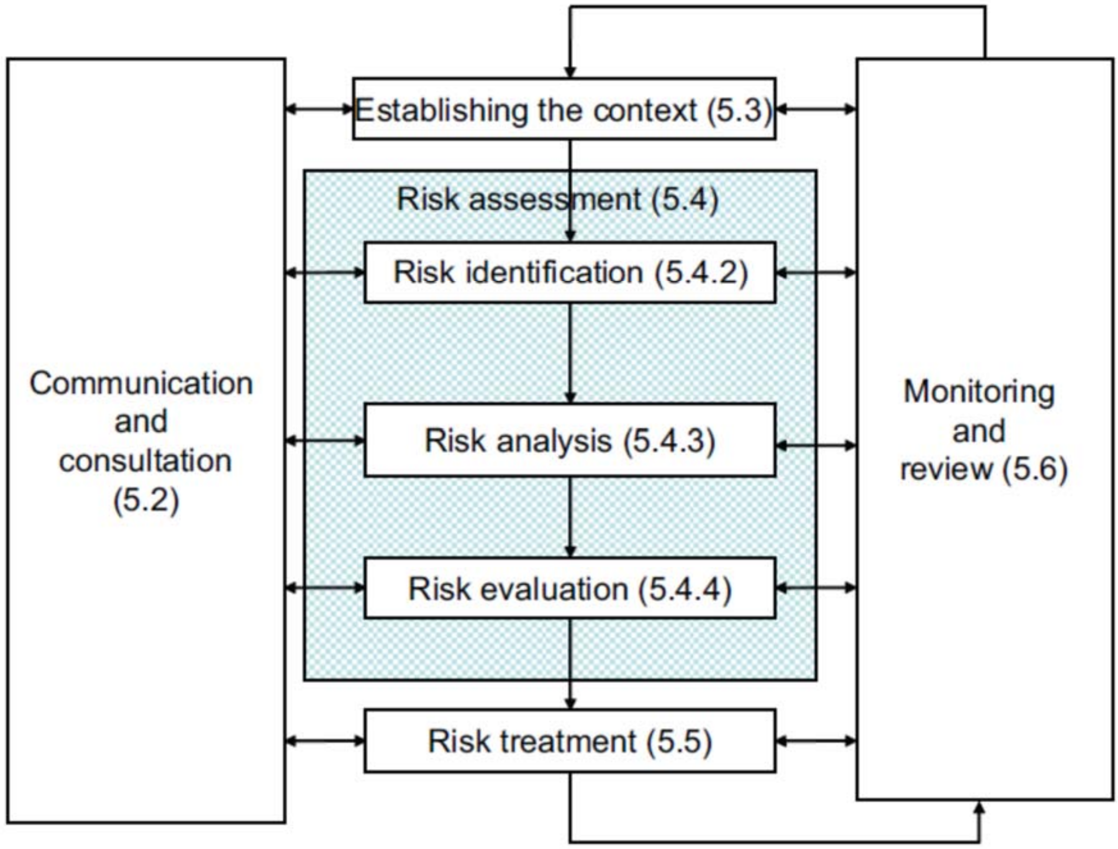

Figure 1-5 Risk management process (ISO, 2009a)

As can be seen, consultation and communication are part of the process. They take place during all the stages of the process, both with external and internal stakeholders. This is to ensure accountability and understanding are well settled among all those concerned with the process as well as it is a basis on which decisions are made. Setting the scene by establishing the context allows organisations define objectives, parameters, scope, and risk criteria for all processes. After that, the risk assessment process (risk identification, analysis, and evaluation) takes place. This is followed by risk treatment. Monitoring and review show a continuous improvement way of addressing the issues.

2.2.1.3. Human Factors

The development and use of aeroplanes during World War I and World War II led to the birth of what is called human factors engineering/ergonomics. Increasing technology requirements where design influences human performance, the military necessity, as well as adequate methods for selecting and training qualified pilots motivated the development of this scientific discipline (Meister, 1999; Dekker, 2004; Hollnagel et al., 2009).

Simply defined, human factors is “a science that deals with designing and arranging things so that people can use them easily and safely” (Merriam dictionary) or “anything that affects an individual’s performance” as stated by the Leadership Management Quality (LMQ, 2011). The official definition of ergonomics or human factors adopted by the International Ergonomics Association Council (IEA, 2000) is “the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance”.

For the Health and Safety Executive (HSE, 2005, p.5) human factors “refer to environmental, organisational and job factors, and human and individual characteristics which influence behaviour at work in a way which can affect health and safety”. Simply said, it is the interaction of the job, the individual, and the organisation and their impacts on people’s health and safety.

According to the International Association of Oil and Gas Producers (2001), human factors is the term used to describe the interaction of individuals with each other, with facilities and equipment, and with management systems. The culture of the people involved as well as the working environment influence this interaction.

These definitions show that the efforts are oriented toward dealing only with negative aspects that is the unwanted outcomes or things that can go wrong where safety efforts have generally focused on. The focus should be on the two sides on the coin, things that go wrong as well as things that go right. The performance of the human part of the system is considered as the main source of variability as discussed in section 1.2. Accordingly, the adopted definition of human factors in this thesis is the interaction of the individual, the organisation, and the job and their impacts, negative as well as positive, on system performance.

2.2.1.4. Systems

For business dictionary, a system *is* “an organised, purposeful structure that consists of interrelated and interdependent elements”. These elements influence each other in a continuous way to maintain their activity and the existence of the system so that system goals are achieved. Simply said, it is a set of interrelated and interdependent parts acting together to achieve objectives. Such a definition emphasises how the parts of the system are linked or put together that makes the principle of decomposition of the system understand its functions very obvious and natural (Hollnagel, 2012a) since it has a reference to its structure.

Another way to define a system is by looking at how it functions rather than by what components compose this system and how they are put together. For Hollnagel (2012a, p6.) a system is “a set of coupled and mutually dependent functions”. This implies that the study of the system performance begins by the definition of all the functions.

Technical systems are characterised by the possibility to decompose the system in question such as a pump or a compressor to meaningful components. Such systems have a bimodal functioning (fail or succeed) that is not valid for humans; as such, a probability of failure can be calculated. Databases can be found and used particularly in probabilistic safety assessment techniques. Failures of parts or all of the system may be predicted. Condition based maintenance (or predictive maintenance) for instance deals with the prediction of probable failure by tracking parameters such as vibration.

Socio-technical systems include not only technical systems but also the humans that interact with these systems. According to the Large Scale Complex IT Systems, LSCITS (n.d.), in the “socio-technical system engineering handbook” of Saint-Andrews University, the socio-technical system concept emerged after World War II in Tavistock Institute. The research in this institute found that “the social aspects were also important, particularly the ways that individuals and teams co-operated and collaborated to use the available technologies” (LSCITS, n.d., p.6-7). Such systems are complex because they are difficult to understand hence difficult to predict and control, technology intensive, and complete knowledge is not available (Sussman, 2010; Hollnagel, 2012a; Ladyman et al., 2013). This is due to the fact that parameters continuously change not because of the number of the parameters to deal with (Hollnagel (2012a). Hollnagel (2008a) introduced the notion of tractability/intractability and replaced complexity by intractability. For Hollnagel (2012a), systems are either tractable or intractable. Hollnagel (2008a) differentiated between the two systems by the possibility to make a full description of the system or not. Intractable systems are characterised by elaborate descriptions with many details, high rate of change, principles of functioning partly known, and heterogeneous processes (Hollnagel, 2012a). Table 2.1 gives the main differences between tractable and intractable systems.

Table 1-1 : Tractable and intractable systems (Hollnagel, 2012a)

	Tractable system	Intractable system
Number of details	Descriptions are simple with few details	Descriptions are elaborate with many details
Rate of change	Low: in particular, the system does not change while being described	High: the system changes before a description can be completed
Comprehensibility	Principles of functioning are known	Principles of functioning are partly unknown
Characteristics of processes	Homogeneous and regular	Heterogeneous and possibly irregular

Because socio-technical systems are intractable, work cannot be specified exhaustively in advance, as organisations (as well as the people in them) are in a state of constant flux (Macchi, 2011, p.32).

2.2.1.5. Safety and Risk in Resilience Engineering

Defining safety as a state of absence of accidents means that safety is defined by its opposite that is, lack of safety (Hollnagel, 2012a). This implies that normal states (where things are going right) are out of any focus or concern. When studying these cases (absence of accidents), any system is characterised by situations where both failures and successes within the system exist together.

Actually, systems evolve in situations characterised by lacks (knowledge, competence, resources, and time) according to Hollnagel (2010a). Therefore, systems adapt/adjust their functioning to attain designed goals by anticipating any disturbances and/or opportunities; this makes the performance of the system variable. It may lead to the drift toward hazardous situations and then the unwanted events (failure occurs) or may lead to successes. Studying the intrinsic ability of the system to manage its performance variability through the four cornerstones of resilience engineering (section 1.4) allows identifying, consolidating, enhancing, and boosting the situations where successes are prevalent as well as it permits preventing the drift toward hazardous states by implementing dumping factors and barriers.

The traditional approach has been mainly concerned with the negative or undesired outcomes. According to Hollnagel et al. (2009), Resilience Engineering aims at not only preventing things from going wrong but also to ensuring that things go right. In other words, it focuses on all the probable outcomes. Hollnagel (2010a) gave a range of event outcomes and their associated frequency (figure 2.4)

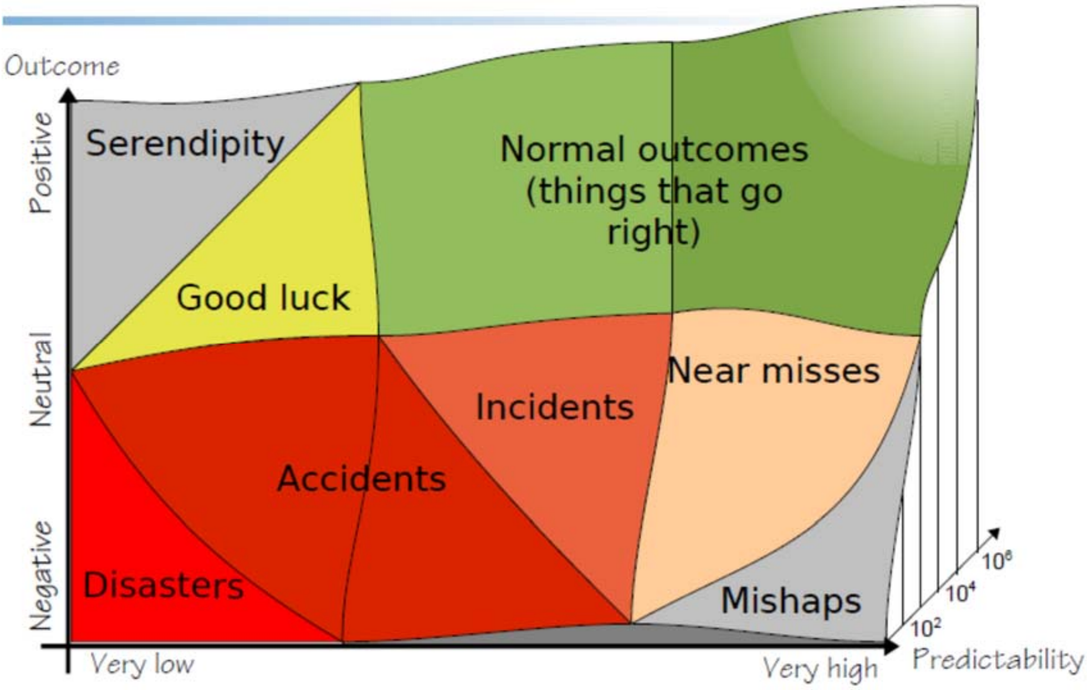

Figure 1-6 Frequency of event outcomes (Hollnagel, 2009a)

As can be seen, the traditional approach focuses on the outcomes that are at the bottom that is, from disasters to mishaps, whereas Resilience Engineering addresses all of them, particularly those in green colour (areas of serendipity depend on fate, as it is known).

Since organisations adapt/adjust their functioning to achieve goals, safety should be seen as a state where the performance variability produced by a system under conditions that are variable, prevents the drift towards a hazardous situation. From this definition, it comes that (1) performance variability deals with what can go wrong/right, (2) produced means something the system does, and (3) prevents the drift indicates that it doesn't allow the system to go beyond certain margins that may lead to negative outcomes. In other words, the systems always succeed. It is clearly meant that such conditions include both opportunities and threats and that the performance in question may be a success or a failure.

Learning from the past, monitoring its performance and the performance of the environment, responding to opportunities/threats, and anticipating the future is what is required to manage safety effectively (Hollnagel, 2008a). This is developed later on in section 3.3.

For Hollnagel (2012a), the risk is the likelihood that people do not succeed; in other words, the drift toward hazardous cases occurs. Accordingly, when this state is determined a priori, it is a step of a process of risk assessment and when it is identified a posteriori, it is a step of an accident investigation. Therefore, the search is for succeeding under all these conditions (when things go right as well as when they go wrong).

2.2.1.6. Maintenance

British Standards Institution (1993) defined maintenance as “the combination of all technical and associated administrative actions intended to retain an item or system in, or restore it to, a state in which it can perform its required function”.

Maintenance activities can have a direct or indirect impact on workplace safety. Such activities are characterized by the nature of work (electrical, mechanical, instrumentation, etc.), the type (corrective, preventive, etc.), and their associated tasks and steps (planning, execution, testing, etc.). Furthermore, the systems and conditions of work, the places where the activities are performed as well as the organisational culture may have adverse effects on people’s health and safety, the environment, and operation costs (Ameziane et al, 2011).

Maintenance has a tremendous impact on a company’s profitability (Wireman, 2003). It contributes to profitability through for example extended life of assets, improved reliability and availability (Lofsten, 1999). Maintenance is either positive where it is managed as a business function or negative where it is considered as a necessary evil, or a non-core business function (Wireman, 2003). Smith (2003) defines world-class maintenance organisations as organisations where proactive maintenance stands for more than 85 % of all maintenance activities. Thus, maintenance activities should provide the required reliability and availability at optimal costs to ensure health and safety of people while avoiding negative impact on the environment.

Since machines become more complex, maintenance tasks are characterised by a high degree of uncertainty putting the stress on maintenance workers to manage highly hazards, unforeseen or unexpected situations that have highlighted a growing need for more skilled personnel (Vicente, 1999; Ray et al, 2000; Grusenmeyer, 2005). Therefore, the competency of maintenance personnel should be proved in a continuous improvement way.

2.2.2. The Traditional Approach to the Management of Safety

2.2.2.1. Risk Assessment Techniques

Controlling risks requires adequate identification of hazards and effective assessment of the risk associated with these hazards. According to Stranks (2006), assessment is crucial to effective control. This implies a complete knowledge of the system that is assessed.

To apply this process, various risk assessment techniques are used. In ISO (2009b), the international organization gives an overview of the techniques that could be applied during this process as well as when they are strongly recommended and when they are not. There are many ways to classify risk assessment techniques. One is dividing the techniques into the use of inductive or deductive reasoning. When the approach is inductive, the analysis begins with a failure or a combination of failures and then it induces forwards the consequences of this failure or a combination of failures on the system or its environment (from causes to consequences). The main inductive techniques are Preliminary Hazard Analysis (PHA), Failure Mode Effects and Criticality Analysis (FMECA), Hazard and Operability (HAZOP), Event Tree Analysis (ETA), etc. Conversely, when the approach is deductive, the system is supposed to have failed and the analysis attempts to find the causes likely to lead to such a failure. One of the main techniques is Fault Tree Analysis (FTA). Risk assessment techniques may also be classified into three major families that is comparative, fundamental, and failure logic families. The comparative methods are those that compare what exists with what should be. Examples include safety-auditing, checklists. The fundamental methods are for instance HAZOP, FMECA, and Hazard Identification (HAZID). FTA, ETA, and cause-consequence diagrams represent the last one that uses Boolean algebra. The hazardous situations as well as the unwanted events, their causes and consequences can be identified methodologically by means of the techniques given above. They can be presented in the form of tables (PHA, FMEA, HAZOP, etc.) or in a pictorial form (FTA, ETA, etc.). They can be used as a means of communication to decision makers on the risks incurred by the company’s activities or facilities. The techniques may complement each other.

These methods have shown limitations (Wells, 1997; Kletz, 1999; NASA, 2002a; NASA, 2002b; Hollnagel, 2010a; Leveson, 2011; Macchi, 2011) since they focus on a single initiating event, one event-cause of deviations. They are based on the system breakdown into meaningful elements, generally components or events that is not valid for socio-technical systems. They generally depend on the analyst with respect to the choice of the initiating event as well as where to stop the analysis. The analyst focuses on equipment failures. These techniques generally show limited examination of human and organisational contribution. On the other hand, the use of simplified mathematics in probabilistic risk assessment (PRA) or Probabilistic Safety Analysis (PSA) means that initiating events are exclusive. For instance, for another sequence of events, there is a need for a new diagram or tree (Hollnagel, 2010a and Leveson, 2011). By focusing on failure events, PRA usually omits design errors and unsafe management decisions and may lead to overly optimistic estimation of risk since the probability of occurrence of an event under an “and” gate is the multiplication of the probabilities of all the events under this gate in addition to the omissions cited previously (Leveson, 2011). They do not consider the interaction of all system components as well as systemic factors.

The main limitations of the most popular techniques are summed up in table 2.2 (Wells, 1997; Kletz, 1999; NASA, 2002a; NASA, 2002b; Hollnagel, 2010a; Leveson, 2011; Macchi, 2011).

Table 1-2 : Main limitations of some traditional risk assessment techniques

The technique	The main limitations
Preliminary Hazard Analysis, PHA	It always needs additional analysis and follow-up since it is performed at early stages Since it relies on expert judgement, the quality of the results of the analysis is dependent on these experts
Failure Mode Effects Analysis, FMEA or Failure Mode Effects and Criticality Analysis, FMECA	The examination of only one single initiating event The limited focus on human and organisational factors The limited examination of external influences such as environmental conditions for instance The non-suitability for software systems The difficulty to obtain failure probabilities The time consuming issue for complex systems The difficulty to determine when to stop an analysis
Hazard and operability technique, HAZOP	Its limitations lie in the fact that it studies only one single failure each time, it is time consuming, and does not analyse human contribution
Fault tree analysis, FTA	It examines only one single failure/accident. To analyse other failures, we must develop other fault trees. The level of details depends on the analyst The statistical data used to predict the uncertain future may not apply every time There is little or not at all focus on human and organisational factors Initiating events at a given level under a gate must be independent from one to another
Event tree analysis, ETA	It examines only one single initiating event There is an overly optimistic estimate of risk since some elements in the tree may be overlooked: common components for instance if there is a negative occurrence such as no loss is ignited after a release of a flammable material. There is little or not at all focus on human and organisational factors The mathematics used are less sophisticated than for the FTA
Cause-consequence analysis and Bow-tie	These techniques are a combination of fault trees and event trees; therefore, their description as well as their advantages and limitations are those of fault trees and event trees

Despite these limitations, these techniques are good for technical failures in non-complex systems. They may be used in combination with more powerful techniques that is, systemic techniques.

To address some limitations given above regarding human factors, Human Reliability Analysis (HRA) was born in the early sixties (Swan, 1990). HRA tried to incorporate human factors in PRA and take into account human error where the use of barriers in design could not be transposed to human intervention (Hollnagel, 2010a and Macchi, 2011). The estimation of

Human Error Probability (HEP) and hardware failure were done the same way (as in PRA) by looking at failure rates. Dougherty (1990) critically analysed HRA methods and highlighted the shortcomings. In particular, Dougherty (1990) demonstrated the non-accuracy of HRA. Dougherty (1990) and Hollnagel (1998) distinguished two generations of HRA: the first focusing on a quantitative estimate of human error and the second changing to put a stress more on working conditions.

According to Hollnagel (2010c), these traditional techniques require the possibility to characterise what goes on inside the system to be risk assessed and for safety to be managed, as well as to give a sufficiently clear description of it: the human-machine system must be tractable. For Hollnagel (2010c), unfortunately, most socio-technical systems are intractable. Yet, socio-technical systems become so complex that it is difficult to describe them entirely, thoroughly. Therefore, these techniques are still limited. Hollnagel (2010c) came up with two theories, the W and the Z theories that will be examined in Chapter 3.

To conclude, systems have become very complex and socio-techniques by the introduction of information systems such as Distributed Control Systems (DCS), Supervisory Control and Data Acquisition (SCADA) systems for instance. Consequently, this kind of techniques cannot be used to provide reliable results; hence, techniques that are more powerful are required. In addition to the limitations given in table 2.2 above, the external factors (environment, weather, human and organisational factors, etc.) are rarely taken into account or not at all. Besides, the estimation of risk is generally subjective including the probability estimates (Leveson, 2011and Macchi, 2011).

2.2.2.2. Accident Causation Models

For Hollnagel (2006), accident causation models evolved from the simple linear or sequential model (accidents are the culmination of a series of events or circumstances which occur in a specific and recognisable order), via complex linear or epidemiological model (accidents result from a combination of active failures and latent conditions), to non-linear or systemic model (accidents result from unexpected combinations –resonance- of variability of normal performance). Heinrich’s domino model, Reason’s Swiss cheese model, and the systemic model (Leveson, 2004; Hollnagel, 2004), respectively, represent the three types. Conventional event-chain models explain an accident as a linear sequence of events one leading to another making the accident happen. Breaking the chain before an accident happens and looking for the "root causes" is, therefore, the solution to prevent its occurrence.

The important limitations lie in the subjective choice of "initiating events" and other events to include as well as the subjective identification of chaining conditions (Leveson, 2011). These models often fail to handle complex safety critical systems where accidents can emerge not from few components only, but from the interactions between system components. They fail to explain human, system and software errors as well (Leveson, 2004; Hollnagel, 2004). Dealing only with one simple system constitutive element each time, they cannot address the dynamic aspect of the system, particularly the drifting toward a state of increasing risk, leading to accident occurrence. According to Qureshi (2008), these models describe an accident process as a simple cause-effect chain of events whereas systemic accident models describe it as a complex and interconnected network of events.

2.2.3. The Organisational Approach to Accidents

After major accidents that have been cited in Chapter 1, organisational factors have been highlighted as playing an important part in accident occurrences and new theories were born. There have been then two organisational approaches to safety- two general competing schools of thought according to Marais et al (2004). Sagan (1993) characterised them as one presenting an optimistic view "the high-reliability organisation", HRO, and another one presenting a much more pessimistic prediction "the normal accident theory", NAT.

Perrow (1999) considered system accidents as normal accidents. For Perrow (1999), these accidents that are caused by multiple and unexpected interactions of failures, are inevitable or normal for high-risk systems such as nuclear facilities which are both complex and tightly coupled. Woods et al (2010, p.62) stated that ...Normal accident theory predicts that the more tightly coupled and complex a system is, the more prone it is to suffering a "normal" accident.

La Porte and Consolini (1991) characterised some organizations as "highly reliable" based on their high safety records over long periods. Highly reliable organisations are hazardous systems that produce "nearly accident-free performance" or achieve failure-free operations (La Porte, 1996) over a long period of time that is, organizations that have not failed, resulting in catastrophic consequences on the order of tens of thousands of times (Roberts, 1990).

Adjusting the system performance has also been a concern of such organisations. Weick and Sutcliffe (2007) recognised that HRO's are resilient organisations since they manage the unexpected (resilience is addressed in Chapter 3, section 3.3). They identified five principles split into two categories (anticipation and containment) that might lead organisations to become highly reliable. These principles are summed up in table 2.3 below.

Table 1-3: Principles leading to high reliability (adapted from Weick and Sutcliffe 2007)

Category	Principle	Meaning
Anticipation	(1) Preoccupation with failure	Everything that makes the system perform under standard is immediately treated as a symptom and steps are taken in order to avoid accumulation, hence adverse outcomes by encouraging reporting
	(2) Reluctance to oversimplification	Every simplification that may reduce perceptions (e.g. risks and hazards) is avoided and encouraging at the same time diversity of opinions
	(3) Sensitivity to operations	Every event that may affect the front-line of the organisation is under focus. This enables personnel to make adjustments since the organisation sees accidents are not the result of a single active "error"
Containment	(4) Commitment to resilience	The organisation is able to recover from "errors" by correcting them before they cause more damage. It recognises the learning opportunities and the importance of learning
	(5) Deference to expertise	The organisation appreciates expertise through decentralisation of decisions where expertise and specific knowledge exist

This shows progress as it highlights the aspects of anticipation, adjustments and commitment to resilience but still lacks important ones; they focus on failures and "errors" instead of focusing on how work is performed in order to increase system performance. Nevertheless, these approaches "have made important contributions to theory although both of them limit the progress that can be made toward achieving highly safe systems by too narrowly defining the problem and the potential solutions" (Leveson et al, 2009, p.246).

2.3. The Management of Safety in the Maintenance of Industrial Assets

2.3.1. The Impact of Maintenance Activities on Plant Safety

The public expects organisations dealing with hazardous domain including nuclear, aviation, and oil and gas, to function reliably and anticipate risks created by either technology, organisational structures or practices (Reiman and Oedewald, 2006). Maintenance activities are labour intensive, thus prone to generating “errors”; the concept of “human errors” is discussed in section 3.2, Chapter 3 in more details. For Reason and Hobbs (2004), maintenance errors have been among the principal causes of many major accidents in a wide range of technologies. In high hazard domain, maintenance staff work under conditions that are accidents prone; they are often under pressure to finish work as rapidly as possible, and sometimes lack the necessary knowledge to perform certain tasks as required. This is particularly accentuated where reactive maintenance is dominant and where organisations have blame and production driven culture.

Unsafe conditions of work (e.g. confined space, pressurised vessels, and isolated equipment) and bad work practices (e.g. poor permit to work systems, complicated work procedures and instructions) are some of the contributing factors of major accident hazards. In addition, maintenance activities are often outsourced to service companies with different perception of safety.

44 % of fatal accidents reported in 2000 were maintenance activities related accidents, among these, 31.8 % (57) implied machinery and working equipment (Grusenmeyer, 2005). Corrective maintenance causes more accidents (Grusenmeyer, 2005) and a strong relation exists between this maintenance type and accidents/incidents (Idhammar, 2004). To illustrate, 50 % of major accidents in aviation involved maintenance deficiencies according to Hobbs and Williamson (2003). Hobbs and Williamson (2003, p. 187) concluded critical incident interviews with airline maintenance personnel by the fact that “error factors included not only technical problems, such as poor procedures and inadequate trade knowledge, but also nontechnical issues, such as time pressure, communication breakdowns, inadequate supervision, and the physical environment”.

A study by Boeing and US air transport association from 82 to 91 concluded that 15 % of accidents are due to maintenance “errors” (Rankin et al, 1997). In a report studying the oil and gas sector for the Health and Safety Executive (HSE), Burton et al. (2004, p.23) stated that “approximately 20% of maintenance-related incidents are because of poor positioning/posture during the execution of a task and a further 38% are due to, ‘poor practice’. This arises from a combination of a ‘Failure to follow procedures/ industry practice’ and ‘Poor preparation/ completion of tasks’”.

It is worth noting that there is a lack of updated data regarding studies of the impact of maintenance activities on safety. Grusenmeyer (2005) observed the lack of studies in this domain; unfortunately, the lack of data still exists in the literature and this is confirmed in a recent work carried out by Dhillon (2014) where the majority of examples are tracked to the seventies and eighties. Okoh and Haugen (2014) have carried out the most recent works. Okoh and Haugen (2014) studied reports and databases respectively from the US Chemical Safety Board (CSB) and the Bureau for Analysis of Industrial Risks and Pollution. Okoh and Haugen (2014) concluded that from 2000 to 2011, 53 % of accidents are maintenance related in the USA and 38 % in Europe. Table 2.4 gives an overview of some available records found in the literature.

Table 1-4 : Maintenance accidents related

Records	Reference
44 % of fatal accidents (179 from 407) reported in 2000 were maintenance activities related accidents. Among these, 31.8 % (57) implied machinery and working equipment.	Grusenmeyer, 2005
OSHA Recordkeeping overview estimated that 122 fatalities, 2,840 lost workday injuries, and 31,900 non-lost workday injuries per year due to accidents involving equipment maintenance or repair	Ray et al, 2000
During the period from 1982 to 1985, 30 % of accidents among 2146 incidents in the chemical industry were maintenance related. It is estimated that 125 persons are injured or even killed per year due to maintenance activities	Health and Safety Executive, 1987
A safety incident was 28 % more likely when maintenance work was reactive versus planned and scheduled before execution.	Idhammar, 2004
A study by Boeing and US air transport association from 82 to 91 concluded that 15 % of accidents are due to maintenance errors	Rankin et al, 1997
30 to 40 % were linked to maintenance activities	Hale et al, 1998
40.4 % of 109 fatal accidents were linked to maintenance activities in confined space entries from 1983 to 1993	NIOSH, 1994
Between 1990 and 2001, there were 1275 fatal accidents in Quebec, 13 % (163) were related to maintenance activities and 45.9 % of the tasks involved concerned repair and fixing activities. According to this study, 51 % of people affected were maintenance personnel whereas 35.5 % were operators, and for 81 % there was an energy isolation problem involved (lock out issue)	Giraud et al, 2008
6 % of accidents were linked to maintenance activities from 1992 to 2001	ARIA, 2000 in Giraud et al, 2008
20 % of deathly accidents in France in 1997 and a bit more than 20 % in 1998 were linked to maintenance activities	Agence, 1998 in Giraud et al, 2008
The occupational health occurrence in maintenance are 8 to 10 time more than the average in France	AFIM, 2004 in Giraud et al, 2008
30 % of accidents were linked to maintenance activities in the chemical industry in the UK between 1982 and 1985	Underwood, 1992 in Dhillon, 2014
Between 55 and 65 %, human-performance-related problems surveyed in the area of power generation were concerned with maintenance activities	Reason, 1997 (in Dhillon, 2014)
The major incident/accident reports of nuclear power plants in Korea indicate that about 20 % of the total events occur due to human error 25 % of unexpected shutdowns in Korean nuclear power plants were due to human errors, out of which more than 80 % of human errors were resulted from usual testing and maintenance tasks	Heo and Park, 2009 (in Dhillon, 2014)

Various research works have been carried out within the industry with respect to safety and maintenance. According to Reason (1990), about 80 to 90% of industrial accidents are a result of human factors, majority of which are maintenance related (Ray et al, 2000; Hobbs and Williamson, 2003; Idhammar, 2004; Grusenmeyer, 2005; Giraud et al, 2008) and occur mainly during the execution phase (Grusenmeyer, 2005). The impact of human factors in the maintenance of assets is briefly discussed in the following section.

2.3.2. The Human Factors in the Maintenance of Industrial Assets

The job, the organisation, and the individual are the three aspects, termed human factors that influence human behaviour at work and can affect health and safety (HSE, 2005). As discussed in the previous section, there is a significant impact of maintenance activities on accident occurrences because of human factors. Human factors inherent in such accidents are difficult to identify in most cases. Therefore, there is a need to analyse the link between maintenance activities and occupational health and safety to determine ways to overcome the lack of data and assess the inherent conditions of maintenance human factors. The negative contribution of the human part of a system is generally highlighted to explain the occurrence of accidents. According to Reason and Hobbs (2004), people, generally those who are at the bottom of the pile are blamed for these occurrences. Human factors in the maintenance of assets in various industries are discussed in the following subsections.

2.3.2.1. The Aviation Industry

The aviation industry is a leading industry with respect to the amount of work carried out in the field of human factors and maintenance. The aviation organisational culture with particular emphasis on the human and organisational factors as well as safety climate in the maintenance of aircrafts have been largely examined.

Maintenance “error” has been found to be one of the major causes of aircraft accidents (Rankin et al, 1997). The increasing number of maintenance and inspection “errors” in the aviation industry initiated and prioritised the need for human factors related research (Taylor, 2000b; Reason and Hobbs, 2004). From the taxonomies of “human errors” (Reason, 1990), Hobbs and Williamson (2003) associated “errors” with contributing factors that led to accidents in aircraft maintenance. Hobbs and Williamson (2003, p.188) explained that “...accident prevention strategies can be targeted at key factors that contribute to error, human error probabilities can be estimated with greater accuracy, and organizational safety performance can be monitored by evaluating the relative prevalence of conditions that are known to promote errors". In managing maintenance "errors" book, Reason & Hobbs (2004) presented twelve principles of "error" management depending on what they called the four P's which are Philosophy (counting for double comparing with the others), Policy, Procedures, and Practices. These principles include the universality and inevitability of "human error", the usefulness of "errors" (errors are not intrinsically bad), changing the conditions under which humans work instead of the human conditions, worst mistakes can be made by best people. The "human error" concept has been found elusive and should be replaced by the performance variability concept (see Chapter 3, section 3.2).

Surveys and questionnaires have been used to study safety/organisational culture and human factors. In fact, there is a debate in the scientific community about the concept of safety culture that is, using safety culture or organisational culture. Safety is something an organisation "does"; hence, it should be included in its culture.

Not until the accident of an Aloha Airlines in 1988, any mistake made by a mechanic was addressed by blaming that person since it was considered a matter of individual failure (Patankar and Taylor, 2008). Following the investigation of this accident, "human error" received a great focus that led the aviation to put in place a training program called the Maintenance Resources Management. The recommendations started the shift toward the identification and resolution of the contributing factors within the system that enabled "error" occurrences, hence addressing the systemic failures (Patankar and Taylor, 2008). Taylor (2000b), described maintenance resource management (MRM) as the part of the maintenance human factors which addresses the issues of management, organisation, communication, problem solving, and decision making. It addresses "error" correction and avoidance in the stressful and complex environment of commercial aviation. The MRM was adapted from the Cockpit (Crew) Resources Management (CRM). There have been four generations training programs (Patankar and Taylor, 2001) that have addressed awareness contents:

- The dirty dozen elements (lack of communication, complacency, lack of knowledge, distraction, lack of teamwork, fatigue, lack of resources, pressure, lack of assertiveness, stress, lack of awareness, and norms),
- Accident case analysis (based on chains of events, already discussed in Chapter 2),

- Organisational specific problems that should be corrected immediately (for example shift turnovers or lost time injury, LTI), and
- Interactive exercises (for example team-working values).

The Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) jointly funded a research program to evaluate the effectiveness of MRM training program over ten years (Taylor, 2000a). The Maintenance Resource Management/Technical Operations Questionnaire (MRM/TOQ) was used to perform this evaluation during this period. Participants to MRM training completed a self-report questionnaire consisting of 25 questions using a five-point Likert rate during each survey. The MRM/TOQ survey revealed a high degree of participants' enthusiasm for MRM training. The results showed also participants' intent to do something positive about individual attitude. The report, unfortunately, observed a "gradual diminution over time of participants' perception of management's safety practices and goals setting/sharing" (Taylor, 2000b, p.90). At the same time, there has been no noticeable change in organisational behaviour.

Taylor and Thomas (2003) used the MRM/TOQ to measure what they regarded as two fundamental parameters in aviation maintenance: professionalism and trust. Patankar (2003) constructed a questionnaire called the Organizational Safety Culture Questionnaire that included questions from the MRM/TOQ along with items from questionnaires developed outside the maintenance environment. Patankar (2003) identified four factors as having particular relevance to the safety goals of aviation organizations; namely the emphasis on compliance with standard operating procedures, the collective commitment to safety, the individual sense of responsibility toward safety, and the high level of employee-management trust.

Patankar & Taylor (2008) studied the MRM training program again. Their findings include:

- The programs are effective to raise awareness about human performance limitations,
- The two key parameters that allow improving safety in aviation maintenance are individual professionalism and interpersonal trust, and
- The return on investment (ROI) of such programs is good.

As stated previously in this section, these programs had initially a positive effect on performance that actually lasted short; it might be due to the lack of management support and co-workers. Such programs based on changing people behaviours might be good to some extent. The question is whether it is more important to change individuals' behaviour or to understand and change the conditions under which those individuals work.

In addition to MRM programs and related tool MRM/TOQ, McDonald et al (2000), proposed a self-regulatory model to examine how organisations manage safety highlighting particularly the human and organisational factors in the maintenance of aircrafts. The model explored the different aspects of safety culture and safety management systems. The research techniques used were an analysis of documentation and qualitative interviews, surveys of safety climate and attitudes, expected response to incidents, and compliance with task procedures.

Gill and Shergill (2004) assessed employees' perceptions of safety management and safety culture in the maintenance activities by means of a wide survey data. Designed to study the individual perception and opinions of safety management within the organisation, the survey tool did not take into account the important role of the human part of the system which represented less than 10 % of statements devoted to the individual.

Evans et al (2007) identified a consistent set of safety climate factors from the literature review and consultation with the industry's safety experts to provide a basis for benchmarking within the aviation industry.

Chang and Wang (2010) examined the significance of human risk factors in the activities of aircraft maintenance technicians. Chang and Wang (2010) developed expert questions, and modified Hawks' human factors model SHELL (Software, Hardware, Environment, Liveware) to characterise the risk factor by adding the O dimension (organisation). For each dimension, risk factors from the existing literature and maintenance experts from Taiwan aviation (77 preliminary factors for the 06 dimensions) were selected. A questionnaire was distributed to determine the importance of these factors. Forty-six were found important. A second questionnaire revealed that 09 factors ranked first with regard to the 06 dimensions. To illustrate the direction of this study in the discussion of the results for the liveware dimension (L), safety attitude was seen as the most significant factor. The results of this survey showed that airline companies might be interested in proposing risk management strategies based on the nine significant factors so that "human error" are minimised under limited resources conditions (Chang and Wang, 2010). Again, the strategy is directed toward minimising "human error", a concept considered elusive in this thesis (see Chapter 3). Chang and Wang (2010) considered personnel who believed that safety standards would make the company more competitive as professional with positive attitude whereas those who felt that such rules would impede operations and reduce efficiency in this highly competitive business as employees who had a negative attitude. To illustrate, Chang and Wang (2010) used an example of a previous survey carried out by Australian Transport Safety Bureau (ATSB) in 1997 where 69 % of personnel surveyed felt that it was sometimes necessary to bend the rules to get the job done. This is actually a conservative opinion vis-à-vis the human element that has an influence on the performance of the system. In resilience engineering, the variability of the performance of a system is an asset rather than a threat (see Chapter 3, section 3.3).

In order to overcome the lack of data and take a snapshot of daily activities, Hobbs and Tada (2006) developed a maintenance environment questionnaire designed to collect information on maintenance human factors. MEQ is presented in Chapter 5; it has been used to explore the maintenance working environment of SONATRACH, and eventually critically reviewed.

Particular hazards have been also tackled. Neitzel et al, (2008), addressed falls and described rates of non-compliance with the requirements of fall hazard prevention in commercial aircraft maintenance activities.

Herrera et al, (2009), carried out an investigation led by the Accident Investigation Board Norway, AIBN to examine how Norwegian aviation safety had been affected due to major organisational changes. They determined the status of safety through an evaluation of safety in the management of maintenance. They described a method that assesses how safety has been maintained in the maintenance organisations of the airlines while there have been concurrent ongoing internal and external organisational changes.

Most of the examples discussed above adopted an approach based on “human errors” concept and a strategy constructed on the search to find and minimise these “errors”. This concept is discussed in more details in Chapter 3, section 3.3.

2.3.2.2. The Nuclear Industry

The Three Miles Island (TMI) and Chernobyl accidents highlighted the need to better understanding inherent human factors and improving training and procedures and promoting worldwide the concept of safety culture (Manna, 2007). According to Dhillon (2014), maintenance is an important activity which significant budget represents a large part of the total amount of money spent on power generation. The interest in human factors related issues was relatively new in comparison with the aviation (aerospace) industry. In nuclear power plants, the cost of maintenance activity has been found potentially very high because damage may decrease equipment/system life significantly and may harm humans seriously (Dhillon, 2014). The orientation was therefore directed toward “human errors” occurrences prevention that had received increasing attention in NPP’s (Dhillon, 2014). As can be seen in the examples presented in this section, majority of them are oriented toward ways and techniques devoted to find and reduce “human errors” since the latter have caused and continue to generate accidents according to the different authors cited in the following.

For the International Atomic Energy Agency IAEA (2005), there is an increasing use of Probabilistic Safety Analysis (PSA) in the nuclear facilities while the deterministic approach has been used for many years. It is broadly utilised to address human factors and manage safety risks (PSA has been reviewed in section 2.2.2). IAEA (2001) proposed a risk management tool for improving Nuclear Power Plants (NPP’s) performance. It consisted of a four-step systematic approach framework outlined as follows: (1) identification of possible risks, (2) identification of techniques or strategies to manage those risks, (3) implementation of chosen techniques or strategies, and (4) monitoring of solutions and feedback provision. According to the report issued by IAEA (2005), the appropriate technique that should be used was Probabilistic Safety Analysis (PSA), not only to managing nuclear safety risks but to improving operational and financial performance as well.

He et al (2007) carried out another application of PSA in a pilot study. A pilot risk-informed Probabilistic Safety Analysis application for maintenance risk management to assess and manage plant risk was presented, technical issues stemming from traditional PSA outlined, and a risk matrix and a computerised risk monitor developed (He et al (2007).

Hulsmans and De Gelder (2004) used PSA as a tool to analyse how an operational event might have developed adversely; in other words, PSA was used as a probabilistic accident precursor analysis and a complement to the root cause analysis approach. Hulsmans and De Gelder (2004) called this process a PSA-based event analysis (PSAEA).

Vaurio (2009) described how PSA could be used to reduce “errors” and improve human factors and pointed out a certain lack of consensus in human reliability analysis (HRA) methodologies.

Like the aviation industry, maintenance human “errors” have been extensively addressed. In an attempt to characterise “human errors” leading to unplanned reactor trips in Korean nuclear power plants, Kim et al (2009) used James Reason's basic error types (Reason, 1990) with a slight modification of the error types into 'planning failure', 'execution failure', and 'rule violation'. The approach was oriented toward the management of "human error" by studying the two phases (planned and execution) of maintenance activities. Kim et al (2009) concluded by highlighting the difficulty in identifying a priori "human errors" due to a planning failure. Kim et al (2009) suggested the search for a more detailed and systematic approach comprising a structured method or computational tools to identify the potentials for "human error". This may be actually an interesting change (move) but still necessitates more progress to get out of the concept of "human error". Following Kim et al (2009) work, Kim and Park (2012) introduced procedures to "human error" analysis by focusing on the recurrent error forms and then identifying factors that influence work context or performance.

According to Khalaquzzaman et al, (2010), in the nuclear industry, a spurious trip frequency is considered as an important parameter that affects plant safety and plant economics. A modelling approach for the quantification of nuclear reactor spurious trip rate (STR) by means of fault tree considering maintenance "human errors" was presented. Khalaquzzaman et al (2010) set a number for human error probability (HEP); they had not considered the results impractical estimation despite the absence of sufficient human failure data, based on plant operation and maintenance experiences.

To remedy unexpected reactor shutdowns, Gyunyoung and Jinkyun (2010) developed a four component framework to estimate the qualitative and quantitative consequences of "human errors" that might occur during maintenance tasks. This set included (1) the human-error analyser, (2) the frequency estimator, (3) the risk estimator, and (4) the derate estimator. Gyunyoung and Jinkyun (2010) determined minimal cut-sets using Fault Tree Analysis and turbine simulation and estimated electrical power loss using derate estimator.

Jones and Thomas (2009) presented two methods to calculate the loss of life expectancy to achieve improvements in nuclear safety that a safety measure brings about by means of the J-value framework (J stands for judgement). These two methods were: (1) an equivalent, prolonged radiation exposure to represent the effects of the accident occurring once per year over the given period of operation and (2) the loss of life expectancy brought about by a single accident occurring during the given period of operation. The latter was seen slightly more conservative than the first, and somewhat more accurate.

By means of an organisational questionnaire, Reiman and Oedewald (2006) carried out a case study in a nuclear power plant (NPP) maintenance unit. Reiman and Oedewald (2006) characterised, assessed the organisational culture, and illustrated cultural conceptions prevalent in the maintenance system in question and how these practices, tools, and work organisation influence each other.

2.3.2.3. The Oil and Gas Industry

Despite the accident records cited earlier, researches in the area of human factors in maintenance management within the oil and gas sector are limited due to lack of credible data (Ray et al, 2000; Burton et al., 2004; Grusenmeyer, 2005; Giraud et al, 2008; Kanki and Hobbs, 2008). The vulnerable accident reporting systems (Gordon et al, 2005) as well as an uncovering of maintenance functions during accident investigations (Reiman and Oedewald, 2006) are among the major contributors to this lack. This is may be due to low management priority, lack of sophisticated analytical tool, etc. (Ray et al, 2000).

Burton et al (2004) also highlighted the limited research in the area of human factors in maintenance management within the oil and gas sector in VECTRA report for the Health and Safety Executive (HSE) as guidance dealing with human factors to select appropriate maintenance strategies for safety in offshore oil and gas industry. The report noted a lack of research with regard to safety and maintenance in the oil and gas industry. The document was based on the analysis of Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) reports and semi-formal interviews. The report came up with a question-set as guidance for settling down appropriate maintenance strategies for safety in offshore oil and gas industry. The human factors issues identified from the literature include for instance learning from experience, communication, supervision, competency, etc. However, the report followed an approach based on the conventional view of safety management (critically reviewed in section 2.2.2 and 2.4) and the search for “human errors” (see Chapter 3, section 3.2).

Recently, Antonovsky et al (2014) carried out a study to identify the most frequently occurring human factors contributing to maintenance-related failures by means of structured interviews based on the Human Factor Investigation Tool (HFIT). The most contributing factors found, were assumption (79% of cases), design and maintenance (71%), and communication (66%).

The main asset is to benchmark between high hazards domain prior to adopting the way the organisational culture is investigated in these industries. The Oil and Gas sector can learn from the experiences of the above industries to enhance its safety performances by adapting frameworks encompassing best practices. These include the use of tools that have shown good results such as risk assessment techniques, training toolkits as well as the way organisational cultures are assessed in these industries. Despite the limitations shown previously, these techniques are good for technical failures in non-complex systems. They may be used in combination with more powerful techniques that is, systemic techniques.

2.4. The limitations of the conventional approach

The conventional approach to safety management uses risk assessment techniques to manage safety that have limitations, particularly the fact that they deal only with a single failure at time which can be suitable for well described equipment failure for instance. Besides, to prevent something negative happening again, barriers are implemented. Such barriers result from the recommendations of risk assessments or accident/incident investigation, which in both cases is a reaction to something since the former is based on data taken from history (responding or reacting to a situation), and the latter is definitely reactive since it is based on something that has already occurred. This is not true for complex socio-technical systems where things usually occur or change quickly, where people have to be aware and stay receptive to the possibility of failure, and where demands and resources are often unpredictable (Hollnagel, 2012b).

The conventional approach deals only with adverse outcomes that is, things that went (or may go) wrong. It takes only account of threats whereas it has to take account of both opportunities and threats. It does not show the dynamic variability of the system performance to compose with available resources to be as efficient as possible which means system making trade-offs between efficiency and thoroughness to achieve assigned objectives where people do something reasonably precise and correct, rather than spend all their time evaluating the best possible option (Hollnagel, 2010a; Macchi, 2011).

It has also been shown in this Chapter that human factors in maintenance have an important impact on safety. At the same time, there is a lack of updated data. Most of the studies presented in this Chapter that are based on the traditional approach to the management of safety have dealt with failures identification and human factors contributors to failures. They have focussed on violations of workplace procedures as the root cause of failures and the search for human malfunctions. All these works contribute to the research with respect to maintenance activities and safety. Unfortunately, some limitations are worth exploring.

In the traditional approach, systems are assumed well designed and safe. If any adverse outcome (majority of the examples given in this Chapter deal only with negative outcomes) occurs, the search is for any deficient performance or “error” that have led to a degradation within the system. In other words, if a system presents good safety records (the system in question is considered safe), the human performance (the only element of the system which performance is variable in comparison to the organisation and machinery; see Macchi, 2011) is constrained to remain under the “safe system boundaries”; these boundaries are delimited by rules, procedures, instructions, etc. In order to understand accident occurrences, the search is directed toward describing qualitatively and quantitatively deviation from performance standards. This is acceptable and well done for components failures using indices such as Mean Time Between Failures (MTBF), or probability of component failures, or probability of component failures on demand. Unfortunately, this has also been translated and applied to human performance (the human functioning is not bimodal i.e. success/failure, see Hollnagel, 2010a). As a result, recommendations that have been issued from risk assessments as well as accident investigations have also been based on this way of reasoning. Generally, the recommendations have been directed toward the limitation of the human intervention by more automation and/or the introduction of more program training, procedures, regulations, etc.

From the examples given above, system performance has been only described in terms of failures, “errors”, etc. Many examples of personnel actions that have ended in negative outcomes have been provided but nothing about any single positive action has been reported. In everyday activities, particularly when the maintenance system is reactive and when organisational culture is production driven, time is a very important resource. Personnel are always under pressure to finish work as rapidly as possible; hence, they do not have sufficient time to be as thorough as expected. Therefore, trade-offs are made (Hollnagel, 2010a), generally efficiency is prevalent. Consequently, people make adjustments, shortcuts, adapt their functioning; this makes the system performance vary which is a normal functioning otherwise work will not be accomplished and goals not achieved. It appears in a life cycle of an asset that individuals generally have contributed positively rather than in a destructive way, using their knowledge (or lack of), their expertise, the resources (or lack of) they have in hand (resources is used in this case very broadly that is, from available personnel to spare parts through time), to achieve goals. They always adapt to changes, disturbances, unexpected events, and take benefits of opportunities.

Safety is managed proactively by a priori intervention that is before any adverse effect occurs by making the adjustments before something happens rather than after (Hollnagel, 2012b). According to Hollnagel (2012b), there are advantages assuredly lying behind this statement. The most important one is that responses can be given in time, or may be ahead of time. By responding earlier enough, the system requires less effort because it prevents the effects to develop and spread (Macchi, 2011; Hollnagel, 2012b). Systems will not be able to do so if they cannot monitor effectively the situation by means of suitable leading indicators that require a culture of learning from past experiences, learning the right lessons (Hollnagel, 2012b). To complete the picture, the ability of the system to know what to expect that is to anticipate should be proven too.

On the other hand, negative situations such as accidents (things that go wrong) represent a very small part in the life cycle of systems whereas the majority of cases represent things that go right (see Chapter 3, section 3.3). This means the former represent an exception rather than the rule. Moreover, for a given complex socio-technical system, designers cannot provide a full set of procedures, work instructions, or guidelines that answer every single situation (or variation) within the system. Consequently, the system performance varies to match the conditions of work and the variability that leads to things that go wrong/right is mainly due to the human intervention. In addition, it is also worth focusing on what makes the performance of a system succeed rather than focussing only on why it fails. In other words, looking at both things that have gone (or go) right and wrong will ensure that things will go right continuously. Resilience engineering deals with such an approach. Therefore, managing safety proactively is achieved by managing safety by resilience engineering. This is developed in more details in Chapter 3. An obvious direction is to bridge the theoretical research with the practice within the oil and gas industries.

2.5. Chapter Summary

In this Chapter, an overview of the management of safety was given. Some important definitions of the key words related to the aim of this thesis were introduced. Limitations of the traditional definitions of risk designed to be applied only for very simple cases where the probability and the severity of the outcomes are well known and easily estimated were shown.

As a result, a definition of safety based on resilience engineering precepts has been proposed. A critical review of the conventional approach to the management of safety was carried out and the main limitations of traditional risk assessment techniques and accident causation models were highlighted. These limitations lie within the fact that they do not consider the interaction of the elements of the system. Besides, the external factors (environment, weather, human and organisational factors, etc.) are taken into account very little or not at all. Moreover, the estimation of risk is generally subjective including the probability estimates. Therefore, this kind of techniques cannot be used to provide reliable results for socio-technical systems that have become very complex; hence, techniques that are more powerful are required. The contribution of the organisational approach to safety management and its limits was introduced.

In addition, the impact of maintenance activities on plant safety was addressed. These activities were found labour intensive, thus prone to generating accidents. As revealed in this Chapter, accident records due to maintenance are very high and human factors have a significant impact on these occurrences. Despite the difficulty to address these impacts, it has been found that nuclear as well as aviation industry have devoted huge efforts to tackle these issues in comparison to the oil and gas sector. However, the works presented in this Chapter are based on the conventional approach to safety management that are mainly based on the search of failures and/or "human errors" that have been critically discussed. Only lacks have been reported as if there have been only negative behaviour or simply positive actions are judged normal, people are paid to perform such actions.

It has been highlighted that in nowadays systems, safety should be managed proactively based on resilience engineering approach by a priori intervention focusing also on what makes the performance of a system succeed rather than focussing only on why it fails. In the next Chapter, this approach is introduced.

CHAPTER 3. RESILIENCE ENGINEERING

3.1. Introduction

As explained in Chapter 2, conventional risk assessment techniques as well as accident causation models fail to handle complex socio-technical systems since the latter are intractable. For such systems, conditions of work continuously change resulting in the intervention of the human element of the system to adapt/adjust current conditions so that corporate goals are achieved. Consequently, successes or failures may happen.

To date, the majority of research in safety has focused on explaining why accidents happen and what should be done to avoid their recurrence; the focus has been therefore on component failures and/or "human error". In this way, significant efforts have been devoted towards reducing accident rates and avoiding recurrence. These efforts may be incomplete without analysing properly such occurrences (Ullah et al., 2000). Moreover, the best way to tackle accident prevention is also to highlight what the system did so that accidents did not happen instead of focussing only on accidents that occurred. Resilience engineering answers such a question (Hollnagel, 2012a).

In this Chapter, resilience engineering concepts and precepts are reviewed. First, the concept of human error is discussed. This is followed by a section devoted entirely to resilience engineering from why performance varies, to the concepts and precepts of this approach. This section is ended by the introduction of a new concept that is As High Resilient As Possible, AHRAP. Eventually, a Chapter summary is given.

3.2. The Concept of "Human Error"

3.2.1. Definitions

"Human error" is defined in the dictionary as an error that is typical of humans rather than machines (Collins), or the making of an error as a natural result of being human (dictionary reference). Simply said, it is an error made by a human. Error is defined as something that is not correct: a wrong action or statement (Merriam-Webster), or a mistake, especially one that causes problems or affects the result of something (Oxford dictionary). A mistake is defined in the same dictionary as an action or an opinion that is not correct, or that produces a result that you did not want. Sanders and Mc Cormick (1993) define “Human error” as an inappropriate or undesirable human decision or behaviour that reduces, or has the potential for reducing, effectiveness, safety, or system performance. For Reason (1997), “human error” is the failure of planned actions to achieve their desired ends, without the intervention of some unforeseeable events.

3.2.2. The Evolution of the “Human Error” Concept

“Human error” is a term used in daily language. It is often a conclusion of an accident/incident investigation that expresses inappropriate or undesirable action or decision made by people that led to an unwanted outcome. According to Hollnagel (2005b), at least, there are three different denotations of “human error”. It can mean either the cause of something, the event itself (the action), or the outcome of the action; even if the use of the term “human error” is limited to denote “error as event”, the notion of an action gone wrong is a serious oversimplification.

Amalberti (1996) classified actions as follows:

- Those that are correctly carried out where the actual outcome matches the intended outcome
- Those for which there is a perception of having been carried out incorrectly in some way, but where the discrepancy is detected and corrected
- Those that are incorrectly carried out and where recovery is possible
- Those that are incorrectly carried out and where the discrepancy is ignored
- Those that are incorrectly carried out and which are not detected at the time and therefore not recovered

From the first time it appeared in the safety jargon, there has been a lot of works to model this concept. It actually began in the military domain in missile development systems where identification and classification of “human errors” were established along with hardware reliability approaches according to a report released by EUROCONTROL (2002). The development of the research in the field of “human error” grew after major accidents such as Three-Mile Island (TMI), Chernobyl, the Bhopal poisonous gas release, the Challenger explosion, and the Piper Alpha oil platform fire (EUROCONTROL, 2002).

To address the limitations of traditional risk assessment techniques, particularly after the TMI accident, the nuclear industry imposed the introduction of "human error" analysis (see Chapter 2).

3.2.3. The Use of the Concept

The following two examples allow discussing the use of the "human error" concept:

- An engineer was obliged to whelm a valve to let production flow continues.
- Operators use steel wire to close a valve in the pipeline connected to the flare system

In the first example, a production engineer found himself/herself without spare parts when there a trip in the automatic valve located in the line of crude oil production occurred. He/she unsuccessfully spent hours by phone seeking for spare parts hundreds of kilometres around the plant. He/she decided to whelm in order to let production flow continue. Approximately the same situation happened in another location where operators used steel wire to close or open an automatic valve in the pipeline connected to the flare system. When there was a need to direct fluids toward the flare system, they removed the wire and put it again after the operation was finished.

No one looked after these people since production continued to flow. Nobody wants accidents to happen. However, if something bad happens, people will then be blamed for not following the procedures. Generally, the reports after accident investigation point out that "root causes" are either "human error" and/or equipment failures.

Many authors (Rasmussen, 1999; Reason and Hobbs, 2004; Hollnagel, 2005b; Woods, 2006) have noticed that people have often been blamed for the occurrence of accidents. The authors have claimed that:

- These people are generally those who are at the bottom of the pile, or
- The "root cause" reflects the interests of stakeholders, or
- It is easier to stop the search for causes when a human or group who have acted so that a bad outcome occurs are found, or
- It is subjective and guided by the toolbox of the analyst.

The “theory of bad apple” has then been applied. Decisions have been made to remove the persons from practice; or the call has been made for more training, procedures, policies, and even more automation.

In fact, people often tend to simplify things because it is easy to understand, moreover, it is easy to “sell”. According to Hollnagel (2005b), the search for a cause is a case of expediency as much as of logic. As stated earlier (section 3.2.2), there are three ways to view the use of “human error”. Whatever the way this concept is used, there would be always connotations. But is the use of this concept that has a connotation of seeking to blame people appropriate?

3.2.4. The Variability of Performance as an Alternative to the Concept of “Human Error”

For Hollnagel (2005b), time is close to saying that the concept of “human error” has ceased to be meaningful. This concept may be seen as a constraint to the flexibility of the system. Actions that may lead to great successes may be inhibited if systems are not flexible enough. Actually, individuals, as well as organisations, always do what they see appropriate to achieve corporate goals notwithstanding sabotage of course.

As explained in the previous sections, the concept of “human error” concerns individuals. In the oil and gas industry alike other complex socio-technical systems, there are many more details to consider such as incomplete modes of operation, tight couplings among functions, changes within systems faster than their description so that these systems are underspecified hence intractable (Hollnagel, 2012b). Actually, individuals, as well as organisations, work under pressure using what they have in hand to achieve corporate goals. They perform work under conditions characterised by a lack of resources, competence, knowledge, and time. For this reason, they adjust/adapt their functioning to match current demands, resources, and constraints. For Hollnagel (2012b), these adjustments/adaptations are at the heart of successful performance. However, it is worth noting that this may lead to positive outcomes as well as to negative ones. The performance of these systems is, therefore, variable. The performance variability should be therefore considered as an asset rather than a threat and this variability is behind successes as well as failures. According to Hollnagel (2012b), instead of searching models and theories for “human error”, there is a need to develop models and theories for human performance variability. Performance variability is discussed in more details in section 3.3.

To conclude, the concept of performance variability is a great opportunity to be an alternative to the concept of "human error". Therefore, it is time to make the shift from the old way of thinking that consists of attempting to understand how systems perform in the real world based on the search of probability of failures, taxonomy of "human errors", etc. to the new one that consists of understanding why performance varies. Performance variability is normal, inevitable and necessary (Hollnagel, 2010a). It is the underlying condition without which success cannot happen. This is developed in more details in the next section.

3.3. Resilience Engineering

Majority of accidents are usually preceded by behaviours that make the system drift toward states of increasing risk (Hollnagel, 2006). They result not simply from component failure (which is treated as a symptom of the problems) but from inadequate control of safety related constraints on the development, design, construction, and operation of the socio-technical system (Rasmussen, 1997; Leveson, 2011). Consequently, there is a need to find better ways to tackle accident prevention by focusing on what the system did so that accidents did not happen. A number of questions are therefore raised. Are existing techniques appropriate? Hence, are new approaches to managing safety proactively needed? The answer to these questions is given in the next section. The search for more powerful techniques founded on resilience engineering is the concern.

The database of WEB of SCIENCE was searched to find the number of articles that dealt with resilience during the last five years. 30327 were found out of which 1196 were related to science technology domain. When the keyword "engineering" is added, the search yielded 403 articles out of which 380 were related to science technology domain from 2010 to mid- 2014. It is worth noting that there could be confusion between the search for engineering resilience and resilience engineering (see 3.3.1). Figure 3.1 shows the evolution of publications related to resilience engineering from 1985. It can be seen from this figure that the number of publications increased during the last five years (48 publications in 2010 to 66 publications in mid-2014) whereas there were only 13 publications in 2005, 1 in 1990, and 0 in 1985. This implies an increasing interest in this area of research that appears from 2000 on.

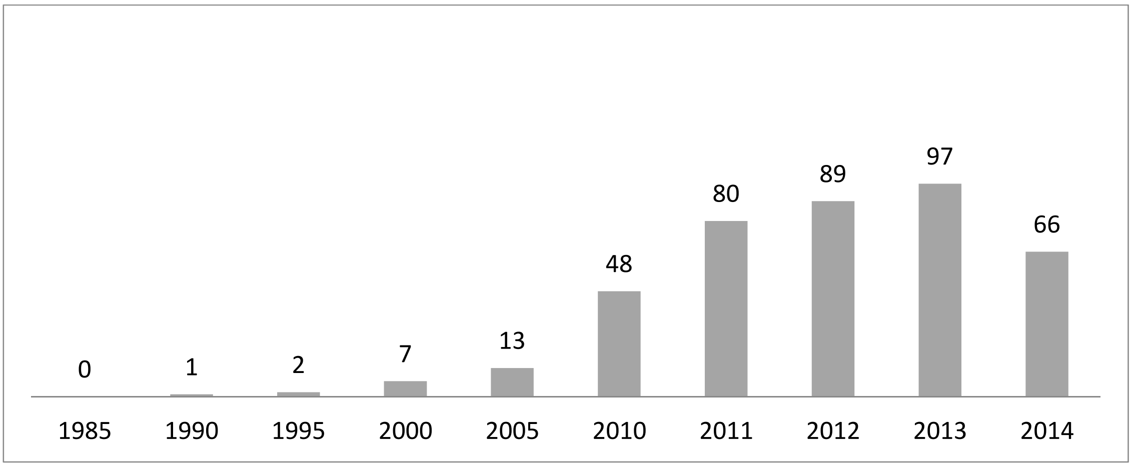

Figure 1-7 : Evolution of resilience engineering publications

This section investigates resilience and resilience engineering precepts/concepts in order to provide the background that will be used in this thesis.

3.3.1. Evolution of the Use of Resilience

The term resilience was introduced in physics to characterise materials that can adapt to changes or withstand some conditions such as certain types of wood that do not break when they are subjected to large loads. The first use of the term resilience was in physics. "On the Transverse Strength and Resilience of Timber" paper published in the *Philosophical Magazine*, Tredgold (1818) explained the property of certain woods such as timber to accommodate to high loads without cracking by the concept of resilience. The concept of resilience was used by Mallet (1856) as a means to measure and compare the different strengths of materials by developing the "resilience modulus"; this led to measure the ability of materials to withstand severe conditions and predict the elasticity of a material; it allowed determining the force that could be applied before it breaks.

The use of resilience saw the bird of two measures respectively the ecological resilience (Holling, 1973) and the engineering resilience (Pimm, 1984). Holling (1973) used resilience to explain the ability of an ecosystem to absorb changes and persist. Holling defined resilience as "a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist" (Holling, 1973, p. 17). Pimm (1984) used resilience to evaluate the ability of an ecosystem to turn back to its initial state after it was moved away by a perturbation and defined the measure as the speed at which a system returns to its original shape. As can be seen, Pimm (1984) used resilience to show the stability of an ecosystem that is the existence of an equilibrium state from where the system moves away and always turns back with a certain ease (or difficulty) and celerity (or slowness).

The use of resilience was transposed to the human sciences too. In psychology, it characterises the individual management of stress and strain. This shows that features of resilience are actually embedded in the survival instinct of human being; in nowadays complex socio-technical systems, the human part of such systems is the essential one.

Besides, it is worth noting that some governments and non-governmental organisations have rewritten certain laws according to this concept and introduced others. To illustrate, examples are given in the following:

- The UK government (e.g. the Civil Contingencies Act, 2004). Resilience was defined as the ability of assets, networks and systems to anticipate, absorb, adapt to and / or rapidly recover from a disruptive event (UK cabinet office, 2010)
- The US Department Homeland Security Steering Committee (2008). The committee defined resilience as the ability to resist, absorb, recover from or successfully adapt to adversity or a change in conditions. In addition, the US released in 2009 a standard called the standard Organizational Resilience: Security, Preparedness and Continuity Management Systems (ASIS SPC.1-2009) which aim was to provide a comprehensive management framework to anticipate, prevent if possible, and prepare for and respond to a disruptive incident.
- The UN framework of Hyogo “Building the resilience of nations and communities to disasters” (UN/ISDR, 2005). In the conference report, the UN report defined resilience as the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This might be determined by the degree to which the social system would be capable of organising itself to increase this capacity for learning from past disasters for better future protection and to improve risk reduction measures.

The adaptability of systems has also been emphasised (see Adger et al, 2005 and Folke et al, 2010).

In this thesis, safety management within complex socio-technical systems is addressed based on the resilience engineering concept. The concept of resilience engineering has been introduced to deal with such systems during the last decade. The use of resilience evolved from the consideration of situations of threats, risks or stress only to reducing the focus on these aspects to end currently with the emphasis on both threats and opportunities. This is developed in more details in the following section.

3.3.2. Resilience Definitions

Relevant definitions with respect to the scope of this thesis have been searched in the literature. Among findings, some have been found of interest to discuss and comment on. According to the "online etymology dictionary", resilience was first used in 1620 as an act of rebounding; the word is derived from Latin resilire i.e. to rebound whereas its elasticity meaning was introduced in 1824. Other dictionaries define resilience as:

- "The ability of a substance or object to spring back into shape; elasticity or the capacity to recover quickly from difficulties; toughness" (Oxford dictionary)
- "The ability to become strong, healthy, or successful again after something bad happens or the ability of something to return to its original shape after it has been pulled, stretched, pressed, bent, etc". (Merriam-Webster),
- "The power or ability to return to the original form, position, etc., after being bent, compressed, or stretched; elasticity, the ability to recover readily from illness, depression, adversity, or the like; buoyancy, and the physical property of a material that can return to its original shape or position after deformation that does not exceed its elastic limit" (the free dictionary).

According to Jackson (2010), it has been agreed in the resilience community that the words "resilience" and "resiliency" are used in the same way. However, there is a difference between resilience and resilience engineering; actually, resilience concerns the ability (or abilities) of a system whereas resilience engineering deals with the approach that makes a system resilient (see the definitions given below). Citing Westrum (2006), Jackson (2010) highlighted three aspects that are considered as sources of resilience and constitute the resilience of a system that is, accident avoidance, survival, and recovery. Jackson (2010) explained these aspects by the ability of a system to (1) prevent something bad to happen, (2) prevent something bad from becoming even worse, and (3) recover from something bad before it becomes even worse than before. Used this way, resilience would only take account of bad/adverse outcomes. Actually, the human intervention would make these outcomes count for very little allowing in major cases the system to perform positively. Thus, the following additions should accompany the three aspects. Instead of dealing only with accident avoidance, it is worth adding continuation that is taking benefit of opportunities. Along with survival, organisations should establish a continuous improvement way of management. Eventually, organisations should build healthy systems rather than focusing only on how to recover from any adverse outcome. Adverse/negative outcomes represent actually rare occurrences as it is explored in this section.

Fairbanks et al (2014) definition (see Chapter 1, section 1.2) shows an important evolution: the term opportunities is added bringing a correction and a move from dealing only with threats to address both threats and opportunities. Fairbanks et al (2014) defined a brittle system as the opposite of a resilient one. It is characterised by the inability to accommodate even minor disturbance (Fairbanks et al, 2014).

As explained earlier in the evolution of the use of resilience, many definitions have been introduced. In addition to those given above, the relevant ones are summarised in appendix 1 taking into account the system feature addressed and what the system faces.

All these definitions present resilience as a set of abilities, capabilities, or capacities of a system to face changes, disturbances, stress, new situations, unanticipated dangers, changing conditions, harmful influences, major mishap, adversity, the unexpected, deviation, or simply something bad. They actually all refer to an ability to face some threats, changes, or unexpected situations expecting as a result a positive outcome (recover, regain a stable state, maintain, persist, achieve goals, etc.). These abilities must be linked to a ready organisation to cope with such situations; the organisation is prepared to respond and sustain its functioning to achieve goals by adapting/adjusting to the dynamic movement of the environment. This in fine may make the system learn from what happened.

Only one definition is explicit about the ability of a system to face both negative events and opportunities (see Fairbanks et al, 2014). This definition shows the evolution of the approach that underlies resilience perspective. This section develops such an approach based on performance variability of a system.

Following what was stated previously, resilience deals with how systems perform, that is achieving corporate goals, being safe, reducing costs, etc. Resilience can be seen therefore as the intrinsic ability of a system to cope successfully with the variability of its performance under expected and unexpected conditions. In this definition, resilience is concerned by system’s ability; it acknowledges the existence of performance variability and the successful actions carried out to face whatever events. For Hollnagel (2009a, p.97), “performance variability is the reason why things most of the time go right, as well as the reason why things sometimes go wrong". Consequently, for a system, dealing successfully with its performance variability means continuing to function in order to achieve designed goals under varying conditions. It comes that any system must search to be As High Resilient As Possible (AHRAP). This is further discussed in the following sections.

3.3.3. Why Does System Performance Vary?

3.3.3.1. System Under-specification

Nowadays systems have become more complex and their performance varies according to the situation. This is because they are intractable. Clarke (2000) defined intractable systems as underspecified systems where details may be missing or unavailable. This under-specification is either due to the need to consider many more details, or incompletely known modes of operations, or tight couplings among functions, or because systems change faster than they can be described (Hollnagel, 2012a). This is may be due to the combination of these factors altogether.

Current conditions of work are dramatically different from the conditions that existed from the 1960's until 1980's; particularly systems are more dependent on information technology than ever and lack the detailed specification required to accomplish work as imagined. Accordingly, the management systems that have been developed based on assumptions considered reasonable for that conditions are not valid for nowadays systems that have become more complex and socio-technique where situations are underspecified. If any issue was raised, the problem was isolated and a technical solution was looked up by acting upon the technological part by more automation or more safety devices considered nicer and cleaner than the socio-technical one.

Among these assumptions, Hollnagel et al (2013) cited: (1) well designed and correctly maintained systems, (2) comprehensive, complete and correct procedures in place, (3) operators' behaviour as expected and trained, and (4) every contingency is foreseen at design and a solution is provided. Moreover, methods such as those dealing with human factors, object of this research, have actually been based on the principles that systems and particularly the relationship between the human part and the other elements of the system can be known and described thoroughly. This is not the case for socio-technical systems, these systems are underspecified and intractable (Hollnagel, 2006). Actually, system elements/components are interdependent of each other and cannot be isolated (see the example discussed in Chapter 5, exploring maintenance environment).

3.3.3.2. System Conditions of Work

Working under pressure, lacking important elements (e.g. time, knowledge, resources, and competence), and dealing with complexity requires human performance to be adaptive to meet the changes systems face in everyday activities by doing local adjustments or adaptations. The adjustments that are approximate imply the variability of the system's performance be inevitable and necessary (Hollnagel, 2010a). Moreover, it may lead to unpredictable results in both directions that is, hazardous or positive ones.

Lack of time implies a reactive culture of the system. The latter is always under pressure to achieve production goals for instance. It responds as a fire fighter to fix broken components. There is no time to think strategy, develop vulnerability models, analyse trends from system performance monitoring and surrounding environment monitoring, detect opportunities and take benefit of them, etc.

Lack of knowledge implies the absence of expertise to think the unthinkable, to go beyond what is known in order to anticipate threats as well as opportunities (e.g. developing strategic plans for the future) by searching what may actually help perform such actions. Even though a system is not reactive but is rather proactive and possesses the required expertise, the necessary resources that make the system able to respond to threats/opportunities must be available; in addition, systems must know beforehand how these resources will be used and when.

As a result, trade-offs are daily made in order to achieve goals and people make adjustments that are actually approximate.

3.3.3.3. Trade-Offs

People face real conditions at the bottom of the pile and generally behave as fire fighters (reactive) trying to be more efficient than thorough; they work continuously under pressure. Accordingly, at all levels, particularly engineers/front-line managers lack the necessary time to think strategy and to apply what they learned in the universities to improve work performance for example in maintenance departments. In other words, learning from past experiences, developing vulnerability models to anticipate future uncertainties, improving costs of maintenance activities among others have become secondary interests, letting equipment availability at all costs the primary objective.

Trade-offs are always made in daily activities; that is either being thorough and complete or being efficient thus carrying out activities as rapidly as possible. Hollnagel calls this Efficiency Thoroughness Trade-Offs (Hollnagel, 2009a). In ETTO, thoroughness can be seen through the analysis of daily activities that go right which lead the system to be more efficient when actions are needed. The following example illustrate the trade-offs made continuously at the shop floor. Managers face the choice to shut down an oil/gas field in order to intervene (following the procedure thoroughly and loosing days of production) or to make the decision not to follow the procedure and find out a way to solve the problem without stopping the work (see examples given in Chapters 5 and 7).

3.3.3.4. Explaining System Performance Variability

To explain performance variability, Hollnagel (2010a) came up with two theories, the W and Z theories. The W theory stipulates that certain conditions (well-designed systems, complete and correct procedures provided, and well trained people behaving as expected) must be met so that systems work properly. The efforts to manage safety are generally directed to implementing barriers of all kinds (see Swiss cheese model of accidents) because accidents are attributed to technology, human “errors”, and/or organisational failures. This leads to the perception (Macchi, 2011) that every resource allocated to safety is in competition with production goals (obviously, trade-off safety-production is in favour of production) and to restrict the opportunity of organisational learning, if this culture exists, to negative events only.

In daily life examples, things go (have gone) right because of the human intervention that makes (has made) the correct adjustments/adaptations and not because systems have been well-thought/designed and people have been well trained and have performed their work as imagined. To respond to actual conditions, individuals take decisions and make required adjustments they judge appropriate to meet demands and achieve objectives. The cup is mid-full or mid-empty. Trying to understand why things go (have gone) right to increase the number of those that go right, is more productive than focusing only on things that go (have gone) wrong. Comparing work as imagined and work as performed allows assuredly understanding why adjustments/adaptations succeed; it is therefore important to find indicators that monitor such performance. As explained in the maintenance system of the Company (Chapter 5), tasks are regularly performed by adapting current conditions (procedures, tools, etc.) that generally result in successes and rarely in accidents.

Hollnagel (2010c) sorted out the main sources of performance variability. Performance varies because of psychological factors (that may affect perception, vigilance, ingenuity, creativity, etc.), organisational factors (such as meeting performance demands, stretching resources, etc.), social factors (such as meeting oneself, colleagues, or managers' expectations, etc.), and contextual factors (such as workplace environment). To achieve safety, all kinds of performance variability are constrained (rules, procedures, strict training, etc.) in order to avoid malfunctions or failures. This cannot be attained since systems are intractable (Hollnagel, 2010a). The solution lies within the capability of the humans to make the correct adjustments to fill in the gap between "what should be done" and "what could be done" using available resources. Since adjustments/adaptations made by the human element in particular are omnipresent within complex socio-technical systems, the performance of such systems is variable. Performance variability explains successes through the dynamic processes of adjustments/adaptations to achieve goals. However, it can also lead to undesired outcomes.

Management commitment is among the important themes that make an organisation resilient (Hollnagel, 2008a). This is to say that from top management to the shop floor, the role of performance variability must be recognised, the conditions that led to this variability understood, and the performance variability must be regarded as an asset. Failures actually are an expression of everyday performance variability as well as successes.

On the other hand, the occurrence of any negative outcome cannot be described by means of a decomposition of a linear chain of cause-effect tracking backward a potential "root cause" that is generally decided by the analyst. Consequently, building techniques/methods of risk assessment or designing models of accidents investigation based on principles of bimodality and/or causality that are in contradiction respectively with the principles of performance variability and emergence is not appropriate.

According to Hollnagel (2010a), accident investigation and risk assessment techniques should be based on the Z theory where systems work because the following conditions are met:

- People learn to identify and overcome design flaws and functional glitches
- People can recognise the actual demands and adapt their performance accordingly

- When procedures must be applied, people can interpret and apply them to match the conditions
- Finally, people can detect and correct when something goes wrong or when it is about to go wrong, and hence intervene before the situation seriously worsens

The reliability of such systems is because people are flexible and adaptive, rather than because the systems have been perfectly thought out and designed (Hollnagel, 2010a).

According to the Efficiency–Thoroughness Trade-Off (ETTO) principle introduced by Hollnagel (2009a), people tend to be efficient rather than thorough doing something reasonably precise and correct rather than spending all their time to evaluate the best possible option (Macchi, 2011). This can be achieved through the description and measurement of system abilities that may lead to success or failure.

3.3.3.5. System Abilities

A system can be characterised by abilities that let it perform daily work (what an organisation does) to achieve objectives. The set of all these abilities defines a resilient system. Because safety is treated as a core value, not a commodity that can be counted, Hollnagel (2010b) stated that a resilient organisation is also safe. To be resilient, an organisation must be able: (1) to respond to threats/opportunities that is, know what to do, (2) to flexibly monitor that is, know what to look for, (3) to anticipate any development that is, know what to expect, and (4) to learn that is, know to learn from past experiences (Hollnagel, 2010b). It is worth adding the ability to transform the system from current state to another facing all kind of resistance particularly the resistance to change. Current system state will produce inevitably its end if it continues to follow the same way of thinking i.e. the same culture. This may be characterised by lack of resilience or a tendency to brittle. The solution resides therefore in its ability of transformation to build resilience from a given level to a more resilient one. As explained by Hollnagel and Woods (2005), the system actually makes trade-offs between all these capabilities to achieve designed goals.

Filling the gap of knowledge should be directed toward taking benefit of performance adjustments/adaptations by learning from them. That is, the learning process should take place around both positive and negative outcomes. The majority of adaptations/adjustments are actually successful (Hollnagel, 2009b), see section 3.3.4 related to the AHRAP concept. Since nowadays systems have become more complex, the need for such adjustments/adaptations is a great opportunity to grasp to understand system performance. According to Hollnagel (2014), risks can be understood only if the operational environment is sought, bearing in mind that all outcomes result from performance variability of systems, particularly the performance of the human element.

3.3.3.6. Functional Resonance

Hollnagel (2004, 2012b) introduced the concept of functional resonance to explain the non-linear interrelation between nowadays system elements to show that in such systems events do neither happen one after another nor have cause-effects relationship between them. Rather, systems evolve in a complex dynamic environment where its performance is always variable (see previous sections) leading usually to successes and rarely to failures; successes are the flip side of failures. The latter are stemming from inappropriate or insufficient adjustments/adaptations of system components to the changing environment. They should therefore be described using functional resonance in order to explain what could happen in such systems.

Resonance is used in physical phenomena to explain the oscillation of a system with larger amplitude when for instance intensity of electrical current is in phase with the voltage. In resilience engineering approach, functions refer to activities; they describe something a system element does and/or the interaction between the human part of the system and the others. For Hollnagel (2012b), the approximate adjustments that are carried out by the human part of the system, are made in response –and anticipation- of what others do individually or collectively; functional resonance can be therefore defined as "the detectable signal that emerges from the unintended interaction of the everyday variability of multiple signals" (Hollnagel, 2012b, p. 29). In other words, some signals are detectable whereas others are not; when the variability of functions within the system resonates and gains larger amplitude exceeding the limits of system capacities, the signal is therefore detectable. A resilient system is one that is also able to detect such signals beforehand, act upon to minimise or eliminate those that may exceed the limits of systems capabilities.

For Ferreira (2011), people and organisations should be provided with tools that allow monitoring sources and changes in system performance variability. Providing a tool to measure system abilities is a great challenge thus.

3.3.4. From ALARP to AHRAP: Looking Ahead

The challenge is therefore how to manage properly a situation in order to enable the optimisation of human factors by consolidating and enhancing positive adjustments and mitigating or reducing negative ones.

In the traditional approach, risk must be reduced until what is called As Low As Reasonably Practicable, ALARP. According to this concept, the reduction of risk must take into account costs and benefits of risk reduction so that risk becomes tolerable. In other words, reduce the risk to the level that putting more money will be vain. As explained by Hollnagel in *resilience engineering in practice, a guidebook* (2011), such a principle deals with what is called the unwanted outcomes or things that can go wrong where safety efforts have generally focused on. In resilience engineering, the focus is on the two sides of the coin namely things that go wrong as well as things that go right. Figure 3.2- that has been adapted from Hollnagel (2010b) - depicts the reality of what happens in a system. In the life cycle of a system, things that go wrong represent only a small fraction, the exception, e.g. no more than 5 % whereas things that go right represent the large majority, may be more than 95 % of the situations. Why put a strategy that focuses only on things that go wrong which represents the rare cases? The time has come to make the shift to understand why things go right too. Therefore, what will happen if a strategy that addresses all cases is set? This may allow putting barriers to situations where there could be a drift toward hazardous states and boost situations that have positive outcomes. In other words, increasing the situations that go right will decrease situations that go wrong.

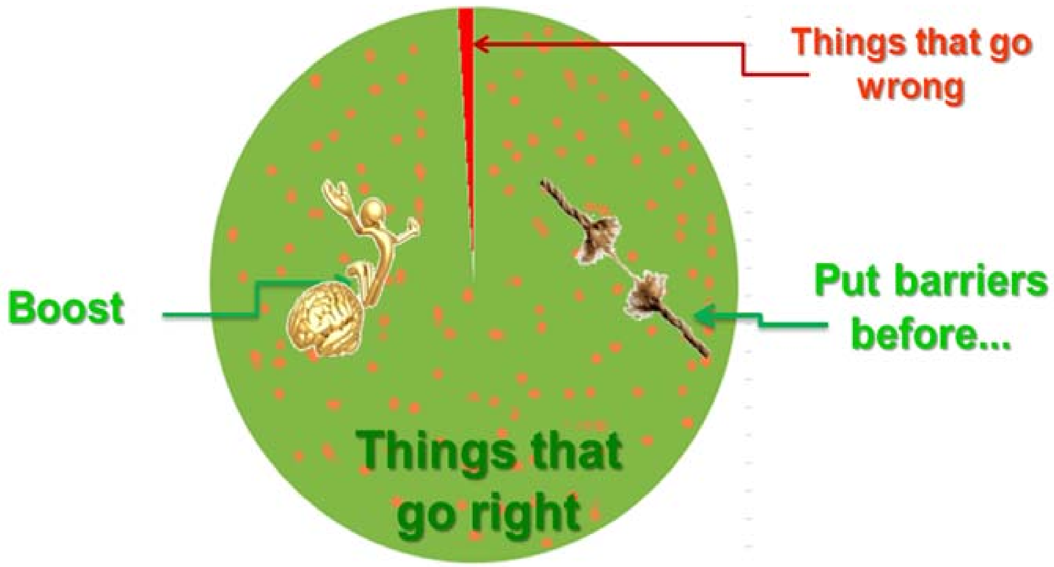

Figure 1-8 : Make the shift to understand why things go right too (adapted from Hollnagel, 2010b)

For Hollnagel (2012a), resilience engineering assumes that things that go right and those that go wrong are a result of the same underlying processes. Accordingly, it is worth knowing what the four cornerstones, cited previously in section 1.2.3., are in a given system and attempt to increase these abilities. Concisely, increase the resilience of a system that makes it As High Resilient As Possible. It has also been shown in previous sections that organisations adapt their functioning to achieve assigned objectives by adjusting available resources and time. As a result, there must be a move from following the principle of As Low As Reasonably Practicable (ALARP) to adopt the principle of As High Resilient As Possible (AHRAP).

The terms found in resilience definitions are system features that allow responding to unanticipated disturbances that may lead to failures and resume normal operations on the one hand, and grasp any opportunity to improve this performance on the other hand. The characteristics of high resilient systems allow them to succeed under all conditions including achieving goals, preventing drift towards hazardous situations, recovering from disturbances (bounce back), taking benefit of opportunities and so forth.

On the other hand, a resilient system may also fail to face opportunities/threats, it is the reason why it is more interesting to address levels of resilience and levels of improvements; hence, a system must attempt to become AHRAP. In the large majority of cases, these adjustments lead to successful outcomes and only rarely result in undesired events.

As explained in the previous Section 3.3.3, in order to be resilient, an organisation must be able: (1) to respond to threats/opportunities i.e. know what to do, (2) to flexibly monitor i.e. know what to look for, (3) to anticipate any development i.e. know what to expect, and (4) to learn i.e. know to learn from past experiences. System resilience should be increased in a continuous improvement way by the ability of the system to transform its maturity level to a higher one. Since resilience concerns the ability of a system to deal successfully with any situation, resilience engineering is the approach that engineers (plan for, design, and build) practices to identify and implement strategies that make a system AHRAP.

The underlying process that guides this research work is based on making a system more resilient by measuring its four abilities and identifying strategies to increase these abilities in a continuous improvement way to make the system AHRAP. This is actually an endless process. Measuring system's resilience does not mean measuring percentage of compliance/non-compliance to rules, standards and so forth as required by the traditional approach in auditing any management system. What is required, is measuring actual system performance. In this research work, it is achieved by the development of a tool, MASRAT, which measures the four abilities of the maintenance system of an oil and gas asset, and identifies maturity levels and strategies for improvement. This is addressed in Chapter 6 and Chapter 7 of this thesis.

3.4. Chapter Summary and the Way Ahead

3.4.1. Chapter Summary

In this Chapter, resilience engineering concepts and precepts were reviewed. First, limitations of the traditional approach were recalled. It has been shown that the traditional approach is based on a supposition that the underlying principles applied to equipment/component failures (failures, causes, consequences, probability of occurrence, etc.) can be used to characterise the human intervention that includes for instance the search of “human errors”, taxonomy of “human errors”, a probability of “human errors”. This assumption was found not valid; the human intervention is rather considered as an asset. Then, the concept of human error was discussed. It has been exposed that such a concept is meaningless and elusive that hinders the examination of various conditions, pressures, conflicting goals, trade-offs in decision making, etc. that may lead to an outcome.

The remainder of the Chapter was devoted to the resilience engineering concept. It has been found that most definitions of resilience refer to an ability to face some threats, changes, or unexpected situations expecting as a result a positive outcome. After that, performance variability was thoroughly addressed. It has been shown that systems are underspecified due to a combination of multiple factors implying approximate adjustments based on trade-offs made in daily activities. It has also been shown that systems can be characterised by abilities to perform daily work to achieve objectives that make them resilient, namely the ability to respond, monitor, anticipate, and learn to which the ability to transform is added. Eventually, it has been shown that it is necessary to move from following the ALARP principle to adopt the principle of AHRAP and measure system performance through the measurement of its abilities.

3.4.2. The Way Ahead

The first part of this thesis dealt with a review of relevant literature and theoretical background covering the key important issues of this research work that have been tackled by some researchers. This addressed objective 1 of this research work.

The literature review revealed that despite the significant amount of money spent to reduce the rate of accidents, people continue to be injured and/or killed in the workplace. It also revealed that maintenance tasks are one of the major contributors to industrial accidents. However, the impact of poor maintenance on industrial accidents has not been adequately examined in the oil and gas sector and research in the area of human factors in the maintenance in this industry is limited. Moreover, it has been shown that more powerful, non-linear models, based on system theory and resilience engineering, are needed. This approach was found the appropriate way to address the management of safety. However, there is a need to bridge the gap that exists between theory and practice of resilience engineering.

In this thesis, resilience engineering has been defined as the approach that engineers (plan for, design, and build) practices to identify and implement strategies that make a system AHRAP.

The remainder of this study addresses the different components of this definition and remedy the limited number of studies in the oil and gas industry by exploring the maintenance system of the national oil and gas Company, developing, and validating a tool that measures the resilience of this system.

CHAPTER 4. THE RESEARCH STRATEGY

4.1. Introduction

This Chapter is devoted to outline the chosen research strategy to achieve the aim and objectives of this work. The research process is dealt with in Section 4.1. The class of research and the research strategy are introduced in Sections 4.3 and 4.4 respectively. In Section 4.5, the most common paradigms underpinning a research strategy are described and the reasons for the paradigm choice for this study are explained. Section 4.6 addresses the research design. The adopted methodology and the selected methods are presented in Section 4.7. Data collection and analysis are given in Section 4.8. The ethical issues and considerations are discussed in Section 4.9. Section 4.10 summarises this Chapter.

4.2. The Research Process

Three phases have been designed to carry out this piece of research. Phase one was concerned by the theoretical part of the study. Phase two related to the empirical studies. Phase three addressed the validation and testing part. Figure 4.2 shows the three stages of the research process.

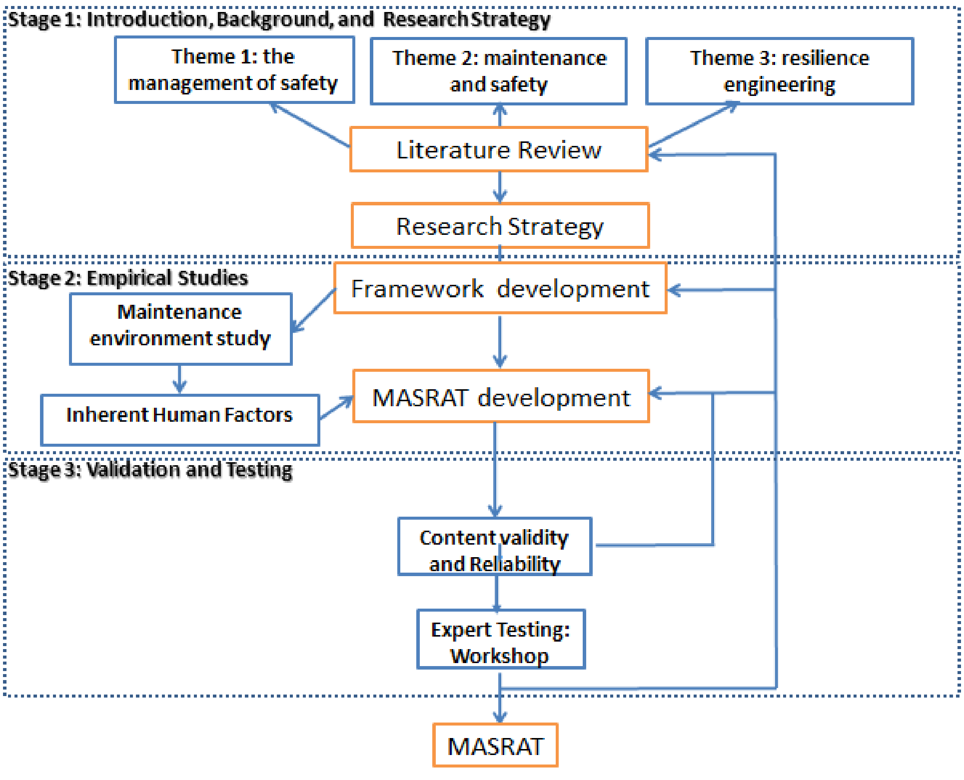

Figure 1-9 : The research process

4.2.1. Stage One

Stage one involved building the foundations of this study. It includes Chapters 1 to 4 that comprise the introduction, the theoretical background to the study, and the research strategy. The theoretical background to the study encompassed three themes. Firstly, an overview of the management of safety was given. A critical review of the conventional approach to the management of safety was carried out and the main limitations of traditional risk assessment techniques and accident causation models were addressed. Secondly, the impact of maintenance activities on safety was critically reviewed. Thirdly, the resilience engineering concepts and precepts were explored. The research strategy emanating from the literature review was then designed.

4.2.2. Stage Two

This stage covered the empirical studies based on resilience engineering. First, the maintenance system of SONATRACH was explored. A study of the maintenance environment was carried out by means of the Maintenance Environment Questionnaire to identify Human factors inherent in such activities and a functional analysis was performed to show the complexity of the maintenance system by the FRAM method; this was completed by storytelling. Then a strategy to achieve safety excellence in the maintenance of SONATRACH facilities and the required tool, the MAintenance System Resilience Assessment Tool, MASRAT, which measures the resilience of the maintenance system to achieve this goal, was outlined. This is reported respectively in Chapter 5 and Chapter 6, part 1.

4.2.3. Stage Three

Stage three concerned the validation and testing phase of MASRAT. The content validity and reliability of the tool regarding the most significant human factors identified by this study including field-testing to get psychometric information to validate the tool was addressed. This is reported in Chapter 6, part 2. Then the field-testing of the tool by means of expert panel in a workshop arranged in three ateliers to study the three significant human factors identified in stage two was evaluated; this is reported in Chapter 7.

4.3. The Class of Research in the Research Process

In the research process, there are five main elements to consider which are linked together as shown in Figure 4.1 (adapted from Walliman, 2011). It shows the way these elements are interrelated and particularly displays the central role of the research theory.

Figure 1-10 : The research process (adapted from Walliman, 2011)

It is worth beginning by defining the word research itself. According to Singh (2006), research seeks to answer questions that have not been answered so far. For Crawford (cited in Singh, 2006, p.3), research is defined as a "systematic and refined technique of thinking, employing specialised tools, instruments and procedures in order to obtain a more adequate solution of the problem than would be possible under ordinary means. It starts with a problem, collects data or facts, analyses them critically and researches decisions based on the actual evidence".

Research may be applied or basic. Whereas basic research focuses on fundamental principles and testing theories, applied research uses the data directly for real world application (Hale, 2011). The former is generally called pure research and targets for instance a general phenomenon; it may be considered as a starting point to gain and expand knowledge. The latter is oriented towards finding solutions to a specific issue by using available knowledge. Starting from the current situation in the maintenance of oil and gas assets characterised by activities that are accidents prone where human factors play an important role, the research work was oriented toward finding the appropriate way to approaching the problem. The theoretical background, a systemic approach based on resilience engineering played therefore the central role in this study. Accordingly, this research work is applied research oriented.

4.4. The Research Strategy

To guide the work, a research strategy must be adopted. It consists of choices leading to answer the research question and achieve the aim of the research. These choices start by identifying the philosophy underpinning the study through a set of beliefs known as the research paradigm that guides the design of the research and permits choosing the research methodology. The methods applied in this study, data collection and analysis as well as the presentation of findings are selected according to the methodology adopted. Ethical issues and considerations are then discussed. All these choices are outlined in the following sections and the reasons for a particular choice are given.

4.5. The Research Paradigm

Saunders et al. (2009) defines research philosophy as an over-arching term relating to the development of knowledge and the nature of that knowledge. It contains important assumptions about the way in which the world is viewed. Bogdan and Bikken (2003) and Mertens (2005) see the research paradigm as the theoretical framework underpinning a research study. Creswell (2009) uses worldviews instead of paradigm and classifies paradigms into two major ones: quantitative and qualitative; any paradigm falls into one of them. Qualitative research copes with exploring and understanding the meaning individuals or groups ascribe to a social or human problem while the other is a means for testing objective theories by examining the relationship among variables (Creswell 2009). However, a researcher may combine or associate them so that the overall strengths of a study is greater (Creswell, 2009).

In the following sections, the most used paradigms are described so that the current research can be placed into its theoretical context. The subsequently arising methodology (how the current research was practically carried out) is explained and the way in which the data was gathered and analysed is detailed.

4.5.1. Positivism

According to Creswell (2009), positivist and post-positivist worldview are the same and are sometimes called the scientific method since it has represented the traditional form of research.

Post-positivism replaced positivism after World War II (Mertens, 2005). This worldview is called post-positivism because it represents the thinking after positivism (Creswell, 2009). Based on the deterministic philosophy of August Comte, it narrows down the ideas into some small and discrete set ones to test (variables comprising hypothesis and research questions), it develops knowledge based on careful empirical observation and measurement of the real world, and eventually theories are tested or verified and refined (Creswell, 2009).

The aim of this deterministic philosophy is to observe directly, measure quantitatively and predict objectively the relationships between studied variables (Mackenzie and Knipe, 2006). For Macleod (2009), positivism is linked to the real world, a world of science and testing hypothesis, where sources of bias are minimised wherever it is possible and researchers are objective. It deals with the real world and can be demonstrated by significant statistic numbers. It uses therefore a quantitative analysis method. For Mackenzie and Knipe (2006), positivism and post-positivism research is most commonly aligned with quantitative methods of data collection and analysis.

4.5.2. Constructivism

As its name says, there is a kind of construction of own reality by individuals in contrast with the positivism paradigm. For constructivists, individuals seek at finding meanings and understanding of the world in which they live and work (Creswell, 2009). The researcher listens carefully to what people say and do in their life by using open-ended questions (Creswell, 2009). People may construct the same reality in quite different ways (Macleod, 2009). A theory or pattern is generated or inductively developed in the constructivist approach by contrast to the positivist one. The goal of constructivist research is to understanding and structuring, as opposed to predicting (Macleod, 2009). Mackenzie and Knipe (2006) associate constructivism with interpretivism. For Mackenzie and Knipe (2006, citing Cohen and Manion, and Mertens), the constructivist/interpretivist approaches aim at understanding the world of human experience (Cohen and Manion, 1994) and suggesting that reality is socially constructed (Mertens, 2005). Qualitative data collection methods and analysis are most likely used or mixed methods (Mackenzie and Knipe, 2006)

4.5.3. Pragmatism

A study may be more quantitative than qualitative or vice versa (Creswell, 2009). Researchers may find that the use of both designs provides a better understanding of the studied problem. They seek a kind of freedom to choose methods that may strengthen the research by taking benefit of the advantages of any method. The philosophy underpinning such an approach is called pragmatism. According to Creswell (2009), it is problem centred and real world oriented. It provides a philosophical basis of research that is not committed to anyone system of philosophy and reality where the researchers are free to choose methods, techniques, and procedures of research that best meet their needs and purposes (Creswell, 2009). According to Creswell (2009), pragmatism is the philosophy that underpins mixed methods where investigators use both qualitative and quantitative data because they work to provide the best understanding of a research problem. The research work benefits in fine from the advantages of any method used to make the study stronger.

4.5.4. Critical Theory

This paradigm looks at power relations, politics, and patterns of dominance (Macleod, 2009). As a result, it does not concern the subject of this research, thus it is not developed.

4.5.5. Paradigm Choice

There are three major ways of thinking that guide a research namely ontology, epistemology and methodology; Creswell (2009) added axiological and rhetorical, that is respectively the role of values and the language of research (see table 4.1).

Table 1-5: Ways of thinking guiding a research (adapted from Creswell, 2009)

Assumption	Question	Quantitative	Qualitative
Ontological	What is the nature of reality?	Reality is objective and singular, apart from the researcher	Reality is subjective and multiple and seen by participants in a study
Epistemological	What is the relationship of the researcher to that researched?	Researcher is independent from that being researched	Researcher interacts with that being researched
Axiological	What is the role of values?	Value-free and unbiased	Value-laden and biased
Rhetorical	What is the language of research?	Formal based on set definitions, impersonal voice, use of accepted quantitative words	Informal, evolving decisions, personal voice, accepted qualitative words
Methodological	What is the process of research?	Deductive process Cause and effect Generalisations leading to predictions, explanation, and understanding Accurate and reliable through validity and reliability (testing)	Inductive process Mutual simultaneous shaping of factors Patterns and theories developed for understanding Accurate and reliable through verification

Terre Blanche and Durrheim (1999) defined the three major ways respectively by the specification of the nature of the reality to be studied, the specification of the nature of the relationship between the researcher and what can be known, and the practical way in which the researcher goes about doing the research.

The choice of a paradigm sets down the intent, motivation and expectations for the research (Mackenzie and Knipe, 2006). If a paradigm is not nominated at first step, there will be no basis for any subsequent choices concerning the methodology, methods, literature or research design (Mackenzie and Knipe, 2006). Quoting Bogdan and Bikken (2003), (Mackenzie and Knipe, 2006, p 194.) define a paradigm as “a loose collection of logically related assumptions, concepts, or propositions that orient thinking and research”.

There are many reasons to choose a paradigm. For Creswell (2009), they include worldview or assumptions of each paradigm, training and experience, psychological attributes, nature of the problem, and audience for the study. Table 4.2 reproduces and explains these reasons.

Table 1-6: Reasons for choosing a paradigm (adapted from Creswell, 2009)

Criteria	Quantitative paradigm	Qualitative paradigm
Researcher's worldview	A researcher's comfort with assumptions of the quantitative paradigm	A researcher's comfort with assumptions of the qualitative paradigm
Training and experience of the researcher	Technical writing skills Computer statistical skills Library skills	Literary writing skills Computer text- analysis skills Library analysis skills
The researcher's psychological attributes	Comfort with rules and guidelines for conducting research Low tolerance for ambiguity Time for a study of short duration	Comfort with lack of specific rules and procedures for conducting research High tolerance for ambiguity, may lack lengthy study
Nature of the problem	Previously studied by other researches so that the body of literature exists, is known along with the variables, and existing theories	Exploratory research, variables unknown, context important, may lack theory base for study
Audience for the study	Individuals accustomed to supportive of quantitative studies	Individuals accustomed to supportive of qualitative studies

This research work aims at developing an approach based on resilience engineering to achieve safety excellence in the maintenance of oil and gas assets. It is considered as an applied research in contrast to a basic on; it narrows down this topic from a general application of resilience engineering to a more specific one tailored to the maintenance of oil and gas assets.

In addition, the following elements are taken into consideration to choose the research paradigm.

- Way of thinking guiding the research: reality is both objective from the researcher and subjective from the participants particularly during the workshop is presented in Chapter 7. Furthermore, the researcher is independent from that being researched and interacts with it (see Chapter 7); the methodology adopted, as argued in section 4.7, is deductive and context bound. The way of thinking guiding this research is quantitative but it contains also some qualitative approach as discussed in section 4.8.
- Reasons for choosing the paradigm: there is a comfort with regard to the way of thinking as described above and the assumptions of each paradigm (quantitative and qualitative paradigm) as well as the rules and guidelines for conducting this research. In addition, human factors in maintenance activities are studied in other industries such as aviation and nuclear in comparison to the oil and gas sector as it has been shown in Chapter 2. This constituted an exploratory aspect. On the other hand, resilience engineering is a powerful approach that needs more exploration in the oil and gas industry.

Accordingly, the research paradigm chosen was pragmatism. It allowed the freedom of choice for the most appropriate methods that can be used to achieve aim and objectives of this research. It is a quantitative approach as well as a qualitative one dealing with the human part of the complex studied system.

4.6. The Research Design

According to Yin (2009), a research design deals with a logical problem and not a logistical problem. It is therefore a clear thinking based on a philosophical approach that allows setting the strategy and the way of conducting the research. It is not just a work plan; it is directly linked to the research questions to ensure finding answers as clear as possible. It is not related to a particular method of data collection; it is a logical task undertaken to ensure that the evidence collected enables the researcher to answer questions or to test theories as unambiguously as possible. The identification of type of evidence required to answer the research question is also essential when designing research (Kirshenblatt-Gimblet 2006).

There are actually many types of research design. The most important ones (among them those that could be used in this research) are briefly outlined in table 4.3.

Table 1-7: Types of research design

Research design	Meaning and uses
Philosophical design (Maykut, 1994)	Based on philosophical analysis and argumentation, it is a broad approach rather than a methodological design which critically explores the relevance of logic and evidence in academic debates. It has limited application to specific research problem
Observational design (Patton, 2002; Rosenbaum, 2010)	Used to compare subjects against a control group. It can be direct or unobtrusive observation. It is useful for discovering what may be important before applying other methods like experiments. It may reflect a unique sample population; thus it cannot be generalised to other groups (low data reliability).
Longitudinal design (Ployhart and Vandenberg, 2010; Anastas, 1999)	In this approach, researchers make repeated observations by doing the same sample over time. It is also referred to as a panel study.
Cross-sectional design (Barrat and Kirwan, 2009)	Focuses on finding relationships between variables at one moment in time whereas longitudinal design involves taking multiple measures over an extended period of time.
Historical design (Gall et al, 2007)	Aims at collecting, verifying, and synthesising evidence from the past.
Exploratory design (Brown, 2006)	Used when there are few or no earlier studies to refer to. It may determine the nature of the problem, the feasibility of the study in question in the future and help gain background information on a particular topic but the findings are often not generalizable.
Experimental design (Anastas, 1999	Enables the researcher to maintain control over all factors that may affect the results of an experiment. It allows identifying cause-effects relationships between variables. On the other hand, results of such studies may not generalise well to the real world.
Descriptive design (Anastas, 1999)	Used to obtain information concerning the current status of the phenomena and to describe "what exists" with respect to variables in a situation.

Moreover, the case study design (Anastas, 1999; Hancock and Algozzine, 2006; Yin, 2009), on which this study is mainly based, is presented deeper in the following.

The case study design is seen as an in-depth study of a particular research problem by conducting an empirical investigation of a contemporary phenomenon within its natural context using multiple sources of evidence (Yin, 2009). More often, it addresses a phenomenon studied in its natural context, bounded by space and time. It is richly descriptive and the information is explored and mined in the case study environment for a more thorough examination of the given phenomenon. Used to narrow down a very broad field of research into one or a few easily researchable examples, the case study research design is also useful for testing whether a specific theory and model actually applies to phenomena in the real world. It is a useful design when not much is known about a phenomenon. A case study design can apply a variety of methodologies and rely on a variety of sources to investigate a research problem. It is generally more exploratory than confirmatory in comparison to experimental research.

Furthermore, mixed methods approach may be sequential or concurrent. In the former, researchers look for expanding on the findings of one method to another one whereas for the latter, the researcher converges or merges quantitative and qualitative in order to provide a comprehensive analysis of the research problem (Creswell, 2009)

The study of human factors in the maintenance of oil and gas industry is limited in comparison to the aviation and nuclear sectors as stated in Chapter 2. Exploratory design therefore helped gain information on this topic by the identification of inherent human factors and their impact on safety as it is developed in Chapter 5 in the study of the maintenance environment. Using the developed tool, MASRAT (see Chapter 6), description to obtain information on what exists with respect to the three most important human factors studied (resources, time-pressure, and supervision/coordination) were dealt with. Finally, yet importantly, most of this research work was a case study that looks in-depth at the way to implement a resilience engineering based approach in the maintenance of oil and gas assets to achieve safety excellence (see Chapter 7). This was done by investigating the maintenance activities within their natural context and narrowing down to the three most significant human factors.

In addition, testing MASRAT necessitated an evaluation. There is increasing recognition of the inherent complexity of implementing research into practice. According to Worthen and Sanders (1987), evaluation is a formal or disciplined approach to examine the value of a program based not only on its outcomes but also on its context, inputs, processes and procedures, and products. For Taylor-Powel (2003), a researcher must ask certain questions while performing an evaluation. They include:

- What is the purpose of the evaluation?
- What are the circumstances surrounding the program?
- What resources are available for the evaluation?
- What accountability is required?
- What knowledge generation is expected or desired?

Evaluation can be formative and/or summative. Formative evaluation is defined as a rigorous assessment process designed to identify potential and actual influences on the progress and effectiveness of implementation efforts while summative evaluation as a systematic process of collecting data on the impacts, outputs, products, or outcomes hypothesized in a study (Stetler et al., 2006)). This is to find out whether issues may arise during the process of implementation and make the correct adjustments for the former and to provide information on the degree of success, effectiveness, or goal achievement of an implementation program that is to know whether the program has met the assigned goals or not for the latter. In other words, summative evaluation allows to prove and adopt a program whereas formative evaluation permits improve a programme. Table 4.4 gives potential uses of formative evaluation.

Table 1-8: Potential uses of formative evaluation (adapted from Stetler et al, 2006)

Potential uses of formative evaluation
Understand the nature of the local implementation setting
Assess whether a program or intervention addresses a significant need
Modify a proposed program or intervention, as needed
Determine the extent, fidelity, and qualities of the implementation of an intervention program...(e.g.) to describe the activities actually implemented...(and) ...explain program operations
Systematically detect and monitor unanticipated events (and adjust if appropriate)
Optimise/control implementation to improve the potential for success
Document continual progress
Inform future similar implementation efforts
Understand the extent/dose, consistency, usefulness, context, and quality of an intervention's implementation
Understand the nature and implications of local adaptations
Understand the experience of those directly affected by implementation efforts

There are various uses of formative evaluation for implementation research associated to each stage of the research that is, developmental, implementation-focused, progress-focused, and interpretive (Stetler et al, 2006).

A collection of relevant data was performed to build judgments about MASRAT regarding its improvement; this was done by means of a formative evaluation and/or to prove its appropriateness carried out by means of a summative evaluation. In this study, both formative and summative evaluations were used as argued in the following section with respect to data collection methods.

4.7. Methodology

This research work was applied research oriented, deductive and context bound. Human factors in the maintenance of oil and gas assets are not studied in comparison to other industries such as aviation and nuclear as it has been shown in Chapter 2. On the other hand, resilience engineering is a powerful approach that needs more exploration in the oil and gas industry. This constituted an exploratory aspect.

The research paradigm chosen was pragmatism. It allowed the freedom of choice for the most appropriate methods that can be used to achieve aim and objectives of this research. The way of thinking guiding this research was a quantitative approach as well as a qualitative one dealing with the human part of the complex studied system.

Exploratory design helped gain information on this topic by the identification of inherent human factors and their impact on safety. Using MASRAT (see Chapter 7), information on what exists with respect to the three most important studied human factors (resources, time-pressure, and supervision/coordination) was obtained. This research work was a case study. MASRAT has been developed to look in-depth at the way to implement a resilience engineering based approach in the maintenance of oil and gas assets to achieve safety excellence. This was done by investigating the maintenance activities within their natural context and narrowing down to the three most significant human factors.

Table 1-9: The research methodology

Class of research	Applied research
Paradigm	Pragmatism
Aim & objectives	Descriptive Explorative
Way of thinking	Quantitative Qualitative Deductive and context bound
Design	Case study Exploratory
Implementation evaluation and field testing	Formative Summative
Chosen methodology	Mixed methods approach

Besides, testing the tool necessitated an evaluation. In this study, both formative and summative evaluations were used. A summary of the adopted methodology is given in table 4.5. As a result, mixed methods approach was applied in this study.

4.8. Data Collection and Analysis

This section deals with data collection and analysis. First, data requirements are addressed. From each of the objectives set in Chapter 1, research questions, research methods, and variables are identified. Then, the chosen data collection methods for each objective are explained. Eventually, the analysis of data is specified through a content validity and a reliability analysis.

4.8.1. Data Requirements

The research strategy adopted in this thesis is based on the context of SONATRACH (Chapter 1) and relevant elements taken from the literature review. In Chapter 1, the different entities that constitute the company were described along with the relationships that exist between them.

There are two kinds of data required to ensure achieving the objectives set so that the aim of this research work is attained. First, the theoretical background that made the concepts, models, and methods clearer was taken from the literature review and based on resilience engineering concepts and precepts. Then, the empirical study designed to fill in the gap between the resilience engineering approach theory and its practice was considered. The first part has already been tackled in Chapters 2 and 3. The empirical part comprised review and analysis of available documentation, interviews, expert panel testing, and field visits and observations.

The maintenance system was explored through the analysis of the maintenance system documentation and processes, interviews with maintenance staff, questionnaires, field observations, functional analysis, and storytelling. This was done to find out how the system is organised, how it is linked to other departments, and how the activities affect the safety of facilities. As a result, a snapshot of daily activities regarding variables such as resources (available and easy to obtain), time pressure, supervision, coordination, defences, and fatigue was taken; and a profile comparing the maintenance system of oil and gas assets with other industries was drawn.

On the other hand, this study provided with data concerning the contribution of maintenance activities to achieve goals successfully as well as the activities that may lead to failures and determine critical human factors. Besides, it delivered information about the complexity of such systems along with sources of performance variability.

Based on resilience engineering concepts and precepts stemming from the inherent literature review, a strategy to reach safety excellence in the maintenance of oil and gas facilities was designed through a gap analysis, questionnaires, and interviews with maintenance staff. To achieve this objective, a framework was developed. Resilience of the maintenance system was assessed to serve as a diagnosis of current situation by the determination of a maturity level and maintenance department profiles according to the four cornerstones of resilience: ability to respond, to monitor, to anticipate, and to learn (see Chapter 4), and to design strategies for improvement in a continuous way.

Based on the analysis of required information taken from related literature review and interviews of maintenance staff and HSE practitioners, MASRAT was outlined to measure the resilience of the system. The questions (statements) were then written accordingly.

Afterwards, MASRAT was tested and validated by means of congruency and principal components analysis, and Cronbach's alpha to determine respectively its content validity and reliability. An expert panel testing was carried out to test the usability of the tool where the four cornerstones of resilience are examined in three ateliers according to the critical human factors identified during the exploratory study.

For daily activities snapshot, the use of the Maintenance Environment Questionnaire imposed the retention characteristic of the data collected since the 36 questions begin with "At work in the last six months, on average, how often have you…"

To analyse the successful contribution of the maintenance system to achieve goals, there should be documented data. Actually, this is not the case; the only way to access such pieces of information is by means of storytelling. Therefore, the maintenance staff was approached by directed questions. People were asked to describe actions that necessitated local adjustments without which negative outcomes would have occurred but fortunately such actions have successfully ended and goals have been achieved. These actions are those that have been performed with lack of resources, or time, or competence, or knowledge, or altogether.

The only documented actions are those that ended by an incident/accident where investigations have been carried out without having access to reports; the only available data are numbers. For the study of archival data where data are available, ten years were found acceptable.

After the validation of the tool, data requirements currency should be current maturity level measurement each month where the inputs are:

- A review of available records,
- Past interviews,
- Focus groups in the form of ateliers,
- Anonymous questionnaires,

- Comments about existing and collected data, and
- Decisions about what users really do, what they use, and what they need.

A summary of data requirements is given in table 4.6.

Table 1-10: Data requirements

Objectives	Research questions	Research methods	Variables
Explore the maintenance working environment of SONATRACH	How is the maintenance system organised? How is the maintenance department linked to other departments? How are daily activities in the maintenance department performed? What are the impacts of maintenance activities on safety? How often accidents/incidents occur due to maintenance activities? How often maintenance activities contribute to achieve goals successfully? What are the main critical human factors in maintenance? In comparison to other industries, what is the profile of SONATRACH maintenance system? How complex is the maintenance system in SONATRACH? What sources of performance variability can be found in the maintenance system of SONATRACH? How functions are linked together and how do they interact?	Analysis of maintenance system documentation and process Interview with maintenance staff Questionnaire Functional analysis Field observations	Nature of maintenance activities Types of maintenance Staff experience Structure of the organisation Snapshot of daily activities for the last six months with respect to parameters such as resources, time pressure, defences, supervision, coordination, fatigue, etc. Things that went wrong Things that went right Profile comparison
Identify a strategy based on resilience engineering to achieve safety excellence in the maintenance system of SONATRACH	What framework may allow to achieve safety excellence in the maintenance system of SONATRACH? How can current situation be assessed? How can the resilience of the maintenance system be measured? How can the different profiles of the maintenance system of SONATRACH be identified? How can strategies for improvement be designed?	Framework Gap analysis Questionnaire Interview with maintenance staff	Current situation level of maturity Four cornerstones of resilience Maintenance system profiles

Data requirements (continued)

Objectives	Research questions	Research methods	Variables
Outline a tool to measure the resilience of the maintenance system of SONATRACH	What tool can be developed to measure the maintenance system of SONATRACH?	Analysis of required information to fulfil the aim and objectives from the literature and interview Writing the questions (statements) Questionnaire	Four cornerstones of resilience
Test and validate the tool	What kind of validation is required?	Carry out a content validity analysis Carry out a reliability analysis Structured interviews Expert panel testing Semi-structured interviews with participants and facilitators	Congruency Principal component analysis Cronbach's alpha Current situation level of maturity Four cornerstones of resilience Maintenance system profiles Next level of maturity

4.8.2. Data Collection

The data that should be collected and the way to collect them must be first specified. Then, the data collection procedures are identified. Data may be primary (that has been collected for the first time) or secondary (that comes from other researches or from manuals and reports, etc.). In this study, both were used. Data may be collected from three main sources: documents, observations, and interviews.

Yin (2009) identified six sources of data collection including documentation, archival records, interviews, direct observation, participant observation, and physical artefacts. Yin (2009) showed strengths and limitations of the six sources (table 4.8); if three principles relevant to all six sources are followed, then maximum benefits are yielded. The three principles of data collection linked to concepts such as reliability, triangulation, and quality control are: (1) the use of multiple sources, (2) the creation of a case study database of materials for later use by the researcher or interested others, and (3) the maintenance of a chain of evidence.

Table 1-11: Strengths and weaknesses of six sources of data (adapted from Yin, 2009)

Source of evidence	Strengths	Weaknesses
Documentation	• Stable-can be reviewed repeatedly • Unobtrusive-not created as a result of the case study • Exact-contains exact names, references, and details of an event • Broad coverage-long span of time, many events, and many settings	• Retrievability- can be low • Biased selectivity, if collection is incomplete • Reporting bias-reflects (unknown) bias of authors • Access- may be deliberately blocked
Archival records	• Same as above for documentation • Precise and quantitative	• Same as above for documentation • Accessibility due to privacy reasons
Interviews	• Targeted- focuses directly on case study topic • Insightful- provides perceived causal inferences	• Bias due to poorly constructed questions • Response bias • Inaccuracies due to poor recall • Reflexivity- interviewer wants to hear
Direct observations	• Reality- covers events in real time • Contextual- covers context of event	• Time consuming • Selectivity- unless broad coverage • Reflexivity- event may proceed differently because it is being observed • Cost- hours needed by human observers
Participant-observation	• Same as above for direct observation • Insightful into interpersonal behaviour and motives	• Same as above for direct observation • Bias due to investigator's manipulation of events
Physical artifacts	• Insightful into cultural features • Insightful into technical operations	• Selectivity • Availability

Accordingly, except physical artefacts, all the remaining sources were used in this research work.

The study dealt with the identification of strategies to improve current resilience maturity level of the maintenance system. It identified first the human factors in the maintenance environment of oil and gas assets. A variety of data collection methods could be used. Among these methods, observations, interviews, questionnaires, and quantitative performance or achievements were used to perform the evaluation.

To address the lack of data within SONATRACH, the impact of maintenance working environment on plant safety was investigated by adapting Hobbs' MEQ. The objective of the questionnaire is to gather information regarding the workplace conditions that promote unsafe acts as well as defences designed to manage human-induced hazards. By defences, the authors meant system elements that are intended to detect maintenance errors (Hobbs and Tada, 2006). The choice of such a tool was actually done to overcome the lack of data due to poor recording of failures, lack of trend analysis, poor communication, and blame and production driven organisational culture. The questionnaire was tested to determine its reliability and construct validity by means of Cronbach's alpha and confirmatory factor analysis (CFA). This analysis was performed on data collected in 2006 in English speaking countries (see Hobbs and Tada, 2006). On the other hand, the Functional Resonance Analysis Method, FRAM, which has been introduced in section 1.2.2, is an opportunity to explore how work is actually performed in real world by carrying out a functional analysis; therefore, it was used to perform a functional analysis. Storytelling was the third chosen method to explore the maintenance system environment.

Following this, the design of the required tool in the form of a questionnaire was the next step. The methodology that has been adopted to design the questionnaire included writing items and assembling/organising them. A number of principles have been taken into account during this design phase. They included the following. The wording of the questions/statements must be as clear and concise as possible about what is being studied. According to Lietz (2010), a general advice is to keep questions/statements as short as possible so that respondents' comprehension is increased. In addition, for Lietz (2010), maximum number of 16 words for each sentence (according to Brinslin, 1986) or 20 words for each sentence (citing Oppenheim, 1992) for English language, active rather passive voice, specific rather than general words, and the use of adverbs of frequency are recommended. Besides, it is not good practice to use negatively worded questions (Lietz, 2010).

Afterwards, field test for psychometric information needed to validate the tool was carried out to determine content validity and reliability. This was followed by a workshop to test the usability of MASRAT by experts from SONATRACH (Chapter 7). The use of questionnaires, interviews, documents, and observation were therefore the sources of data collection.

These activities required evaluation as stated previously. The main concerns were seeking (1) the implementation goal (s), (2) the activities during the implementation process, and (3) the values expected from the implementation. The information needed during the field test included to know if the tool was workable for the users in real world as well as if it achieved the goals for which it has been designed.

4.8.3. Data Analysis

There are actually two parts in analysing the data collected (notwithstanding the secondary data needed retrieved from the state of art literature review). The first part consisted of analysing the data collected to validate MASRAT, the developed tool. The methods used are explained in Section 4.8.4. It included a content validity analysis using item-objective congruence performed with a panel of experts (in this case, an index of congruency was computed to determine content validity) and principal component analysis. Then a reliability analysis was performed. SPSS software was used for the two last tests.

The second part concerned the analysis of MASRAT testing in a workshop where a panel composed of maintenance managers and engineers representing the main branches of the Company were invited to apply the tool. The analysis of findings was performed to find out whether the tool was workable for the users in real world as well as if it achieved the goals for which it was designed.

4.8.4. Validation

4.8.4.1. Content Validity

i. The Index of Item-Objective Congruence

The first operation consisted of a content validity. An efficient way to measure the assessment made by a panel of experts is the use of the index of item-objective congruence according to Turner and Carlson (2003). “This is a process by which content experts rate individual items based on the degree to which they measure specific objectives listed by the test developer” (Turner and Carlson, 2003, p. 164). The method consisted of measuring the adequacy of the 32 statements (representing the items, see Chapter 6 for more details) for three (03) factors and four (4) objectives (the cornerstones of resilience engineering). This was performed by giving the statement a score of +1 when the statement clearly measures the objective for each factor, -1 when clearly does not measuring the objective for each factor, or 0 degree to which its measure of the content area is unclear (the expert is undecided or uncertain). Factors and objectives are given in Table 4.9. For each statement, the expert attributed a value to each objective. An index ranging from -1 to +1 was then computed according to panel expert responses using equation (1) developed by Rovinelli and Hambleton (1977); a value of +1 indicates that all experts agree that the item is clearly measuring that objective (Turner and Carlson (2003). See Chapter 6 for more details.

$$I_{ik} = \frac{(N-1)\sum_{j=1}^{n} X_{ijk} - \sum_{i=1}^{N}\sum_{j=1}^{n} X_{ijk} + \sum_{j=1}^{n} X_{ijk}}{2(N-1)n} \qquad \text{Eq (1)}$$

Where:

Iik is the index of item-objective congruence for item k on objective i, N is the number of objectives (i = 1, 2… N), n is the number of content specialists (j = 1, 2 … n), and

Xijk is the rating (1, 0, –1) of item k as a measure of objective i by content specialist j

Table 1-12 : Factors and objectives

Studied factors	1. Resources 2. Time pressure 3. Supervision/coordination
Objectives (aspects)	Ability to respond: know what to do Ability to flexibly monitor: know what to look for Ability to anticipate: know what to expect Ability to learn: know to learn from past experiences

ii. Principle Component Analysis Approach

This analysis was carried out in order to test whether the items (statements) of MASRAT actually measure that for which they have been designed and to review these items according to the feedback and the statistic study. In other words, the objectives of this action were as follows:

- Do the set of items designed to measure for instance “the ability to respond” actually do it? (The same is performed for the other sets)
- What could be changed in the four sets of items according to the feedback and statistics data so that they can achieve what was intended?

According to Tabachnik and Fidell (2007), principal components analysis (PCA) and factor analysis (FA) are used by researchers to discover which variables in the set form coherent subsets that are relatively independent of one another by means of statistical techniques that are applied to a single set of variables; in other words, variables that are correlated with one another but largely independent of other subsets of variables are combined into factors. These methods are carried out to confirm/explore to what extent items (variables) in the assessment are correlated.

To conduct a PCA method, it is required to follow steps including (Tabachnik and Fidell 2007):

- The selection and measurement of a set of variables,
- The preparation of the correlation matrix,
- The extraction of a set of factors from the correlation matrix,
- The determination of the number of factors,
- The rotation of the factors to increase interpretability, and, finally,
- The interpretation of the results.

In the following, the steps carried out are given in more details.

a. Assumption of Normality

The first step of analysing a set of data is the assumption of normality. This can be performed by running Skewness and Kurtosis tests. Values for departure from normality, hence dismissal of variables, are given in the literature. For instance, West et al (1996) recommended an absolute skew value above two and an absolute kurtosis value above seven and Ferguson and Cox (1993), a cut-off of +/- 2 for both values. Neither Skewness values nor Kurtosis ones suggested any dismissal of variables; Skewness values ranged from -0.450 to 0.474 and Kurtosis ones ranged from -0.877 to 0.440. According to Henson and Roberts (2006), a correlation matrix is the most used by researchers in factor analysis. For the set of data studied, the correlation matrix showed a large number of correlations above 0.300.

b. The Factorability of Data

In this section, sample size requirement for factor analysis is addressed. There is a debate among statisticians about the accepted size of a sample for analysis. For Hale et al (1998), the more acceptable sample size would have a ratio of 10:1 and the minimum is a ratio of 5:1. In other words, the sample would have a number of respondents at least five times the number of variables to be accepted.

Before performing a factor analysis, two statistic tests should be carried out: the Kaiser-Meyer Olkin measure of sampling adequacy (KMO) and Bartlett’s test of sphericity. The factorability of data is regarded through these two tests to determine the strength of the relationship among the studied items. For Tabachnick and Fidell (2007), a KMO value above 0.6 is acceptable.

c. *Eigenvalues and Scree Test*

Two other criteria should be considered: the eigenvalues and the scree test. From a variance perspective, if the eigenvalue of a component is less than one, then it is not considered as important (Tabachnick and Fidell 2007). Eigenvalues above one rule is the most frequently used method (Henson and Roberts 2006) for the extraction of the maximum number of components. Quoting Thompson and Daniel, (Henson and Roberts 2006) wrote… "this extraction rule is the default option in most statistics packages and therefore may be the most widely used decision rule, also by default". Another criterion is the scree test of eigenvalues plotted against factors. It is considered by Tabachnick and Fidell (2007) as a reliable indicator for the most appropriate number of components to be extracted.

Ferreira (2011) suggested the use of the concept of "simple structure" described by Kline (1994) to select the most appropriate solution. According to Ferreira (2011), a simple structure is defined by the following principles:

- Each of the rotated matrix should contain at least one zero.
- In each factor, the minimum number of zero loadings should be the number of factors in the rotation.
- For every pair of factors, there should be variables with zero loadings on one and significant loadings on the other.
- For every pair of factors, a large proportion of the loadings should be zero, at least in a matrix with a large number of factors.
- For every pair of factors, there should be only a few variables with significant loadings on both factors.

d. *Rotation*

Rotation is carried out after the factor extraction in order to increase the interpretability and scientific utility of the solution because when rotation is not performed, the results of factor extraction are difficult to interpret regardless of which method of extraction is used. It is done to maximise high correlations between factors and variables and minimise low ones; it is not used to improve the quality of the mathematical fit between the observed and reproduced correlation matrices because all orthogonally rotated solutions are mathematically equivalent to one another and to the solution before rotation (Tabachnick and Fidell 2007). Varimax is a variance maximising procedure with the goal of maximising the variance of factor loadings by making high loadings higher, and low ones lower for each factor and orthogonal rotation using the Varimax method offers ease of interpreting, describing, and reporting resu1ts according to Tabachnick and Fidell (2007).

e. Interpretation

This step of principle component analysis addresses the interpretation of extracted components to characterise the meaning of each component. Once interpretability is adequate, the last, and very large, step is to verify the factor structure by establishing the construct validity of the factors (Tabachnik and Fidell 2007).

iii. The Choice between PCA and FA

Some issues are raised with regard to the use of these methods such as the nonexistence of readily available criteria against which to test the solution and the infinite number of rotations available, all accounting for the same amount of variance in the original data, but with the factors defined slightly differently, after extraction. The final choice among alternatives is then given to the researcher for interpretation (Tabachnik and Fidell 2007).

According to Rybakov and Marcoulides (2008), there exists some confusion with respect to principal components analysis and factor analysis in applied literature, probably due to a number of similarities that are exhibited by these methods. It is the reason why it is worth situating the differences. Table 4.10 summarises these differences.

Table 1-13: Differences between PCA and FA (adapted from Suhr, 2005; Rybakov and Marcoulides 2008)

Principal Component Analysis	Exploratory Factor Analysis
Principal Components retained account for a maximal amount of variance of observed variables	Factors account for common variance in the data
Analysis decomposes correlation matrix	Analysis decomposes adjusted correlation matrix
Ones on the diagonals of the correlation matrix	Diagonals of correlation matrix adjusted with unique factors
Minimizes sum of squared perpendicular distance to the component axis	Estimates factors which influence responses on observed variables
Component scores are a linear combination of the observed variables weighted by eigenvectors	Observed variables are linear combinations of the underlying and unique factors
A mathematical technique that does not allow for error terms as random variables and has no model underlying PCA	A statistical technique that utilizes specific error terms within a particular model
The resulting principal components are linear combinations of the observed variables	Factors are not linear combinations of the manifest measures

For Tabachnik and Fidell (2007), there are two major goals (and the motivation behind extraction) for using principal components analysis and factor analysis:

- To discover the minimum number of factor axes needed to reliably position variables
- To discover the meaning of the factors that underlies responses to observed variables.

The choice between principal components analysis and factor analysis depends on the interest of the researcher. For Tabachnik and Fidell (2007), principal component analysis analyses all the variance of the observed items whereas factor analyses deal rather with the covariance. Accordingly, principal component analysis was found more convenient and appropriate to achieve the objectives of this research work.

4.8.4.2. Reliability

The second action consisted of a reliability measure of the tool to check the internal consistency of data collected. In order to determine a tool’s reliability, Cronbach’s alpha is used. Cronbach's alpha is a coefficient of reliability (or consistency); it measures how closely related a set of items are as a group. Cronbach's alpha increases when the correlations between the items increase. It measures the internal consistency and shows the amount of measurement error in a test (Tavakol and Dennick, 2011). This coefficient ranges from zero to one; the nearest the value to one is, the highest the internal consistency of studied items. It calculates the correlation coefficient between items (statements). Cronbach's alpha is the most widely used objective measure of reliability because it is easier to use in comparison to other estimates (Tavakol and Dennick, 2011). Reliability estimates show the amount of measurement error in a test (Tavakol and Dennick, 2011). The index of measurement error is produced by subtracting from 1.00 the squared value of Cronbach's alpha. For instance, if the value of alpha is 0.80 then there is 0.36 error variance in the scores calculated as follows $1-(0.80)^2= 0.36$. When Cronbach's alpha increases, the error variance decreases

4.9. Ethical Issues

Ethical issues may arise during the research work itself as well as during the phase of writing (either writing the proposal, journal and conference papers, reports to management, or the thesis itself). The researcher must apply the principle of doing well and avoiding harm (Sanjeev and Khanna, 2009). Resnik (2011) presented five main reasons why it is important to adhere to ethical norms in research. They are summed up in the following:

- Promoting the aims of research, such as knowledge, truth, and avoidance of error.
- Promoting the values that are essential to collaborative work, such as trust, accountability, mutual respect, and fairness.
- Being held accountable to the public.
- Building public support for research.
- Promoting a variety of other important moral and social values

These principles have been linked to the research strategy and design adopted in this piece of work - a mixed method approach (case study and exploration of the maintenance environment of an oil and gas company) - where individuals are involved as well as data belonging to the company. The following important issues that might arise during this research work have been taken into consideration as thoroughly argued by Laerd dissertation (2012):

- Minimising the risk of harm
- Obtaining informed consent
- Protecting anonymity and confidentiality
- Avoiding deceptive practices
- Providing the right to withdraw

Moreover, before performing any interview or storytelling, the consent of interviewees was sought. These activities were completely anonymous.

4.10. Chapter Summary

The research strategy guiding the progress to achieve aim and objectives of this research work was outlined in this Chapter. Pragmatism paradigm was chosen as a philosophy underpinning such a research work. This study is descriptive and explorative. Its way of thinking is quantitative and qualitative as well. Case study and exploratory design were chosen for the research design. For data collection and analysis, investigative research questions were defined as well as appropriate research methods and required variables. Theoretical and empirical data requirement to ensure achieving the aim and objectives of this research work were identified. For testing and validating the developed tool, appropriate content and reliability methods were chosen. Formative and summative evaluations were selected to perform the evaluation of the implementation and field-testing. Mixed methods approach was adopted. In the next Chapter, the maintenance-working environment of SONATRACH is explored.

CHAPTER 5. EXPLORING THE MAINTENANCE SYSTEM OF OIL AND GAS ASSETS

5.1. Introduction

It has been revealed in the first part of this thesis that the impact of poor maintenance on industrial accidents has not been adequately examined in the oil and gas sector and research in the area of human factors in the maintenance in this industry is limited. The aim of this Chapter is to discuss and analyse the maintenance working environment of SONATRACH, the national Oil and Gas Company. This was performed by studying the impact of human factors in maintenance activities on safety as presented in section 5.2. The Maintenance Environment Questionnaire (Hobbs and Tada, 2006) was used to collect data; this tool gave a snapshot of daily activities and allowed to identify the critical human factors in the maintenance activities. The study was concluded by identifying human factors, highlighting the most significant ones, and showing the limitations of the questionnaire to respond to data requirements. Sections 5.3 and 5.4 complete the exploration of the maintenance system by describing how functions are linked together and how the elements of the system interact in order to show whether they are tightly coupled, hence the system is complex on the one hand, and what could be the sources of performance variability on the other hand. This was achieved respectively by conducting a functional analysis and by means of storytelling (see Chapter 4, section 4.7). The need to measure the four cornerstones of resilience engineering is addressed in section 5.5.

5.2. The Impact of Human Factors in Maintenance on Safety

The maintenance working environment is one of the most critical factors that affect safety within any industry that utilises physical assets. It is often the reflection of the combination of organisational culture and human behaviours. These are often overlooked when designing overall maintenance improvement strategies as too much effort is focused on hardware than people-ware (Ameziane et al., 2011). A review of pertinent literature regarding industrial accidents has revealed that most accidents were maintenance related (see section 2.3). Despite these records, there is a limited research in the area of human factors in maintenance management within the oil and gas industry and there is a need to overcome the unavailability of data.

Anonymous surveys are used to collect information on maintenance human factors that could not be obtained from the existing failure reporting systems. To assess the actual situation, a review of existing tools has been carried out (section 2.3). The Maintenance Environment Questionnaire, MEQ, (Hobbs and Tada 2006) has been found of interest since it might give a snapshot of daily activities with respect to human factors and allow a comparison between SONATRACH's profile and profiles from other industries.

The following sections critically assess the maintenance working environment within the Algerian National Oil and Gas Company by means of the Maintenance Environment Questionnaire, MEQ, (Hobbs and Tada 2006). It identifies maintenance human factors inherent in the current working environment.

5.2.1. Data Collected from the Maintenance Working Environment

To address the lack of data within the Company, the impact of maintenance working environment on plant safety has been investigated by means of Hobbs' MEQ (see section 4.7.2 for details regarding MEQ construct validity and reliability). To ensure data information was accurate, precautions have been taken. They include reviewing data entries (each data has been verified for accuracy and input meticulously when transferred from original questionnaire to spreadsheet and reviewed again after entry), double entering and proofreading the data, and administering the questionnaire simultaneously within a day in a given place. In addition, it has been ensured that the respondents were ready and willing to answer the questions and have clearly understood what was expecting from them as well as questions were clear enough. Moreover, Hobbs' MEQ has been translated to French (French is the speaking language within the Company).

The objective of the questionnaire as stated by Hobbs and Tada (2006) was to gather information regarding the workplace conditions that promote unsafe acts as well as defences designed to manage human-induced hazards (section 4.7.2). The Maintenance Environment Questionnaire was distributed anonymously to maintenance staff during first semester of year 2010, in March and April. Workers have received a set of 36 questions beginning all by "At work in the last six months, on average, how often have you ..." followed by the desired item. They were encouraged to report the frequency of specific workplace situations using a 5-point Likert scale ranging from "everyday" to "never". The items covered include defences, procedures, fatigue, coordination, supervision, equipment, time-pressure, and knowledge as suggested by Hobbs and Tada (2006). One hundred and fifty questionnaires were distributed out of which one hundred and twenty-two responses were received (57 engineers, 58 technicians and 7 not mentioned); this represented a response rate of 81%. Figures 5.1 and 5.2 give a distribution of the answers according to the nature of work for engineers and technicians.

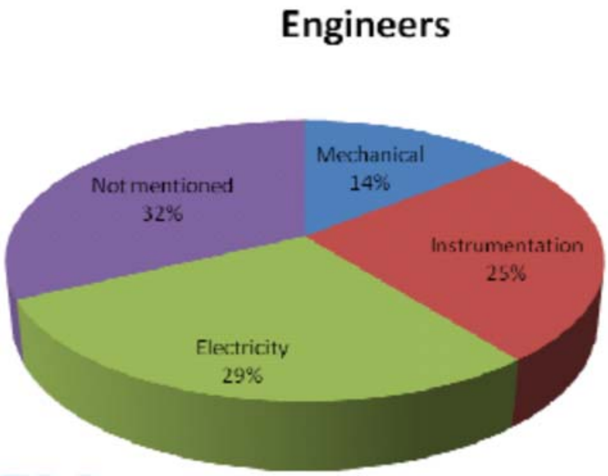

Figure 1-11**:** Distribution of the answers according to the nature of work for engineers

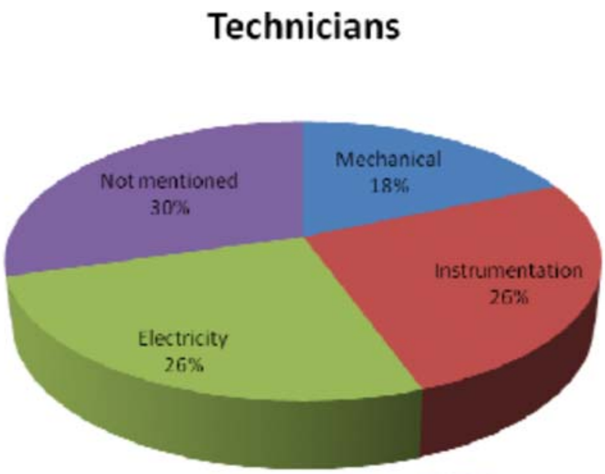

Figure 1-12**:** Distribution of the answers according to the nature of work for engineers

The information gathered from the questionnaires is discussed in the following subsection. The data presented in the following figures are for both engineers and technicians. Figures 5.3, 5.4, 5.5, and 5.6 provide samples of the MEQ and show the percentage of respondents that reported a situation occurred at least once in 6 months or more frequently for a given item.

5.2.2. Analysis of Data from the Maintenance Working Environment

The results of data collected were analysed by SPSS (STATISTICA). The analysis of responses to the MEQ gave a "snapshot" of everyday maintenance activities. Figure 5.3 shows the items that received the most frequent rating for a situation that occurred at least once in six months or more frequently with respect to the year of study (2010).

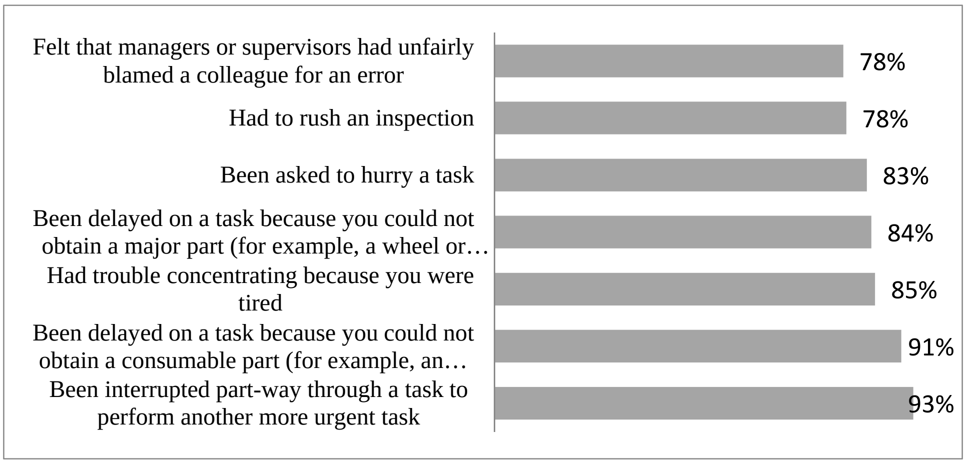

Figure 1-13**:** Percentage of respondents that reported the situation occurred at least once in 6 months or more frequently

Figures 5.4, 5.5, and 5.6 provide the percentage of respondents that reported the situation occurred at least once in six months or more frequently for equipment, time pressure, and supervision/coordination issues for the same period of time.

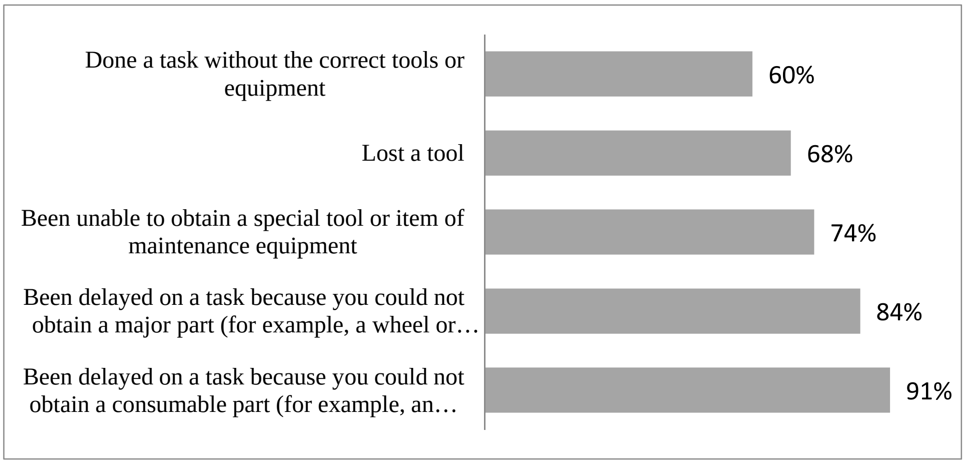

Figure 1-14**:** Percentage of respondents that reported the situation occurred at least once in six months or more frequently for equipment issues

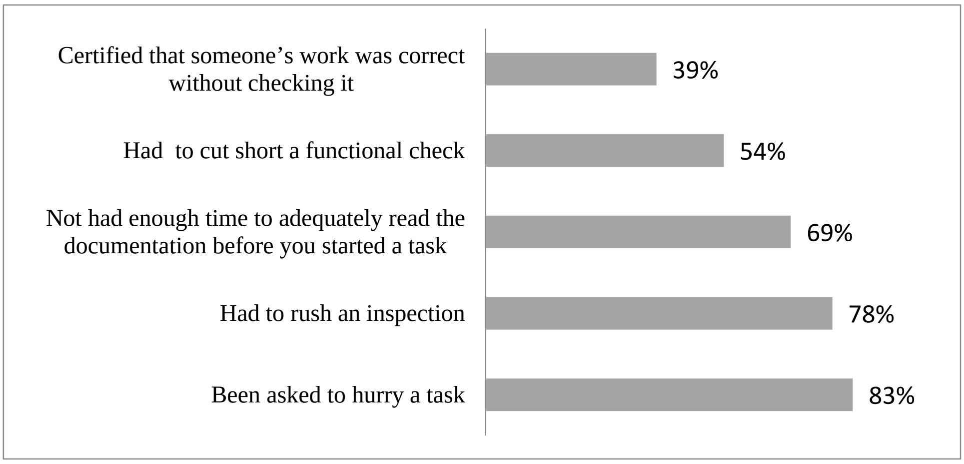

Figure 1-15**:** Percentage of respondents that reported the situation occurred at least once in six months or more frequently for time pressure issues

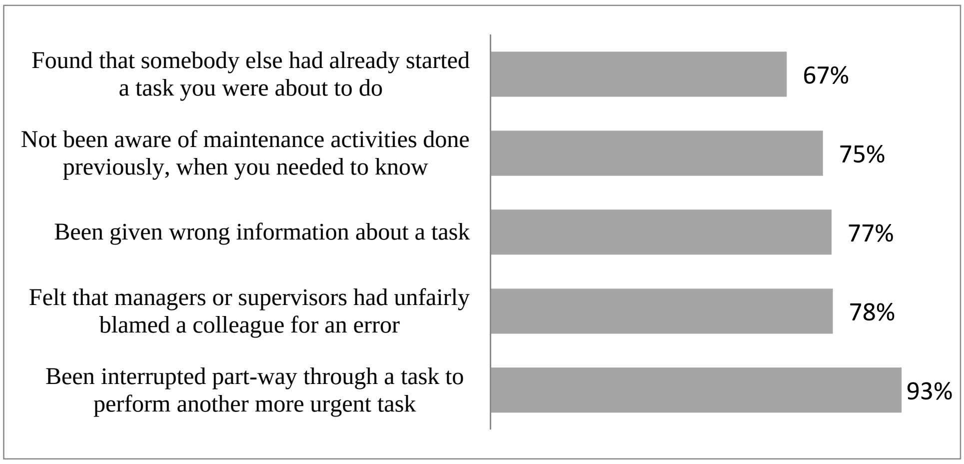

Figure 1-16**:** Percentage of respondents that reported the situation occurred at least once in six months or more frequently regarding supervision/coordination

5.2.3. Discussion

Examining closely the responses, the information collected could supplement the lack of data that was not available directly from the safety management system when implemented. The implementation of the Company's HSE management system (HSEMS) has already begun (February 2014) in the upstream branch (Exploration and Production) by a training program for the steering committees where the researcher is involved. Actually, the program content has been based on resilience engineering concepts according to the researcher's orientation. This has been found a great opportunity to introduce these concepts and make them embedded in the culture of the organisation.

If the analysis of the results was stuck to the underlying theory on which MEQ has been developed, then the result would be oriented towards looking up what may lead to maintenance "errors" and consequently towards accidents and undesired outcomes. Accordingly, items that received the most frequent rating resulted in the identification a priori of such issues. The results would be as follows.

Respondents highlighted enormous problems of equipment, time pressure, and supervision/coordination issues. For example, more than 93% reported they were interrupted partway through a task to perform a more urgent task. More than 90% said they had been delayed on a task because they could not obtain a consumable part. Procedures were underlined too. About 75% of respondents said they had used informal source of maintenance (e.g. personal notebook) and 67.23 % of them had difficulty understanding a maintenance document. More than 66 % of respondents reported they found an error in a maintenance document at least once in six months or more frequently. On the other hand, the MEQ questionnaire did not focus on the blame factor. Only one question dealt with this issue. 71.3 % of respondents felt that "managers or supervisors had unfairly blamed a colleague for an error" at least once in six months. According to this approach, factors such as lack or poor supervision, equipment issues, absence of or unworkable procedures, and time pressure/fatigue might push workers to find an easier and/or quicker way to perform tasks than the formal one. Moreover, mistakes might stem from coordination issues, inadequate training and supervision, procedures, time pressure/fatigue, and equipment deficiencies. This might be linked to parts damaged during repair, equipment or part of it wrongly installed, etc. Slips/lapses might derive from time pressure/fatigue and management pressure. Memory lapses such as leaving tasks incomplete might come from workers being under pressure or fatigue. As a result, maintenance working environment might generate conditions giving rise to accidents and causing harm. For the traditional approach, such behaviours are reprehensible or to some extent blameworthy for some managers. It is not the case in resilience engineering.

Analysing the results from a resilience engineering perspective helped find out and understand why things actually go right. As discussed in Chapter three (section 3.4), when things go right, two situations may exist. First, one that may lead to a drift toward hazardous states that necessitates barriers and the other that leads to positive outcomes that needs to be boosted. The MEQ gave a snapshot of work as performed daily by individuals under conditions that were characterised by finite resources, time, and knowledge. When people were asked about accident/incidents occurrences in their facilities (see examples given in section 5.4), the answer was generally no incident/accident, most accidents concern road accidents that happen out of the facilities. This meant that the human intervention actually prevented accidents occurrences most of the time. A study of the maintenance system based on resilience engineering is given in Chapter seven. Three significant factors identified by means of MEQ (resources, time pressure, and supervision/coordination) were studied by means of MASRAT.

Another interesting aspect of MEQ was that it allowed benchmarking profiles with other industries. Data from three other industries (electronic equipment maintenance, railway train mechanics, and airline) have been provided by Dr Allan Hobbs the designer of MEQ. The result of the SONATRACH MEQ profile was then compared to the profiles of these industries as shown in figure 5.7. The profiles showed that results were comparable even with different cultures and stage of country development. When drawing the profile, the scale ranges from zero to four where zero stands for never, and four for every day. From this benchmark, majority of items were comparable with some slight differences however. Especially, airlines and oil and gas industries gave quite the same frequency ratings on questions dealing with procedures, time-pressure, supervision/coordination, knowledge and defences whereas rail industry showed a slight higher frequency score regarding procedures and supervision. At the same time, rail and petroleum showed a slight higher frequency scores given by respondents to equipment item. On the other hand, all industries presented quite the same scoring for knowledge whereas electronic industry displayed a lower frequency score for quite all items except fatigue and time pressure where rail reported the lowest score.

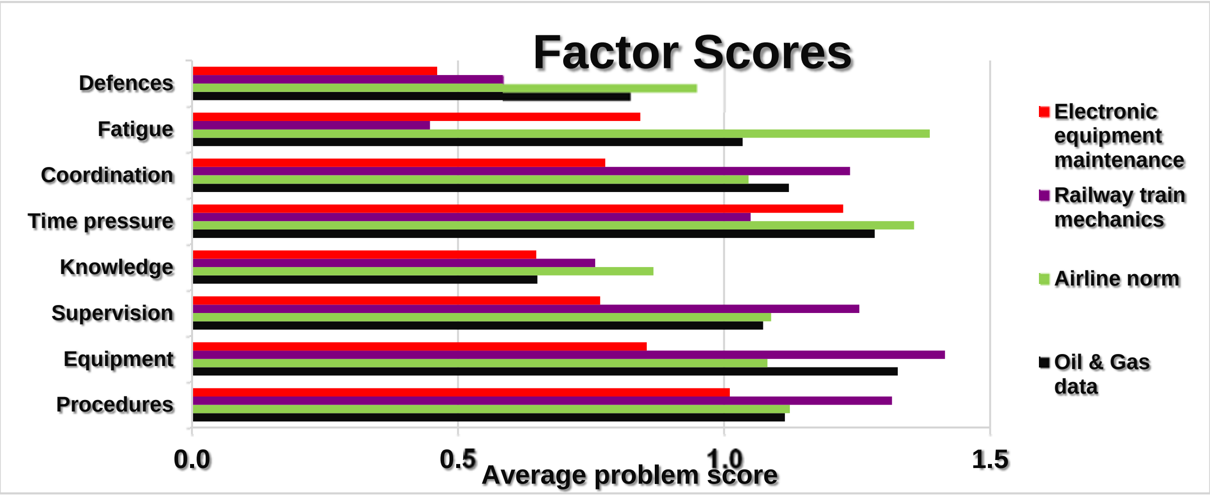

Figure 1-17**:** MEQ profile of SONATRACH compared with other industries

This comparison shows that for complex socio-technical systems, even with different cultures or different levels of country development, the results are comparable.

5.2.4. Limitations of the MEQ and the Way Ahead

The analysis of the responses to the Maintenance Environment Questionnaire (MEQ) gave a "snapshot" of everyday maintenance activities to guide organisation intervention. This study came up with the most significant human factors affecting maintenance activities within the oil and gas industry particularly in onshore activities. It showed the existence of important resources availability, time pressure, and supervision/coordination issues.

A number of questions that need attention rose from this study. These questions were directly linked to the chosen strategy to achieve excellence as presented in Chapter 6. In particular,

(1) Did MEQ allow performing a gap analysis as required by the framework?
(2) Did it identify strategies for improvement as required by the framework?
(3) Did MEQ study why things go right? Eventually,
(4) Was MEQ appropriate for complex safety critical systems such as the oil and gas industry?

Question 1

MEQ gave a rapid snapshot of daily activities to guide organisational interventions rather than intending to represent a precise evaluation of the state of the workplace according to Hobbs and Tada (2006). Since it was based on survey responses, there might be subject to biases such as memory effects, a reluctance to report issues, language ability, etc. (Hobbs and Tada, 2006). Hence, it could not be used to perform a gap analysis as required by the framework (Chapter 6).

Question 2

MEQ was developed to meet the need for a tool to gather information on everyday incidents and near misses in maintenance in a standardised form that could be statistically analysed to detect trends over time (Hobbs and Tada, 2006). It was an interesting tool to collect data from the working environment. Even though there might be a kind of statistical analysis to detect trends over time as carried out in the previous sections, it could not help identify strategies for improvement as sought by the framework.

Question 3

For Hobbs and Tada (2006), the focus of MEQ was on the identification and modification of error-shaping factors in the workplace in order to avoid accidents occurrence. This might look at things that go right but with the eye of seeking “errors” since systems were well designed and people well trained and behaved as expected to do according to this mind-set in addition to available resources and time. It is actually not the case of resilience engineering that considers the performance variability as an asset (Chapters 3, 6, and 7). According to resilience engineering approach, things go right because people can adapt or adjust their performance to the demands, because they can interpret and apply procedures to match the conditions, and because they can detect and correct when things that go wrong (Hollnagel, 2012a). For Hollnagel (2012a), people must be considered as a valuable asset without which the proper functioning of modern technological systems would be impossible.

Question 4

The conditions under which workers performed their tasks were focused on by MEQ without delving into the wider organisational or cultural issues that created these conditions (Hobbs and Tada, 2006). Actually, the use of MEQ was directed at finding what might be done to avoid workers’ “errors”, that is, constraining human intervention since it was not seen as an asset as stated previously. In complex critical systems, it is required to study why and when the human performance varies and to understand the consequences of this variability and how to control it (Hollnagel, 2012a). The performance variability that may lead to negatives outcomes should be stopped before it drifts toward hazardous situation and the one that may lead to positive outcomes should be boosted and reinforced.

MEQ is a tool that helped gather data related to the maintenance working environment but it was not appropriate alone for complex safety critical systems such as the oil and gas maintenance-working environment. Therefore, the need for more appropriate tools that allow a thorough investigation and answer the questions regarding performance variability was highlighted.

5.3. Functional Analysis of the Maintenance Activity

This section explores the maintenance system by describing how functions are linked together and how the elements of the system interact. To carry out this action, a functional analysis by means of the functional resonance analysis Method, FRAM, was carried out.

5.3.1. Purpose of Analysis

As stated previously (Chapter four, section 4.5), this study was an exploratory one and the FRAM method was used to investigate the maintenance system of the national Oil and Gas Company in order to find how functions within the system were linked together, how they interacted, and how complex the maintenance system was.

5.3.2. Functions in the FRAM

Functions describe an activity not a task according to Hollnagel (2012b) i.e. something that can be done or is being done. These functions are characterised by means of the FRAM functional unit (figure 1.2, Chapter 1); this way helps understand how the performance of these functions/activities may vary. Functions vary in the way they are carried out rather than because they fail (Hollnagel, 2012b). For Hollnagel (2012b), functions may be seen as upstream/downstream functions or foreground/background ones. Upstream functions occur before downstream ones as their names show; therefore, they may affect them. They refer to a temporal relation between these functions. Foreground/background functions refer to the relative importance of any function. Foreground functions denote the output that is being analysed whereas background functions contribute to the performance of the system; in this sense, performance-shaping factors (PSF) are considered background functions (Hollnagel, 2012b). Background functions contribute to the working environment and provide support and means for foreground functions (Hollnagel, 2012b; Macchi, 2011). Background functions are identified from the description of foreground functions.

5.3.3. The Maintenance Department within SONATRACH

To study the maintenance activity, the maintenance system procedures were reviewed, field visits and observations done, and interviews with experienced personnel carried out. During these visits, people were asked to answer the following questions:

- How is the maintenance department organised?
- What is the role of each section within the department?
- What process is followed when performing a maintenance task (either preventive or corrective task)?

The maintenance department is organised as follows. Facilities are under production department responsibility. Maintenance department provides counsels and help. Production department issues work demands; it determines priorities. There are actually five priorities for maintenance work:

- P1, the job must be started immediately since there is a risk for people, the environment, or the facility; any other work is stopped; maintenance staff work without preparation/scheduling and do not care about costs for such activities.
- P2, an imminent risk may face people, the environment, or the facility. No more than 24 h delay are allowed; partial preparation is required; any P3 work is stopped or postponed.
- P3, careful preparation/scheduling in order to respect time; work procedures are followed.
- P4, work to be done during normal shut-down
- P5, work is postponed because of lack of personnel, tools, or spares, etc.

Production staff is responsible vis-à-vis maintenance since there is a constant monitoring of equipment status, an anticipation of maintenance needs, a clear description of nature and scope of work, availability of equipment for maintenance, etc. On the other hand, maintenance is responsible vis-à-vis production since work is executed according to state of the art, preventive maintenance is developed and respected, production is informed about spares and critical equipment status, etc.

There are four sections in the maintenance department: preparation, planning/scheduling, statistics, and execution (crafts). The objectives of preparation are to provide the operating procedures, necessary time, and required means. Long-term and repetitive activities are prepared by defining safety precautions, required resources (equipment, tools, and spares), necessary human resources, and estimated time to carry out the activities. P2 work is prepared for the day in question and P3, P4, and P5 work according to the deadline. The role of this section is also to manage the work and improve the way it is performed. The roles of planning/scheduling section are to prepare daily work scheduling for preventive maintenance, normal shutdown and exceptional work, measure human resources need, provide necessary information to measure performance and costs of maintenance. This is work as imagined.

It is not within the scope of this thesis to perform a thorough study of the system. An example is taken into account to show that the maintenance system of an Oil and Gas Company is very complex The example in question concerns a study of a piece of equipment that is, a turbo-compressor for refrigeration in an LNG plant.

5.3.4. Function Characterization

Based on what was said previously in this section, a turbo-compressor for refrigeration in an LNG facility, which is strategic for the plant, was studied to identify the complexity of maintenance activities. The scenario addressed was a breakdown in the compressor noticed by operators. The breakdown was reported and a request for an inspection was made. Then, the maintenance system procedure was unfolded. Twenty-eight functions were identified out of which nine functions were considered foreground functions and the others background ones. They were characterised by the six parameters of the FRAM unit (section 1.2.1) and presented in appendix 2. The consistency and completeness of the study was checked by verifying that same aspects referred to the same names or labels and that all aspects describing a function should be included in other functions as one or more of the aspects that characterised the function.

For instance, excessive vibration of the turbo-compressor (e.g. in the spacer couplings) might cause the shutdown of the equipment either automatically or manually by operators. This excessive vibration could be due to a bad grease operation, axial movement of the rotor (process), or wear in the bearings, etc. If the intolerable threshold of vibration was attained, a shutdown of the LNG train would take place, provoking variability in the system. If this situation happened during winter where the demand on LNG is very high, the pressure on all staff became critical. In the case of all functions performed as imagined, the outage would last eight to ten days; this was actually a big loss. As explained earlier in this section, this action was considered priority P1 which meant any other function was put aside by staff so that they could join the rest of the personnel to solve such an issue; two or three teams would work 24h/day to restart the LNG train in an optimum time.

The instantiation of the relations between the inputs and outputs of the functions are given in appendix 2. It can be seen that a negative variability of outputs of functions might lead to increase the duration of the shut-down of the LNG train or might generate in the future another non-planned shut-down which in fine costs a lot of money for the Company. Since the refrigeration turbo-compressor was a strategic piece of equipment that was not redundant, this variability was affected mainly by the availability of resources. Lack of spares and inadequate tools and equipment might lead to safety margin reduction and/or operational capability of the plant. The organisational culture affected these functions (strategy- production first, procurement procedures, etc.). The available time (time-pressure) to perform assigned tasks which was very common since the organisation is somewhat reactive (many tasks are done urgently), the supervision/coordination issues, the stress due to lack of necessary knowledge or experience to do an assigned task, and the absence of a vulnerability model were other sources of variability. The trade-off production/safety went towards satisfying production aspects. This might lead in fine to the systematic loss of safety defences. This is particularly emphasised is Chapter 7.

On the other hand, even though such variability was noticed, it is worth highlighting the positive aspects characterised by the adaptation of people to the environment as well as actions to change this environment to perform required activities despite lacks (adaptation to lack of documentation, training, spares, etc.). The organisation as a whole also adapts to maintain a certain “health” of facilities to respond to production goals and objectives.

The use of the FRAM was only for an exploratory purpose of the maintenance system. The method could allow to perform a gap analysis; consequently, the variability of functions has not been measured in this study. However, some barriers and specific performance monitoring of variability were proposed. At company level, the implementation of management systems (HSE, maintenance, etc.) and the acceleration of the introduction of the new permit to work system were judged of great importance. In addition, regulations regarding spares procurement should be evaluated and reviewed. The use of fully exploited information system for the maintenance management system could be the sought damping factors to prevent any undesirable future events stemming from maintenance activities.

The strategic objectives might be: maintenance effectiveness, maintenance activities cost-effectiveness, the improvement of equipment availability through improved maintenance materials/tools/equipment management, and the insurance of suitable training levels to fulfil the required missions. Performance indicators should be designed to follow up these objectives. Since FRAM method deals with functional resonance, the indicators should follow the same concept. Therefore, these indicators should be functional indicators. Examples of indicators include (Márquez, 2007):

- Maintenance effectiveness (the follow-up of the number of critical assets, the number of repetitive failures for those assets, the total number of failures and the reduction in preventive maintenance tasks, percentage of preventive maintenance),
- Maintenance cost-effectiveness (compliance to maintenance planning and scheduling, quality of work and learning, etc.),
- Equipment availability (spare parts service level, spare parts turnover and urgent purchase orders released), training level per each maintenance level.

Additional strategies for improvement at both department and corporate levels are discussed in Chapter 7.

5.3.5. Limitations of FRAM and the Way Ahead

The same questions regarding MEQ were applied for the use of the FRAM. In particular,

(1) Did the FRAM allow performing a gap analysis as required by the framework described in Chapter 6?
(2) Did it identify strategies for improvement as required by the framework?
(3) Did it study why things go right? Eventually,
(4) Was it appropriate for complex safety critical systems such as the oil and gas industry?

Question 1

It was not the purpose of the FRAM to perform a gap analysis as required by the framework. The FRAM is rather used to carry out a risk assessment, an accident investigation, or simply to explore a system by finding how functions are linked together and how they interact to identify the variability of the outputs of these functions; in fine, how they may resonate.

Question 2

Actually, the FRAM allowed identifying strategies for improvement by finding dumping factors and specific performance monitoring of variability. However, the research aimed at identifying strategies that might lead the system to excellence. This is developed in more details in Chapters 6 and 7.

Questions 3 and 4

The answer for these questions was yes. The FRAM method uses a systemic approach based on the precepts of resilience engineering as stated in Chapter 3. This method is still under development. Hollnagel (2012b) highlighted the need to develop a way of calculating the magnitude of functional resonance. The use of the Fuzzy Cognitive Maps (FCM) is something that needs exploration

5.4. Storytelling

After the use of the Maintenance Environment Questionnaire and the FRAM method, storytelling was used to collect some missing data, particularly sharing experiences about positive actions (things that went right) performed by maintenance staff generally characterised as "taken for granted" or "people are only doing their job"; hence they did not need to be documented. Moreover, this method gave valuable information that made the storyteller feeling proud of what he (she) did. It particularly provided rich contextual data (Herrera, 2012).

5.4.1. Use of Storytelling

Among the different uses of storytelling, it is particularly used to share knowledge and experiences (Stewart, 1998; Sole and Wilson, 2002), to understand current situation, to anticipate possible futures, and to prepare the organisation for action (Snowden, 1999). Therefore, the main objective of storytelling method was to collect data that could not be known. The objective was also to let people share their experiences and be proud about what they accomplished.

The storytelling method was used to overcome the lack of recorded data to share experience about things that went right/wrong. Prior to interviewing maintenance staff, the resilience engineering approach was explained to the interviewees. Consent was requested so that the story recorded was anonymous regarding the storyteller and the location where this occurred (see Chapter 4). The interviewees were free to say what they want orally or to write stories that happened in their facilities. In quite all stories, actions were generally carried out in coordination with members from other departments (production and HSE). Stories were recorded when the consent of the interviewees was obtained or when they accepted to write stories on paper.

Part of the seminars delivered by the researcher in his professional activity was devoted to discuss (group interviews about sharing positive actions) as well as during the workshop ateliers (see Chapter 7). After the presentation of the approach, people were asked to tell stories about what they experienced and try to answer why the number of accidents/incidents was low. Was it because individuals hide the truth? Or they simply made local adjustments to achieve goals by accomplishing positive actions. The stories generally showed that work was not carried out as imagined.

Two kinds of actions were performed. When it was possible to have direct contact with maintenance personnel like training sessions for HSE MS, direct interviews and discussions occur. When this was not possible, the same questions were sent to individuals. There have been 20 training sessions; 15 persons on average attended each session out of which 03 to 04 people were maintenance personnel together with personnel from other departments such as production, HSE, and human resources.

5.4.2. Examples of Stories

In the following subsection, excerpts of stories told orally or in a written form are given. Two air instrument compressors have been acquired without instruction manual. One of this important equipment broke down one day so that it necessitated an overhaul. The constructor of the compressor was contacted to provide with the manual. The constructor refused to provide with the manual and required that his staff will carry out the maintenance. Since the equipment was very important and there was an emergency, the maintenance team decided to perform the overhaul. After three days of hard working, they successfully did the job and the testing was conclusive. This action allowed saving time, money, and made the equipment available.

As specified many times in this thesis, maintenance staff often work under pressure, particularly they are asked to perform their job without stopping production. Numerous daily actions have been carried out successfully without stopping production and without incidents. They include for instance:

- Changing valves
- Changing level transmitters
- Fire and Gas signals transfer to new system without incident
- Changing jockey pumps (fire-fighting system) warranting safety by means of the diesel pump
- Switching from existing electrical lines to new ones without stopping electrical equipment

According to a chief mechanics, local adjustments were daily actions performed by maintenance staff. These adjustments such as adding a support to better hold something, adding a current shunt to the ground cable to earth, or designing a specific tool went generally unnoticed. In the following example, shortcuts were made to carry out a maintenance task. It concerned a gas turbine which stop will lead to a loss of production estimated to 1500 barrels per day. Every 48000 operating hours, a major inspection is performed on this equipment. A contractor, that is the machine manufacturer, does the activity. There are four steps in the major inspection: (1) dismantling of the equipment, (2) inspection, (3) remounting, and (4) final testing. During the second step, the contractor judged a mechanical part (the diaphragm) non-repairable and must be changed. There was no spare part, on the other hand the acquisition of a new spare necessitated a long time that was not convenient. A decision was made by management to bypass the procedure, repair the diaphragm, and reuse it. Maintenance staff performed the task and the contractor had an order from management to reuse the diaphragm and finish the major inspection. The latter was carried out until the end and the gas turbine was returned to service to a new life cycle. A new diaphragm was ordered which will be replaced by five years!

5.4.3. Storytelling Limitations and the Way Ahead

The same questions regarding MEQ and the FRAM were applied for the use of the storytelling method. In particular,

(1) Did it allow performing a gap analysis as required by the framework (see Chapter 6)?
(2) Did it identify strategies for improvement as required by the framework?
(3) Did it study why things go right?
(4) Was it appropriate for complex safety critical systems such as the oil and gas industry?

Question 1

As per the other methods, storytelling was not intended to carry out a gap analysis; hence, it could not be used as required by the framework developed in Chapter six. It was rather used to complement the other data collection methods.

Question 2

Again, it was not the case; it was used to put a stress on missing data that could be collected qualitatively by means of interviews.

Question 3and 4

Yes, in both cases. Researchers (Herrera, 2012) have already used it.

5.5. The Need to Measure the Four Cornerstones of Resilience Engineering

Resilience engineering aims at focusing not only on proactivity but has the ambition of being proactive in a systemic sense as well moving beyond classical components and failure orientation to deal with systems and anticipate behaviour at system level (Rosness et al., 2010). According to Hollnagel (2014), it is of great importance to understand how a system functions rather than how it is structured and it is both easier and more effective to manage risks and sustain existence by improving the number of things that go right, than by reducing the number of things that go wrong. Concisely, it is the ability to make the correct adjustments to match actual conditions.

For a system to be safe, it must be resilient. A practical way for resilience engineering is to consider the four abilities (the four cornerstones), none of them can be left out if a system wants to call itself resilient. Hollnagel (2014) illustrated the couplings of the four abilities as shown in figure 5.8, where the ability to anticipate what may happen in the environment, now and in the future, is essential for the system's survival. Consequently, the need to know the four abilities by measuring these abilities was emphasised. Developing and validating a tool based on resilience engineering precepts that measures the four abilities as shown in the previous Chapters and the sections of this Chapter was judged of great importance.

In this research work, such a tool was developed and validated (see Chapters 6 and 7). The tool was used to perform the gap analysis as required by the developed framework that aimed at bringing the maintenance system from actual situation to safety excellence. It allowed achieving objectives 3 and 4 of this piece of research

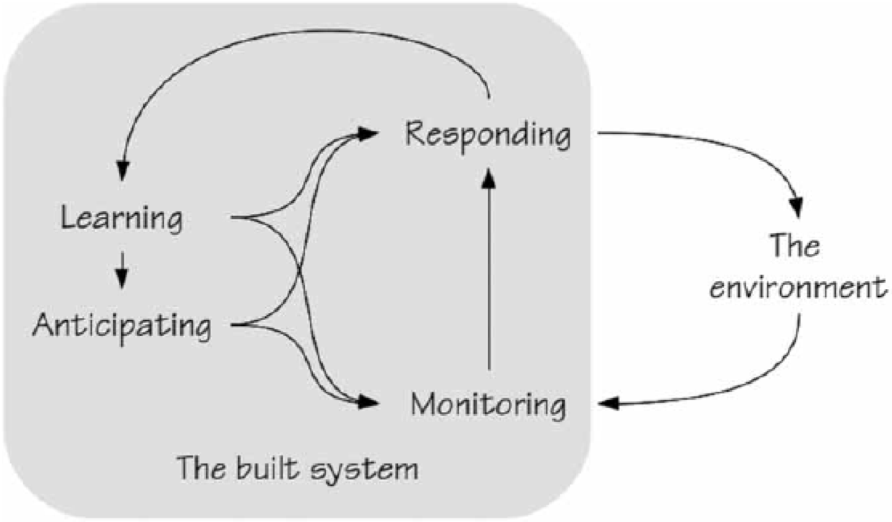

Figure 1-18**:** The dependencies of the four cornerstones adapted from Hollnagel (2014)

5.6. Chapter Summary

In this Chapter, the maintenance environment of SONATRACH was explored by means of three methods that complement each other. Using the Maintenance Environment Questionnaire, a survey of SONATRACH maintenance system was carried out. This survey came up with a snapshot of daily activities and allowed identifying critical human factors and their impact on safety in the maintenance of oil and gas assets. It permitted also identify the most significant factors that will be investigated by means of the developed tool based on resilience engineering precepts (see Chapters 6 and 7). Moreover, in this Chapter the limitations of MEQ to respond to the framework requirements (Chapter 6) have been highlighted. The FRAM method was used then to describe how functions in the maintenance system of an Oil and Gas Company are linked together and how the elements of the system interact. The method that is still under development contributed to understand better the system. It showed the system elements were tightly coupled; hence, the system complex. A third method was used afterwards to complement the two others and to let people tell their experiences and share them with others, particularly positive actions (things that went right). Eventually, the need to measure the four cornerstones of resilience engineering was shown. Next Chapter will address objectives 3 (identify a strategy based on resilience engineering to achieve safety excellence in the maintenance system of SONATRACH) and objective 4 (Outline, test and validate a tool that measures the resilience of Oil and Gas maintenance systems) by developing a strategy to achieve excellence in the maintenance system of SONATRACH and outlining a tool that measures the resilience of Oil and Gas maintenance systems with respect to the most significant identified factors.

CHAPTER 6. DEVELOPMENT OF A MAINTENANCE SYSTEM RESILIENCE ASSESSMENT TOOL

6.1. Introduction

To achieve safety excellence, there is a need to know actual situation and identify strategies for improvement. This can be attained by performing a gap analysis using the appropriate tools and doing the correct assessment that is, the use of a systemic approach based on resilience engineering precepts. It has been shown in Chapters 2 and 3 that industrial systems have become more complex and traditional risk assessment techniques as well as accident causation models have failed to handle such systems. Only a systemic approach based on resilience engineering may address properly such systems. Resilience engineering deals with such an approach. The objective was therefore find out how to make a system become AHRAP (see Chapter 3). This might be achieved by knowing the four cornerstones of resilience as outlined by Hollnagel (2009b) that is the ability to respond (R), to monitor (M), to anticipate (A), and to learn (L) and increase these abilities. Instead of seeking only to avoid and/or eliminate failures (Hollnagel, 2010a), it is worth measuring the resilience of the system in order to find ways to increase each of these abilities to achieve excellence.

On the other hand, in Chapter 5, the most significant factors that impact activities in the maintenance system were identified by exploring the maintenance working environment of oil and gas assets. Among these factors, three were particularly highlighted; resources, time-pressure, and coordination/supervision.

The aim of the Chapter is to achieve objectives three and four of this research work. A strategy, through a framework to achieve safety excellence, is first outlined in section 6.2. The development and validation of the designed tool that allows implementing the framework, the MAintenance System Resilience Assessment Tool, MASRAT is addressed respectively in sections 6.3 and 6.4. Section 6.5 links the results to research objectives.

6.2. A Framework for Safety Excellence

As explained in the research method process (Figure 4.2, Chapter 4), this phase dealt with the development of the tool that allowed to achieve objectives (3) and (4, part 1) of this research work (see Table 4.9, Chapter 4). A general framework to achieve safety excellence was developed to achieve these objectives. To reach safety excellence thus, a long journey toward continuous improvement, a gap analysis using the appropriate tools based on resilience engineering precepts and doing the correct assessment might be performed. Figure 6.1 illustrates this view. A continuous improvement loop that consisted of the assessment of current situation by appropriate tools to identify strategies for improvement was required.

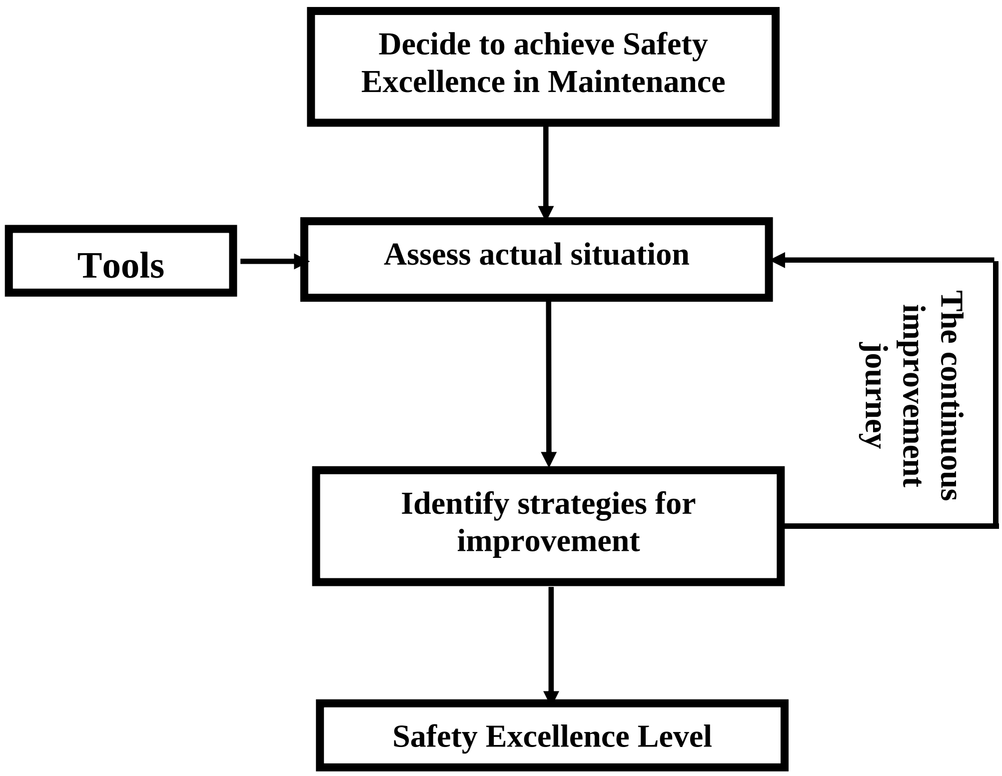

Figure 1-19: A framework for safety excellence

From this generic framework, a more specific and detailed one was designed and tailored specifically to the maintenance system of industrial assets (Figure 6.2). It consisted of a gap analysis. First, a decision to achieve safety excellence was taken. Then, a diagnosis of the situation was carried out with respect to the four aspects of resilience to establish a maturity level (MAL) and identify strategies that may lead a system from a given level to maturity excellence level (MEL) for each of the three factors already identified in Chapter 5. Such an assessment required the development of a tool, a management tool that assesses the resilience of the maintenance system. This tool, the MAintenance System Resilience Assessment Tool, MASRAT, was developed based on the exploration of the maintenance environment system, the literature review, and particularly the probing questions proposed by Hollnagel (2010a); the details are given in section 6.3. It permitted determine the ability of the system to respond to threats/opportunities i.e. know what to do, to monitor flexibly i.e. know what to look for, to anticipate any development i.e. know what to expect, and to learn i.e. know to learn from past experiences. By means of MASRAT, the assessment provided with profiles such as the MAintenance Resilience Department Profiles (MARP), and Maturity Levels (MAL). These profiles were analysed by means of a SWOT analysis to determine strategies for improvement through the identification of opportunities to enhance MAL as well as barriers and required performance monitoring specification (see Chapter 7).

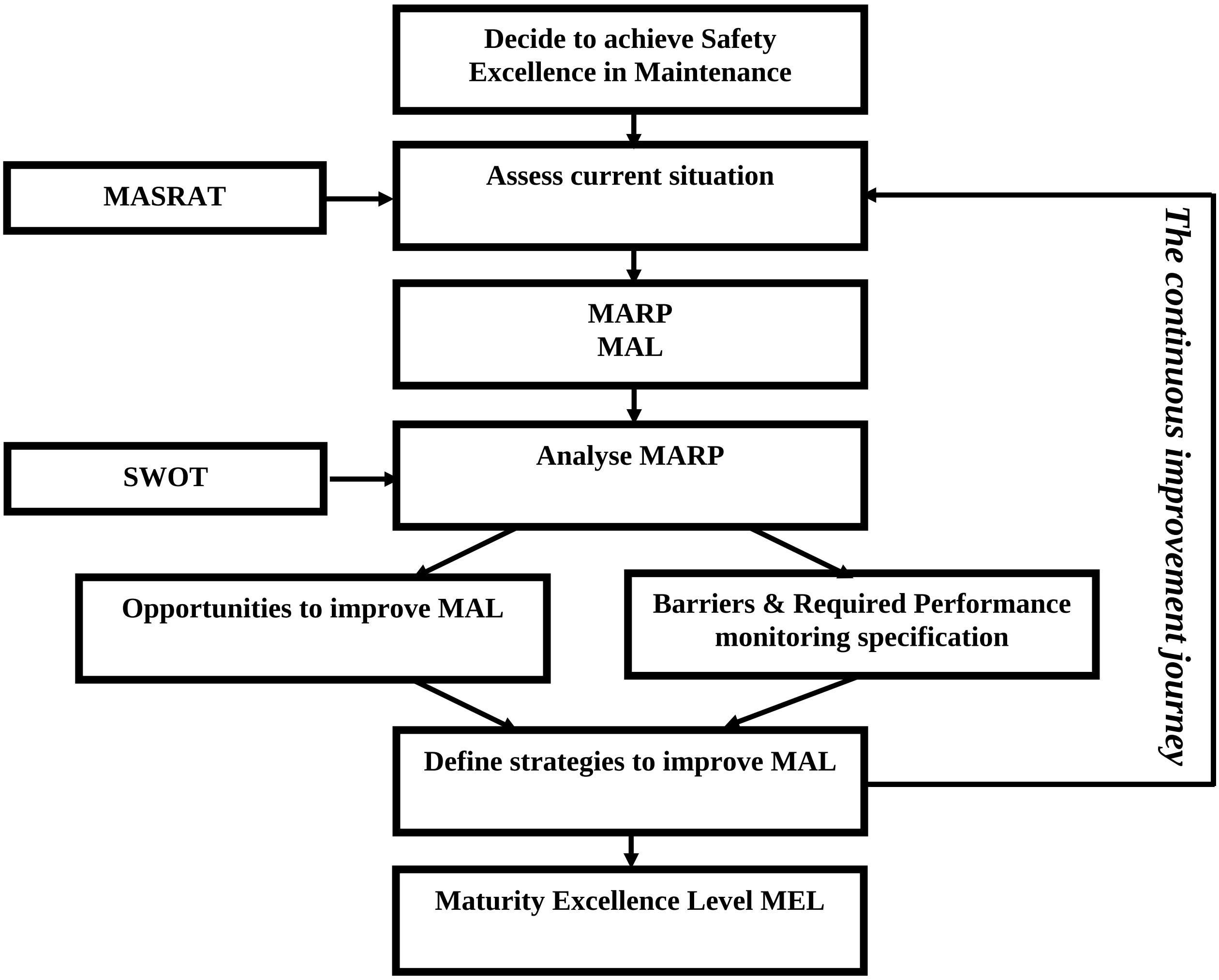

Figure 1-20: A framework for safety excellence in the maintenance system of oil and gas asset

The development phase of MASRAT was performed in three 03 steps. First step was the identification of human factors. This was followed by the creation of the items. Last step was the tool design. The aim of this research work was to identify a strategy based on resilience engineering to achieve safety excellence. The challenge was therefore how to manage properly such a situation in order to reach this goal. The precepts of resilience engineering have been presented in details earlier in Chapter 3, Section 3.4. As safety is treated as a core value, not a commodity that can be counted, a resilient organisation is also safe; in order to be resilient, an organisation must be able: (1) to respond to threats/opportunities i.e. know what to do, (2) to flexibly monitor i.e. know what to look for, (3) to anticipate any development i.e. know what to expect, and (4) to learn i.e. know to learn from past experiences (Hollnagel, 2010b). A tool that allowed measuring these four aspects is presented in the following section.

6.3. The Development of MASRAT

The need to develop something different based on a systemic approach was highlighted in the previous sections. This should be in adequacy with the dynamic movement of the society characterised by (1) fast changes in technology, (2) ineffective approaches to accident investigation and prevention, and (3) the need to include interactions of socio-technical system elements.

Based on the exploratory survey of the Company maintenance environment (Chapter 5), interviews, large consultation of maintenance managers and HSE practitioners within the Company, and the literature review (Chapter 2), a list of 24 factors was identified (see table 6.1). These factors were considered as human factors that influence organisation behaviour. Each of these factors might be studied alone in order to determine system's resilience allowing the identification of improvement strategies from resilience profiles of each of the four aspects of resilience. Table 6.1 below gives a list of the human factors (factors/issues used in the same way) that were identified at corporate level.

Table 1-14 : List of human factors

Category	Factors
Corporate organisational factors	• Clarification of organisational missions and vision • Adequacy of identification, definition, and communication of organisational values and principles • Leadership & accountability within the organisation • Clarification of roles & responsibilities within the organisation • Policies, procedures, and practices foundation upon mutual trust and respect • Adequacy of communication (means & practices) within the organisation • Recognition, reinforcement, and reward of safe behaviour • Community & stakeholders' awareness • Adjustments after disturbances
Elements of the HSE MS factors	• Management of HSE hazards • Management of occupational health • Environmental management • Accident/incidents analysis & prevention and past incidents responses effectiveness • HSE investments • Crisis & emergency management • Management of change • Contractors' management issue
Working environment factors	• Fatigue/workload/personnel motivation issue • Time pressure issue (tasks performed urgently, short-cuts, rushed activities, etc.) • Knowledge/competence issues • Procedures/documentation issues (personnel document understanding, document errors, personnel compliance with rules/procedures, etc.) • Supervision/Coordination issues • Conditions of work (heat, noise, etc.) • Resources availability (planned and easy to obtain)

As explained in Chapter 4, Section 4.8, data requirements section, questions were written first. The questions content was based on the related literature review and the analysis of interviews of maintenance and production experienced personnel and HSE practitioners. During these interviews, the resilience engineering approach and the four cornerstones of resilience were presented and explained. The approach was adopted immediately and found a very innovative one that is worth exploring and encouraging.

Afterwards, these persons (maintenance, production, and HSE managers as well as maintenance, production, and HSE engineers) were asked to give their opinion about the set of questions individually; their consent was requested each time to take notes. The need to measure the four cornerstones to establish the resilience of a system has been highlighted from the literature. In addition, Hollnagel (2010a) raised probing questions that might help design a basis for measuring system resilience. Besides, the exploratory study of the maintenance system of SONATRACH highlighted some factors that were deemed important. Grounded in these elements, a set of questions was designed. Examples include the set of questions given in table 6.2.

Table 1-15 : Designed questions according to aspect and factor

Questions	Aspect (ability) addressed for a given factor
Have you performed analyses to establish prepared responses to fatigue issue?	Respond to fatigue
Have you investigated time pressure issue within the organisation?	Respond to time pressure
Do you have prepared responses for time pressure issue?	Respond to time pressure
For time pressure issue, do you apply any criteria for activating a response?	Respond to time pressure
For time pressure issue, do you evaluate systematically your responses by testing them onsite?	Respond to time pressure
For time pressure issue, have you established effectiveness speed response?	Respond to time pressure
Has the maintenance department performed analyses to establish prepared responses to fatigue issue?	Respond to fatigue
Has the maintenance department established a list of opportunities/threats that necessitate prepared responses?	Respond to opportunities/threats
If not, has the maintenance department (organisation) planned any initial analysis to establish such a list?	Respond by analysis
Have you prepared responses for personnel competence?	Respond to competence
Are resources planned and easy to obtain?	Respond to resources

Majority of respondents said the questions would be difficult to grasp by maintenance personnel. As can be seen, this set of questions could not be used to realise the objective of developing a strategy to achieve safety excellence. Accordingly, the work was directed toward finding a relevant set of questions for each of the four (04) aspects.

First, “the ability to respond” aspect was addressed. It can be illustrated by the ability to know what to do and be able to respond to any opportunity/threat. This is performed by adjusting the way things are carried out and having prepared responses that are effective and done in an appropriate time and have the desired effects before it is too late (Hollnagel, 2010a): the ability to deal with the REAL. The same procedure was applied with the interviewees. Taking into account their opinions again, the following questions were sorted out among all the developed questions; each question was followed by the factor (issue) to analyse (table 6.3),

Table 1-16 : Examples of questions for the ability to “respond”

Questions	Have you investigated within the organisation ...issue? Do you apply any criteria for activating a response to ...issue? Do you have prepared responses to ...issue? Do you evaluate systematically your responses (onsite testing) to ...issue? Do you have sufficient staffing available to respond to ...issue?

The same procedure was applied to the three remaining aspects. It is worth noting that parallel to this, a scale for categorising the assessment was looked out. A list of common used scales according to the possible use was studied (table 6.4).

An example of a combination of the use of a frequency scale (Never: 1; Seldom: 2; Sometimes: 3; Often: 4 and Always: 5) and an aspect (ability to respond) is given in the following. Eight questions beginning by “how often have you investigated...followed by the factors were constructed. The respondents are supposed to answer the questions according to a Likert scale ranging from never to always. It has been found that it might work for “the ability to respond” aspect but not for the other aspects which implied finding a different scale for each aspect. Another issue was raised. For some factors and for the same aspect, the questions had to be changed. Instead of beginning the questions by “how often”, it had to begin by “do you often”. Examples included for instance “how often have you investigated time pressure issue?” Moreover, “do you often search to make equipment resources planned and easy to obtain?”

This led to changing the number of factors and adapting the wording to the questions. For example, “adequacy of communication (means & practices) within the organisation” became “messaging and information systems and practices”. The 24 factors (see table 6.1) were reduced to 22 to avoid repetition. Eight (08) questions were eventually set up for the first aspect (ability to respond). Table 6.5 below gives examples of questions.

Table 1-17 : List of common used scales (Mahoney, 2009)

Acceptability	Not at all acceptable, Slightly acceptable, Moderately acceptable, Very acceptable, Completely acceptable
Agreement	Completely disagree, Disagree, Somewhat disagree, Neither agree nor disagree, Somewhat agree, Agree, Completely agree
Appropriateness	Absolutely inappropriate, Inappropriate, Slightly inappropriate, Neutral, Slightly appropriate, Appropriate, Absolutely appropriate
Awareness	Not at all aware, Slightly aware, Moderately aware, Very aware, Extremely aware
Beliefs	Not at all true of what I believe, Slightly true of what I believe, Moderately true of what I believe, Very true of what I believe, Completely true of what I believe
Concern	Not at all concerned, Slightly concerned, Moderately concerned, Very concerned, Extremely concerned
Familiarity	Not at all familiar, Slightly familiar, Moderately familiar, Very familiar, Extremely familiar
Frequency	Never, Rarely, Sometimes, Often, Always
Importance	Not at all important, Slightly important, Moderately important, Very important, Extremely important
Influence	Not at all influential, Slightly influential, Moderately influential, Very influential, Extremely influential
Likelihood	Not at all likely, Slightly likely, Moderately likely, Very likely, Completely likely
Priority	Not a priority, Low priority, Medium priority, High priority, Essential
Probability	Not at all probable, Slightly probable, Moderately probable, Very probable, Completely probable
Quality	Very poor, Poor, Fair, Good, Excellent
Reflect Me	Not at all true of me, Slightly true of me, Moderately true of me, Very true of me, Completely true of me
Satisfaction (bipolar)	Completely dissatisfied, Mostly dissatisfied, Somewhat dissatisfied, Neither satisfied or dissatisfied, Somewhat satisfied, Mostly satisfied, Completely satisfied
Satisfaction (unipolar)	Not at all satisfied, Slightly satisfied, Moderately satisfied, Very satisfied, Completely satisfied

Table 1-18 : Second set of questions for ability to “respond”

Questions	How often have you assessed time pressure issue? Do you have prepared responses to time pressure issue? Do you apply any threshold criteria for activating a response to time pressure issue? How often have you systematically evaluated and tested on site your responses time pressure issue? How often have you established effectiveness speed response to time pressure issue? How often have you established best response duration to time pressure issue? How often have you provided sufficient resources to respond to time pressure issue? How often have you maintained readiness to respond to time pressure issue?

A set of questions were then designed for the second aspect i.e. “the ability to monitor”. Alike the first aspect, it was based on the objective of the aspect. That is the ability to know what to look for or be able to monitor what is changing or may change; this is monitoring systems’ performance or the changes in the environment. This allows the system to deal with opportunities/threats before becoming a reality. It is the ability to deal with the CRITICAL (Hollnagel, 2010a). The first thoughts were directed toward questions such as those given in table 6.6.

Table 1-19 : First set of questions for the ability to “monitor”

Questions	Have you defined pertinent indicators to monitor fatigue issue? When was the list created? How often is the list of indicators revised? On which basis is it revised? Is someone responsible for maintaining the list? Are there leading, current, and lagging indicators?

These questions did not fit in a matrix alike the “ability to respond” aspect. Then, another set was constructed to solve this problem (see table 6.7).

Table 1-20 : Second set of questions for the ability to “monitor”

Questions	Does the organisation support (resources & visibility) flexible monitoring for fatigue issue? Are there Performance Indicators (PI) allowing the monitoring of fatigue issue? Is there an appropriate choice for types of PI (leading, current, lagging) for fatigue issue? Are there PI’s for monitoring shrinking safety margins for fatigue issue? Are there PI’s to measure system vulnerability for fatigue issue? Do you update PI list regularly based on their pertinence for fatigue issue? Is someone responsible for maintaining the PI list for fatigue issue? Are PI measurements reliable for fatigue issue? Are data collected analysed immediately for fatigue issue? Are the results disseminated and the recommendations implemented throughout the organisation for fatigue issue?

Finding ideal set of questions that might match all factors and aspects still remained not solved. This led to changing the strategy and moving toward designing a set of statements instead. The questions were turned therefore into statements. Table 6.8 gives the set of statements for the first aspect that is the ability to “respond”.

Table 1-21 : Set of statements for the ability to "respond"

Statements	The organisation often assesses resources issue The organisation has prepared responses to resources issue The organisation applies threshold criteria for activating a response to resources issue The organisation systematically evaluates and testes on site the responses to resources issue The organisation often assesses effectiveness speed response to. resources issue The organisation often estimates best response duration to resources issue The organisation often provides sufficient resources to respond to. resources issue The organisation often maintains readiness to respond to resources issue

The same action was performed for the second aspect i.e. "ability to Monitor". The set of questions became statements (see table 6.9).

Table 1-22 : Set of statements for the ability to "monitor"

Statements	The organisation supports (resources & visibility) flexible monitoring for resources issue There are Performance Indicators (PI) allowing the monitoring of. resources issue There is an appropriate choice for types of PI (leading, current, and lagging) for resources issue There are PI's for monitoring shrinking safety margins for resources issue PI list is regularly updated based on Indicator's pertinence resources issue Someone is responsible within the organisation for maintaining the PI list for resources issue PI measurements are reliable for. resources issue Data collected are immediately analysed, the results disseminated, and the recommendations implemented throughout the organisation for resources issue

Parallel to this, a five Likert scale was eventually adopted. The scale ranges from fully disagree to totally agree with the statement in question. Table 6.10 shows the category of assessment

Table 1-23 : Scores and meanings (adapted from Hollnagel, 2010a)

Fully agree “5”	The item can be addressed and the system exceeds item requirements
Agree “4”	The item can be addressed and the system meets realistic item requirements
Somewhat agree “3”	The item can be addressed and the system meets the minimum item requirements
Disagree”2”	The item can be addressed but the system performs under the minimum item requirements
Fully disagree “1”	The item can be addressed but the system does not address it
Missing “M”	The system cannot address the item whatever the conditions are

First thoughts regarding the “ability to anticipate” aspect were constructed with respect to some important characteristics of anticipation and proactive actions. These characteristics concerned the frequency of investigating the future (trends), the existence of expertise and tools within the organisation to carry out such activities, and the existence of vulnerability models. All these characteristics dealt with strategic planning to anticipate the future by analysing trends and developing scenarios and contingency plans. This is the ability to know what to expect or be able to anticipate any developments, threats, and opportunities far in the future. The objective is to identify future events and conditions or changes that may affect the ability to function positively or negatively. It is the ability to deal with the POTENTIAL (Hollnagel, 2010a). From a set of twenty statements that were reduced to nine (09), eight (08) were eventually retained. Table 6.11 shows the set of statements.

Table 1-24 : Set of statements for the ability to “anticipate”

Statements	The organisation uses the necessary expertise to investigate the future (analyse trends) with respect to resources issue Threats and opportunities are reviewed each time new data are collected for resources issue The organisation assesses the impact of resource reduction on safety margins due to resources issue The organisation anticipates safety margins reduction due to resources issue The organisation assesses the absence of accidents/failures/hazards, etc. to anticipate the problems raised by resources issue The organisation reviews and updates risk models in the absence of accidents/failures/hazards, etc. for resources issue The organisation possesses analysis tools to predict problems due to resources issue The organisation possesses the abilities and expertise to detect signs of increasing level of risk due to resources issue, etc.

Alike the three previous aspects, the remaining one, “the ability to learn” was developed according to its meaning and objectives that is, the ability to deal with the FACTUAL

(Hollnagel, 2010a). The "ability to learn" aspect was developed more rapidly than the other aspects; particularly the "ability to respond" which was designed in first instance and necessitated more efforts and investigation. A set of statements were designed for this aspect based on organisation support to learn, the learning process itself and its frequency as well as data collection, analysis, and dissemination throughout and outside the organisation (table 6.12).

Table 1-25 : First set of statements for the ability to "learn"

Statements	The organisation supports and trains staff to collect data, analyse, and learn from resources issue The learning process is built throughout the entire organisation for resources issue The organisation allocates necessary resources to investigate, anal disseminate results, and learn from resources issue Learning activity is a continuous process for. resources issue The delay between event reporting, analysis, and learning are the shortest possible for resources issue

The statements were rearranged in a coherent way so that for instance the learning process and the learning activity were put close to each other. The statements became (table 6.13).

Table 1-26 : Set of statements for the ability to "learn"

Statements	The organisation supports and trains staff to collect data, analyse, and learn from resources issue Learning activity is a continuous process for resources issue The organisation allocates necessary resources to investigate, analyse, disseminate results, and learn from resources issue The delay between event reporting, analysis, and learning are the shortest possible for resources issue The outcomes of these analyses are rapidly communicated inside and outside the organisation resources issue The learning process is built throughout the entire organisation for resources issue There are means in place to verify that the intended learning is taking place for resources issue There are means in place to maintain what has been learned for resources issue

The list of factors (issues) was then adapted to fit the maintenance system object of this study. Sixteen factors were therefore sorted out based on the exploratory study of the maintenance environment. They include randomly (table 6.14).

Table 1-27 : Factors fitted for the maintenance system

Factors	Documentation issues (availability, appropriateness, personnel understanding, etc.) Time pressure issues (tasks performed urgently, short cuts, rushed inspection, skipped functional checks, etc.) Fatigue issue (tasks performed between 2.00 and 5.00, working more than 2 night shifts in a row, trouble concentrating, etc.) Procedures/rules issues (errors in maintenance documents, referring to informal document, compliance, etc.) Workload issue (physical and mental) Personnel motivation/conditions of work issue Coordination/supervision issue (not aware of tasks done previously, given wrong information about a task, etc.) Competence/knowledge issue (lack of training, not enough knowledge to do a task, installing parts wrong way) Resource availability (planned and easy to obtain) Incident hazard prevention, investigation, and past response analysis Contractors' management issue Clarification of roles and responsibilities issue within maintenance department Adequacy of communication (means and practices) within maintenance department Recognition, reinforcement, reward of safe behaviour Leadership and accountability issue within maintenance department Clarification of maintenance department missions, vision, values, and principles issue within maintenance department

Since it was quite impossible to study all these factors, the list was reduced to the three ones that were considered the most significant during the study in question (Chapter five, the maintenance working environment study; namely resources, time pressure, and supervision/coordination (to be analysed further during a workshop, see Chapter 7).

The list was then combined with the statements that were designed previously for each of the four aspects in the form of a matrix. This was performed by means of Excel files. The result constituted the developed tool, MASRAT, that allowed to measure the system's resilience. It permitted the drawing of MAintenance Resilience Profiles (MARP) and Factor Resilience Profiles (FRP) for each of the four aspects. A MAturity Level (MAL) was then computed according to the scores obtained by factor and for the department (for ease of calculation, the average scores were rescaled from 0-100). MAL ranges from MAL1 to MEL (Maturity Excellence Level) according to table 6.15 below. This tool necessitated a validation process. A content validity and reliability analysis were then performed.

Table 1-28 : Maturity level according to the score obtained

Score	0-20	21-40	41-60	61-80	81-100
MAL	MAL1	MAL2	MAL3	MAL4	MEL

6.4. The Validation Phase

In order to use adequately and properly any developed tool, a validation process of the measures in terms of content and reliability must be conducted. It allowed the tool user to interpret properly the results obtained by the tool in question. Content validity allows knowing to what degree the tool measures actually that for which it was designed whereas reliability relates to the consistency and repeatability of a test or a measure, in other words the stability of the scores with time. Testing the validity of the developed tool was performed to know to what extent the tool was intended to measure what it said to do and it showed that data are applied and interpreted as accurately as possible. The Statistical Package for the Social Sciences (SPSS) was used as a support to carry out the statistical analyses in this research work. SPSS was chosen for its ability to perform rapidly the required tests whether it was principal components analysis and/or reliability analysis. As explained in the research method process (Chapter 4, figure 4.2), this phase addressed the tool validation in terms of content and reliability. This was done to achieve objective 4, part 1 of this research work.

6.4.1. Content Validity

The first operation consisted of a content validity. As stated in Chapter 4, section 4.7, it consisted of two parts: a measure by a panel of experts of the index of item-objective congruence and a principal component analysis.

6.4.1.1. The Index of Item-Objective Congruence

Six lay experts from maintenance departments of the Algerian oil and gas Company, academia from the Algerian Petroleum Institute, and two well-known international experts in resilience engineering domain were consulted. Comments of the international experts in resilience engineering are given in appendix 3.

The statements (randomly arranged) were sent to the panel who were asked to give each statement a score according to the procedure explained previously (Chapter 4, section 4.7). As a result, all items were above 0.75 that was deemed acceptable; Turner and Carlson (2003, p.

167) stated “a generally accepted value might be a minimum of 0.75”. The number of items was reduced to 28 (some items were removed for redundancy and others have been combined) by taking into account the experts comments

6.4.1.2. Principle Component Analysis

As explained in section 6.2, MASRAT was intended to measure the resilience of the maintenance system of an oil and gas company. This was done by measuring the four abilities of the system namely ability to respond, ability to monitor, ability to anticipate, and ability to learn. The next action consisted of collecting data for psychometric analysis by applying MASRAT and discussing the results. It resided on presenting MASRAT and the underlying theory to a sample of maintenance personnel of the Company and asking these people to respond to the 28 items randomly arranged three times, one for “resources” factor, one for “time pressure” factor, and one for “coordination/supervision” factor. This was carried out in order to (1) test whether the items (statements) actually measured that for what they were designed and (2) review these items according to the feedback and the statistic study. In other words, the objectives of this action were as follows:

- Did the set of items designed to measure for instance “the ability to respond” actually did it? (The same was performed for the other sets)
- What could be changed in the four sets of items according to the feedback and statistics data so that they could achieve what was intended?

Before carrying out the PCA analysis using the SPSS package, missing data and the characteristics of the population are first presented.

i. Missing Data

Missing data means one or more variables are not available for analysis. This issue is addressed by identifying the patterns and relationships underlying the missing data in order to maintain as close as possible the original distribution of values when any remedy is applied (Hale et al, 1998). The analysis was performed by means of the principle components analysis (PCA) approach. In order to study the correlation between items, all missing data (one or more variables are not available for analysis) were excluded. In the case of this research work, missing data were due to the nonresponse to a set of questions by respondents. Two hundreds and two (202) files were distributed. A hundred and ninety-five responses were collected out of which thirteen were removed de facto since data were missing.

ii. Characteristics of the Population

Industrial branches of the Algerian company SONATRACH were visited in six regions. Three regions are located in the North of Algeria, they concern downstream activities that is three LNG plants (two in West and one in East), two refineries (East and Centre), and two LPG plants (West of Algeria). Since South of Algeria, which concerns upstream activity of oil and gas and its transportation, is very large and vast, two representative regions (one for each activity) were chosen. A joint venture facility (SONATRACH and a foreign partner) was also concerned in the South of Algeria for upstream. A distribution of the population involved by type of facility in this action is given in figure 6.3.

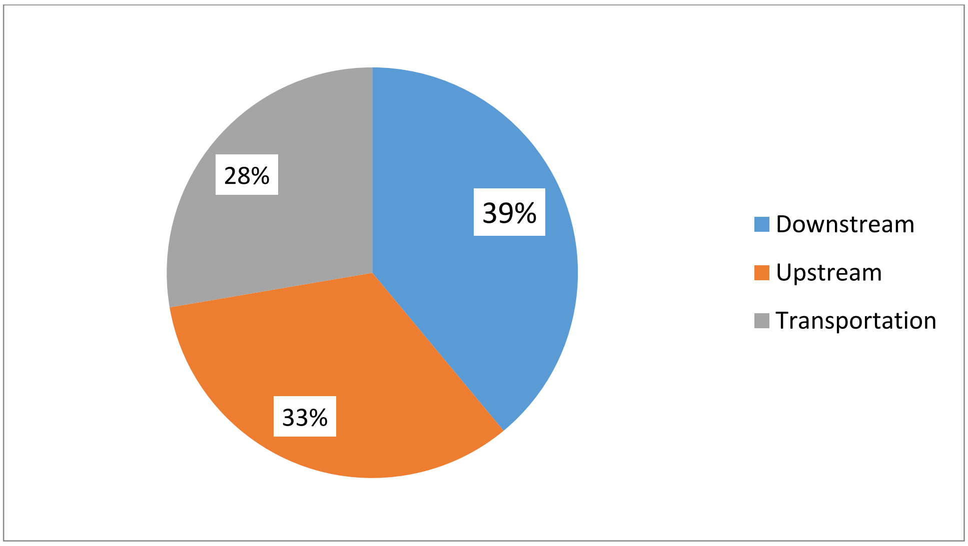

Figure 1-21: Distribution of the respondents by type of facility

It is worth noting that it is pretty easy to visit four plants (downstream) in few days since the plants are situated in the same region (only few minutes are required to travel from one plant to another) than upstream facilities which are very remote and difficult to access in the short period of time allocated to do this action. This was the reason why these sites have been chosen.

The distribution of level of experience in maintenance of the personnel met during this action is given in figure 6.4. The age average of these people was nearly 40 years. As can be seen from this figure, the maintenance personnel are very experienced since the majority of them (55%) have more than 10 years of experience in maintenance department. All people met have more than 03 years of experience in maintenance activities and quite 10% are managers (mid or frontline managers) in maintenance departments.

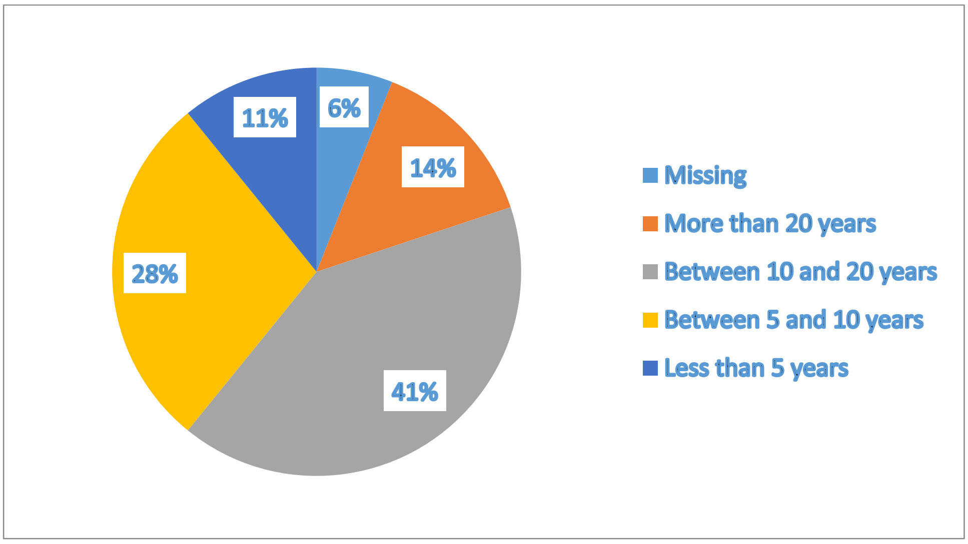

Figure 1-22: Distribution of level of experience of respondents in maintenance activities

iii. Testing MASRAT with Maintenance Personnel

Meetings with middle and frontline managers and engineers/technicians from SONATRACH maintenance departments were held in the main sites and industrial areas where the company is based as explained previously. During these meetings, MASRAT and the underlying theory was presented to the participants and debated. After that, the participants were asked to rate each statement (item) by ticking the relevant box from "1" to "M" to confirm or invalidate the statement in question according to the situation that actually exists in their facilities (see table 6.10 in section 6.3 for scores and meanings). The results were then analysed by means of principal component analysis method.

iv. The Principal Components Analysis (PCA) Results

The principal component analysis approach and the reasons for choosing such a method have been explained in Chapter 4, section 4.8.4. In the following, the results of the different steps carried out are given.

a. Assumption of Normality

The first step of analysing a set of data is the assumption of normality. This can be performed by running Skewness and Kurtosis tests. Neither Skewness values nor Kurtosis ones suggested any dismissal of variables; Skewness values ranged from -0.450 to 0.474 and Kurtosis ones ranged from -0.877 to 0.440. According to Henson and Roberts (2006), a correlation matrix is the most used by researchers in factor analysis. For the set of data studied, the correlation matrix showed a large number of correlations above 0.300.

b. The Factorability of Data

In this section, sample size requirement for factor analysis is addressed. In the case of this research, the ratio was higher than 6:1 (182/28) which satisfied the first test regarding sampling that is a rapid inspection of the sample.

Before performing a factor analysis, two statistic tests were carried out: the Kaiser-Meyer Olkin measure of sampling adequacy (KMO) and Bartlett’s test of sphericity. The factorability of data was regarded through these two tests to determine the strength of the relationship among the studied items. For Tabachnick and Fidell (2007), a KMO value above 0.6 is acceptable. The values of KMO test and Bartlett's test of sphericity are shown in tables 6.16, 6.17, and 6.18 respectively for the “resources”, “time pressure”, and “supervision/coordination” factors.

Table 1-29 : KMO and Bartlett's Test for “resources” factor

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.892
Bartlett's Test of Sphericity	Approx. Chi-Square	2131.084
	df	378
	Sig.	0.000

Table 1-30: KMO and Bartlett's Test for “time pressure” factor

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.903
Bartlett's Test of Sphericity	Approx. Chi-Square	2497.938
	df	378
	Sig.	0.000

Table 1-31 : KMO and Bartlett's Test for “supervision/coordination” factor

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.896
Bartlett's Test of Sphericity	Approx. Chi-Square	2349.942
	df	378
	Sig.	0.000

These values were significant and indicated that the correlations between items were good. Besides, the results of the Bartlet's test of sphericity were below the value p < 0,05 that is, also significant and allowed to reject the null hypothesis that says the population for which the correlation matrix is an identity matrix, this indicated that there existed sufficient correlations between variables to proceed. Therefore, the set of data were suitable for factor analysis.

c. Eigenvalues and Scree Test

Two other criteria were considered in the following: the eigenvalues and the scree test. To begin with the "resources" factor, SPSS extracted a six component solution by applying the eigenvalues above 1 rule even though one component has an eigenvalue very close to 1. The scree test of eigenvalues plotted against factors showed rather a four or five component solution (figure 6.5). It can be seen from the figure that the blue line that has been added to show the number of components above the inflection point (the elbow), indicates that there may be a four or five component solution.

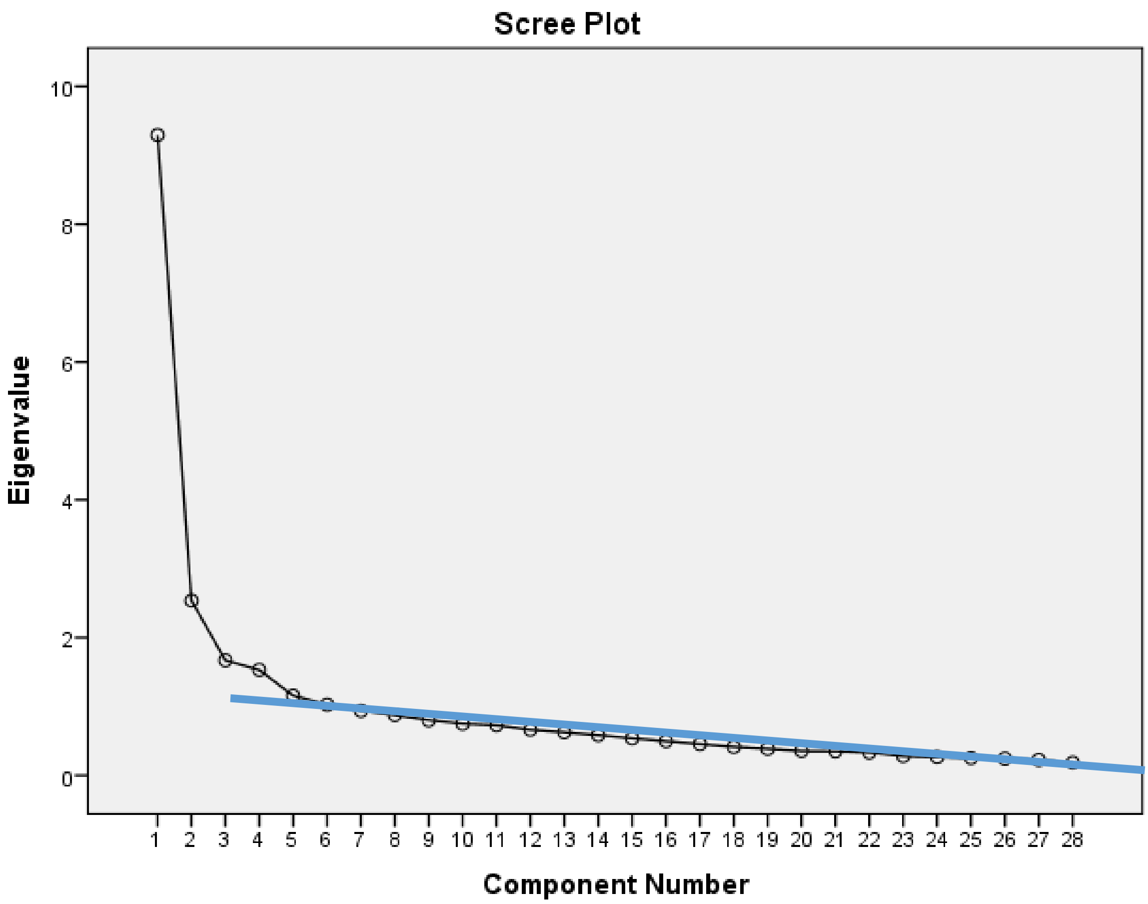

Figure 1-23: Scree plot for the "resources" factor

For the “time pressure” factor, SPSS extracted a five-component solution by applying the eigenvalues above one rule. All the five values were above one, the lowest one was quite 1.1 in comparison to the values extracted for the previous factor. The scree test of eigenvalues plotted against factors showed quite the same plot that is a four or five component solution (figure 6.6).

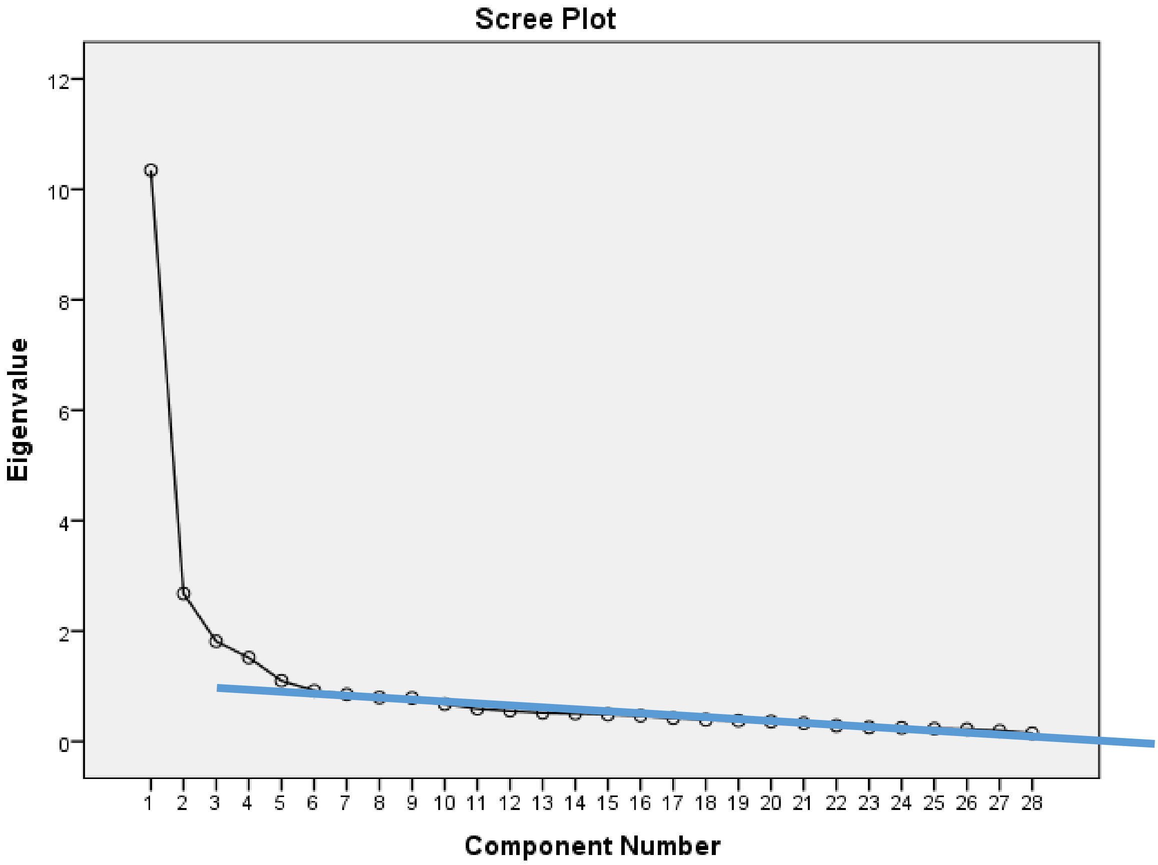

Figure 1-24: Scree plot for the “time pressure” factor

The same action was carried out for the “supervision/coordination” factor. SPSS extracted a five-component solution by applying the eigenvalues above one rule. The scree test of eigenvalues plotted against factors showed quite the same plot that is a four or five component solution (figure 6.7).

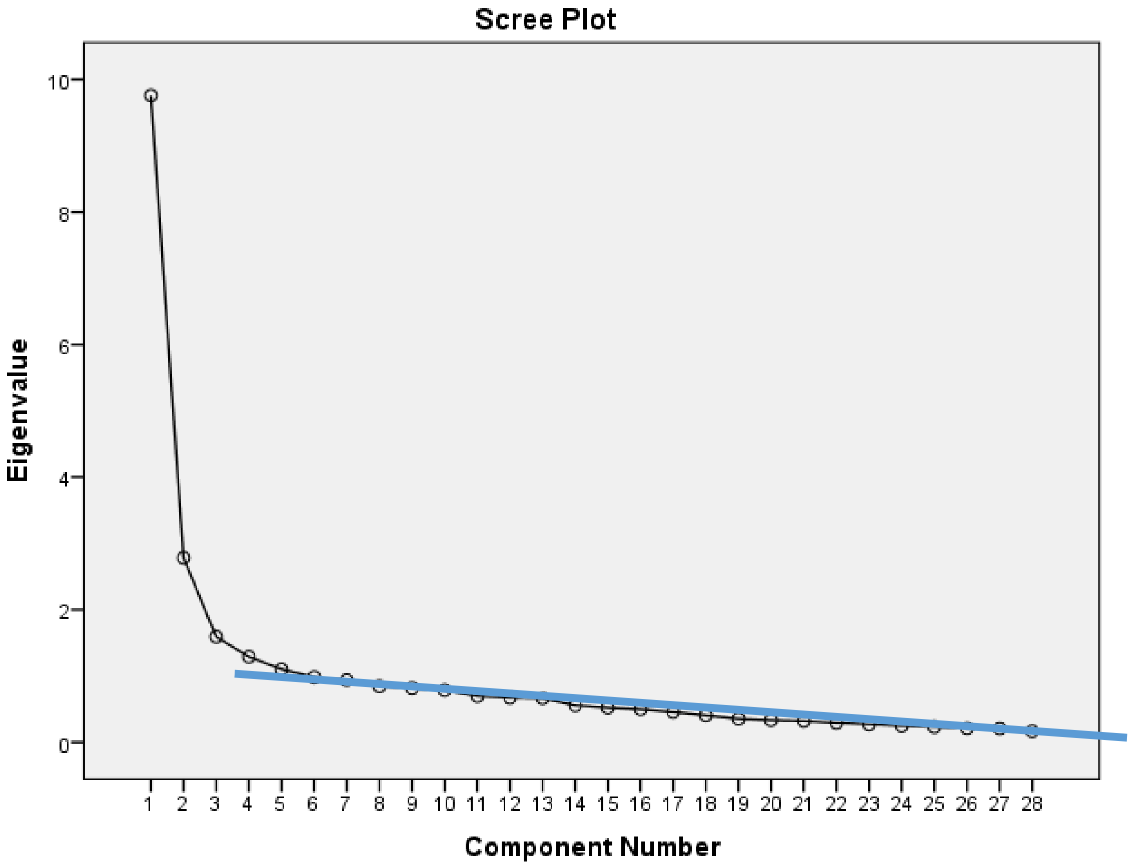

Figure 1-25: Scree plot for the "supervision/coordination" factor

To sum up, the three factors that were investigated showed quite the same scree plot of eigenvalues suggesting a same number of factors (components). From these scree plots, a four or five solution was considered in the rotation test.

d. Rotation

Rotation is carried out after the factor extraction in order to increase the interpretability and scientific utility of the solution to maximise high correlations between factors and variables and minimise low ones. The results of the orthogonal rotation are shown in a loading matrix where the values give correlations between variables and factors. For each of the three factors, solutions for four and five components were extracted and rotated using a Varimax method. The study of these solutions converged toward the fact the four-component solution was judged the most convenient and the one that fitted the criteria of simple structure as suggested by Ferreira (2011).

The recommendations of Tabachnick and Fidell (2007) with respect to loading factors were into account; they are recalled in the following:

- The choice is given to researchers to decide about interpretation
- A loading value of 0.32 or larger for meaningful correlation is suggested as a rule of thumb; in this study 0.400 is chosen as a criterion to construct a factor (component)
- Where there are multiple loadings a minimum difference of 0.200 is imposed
- The variables that have loadings in excess with respect to the chosen criterion (0.400) are put together
- Eventually, interpretation is preformed

Tables 6.19, 6.20, and 6.21 give the loading components for each variable respectively for the "resources" factor, the "time pressure" factor, and the "supervision/coordination" factor. The loading values above 0.400 are in bold.

Table 1-32 : Rotated Component Matrix for the “resources” factor

Rotated Component Matrix for the “resources” factor				
	Component			
	1	2	3	4
The organisation analyses long term effects and develops strategic planning for resources issues	**0.706**	0.121	0.268	0.017
The organisation supports and trains staff to collect data, analyse, and learn from resources issues	0.224	**0.718**	0.022	0.330
The department maintains readiness to respond to resources issues	0.252	0.160	0.061	**0.655**
There are PI’s for monitoring shrinking safety margins for resources issues	0.282	0.190	**0.690**	0.123
Before each management review, the department assesses resources issues	0.294	0.081	0.154	**0.596**
The department systematically evaluates and testes on site the responses to resources issues	0.053	0.292	0.394	**0.417**
The department assesses absence of failures, hazards, and accidents to anticipate resources issues	**0.647**	0.314	0.111	0.150
The learning activity is a continuous process and built throughout the entire organisation for resources issues	0.395	**0.511**	0.093	0.377
Information exchange within the department is a continuous and spontaneous flux that constitutes a basis to locate signs of trouble stemming from resources issues	**0.666**	0.089	0.068	0.210
The outcomes of the analyses are rapidly communicated inside and outside the organisation for resources issues	0.231	**0.691**	0.195	-0.047
The organisation allocates necessary resources to investigate, analyse, disseminate results, and learn from resources issues	0.252	**0.687**	-0.051	0.061
There are Performance Indicators (PI) allowing the monitoring of resources issues	0.355	-0.171	**0.523**	0.295
There is a vulnerability model within the organisation clearly formulated for resources issues	**0.486**	0.180	0.212	0.168
The delay between event reporting, analysis, and learning are the shortest possible for resources issues	0.063	**0.689**	0.254	-0.121
There are means in place to maintain what has been learned for resources issues	0.361	**0.723**	0.139	0.161
PI list is regularly updated based on Indicator's pertinence for resources issues	**0.441**	0.140	**0.648**	0.019
PI measurements are reliable for resources issues	0.135	0.250	**0.660**	0.319
Data collected are immediately analysed, the results disseminated, and the recommendations implemented throughout the organisation for resources issues	**0.532**	0.128	0.262	0.226

Rotated Component Matrix for the "resources" factor (continued)

Rotated Component Matrix for the "resources" factor				
	Component			
	1	2	3	4
The department applies threshold criteria for activating a response to resources issues	0.011	0.011	0.377	**0.553**
There is a regular diagnosis of safety/production trade-off within the organisation for resources issues	**0.584**	0.301	0.076	0.128
The organisation assesses the impact of resource reduction on safety margins stemming from resources issues	**0.535**	0.329	-0.154	0.242
The organisation uses the necessary expertise to investigate the future (analyses trends) for resources issues	**0.539**	0.306	0.240	-0.050
The department has prepared responses to resources issues	-0.106	0.068	0.244	**0.759**
There are means in place to verify that the intended learning is taking place for resources issues	0.150	**0.753**	0.286	0.131
There is an appropriate choice for types of PI (leading, current, and lagging) related to resources issues	0.088	0.137	**0.667**	0.244
The department supports (resources & visibility) flexible monitoring of resources issues	**0.469**	0.177	0.398	**0.423**
The organisation possesses tools to analyse and predict outcomes caused by resources issues	**0.607**	0.214	0.282	0.049
The department provides sufficient resources to respond to resources issues	0.375	-0.032	0.078	**0.558**
Eigenvalues	4.596	4.119	3.184	3.134
% of variance explained	16,41	14,71	11,37	11,19
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalisation.				
Rotation converged in 8 iterations.				

Total % of variance explained 53,690: the four variables explain up to 53.69% of the variance.

The rotation converged after 08 iterations. It can be seen from table 6.19 that all variables have a loading value above the chosen criteria 0.400. Two variables presented cross-loading values. The first variable is “PI list is regularly updated based on Indicator's pertinence for resources issues”. The two loading values are 0.441 for component 1 and 0.648 for component 3. The difference is largely above 0.200. The second variable is “The department supports (resources & visibility) flexible monitoring of resources issues” for which the difference is less than 0.200 (in blue colour). Except these two variables, the others showed significant loadings demonstrating a strong correlation between variables and components.

Table 1-33 : Rotated Component Matrix for the "time pressure" factor

Rotated Component Matrix				
	Component			
	1	2	3	4
The organisation possesses tools to analyse and predict outcomes caused by time pressure issues	0.218	**0.635**	0.212	0.172
There is a regular diagnosis of safety/production trade-off within the organisation for time pressure issues	0.124	**0.725**	0.123	0.267
PI measurements are reliable for time pressure issues	0.228	0.261	**0.604**	0.257
There is an appropriate choice for types of PI (leading, current, and lagging) related to time pressure issues	0.120	0.185	**0.768**	0.157
There are means in place to maintain what has been learned for time pressure issues	**0.802**	0.166	0.169	0.203
PI list is regularly updated based on Indicator's pertinence for time pressure issues	0.269	0.219	**0.706**	0.115
The organisation supports and trains staff to collect data, analyse, and learn from time pressure issues	**0.607**	0.423	0.090	0.191
Information exchange within the department is a continuous and spontaneous flux that constitutes a basis to locate signs of trouble stemming from time pressure issues	0.290	**0.525**	0.229	0.245
There are PI's for monitoring shrinking safety margins for time pressure issues	0.160	0.184	**0.770**	0.108
Before each management review, the department assesses time pressure issues	0.025	0.347	0.078	**0.604**
The learning activity is a continuous process and built throughout the entire organisation for time pressure issues	**0.681**	0.346	-0.021	0.143
There are means in place to verify that the intended learning is taking place for time pressure issues	**0.772**	0.309	0.097	0.181
The department provides sufficient resources to respond to time pressure issues	0.148	0.103	0.254	**0.695**
The organisation allocates necessary resources to investigate, analyse, disseminate results, and learn from time pressure issues	**0.730**	0.275	0.100	0.166
Data collected are immediately analysed, the results disseminated, and the recommendations implemented throughout the organisation for time pressure issues	0.167	0.375	0.360	0.280
The organisation assesses the impact of resource reduction on safety margins stemming from time pressure	0.263	**0.649**	-0.017	0.233
There are Performance Indicators (PI) allowing the monitoring of time pressure issues	-0.023	-0.006	**0.771**	0.217
The outcomes of the analyses are rapidly communicated inside and outside the organisation for time pressure	**0.724**	0.110	0.269	0.059

Rotated Component Matrix for the "time pressure" factor (continued)

Rotated Component Matrix				
	Component			
	1	2	3	4
The organisation analyses long term effects and develops strategic planning for time pressure issues	0.195	**0.743**	0.284	0.015
The organisation uses the necessary expertise to investigate the future (analyse trends) for time pressure issues	0.257	**0.623**	0.305	0.005
The department maintains readiness to respond to time pressure issues	0.215	0.209	0.079	**0.737**
The department systematically evaluates and testes on site the responses to time pressure issues	0.291	0.196	0.246	**0.621**
The department supports (resources & visibility) flexible monitoring of time pressure issues	0.038	0.307	**0.558**	**0.401**
The delay between event reporting, analysis, and learning are the shortest possible for time pressure issues	0.678	**0.067**	0.140	-0.002
There is a vulnerability model within the organisation clearly formulated for time pressure issues	0.143	0.262	**0.424**	0.272
The department assesses absence of failures, hazards, and accidents to anticipate time pressure issues	0.275	**0.580**	0.229	0.165
The department applies threshold criteria for activating a response to time pressure issues	0.144	-0.027	0.222	**0.767**
The department has prepared responses to time pressure issues	0.001	0.186	0.244	**0.765**
Eigenvalues	4.374	4.153	3.993	3.831
% of variance explained	15,62	14,83	14,26	13,68
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.				
Rotation converged in 6 iterations.				

Total % of variance explained 58,394: the four variables explain up to 58,4% of the variance

For this set of data, the rotation converged after 06 iterations. It can be seen from table 6.20 that one variable had loading values below the chosen criteria (in blue colour). This variable is “data collected are immediately analysed, the results disseminated, and the recommendations implemented throughout the organisation for time pressure issues”. On the other hand, two variables presented cross-loading values. The first one is “The organisation supports and trains staff to collect data, analyse, and learn from time pressure issues”, for which the values are respectively 0.607 and 0.423 for component 1 and component 2. As can be noticed, the difference is slightly close to 0.200. The second one (blue colour) is “The department supports (resources and visibility) flexible monitoring of time pressure issues” for which the values are respectively 0.558 and 0.401 for component 3 and 4.

Table 1-34 : Rotated Component Matrix for the "supervision/coordination" factor

Rotated Component Matrix for the "supervision/coordination" factor				
	Component			
	1	2	3	4
There are Performance Indicators (PI) allowing the monitoring of supervision/coordination issue	0.038	**0.773**	0.197	0.033
Before each management review, the department assesses supervision/coordination issue	-0.042	0.216	**0.503**	0.390
The delay between event reporting, analysis, and learning are the shortest possible for supervision/coordination issue	**0.557**	-0.056	0.046	0.393
PI list is regularly updated based on Indicator's pertinence for supervision/coordination issue	0.244	**0.746**	0.129	0.158
There are PI's for monitoring shrinking safety margins for supervision/coordination issue	0.156	**0.699**	0.157	0.255
Information exchange within the department is a continuous and spontaneous flux that constitutes a basis to locate signs of trouble stemming from supervision/coordination issue	0.383	-0.001	0.233	**0.412**
The department has prepared responses to supervision/coordination issue	-0.034	0.041	**0.784**	0.140
There are means in place to maintain what has been learned for supervision/coordination issue	**0.793**	0.243	0.134	0.165
The organisation possesses tools to analyse and predict outcomes caused by supervision/coordination issue	0.209	0.246	0.165	**0.623**
The organisation uses the necessary expertise to investigate the future (analyse trends) for supervision/coordination issue	0.199	0.378	-0.007	**0.600**
The department applies threshold criteria for activating a response to supervision/coordination issue	0.096	0.331	**0.641**	-0.012
The organisation allocates necessary resources to investigate, analyse, disseminate results, and learn from supervision/coordination issue	**0.737**	0.030	0.078	0.289
The organisation supports and trains staff to collect data, analyse, and learn from supervision/coordination issue	**0.728**	0.161	0.133	0.207
There is an appropriate choice for types of PI (leading, current, and lagging) related to supervision/coordination issue	0.120	**0.665**	0.250	0.125
The outcomes of the analyses are rapidly communicated inside and outside the organisation for supervision/coordination issue	**0.694**	0.342	-0.061	0.082
The organisation analyses long term effects and develops strategic planning for supervision/coordination issue	0.326	0.343	-0.049	**0.679**

Rotated Component Matrix for the “supervision/coordination” factor (continued)

Rotated Component Matrix for the “supervision/coordination” factor				
	Component			
	1	2	3	4
The department provides sufficient resources to respond to supervision/coordination issue	0.219	0.370	**0.650**	-0.110
PI measurements are reliable for supervision/coordination issue	0.141	**0.542**	0.339	0.320
Data collected are immediately analysed, the results disseminated, and the recommendations implemented throughout the organisation for supervision/coordination issue	0.303	**0.423**	0.266	0.292
The learning activity is a continuous process and built throughout the entire organisation for supervision/coordination issue	**0.782**	0.214	0.099	0.012
There is a regular diagnosis of safety/production trade-off within the organisation for supervision/coordination issue	0.349	0.163	0.245	**0.557**
The department supports (resources & visibility) flexible monitoring of supervision/coordination issue	0.038	0.317	**0.469**	0.391
The department assesses absence of failures, hazards, and accidents to anticipate supervision/coordination issue	0.369	0.121	0.332	**0.563**
There is a vulnerability model within the organisation clearly formulated for supervision/coordination issue	0.184	**0.409**	0.207	0.294
The department systematically evaluates and testes on site the responses to supervision/coordination issue	0.090	0.266	**0.611**	0.216
The organisation assesses the impact of resource reduction on safety margins stemming from supervision/coordination issue	0.386	-0.008	0.245	**0.408**
There are means in place to verify that the intended learning is taking place for supervision/coordination issue	**0.706**	0.162	0.102	0.342
The department maintains readiness to respond to supervision/coordination issue	0.253	0.066	**0.648**	0.154
Eigenvalues	4.727	3.837	3.467	3.391
% of variance explained	16,88	13,70	12,38	12,11
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.				
Rotation converged in 8 iterations.				

Total % of variance explained 55,079: the four variables explain up to 55,08 % of the variance

For the third set of data, the rotation converged after 07 iterations. Table 6.21 shows no variable with loading values below the chosen criterion and no variable presenting cross-loading values but two variables had loadings that do not match with the component (blue colour). These variables are "The department supports (resources & visibility) flexible monitoring of supervision/coordination issue" and "There is a vulnerability model within the organisation clearly formulated for supervision/coordination issue". An explanation is given in the next section

e. Interpretation

This step of principle component analysis addresses the interpretation of extracted components. After the reduction of the 28 items to four components, the latter were investigated to characterise and interpret the meaning of each component. As can be seen in the following tables (from table 6.22 to table 6.25), there was a choice between removing completely an item deemed not having sufficient loading and/or having the required loading which interpretation asked to move the item to another component. On the other hand, instead of removing an item, it might be more interesting to change the wording to avoid confusion. A summary of the loadings for each component is given in tables 6.22, 6.23, 6.24 and 6.25 below.

Table 1-35 : Summary of variable loadings for the first component

Variables (items) for ability to respond component	Resources issues	TP issues	SC issues
Before each management review, the department assesses…	0.596	0.604	0,503
The department has prepared responses to…	0.759	0.765	0,784
The department applies threshold criteria for activating a response to...	0.553	0.767	0,641
The department systematically evaluates and testes on site the responses to...	0.417	0.621	0,611
The department provides sufficient resources to respond to...	0.558	0.695	0,650
The department maintains readiness to respond to …	0.655	0.737	0,648

For the first component "the ability to respond", table 6.22 shows high loadings for all of the items regarding the three studied factors. The six items that measured this ability were therefore accepted as they were designed first instance since there was no noticeable issue except for the fifth item that required a specification for the word resources as requested by respondents to avoid confusion with the studied factor. Hence, the item became "The department provides sufficient resources (competent personnel, time, etc.) to respond to...

Table 1-36 : Summary of variable loadings for the second component

Variables (items) for ability to monitor component	Resources issues	TP issues	SC issues
The department supports (resources & visibility) flexible monitoring of...	0.398	0.558	0,317
There are Performance Indicators (PI) allowing the monitoring of ...	0.523	0.771	0,773
There is an appropriate choice for types of PI (leading, current, and lagging) related to…	0.667	0.768	0,665
There are PI's for monitoring shrinking safety margins for …	0.690	0.770	0,699
PI list is regularly updated based on Indicator's pertinence for...	0.648	0.706	0,746
PI measurements are reliable for ...	0.660	0.604	0,542
Data collected are immediately analysed, the results disseminated, and the recommendations implemented throughout the organisation for…	0.532 in anticipate component	Missing case under 0.400	0,423

In the case of the component "the ability to monitor", there were two issues (table 6.23). First, the item "The department supports (resources & visibility) flexible monitoring of…" showed insufficient loading with respect to two factors (resources and supervision/coordination) according to the rules defined earlier in this section. It can be explained by the fact that the item was not well written creating some confusion among respondents since the word "monitoring" has not a common utilisation among respondents. The item received a better loading (0.469) regarding the component "the ability to respond" and (0.423) for "the ability to anticipate", (see respectively the rotated component matrices given above in tables 6.19 and 6.21). The solution lied may be in changing the wording of the item. Therefore, the new item became "The monitoring of …issues is of great importance in the maintenance department".

Second, the item "Data collected are immediately analysed, the results disseminated, and the recommendations implemented throughout the organisation for…" was a missing case since it had a loading under 0.400 for the "time pressure" factor and had a good loading 0.532 but in "the ability to anticipate" component regarding the resources factor. Its loading for the supervision/coordination factor was acceptable (0.423) though. This item was therefore moved to the "ability to anticipate component".

Table 1-37 : Summary of variable loadings for the third component

Variables (items) for ability to anticipate component	Resources issues	TP issues	SC issues
There is a vulnerability model within the organisation clearly formulated for...	0,486	0.262	0,294
The organisation uses the necessary expertise to investigate the future (analyses trends) for...	0.539	0.623	0,600
The organisation possesses tools to analyse and predict outcomes caused by ...	0.607	0.635	0,623
The organisation analyses long term effects and develops strategic planning for ...	0.706	0.743	0,679
The department assesses absence of failures, hazards, and accidents to anticipate ...	0.647	0.580	0,563
Information exchange within the department is a continuous and spontaneous flux that constitutes a basis to locate signs of trouble stemming from ...	0.666	0.525	0,412
There is a regular diagnosis of safety/production trade-off within the organisation for...	0.584	0.725	0,557
The organisation assesses the impact of resource reduction on safety margins stemming from…	0.535	0.649	0,408

The only issue for the third component, “the ability to anticipate”, concerned the first item i.e. “There is a vulnerability model within the organisation clearly formulated for...” There were actually some difficulties to grasp the meaning of the word “vulnerability” in addition to the translation from English to French and vice versa. This is explained in more details in Chapter 7. To solve this issue, an explanation of the desired meaning of this word was added. The item became “There is a vulnerability (fragility, weakness) model within the organisation clearly formulated for...”

Table 1-38 : Summary of variable loadings for the fourth component

Variables (items) for ability to learn component	Resources issues	TP issues	SC issues
The organisation supports and trains staff to collect data, analyse, and learn from...	0.718	0.607	0,728
The learning activity is a continuous process and built throughout the entire organisation for ...	0.511	0.681	0,782
The organisation allocates necessary resources to investigate, analyse, disseminate results, and learn from...	0.687	0.730	0,737
The delay between event reporting, analysis, and learning are the shortest possible for...	0.689	0.678	0,557
The outcomes of these analyses are rapidly communicated inside and outside the organisation for...	0.691	0.724	0,694
There are means in place to verify that the intended learning is taking place for ...	0.753	0.772	0,706
There are means in place to maintain what has been learned for ...	0.723	0.802	0,793

With respect to the fourth component "the ability to learn" (table 6.25) , there is no noticeable issue with the loadings. The latter are very high for all items, majority of which are above 0.600. For the three factors, only two items have got loading below 0.600 and above 0.500. To sum up, the new components are shown in table 6.26 according to the interpretation of the results. The statement is followed by the studied factor

Table 1-39 : The new MASRAT items

Measured ability	Items (statements)
Ability to respond	Before each management review, the department assesses…
	The department has prepared responses to…
	The department applies threshold criteria for activating a response to...
	The department systematically evaluates and testes on site the responses to...
	The department provides sufficient resources (competent personnel, time, etc.) to respond to...
	The department maintains readiness to respond to …
Ability to monitor	The monitoring of …issues is of great importance in the maintenance department
	There are Performance Indicators (PI) allowing the monitoring of ...
	There is an appropriate choice for types of PI (leading, current, and lagging) related to…
	There are PI's for monitoring shrinking safety margins for …
	PI list is regularly updated based on Indicator's pertinence for...
	PI measurements are reliable for ...

The new MASRAT items (continued)

Measured ability	Items (statements)
Ability to anticipate	There is a vulnerability (fragility, weakness) model within the organisation clearly formulated for...
	The organisation uses the necessary expertise to investigate the future (analyses trends) for...
	The organisation possesses tools to analyse and predict outcomes caused by ...
	The organisation analyses long term effects and develops strategic planning for ...
	The department assesses absence of failures, hazards, and accidents to anticipate ...
	Information exchange within the department is a continuous and spontaneous flux that constitutes a basis to locate signs of trouble stemming from ...
	There is a regular diagnosis of safety/production trade-off within the organisation for...
	The organisation assesses the impact of resource reduction on safety margins stemming from…
	Data collected are immediately analysed, the results disseminated, and the recommendations implemented throughout the organisation for…
Ability to learn	The organisation supports and trains staff to collect data, analyse, and learn from...
	The learning activity is a continuous process and built throughout the entire organisation for ...
	The organisation allocates necessary resources to investigate, analyse, disseminate results, and learn from...
	The delay between event reporting, analysis, and learning are the shortest possible for...
	The outcomes of these analyses are rapidly communicated inside and outside the organisation for...
	There are means in place to verify that the intended learning is taking place for ...
	There are means in place to maintain what has been learned for ...

To conclude, PCA was performed to analyse the three factors (resources, time pressure, and supervision/coordination). The results showed the reproducibility of the instrument for the three factors; this means that MASRAT can be used for any of the identified factor and may be extended to study all the 16 factors.

6.4.2. Reliability

The second action consisted of a reliability measure of MASRAT to check the internal consistency of data collected. In order to determine its reliability, Cronbach's alpha was used. This coefficient ranges from zero to one; the nearest the value to one is, the highest the internal consistency of studied items. It calculates the correlation coefficient between items (statements).

The data described in the above sections (distributed to two hundreds and twenty-two people) were used to determine the internal consistency. By means of SPSS (STATISTICA), Cronbach's alpha was computed. It is very well known that a value of 0.7 is judged acceptable. The results of Cronbach's alpha values per component and factor are given in table 6.27. They clearly show that the tool has a good internal consistency of data since the values of Cronbach's alpha are higher than 0.7 as required.

Table 1-40 : Cronbach's alpha values per component and factor

Component	Factor	Cronbach's alpha
Ability to respond	Resources	0.758
	Time pressure	0.854
	Supervision/coordination	0.802
Ability to flexibly monitor	Resources	0.840
	Time pressure	0.864
	Supervision/coordination	0.849
Ability to anticipate	Resources	0.837
	Time pressure	0.855
	Supervision/coordination	0.833
Ability to learn	Resources	0.871
	Time pressure	0.892
	Supervision/coordination	0.891

6.5. Link to the Objectives of the Research

In this Chapter, the main contribution of this piece of research was presented. It consisted of a framework that allows performing a gap analysis and define a strategy to achieve the aim of this thesis on the one hand. It comprised the development and validation of a tool that measures the resilience of the maintenance system in the oil and gas industry with respect to the most significant identified factors on the other hand. These represent objective 3 and objective 4, part 1 of this study respectively the identification of a strategy based on resilience engineering and the contribution to the development of a tool that measures the resilience of the maintenance system in the oil and gas industry with respect to the most significant identified factors and validate the tool.

6.6. Chapter Summary

This Chapter was devoted to the development and validation of the tool that allowed performing the gap analysis. MASRAT was developed to measure the resilience of a maintenance system.

The development phase lasted several months. It began with the design of general questions dealing with resilience engineering. Then, it went through the development of a set of questions for each of the four aspects of resilience. It ended by changing the strategy and moving toward the use of a set of statements instead of questions since it has been found difficult to construct a comprehensive and coherent matrix that may address the four cornerstones of resilience engineering. Parallel to this, a scale for rating each statement was adopted. From this scale, maturity levels were defined. The validity and reliability of MASRAT were verified by means of the index of item-objective congruence and principal component analysis for content validity, and Cronbach's alpha coefficient for the internal consistency of data.

To test the content validity, experts were asked to rate each statement to see whether it clearly measures the objective for each factor or not. The results were positive (all items were rated above 0.75). Expert comments were taken into account to change the wording and improve the elements of the instrument.

A principal component analysis was then run. Maintenance departments of SONATRACH were solicited to test MASRAT and collect data in order to perform a principal component and reliability analysis. The tool was presented and explained to managers and engineers. They were asked to rate the statements and comment on. The results of the principal component analysis obtained by using SPSS confirmed that the 28 items might be clustered after extraction and interpretation into four components. The components represented the four cornerstones of resilience engineering (the ability of the system to respond to threats/opportunities, the ability to monitor its performance and the environment, the ability to anticipate developments, and the ability to learn from past experiences). The analysis of these results showed that three items did not satisfy the conditions imposed before analysis. The decision was not to remove any of these items but instead review the wording of the item or move it to another factor. As explained earlier (section 6.4), there have been some difficulties to understand words such as "vulnerability" and "monitoring" and the confusion between "resources" as a factor and "resources" as what is required to carry out an action. Therefore, the decision was to rephrase the two concerned items. On the other hand, an item was moved from a component to another because its loading indicated a higher value with respect to the other component as well as a corresponding meaning (the meaning of the item matched the sense of the second component). Since PCA gave good results for the three studied factors i.e. resources, time pressure, and supervision/coordination, it could be concluded that the items of the instrument were reproducible for the three factors that meant that MASRAT could be used for any of the identified factor and might be extended to study all the 16 factors.

Cronbach's alpha was then computed by means of SPSS. The results were higher than what was required that is 0.7 value.

The next Chapter will address the expert panel testing of MASRAT that is to achieve objective four, part 2. The new items were used in three ateliers of a workshop with experts from maintenance departments of the three branches of the Company. The three ateliers represented the three studied factors.

CHAPTER 7. THE MAINTENANCE SYSTEM RESILIENCE ASSESSMENT TOOL, MASRAT, PANEL EXPERT TESTING: WORKSHOP

7.1. Introduction

In the previous chapter, the development and validation of MASRAT was addressed. As explained in the research method process (chapter 4), the following phase dealt with tool testing that is, applying the tool to measure the system's resilience and identify strategies for improvement, and make recommendations to manage safety proactively in the maintenance system; this represented objective 4, part 2 of this research work. The testing phase included a panel expert testing through a workshop held in the Algerian Petroleum Institute. It was organised in three ateliers according to three factors (resources, time pressure, and coordination/supervision). Experts from maintenance departments were invited and asked to use MASRAT.

This chapter presents the results of the workshop. Section 7.2 addresses the workshop design, its structure, and process. Workshop results and analysis are given in section 7.3. It gives the results of the assessment of the system resilience as well as the main recommendations, and eventually the results are discussed. An evaluation of the workshop is carried out in section 7.4. Eventually, section 7.5 summarises this chapter.

7.2. Workshop Design

7.2.1. Participants

The objective of expert testing for any developed tool is to check its usability in real life. The experts contributed to highlight limitations and help identify areas of improvement. Besides, the experts that were chosen to participate in this action came from the maintenance departments where MASRAT was sensible to be used.

A request was sent to the Algerian Petroleum Institute (IAP) management to hold a workshop gathering experts from maintenance personnel representing the three branches of activity of the Company (oil and gas production, pipeline transportation, and gas and refining plants) with the aim of making recommendations to top management of the Company. The approval was got to invite 30 experts (10 persons per branch) for one day and a half workshop. Skilled and experienced people were invited in order to have an effect on the results of validation. Some of these people were located during the validation phase (chapter 6) and were proposed to participate in a workshop in order to carry out this testing while others were chosen by their respective directions.

Actually, there have been two (02) groups of actors in the workshop: the principal actors i.e. the experts from maintenance departments called “the participants” in this thesis and the facilitators. For evaluating the workshop, three (03) actions were retained, namely an immediate evaluation, a questionnaire, and an interview. The first and the second actions concerned all of the actors whereas the third one was directed to the facilitators. The results and analysis of the responses are described in the evaluation section.

7.2.2. The Workshop Structure

After the validation process of the tool, a workshop was held in the Algerian Petroleum Institute (IAP) 27-28 of January 2013. Among the 30 experts from maintenance departments (oil and gas production and pipeline transportation, and gas and refining plants) that were invited, only 23 persons attended the workshop, the others did not for security matters. Among the attendees, 04 were managers (head of maintenance department). An explanatory introduction was sent to the participants explaining the expectations and the objectives of the workshop (see appendix 4).

The objectives set for the workshop were:

a) Communicate and study the data collected during the action of validation,
b) Assess the resilience of the maintenance system and determine the different profiles and maturity levels,
c) Identify strategies for improvement, and
d) Make recommendations to top management.

To achieve these objectives, the following activities were planned.

- Invite experts from maintenance department of all branches of the Company to the workshop
- Send materials to participants and facilitators to prepare the workshop
- Hold the workshop

- Make an explanatory presentation about MASRAT and workshop objectives followed by a debate
- Split the participants into three groups (ateliers) to study the three identified factors (resources, time pressure, and supervision/coordination)
- Use MASRAT to achieve objectives
- Find out suggestions to improve MASRAT

The workshop consisted of two parts. First, a presentation to the participants of the new approach as well as the background underlying the development of MASRAT and the data collected during the validation process were done; this was followed by a debate that concentrated mainly on the new approach. Second, three (03) ateliers were set according to the factors that were studied i.e. resources, time pressure, and supervision/coordination.

In the ateliers, the participants reviewed the 28 items related to the four (04) abilities (ability to respond, to monitor, to anticipate, and to learn) and assessed the resilience of the system. Then, item, factors, aspects, and department profiles were determined. Afterwards, the maturity level according to a scale ranging from MAL 1 to MEL (excellence) was computed. This was followed by the identification of strategies for improvement based on SWOT analysis. Finally, recommendations were made both for department and corporate level; figure 7.1 shows the structure of the workshop. Section 7.3 addresses the activity of each of the three ateliers.

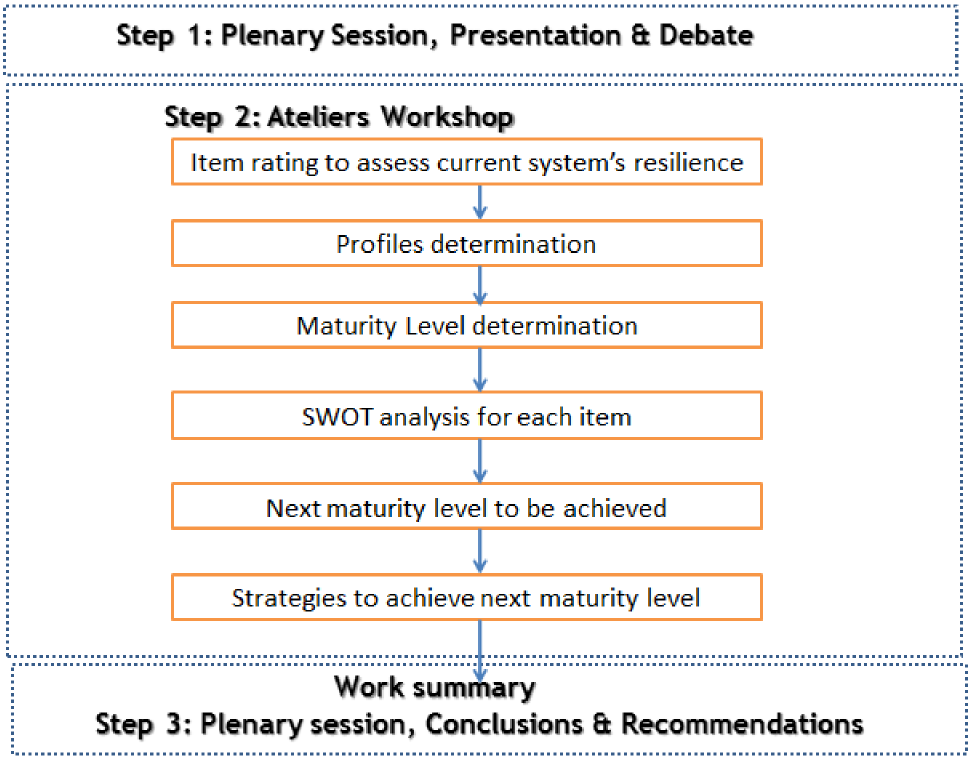

Figure 1-26 : Structure of the workshop

7.2.3. The Workshop Process

In the following, the implementation process is declined. It consisted of:

- Committing stakeholders to this action,
- Describing the implementation process,
- Identifying specific aspects that should be looked at,
- Performing the workshop
- Getting immediate feedback
- Sending questionnaire to participants and facilitators after the workshop to comment on,
- Interviewing facilitators, and
- Eventually carrying out analysis of data collected.

7.2.3.1. Stakeholders' Engagement

The process of MASRAT implementation and goals was explained to IAP managers to help get approval from SONATRACH managers. With respect to the field-testing (from validation to the expert panel testing in a workshop), a total commitment was obtained from top management. However, participants and facilitators deemed the time allocated and imposed to the workshop very short.

7.2.3.2. Program Description

In this workshop, experts from maintenance departments of the company met and debated about the prevailing situation and exchanged experiences. Particularly, the resilience of the maintenance system was evaluated for the first time by means of the MAintenance Resilience Assessment Tool (MASRAT). System profiles and maturity levels were determined. Strategies to improve current situation for both corporate and local level were identified. These strategies might be studied within each department to determine the appropriate mechanisms of implementation. Finally, recommendations were made for top management.

7.2.3.3. Specific Aspects

i. Statement of need

The study of human factors in the maintenance of oil and gas assets is limited in comparison to other industries such as aviation and nuclear as it has been shown in chapters 2 and 3. In response to this, the use of MASRAT was intended to remedy this limitation by studying human factors in the maintenance system of the Algerian National Oil and Gas Company to achieve safety excellence based on resilience engineering,

ii. Expectations

As stated earlier, the usability of MASRAT was tested in real world and suggestions to improve MASRAT were expected.

iii. Activities

In the validation phase, meetings with maintenance staffs were held. During these meetings, MASRAT was presented and a debate followed each presentation. Some participants were seen as experts that could enhance the level of the workshop if they were invited. In addition, managers at corporate level were solicited to propose experts from their branch. Thirty people from maintenance department of all branches of the Company were invited to attend the workshop. Materials were sent to participants and facilitators to prepare the workshop. An explanatory presentation about MASRAT and workshop objectives that was followed by a debate was carried out. The participants were then split into three groups (ateliers) to study the three identified factors. They were asked to use MASRAT and go through the twenty-eight (28) items of the tool.

iv. Stage of development

It concerned the MASRAT implementation phase to see what happens in the real world.

v. Context

MASRAT was used to achieve research objectives.

vi. Resources

Materials were sent to participants and facilitators to prepare the workshop. In the ateliers, templates were distributed with the objective to go through the 28 items in one day maximum according to the deadline imposed by IAP management. Logs were prepared and given to participants

vii. Benefits

The values or benefits of this action consisted of testing the usability of MASRAT and gaining suggestions to improve it. Moreover, it allowed identify strategies for improvement to implement at both department and corporate levels as well as measure the system's resilience. Besides, it entailed making recommendations to top management to improve the system of maintenance and beginning the continuous improvement journey.

7.2.4. Communication about the Validation Phase

During the first part that lasted half day, the expected activity of the workshop was presented to the audience. An introduction was first given where it has been shown that (1) maintenance activities are generally labour intensive hence accidents prone, (2) human factors are most times difficult to identify, and (3) research within the oil and gas industry with respect to human factors in maintenance management is limited. Research in safety had focused on accidents so far and traditional risk assessment techniques as well as accident causation models have been unable to handle current complex safety critical systems. Therefore, the urgent need to develop something different to address such systems as well as to make the shift to understand why things go right too were emphasised. The proposed solution lied in the use of a new approach based on Resilience Engineering and a way to measure the system resilience. MASRAT that was developed to this end was then presented. The development and validation phase were reviewed. The different improvements of MASRAT until the last version were then given. The participants and facilitators were invited to debate. As per the different visits to maintenance departments, the debate concentrated mainly on the new approach based on resilience engineering. Some participants that have contributed during the validation phase stressed on the fact that the meaning of some items were difficult to grasp first instance when they had to give a score. The answer was the activity during the atelier would surely help clarify anything that looks obscure.

7.3. Results

The study of the usability of MASRAT was the main objective of the workshop. The participants examined the system resilience within the three ateliers. In each atelier, the experts went through the 28 items with respect to the four abilities. They established the different profiles for the maintenance department according to the three studied factors. An Excel worksheet allowed the determination of the profiles by means of a star chart as well as a maturity level assessment model. In the following sections, the workshop results by atelier, the system profiles, and maturity levels are given.

7.3.1. Workshop Results by Atelier

In order to determine strategies for improvement with respect to each of the three factors, the experts discussed the 28 items one by one according to the theme of their dedicated atelier. The conclusions that came up from the workshop are summarised in the following tables from table 7.1 to table 7.12. In the ateliers, the current situation was assessed for each of the items to which a score was attributed. After that, an expected higher score to be achieved was devised and adopted and actions to achieve the adopted score were recommended.

Table 1-41 : Atelier resources, ability to respond

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
1.1 Before each management review, the department assesses resources issues	Meetings are held to discuss issues encountered (weekly in certain regions, monthly in others)	2	A preparation of meetings/briefings should be done by the planning section first. Hold daily/weekly evaluation of such issues in the different sections of the maintenance department and monthly meetings at director and maintenance departments dedicated to resources issues. These meetings should be done according to preventive maintenance planning where priority should be given to vulnerable equipment. Contractors' experience should be used to contribute to make these actions succeed. Systematically evaluate value added of these meetings.	3	The maintenance department		
1.2 The department has prepared responses to resources issues	There is no model dedicated to respond to resources issues. An important lack of spare parts exists in addition to a planning problem. Managers cannot conclude direct contracts. Besides, resources are not optimised with other departments and important delays exist in the conclusion of some contracts.	2	Allow managers to conclude direct contracts where suppliers have the exclusivity. Put in place joint ventures for spare parts and maintenance. Conclude O & M contracts. Optimise the use of the CMMS.	3	The organisation should encourage such tasks. The maintenance department		

Atelier resources, ability to respond (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
1.3 The department applies threshold criteria for activating a response to resources issues	Safety stocks and tracker sheets are taken into consideration	2	Evaluate sheets and determine threshold criteria for every important equipment	3	Decisions should be taken at corporate level		
1.4 The department systematically evaluates and testes on site the responses to resources issues	Do not exist	1	Search issues inherent to the obsolescence of spare parts as well as the disappearance of suppliers. To this end, make the existence of spare durable for a period of e.g. 15 years. Put in place technology watch units and internal audits to follow up maintenance activities issues for managers and engineers concerned by the acquisition of spare parts. Follow-up trends about inherent issues of spare obsolescence. Make procedures more flexible to optimise the ability to respond. Allow contracts flexibility with potential suppliers.	3	Decisions should be taken at corporate level		
1.5 The department provides sufficient resources (competent personnel, time, etc.) to respond to resources issues	This is performed according to existing procedures.	3	Maintain the level	3			

Atelier resources, ability to respond (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
1.6 The department maintains readiness to respond to resources issues	To some extent, this is taken into account	2	Define resources that must be exclusively dedicated to prepared responses as well as the criteria that allow a return to normal state. Provide training in supplier centres. Provide long-term specific training and refreshment. Establish at corporate level mutual response assistance plan regarding all kind of resources linked to maintenance activities.	3	The maintenance department Decisions should be taken at corporate level		

Table 1-42 : Atelier resources, ability to monitor

Items	**Current situation**	**Score**	**Actions**	**Expected score**	**Carried out by**	**Debut**	**End of task**
2.1 The monitoring of resources issues is of great importance in the maintenance department	The codification is not the same within the organisation. Separation/isolation between teams/sections/departments does not allow exchanges. There is limited mutual assistance between departments.	2	A module dedicated to the exploitation of spare parts has been developed and added to the CMMS in downstream branch. A possibility exists through the CMMS to put in place a unique codification of spare that may be accessed by all maintenance departments at corporate level. Establish progressively within the organisation mutual response assistance plan regarding all kind of resources linked to maintenance activities. It is of great importance to put in place appropriate PI's and support teams to perform the monitoring of resources issues. The person responsible of the operation and the zone planner may carry out this monitoring before (for preventive maintenance activities) and during actions (interventions while there is an imminent danger).	3	Decisions should be taken at corporate level The maintenance department		

Atelier resources, ability to monitor (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
2.2 There are Performance Indicators (PI) allowing the monitoring of resources issues	By means of the CMMS, standard PI's that allow the monitoring of resources issues exist.	3	The PI's lists have been created during the commissioning of the plants and updated when the CMMS has been put in place. The maintenance departments in collaboration with the other departments should regularly revise this list. It is of great importance to evaluate the maintenance system called G system and harmonise, exploit and make an optimum use of the CMMS. At department level, performance indicators (PI) can be added. PI's that measure how many times a member of the department: • Was unable to find a tool or an item of maintenance equipment • Has delayed a task because a consumable part is missing • Has delayed a task because a major part is missing • Has used an unserviceable equipment • Has performed a task without the appropriate tool/equipment • Has performed a task without the appropriate documentation, etc.	4	The maintenance department Decisions should be taken at corporate level		

Atelier resources, ability to monitor (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
2.3 There is an appropriate choice for types of PI (leading, current, and lagging) related to resources issues	PI's are appropriate for current and reactive	2	A study and review of existing PI's and those proposed in this workshop is important in order to determine a model allowing an appropriate choice for the types of PI's as well as their validity and reliability.	3	The maintenance department Maintenance department coordination throughout the organisation		
2.4 There are PI's for monitoring shrinking safety margins for resources issues	There exist PI's with reliable measures	2	Due to the current spare procedure, there are overstocks for certain spares. Could be done in collaboration with spare parts management sections based on lessons learned.	3	The maintenance department		
2.5 PI list is regularly updated based on Indicator's pertinence for resources issues	Do not exist	1	PI's and safety margin should be evaluated continuously. Put in place annually a study and reflecting group of experts (internal and external)	3	Maintenance department coordination throughout the organisation		
2.6 PI measurements are reliable for resources issues	PI's are evaluated to some extent. There exist PI's with reliable measures	2	There is a need to continuously evaluate PI's and harmonise CMMS at corporate level. The results are integrated in a system; this is the reason why G system must be revised.	3	Maintenance department coordination throughout the organisation		

Table 1-43 : Atelier resources, ability to anticipate

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
3.1 There is a vulnerability (fragility, weakness) model within the organisation clearly formulated for resources issues	There is no model	1	Due to rigid procedures, spirit of initiatives is limited or inexistent at all. Consequently, the organisation should elaborate a vulnerability model recognised and clearly formulated. Improve corporate mid-term plans by including in the resources section these aspects.	3	Maintenance department coordination throughout the organisation		
3.2 The organisation uses the necessary expertise to investigate the future (analyses trends) for resources issues	There is no available expertise to investigate the future	1	There is limited feedback regarding past events. Databases are either unused or do not exist. It is worth reviewing old maintenance reports to analyse trends and including in the new ones (future ones) a component related to trend analysis. It is also recommended to perform benchmarks in relation to these aspects.	3	The maintenance department		
3.3 The organisation possesses tools to analyse and predict outcomes caused by resources issues	CMMS is the only used tool	2	CMMS is under exploited and only used for preventive maintenance. It is a database with respect to spare parts in order to issue work orders. There is experience transfer through retiring personnel. It may be done through the study of maintenance reports and the optimisation of the CMMS use. Besides, it is worth motivating personnel devoted to trend analysis with a better remuneration.	3	The maintenance department Maintenance department coordination throughout the organisation		

Atelier resources, ability to anticipate (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
3.4 The organisation analyses long term effects and develops strategic planning for resources issues	Do not exist	1	Future threats as well as opportunities should be evaluated at least once per year in order to make a projection in the future of the organisation. To this end, experts from maintenance and production departments should be associated to elaborate strategic plans.	3	Maintenance department coordination throughout the organisation		
3.5 The department assesses absence of failures, hazards, and accidents to anticipate resources issues	Do not exist. The organisation culture does not take into consideration this way of thinking	1	There is no awareness regarding such a way of thinking in the maintenance departments; personnel are not sensitive to these aspects. A first approach to remedy is to carry out audits and use external expertise. The explicit recognition of acceptable and non-acceptable risks is not clearly established. The level of awareness of risks is merely individual efforts by personnel and is not a part of the culture. The nature of future threats is seen through the disappearance of spare parts suppliers and the obsolescence of spares. It develops through the non-preparation to such situations. Therefore, perform a monitoring to search all the factors that may influence the existence of these threats. The nature of future opportunities resides in the establishment of joint ventures (in maintenance in general and spare parts in particular); again, the department should perform a monitoring to search all the factors that may influence the existence of these opportunities.	3	Maintenance department coordination throughout the organisation		

Atelier resources, ability to anticipate (continued)

Items	**Current situation**	**Score**	**Actions**	**Expected score**	**Carried out by**	**Debut**	**End of task**
3.6 Information exchange within the department is a continuous and spontaneous flux that constitutes a basis to locate signs of trouble stemming from resources issues	The “silo thinking” is an important issue	2	There is a limited communication and sharing about expectations and future events within the departments. This is achieved by the development of means of communication (horizontal and vertical) and the generalisation throughout the organisation. In addition, it is worth creating new ways of communication such as specialised forums (maintenance, etc.) between the different branches of the company to exchange information, experience, etc.	3	Maintenance department coordination throughout the organisation		
3.7 There is a regular diagnosis of safety/production trade-off within the organisation for resources issues	A regular diagnosis is made but there is limited feedback from management regarding sent reports. Production is generally in favour except when there is imminent danger.	2	This may be achieved by (1) simulating risks scenarios and studying the impact on production, (2) respecting maintenance tasks planning when thresholds are attained, (3) increasing personnel vigilance level regarding events that have occurred in other sites and (4) asking production staff to be more vigilant when they track parameters while there is additional time of production.	3	The maintenance department Maintenance department coordination throughout the organisation		
3.8 The organisation assesses the impact of resource reduction on safety margins stemming from resources issues	The evaluation is performed by the department	3	Maintain current level	3			

Atelier resources, ability to anticipate (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
3.9 Data collected are immediately analysed, the results disseminated, and the recommendations implemented throughout the organisation for resources issues	Do not exist.	1	The implementation of the previous recommendations can remedy the situation. Maintenance management at corporate level can initiate these actions and insure their implementation.	3	Maintenance department coordination throughout the organisation		

Table 1-44 : Atelier resources, ability to learn

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
4.1 The organisation supports and trains staff to collect data, analyse, and learn from resources issues	Insufficient. Besides, there is limited support and training within the organisation regarding analysis and learning.	2	The events are described in intervention reports. The data are not collected, categorised, and analysed. Some events are investigated because accidents have occurred, it is the only criterion used. The learning process concerns only negative events i.e. rare events (failures, accidents, etc.). There is an urgent need to learn also from positive events i.e. successes. Reports should be published within the entire organisation by means of a monthly bulletin. In addition, it is worth reactivating the one-year induction for new recruits.	3	The maintenance department Maintenance department coordination throughout the organisation		
4.2 The learning activity is a continuous process and built throughout the entire organisation for resources issues	Quite inexistent or the learning is event oriented and not a continuous activity.	2	The workload of the management does not allow them to benefit from training actions. The use of all opportunities of learning is emphasised. It is worth training management regarding empowerment and coaching.	3	The maintenance department Maintenance department coordination throughout the organisation		
4.3 The organisation allocates necessary resources to investigate, analyse, disseminate results, and learn from resources issues	Limited; human resources departments make statistics. There are limited resources allocated to the investigation, analysis and dissemination of results, and learning for positives situations.	2	Resources allocation should be reviewed to allow continuous improvement and give more importance to analysis/methods/statistics sections within maintenance departments. Maintenance reports should be harmonised at company level. Besides, the organisation of thematic workshops/studies between the different branches of activity of the company is desirable.	3	Maintenance department coordination throughout the organisation		

Atelier resources, ability to learn (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
4.4 The delay between event reporting, analysis, and learning are the shortest possible for resources issues	Production aspects are immediately taken into account by management in comparison to other aspects.	2	The optimisation of the use of the CMMS after harmonisation within the organisation is a solution for this issue.	3	The maintenance department		
4.5 The outcomes of these analyses are rapidly communicated inside and outside the organisation for resources issues	Do not exist	1	There is an important issue of "silo thinking". No one is responsible for compiling experiences to learn from them. It is therefore worth designating a person by department to perform this action. Lessons learnt should be implemented through top management directives for execution, application notes, etc. Before any implementation, it is important to launch sensitising campaigns.	3	The maintenance department		
4.6 There are means in place to verify that the intended learning is taking place for resources issues	Do not exist	1	Create an internal control/follow-up unit that performs audits annually. In addition, consider the reactivation of the objectives set to management regarding training actions.	3	Maintenance department coordination throughout the organisation		

Atelier resources, ability to learn (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
4.7 There are means in place to maintain what has been learned for resources issues	Do not exist	1	Consider coaching the new recruits by personnel close to retirement to transfer the capital experience at least during the 5 last years of work; carry out sensitising campaigns to increase the level of knowledge within the organisation; use the communication means that exist within the company to encourage training delivered by internal competences to ensure transfer of capital experience; select pertinent information and associate PI's to ensure follow-up, etc.	3	The maintenance department Maintenance department coordination throughout the organisation		

Table 1-45 : Atelier Time Pressure, ability to respond

Items	**Current situation**	**Score**	**Actions**	**Expected score**	**Carried out by**	**Debut**	**End of task**
1.1 Before each management review, the department assesses time pressure issues	Management review is not systematic; these meetings are reactive according to the issue raised. Some kind of evaluation is carried out in some maintenance departments without informing the upper level.	2	Hold daily/weekly evaluation of such issues in the different sections of the maintenance department and monthly meetings at director and maintenance departments dedicated to time pressure issues.	3	The maintenance department		
1.2 The department has prepared responses to time pressure issues	Has much more to do with improvisation than with careful planning to correct problems	2	Can be done by effective exploitation of the CMMS; hold briefings to analyse the evolution and make reporting.	3	The maintenance department		
1.3 The department applies threshold criteria for activating a response to time pressure issues	Responses are generated on management request when the constraint affects the performance (production, safety, etc.). Criteria used: performance disturbance, accident.	2	A team of experts can make recommendations to define threshold criteria.	3	Decisions should be taken at corporate level		

Atelier Time Pressure, ability to respond (continued)

Items	**Current situation**	**Score**	**Actions**	**Expected score**	**Carried out by**	**Debut**	**End of task**
1.4 The department systematically evaluates and testes on site the responses to time pressure issues	Do not exist	1	Establish a list of PI's in relation to the use of the CMMS	3	The maintenance department		
1.5 The department provides sufficient resources (competent personnel, time, etc.) to respond to time pressure issues	Do not exist	1	Define the required resources (competence, expertise, time, material) to respond to time pressure issues	2	The maintenance department Decisions should be taken at corporate level		
1.6 The department maintains readiness to respond to time pressure issues	Do not exist	1	Assign a person from the department to track time pressure issues and establish a list of PI's in relation to the use of the CMMS	2	The maintenance department		

Table 1-46 : Atelier Time Pressure, ability to monitor

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
2.1 The monitoring of time pressure issues is of great importance in the maintenance department	Do not exist	1	May be achieved: assign a person responsible for PI's and allocate required resources; use CMMS.	2	Decisions should be taken at corporate level The maintenance department		
2.2 There are Performance Indicators (PI) allowing the monitoring of time pressure issues	Do not exist	1	At department level, performance indicators (PI) can be added. Examples of reactive and current PI's, based on a study of the maintenance environment, to take into consideration include the measurement of frequency of occurrence of: • Lack of time to read adequately documentation before starting a task • Rushing an inspection • Cut shorting a functional check • Signing for a task before it is completed • Being asked to hurry a task • Interrupting a task to perform a more urgent one, etc. For proactive PI, it is worth analysing the trends by better exploitation of the CMMS. Besides, the frequency for list revision should be defined and a responsibility assigned to a person from the department.	3	The maintenance department Decisions should be taken at corporate level		

Atelier Time Pressure, ability to monitor (continued)

Items	**Current situation**	**Score**	**Actions**	**Expected score**	**Carried out by**	**Debut**	**End of task**
2.3 There is an appropriate choice for types of PI (leading, current, and lagging) related to time pressure issues	There is no choice	1	To begin, consider the use of PI's proposed in 2.2. Define the appropriate lag for these PI's.	3	The maintenance department		
2.4 There are PI's for monitoring shrinking safety margins for time pressure issues	Do not exist	1	May be achieved by a team of experts from CMMS and statistics to analyse the trends monthly.	2	The maintenance department		
2.5 PI list is regularly updated based on Indicator's pertinence for time pressure issues	Do not exist	1	May be achieved: the use of the list of the proposed PI's (2.2) will allow the evaluation and the review	3	The maintenance department		
2.6 PI measurements are reliable for time pressure issues	Do not exist	1	May be achieved by performing internal/external audits respectively quarterly/annually; the use of the list of PI's (2.2) will allow determine their reliability.	3	Maintenance department coordination throughout the organisation		

Table 1-47 Atelier Time Pressure, ability to anticipate

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
3.1 There is a vulnerability (fragility, weakness) model within the organisation clearly formulated for time pressure issues	There is no model	1	The organisation should elaborate a model of vulnerability for such issues by means of the quality, HSE dashboard and check-list	3	The maintenance department Maintenance department coordination throughout the organisation		
3.2 The organisation uses the necessary expertise to investigate the future (analyses trends) for time pressure issues	There is no available expertise to investigate the future	1	There is an absolute necessity to develop internal competence and use external expertise to remedy the situation	2	The maintenance department Maintenance department coordination throughout the organisation		
3.3 The organisation possesses tools to analyse and predict outcomes caused by time pressure issues	Do not exist	1	There is an absolute necessity to possess appropriate tools	2	The maintenance department Maintenance department coordination throughout the organisation		

Atelier Time Pressure, ability to anticipate (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
3.4 The organisation analyses long term effects and develops strategic planning for time pressure issues	Do not exist	1	There is an absolute necessity to evaluate future threats/opportunities on regular basis and establish a projection of the organisation in the future	2	The maintenance department Maintenance department coordination throughout the organisation		
3.5 The department assesses absence of failures, hazards, and accidents to anticipate time pressure issues	Do not exist.	1	There is an absolute necessity to increase managers/personnel awareness to evaluate situations where things go right. This should be further embedded in the organisation culture so that there is an explicit recognition of acceptable and non-acceptable risks.	2	The maintenance department Maintenance department coordination throughout the organisation		
3.6 Information exchange within the department is a continuous and spontaneous flux that constitutes a basis to locate signs of trouble stemming from time pressure issues	Do not exist	1	There is an absolute necessity to communicate and share expectations regarding future events within the organisation through forums, intranet, etc. IT department should play an important role.	2	The maintenance department Maintenance department coordination throughout the organisation		

Atelier Time Pressure, ability to anticipate (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
3.7 There is a regular diagnosis of safety/production trade-off within the organisation for time pressure issues	Do not exist	1	There is an absolute necessity to increase managers/personnel awareness to evaluate situations where there things go right.	2	The maintenance department Maintenance department coordination throughout the organisation		
3.8 The organisation assesses the impact of resource reduction on safety margins stemming from time pressure issues	Do not exist	1	There is an absolute necessity to identify critical resources and establish annually the needs taking into account barriers and thresholds within each plant	2	Maintenance department coordination throughout the organisation		
3.9 Data collected are immediately analysed, the results disseminated, and the recommendations implemented throughout the organisation for time pressure issues	Do not exist.	1	This may be achieved: measurements should be done before each management review; analysis/interpretations should be carried out immediately after measurements and results communicated and used through reporting and discussions during management review.	3	The maintenance department Maintenance department coordination throughout the organisation		

Table 1-48 Atelier Time Pressure, ability to learn

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
4.1 The organisation supports and trains staff to collect data, analyse, and learn from time pressure issues	Do not exist	1	There is an absolute necessity to develop a model that describes the way data from events are collected and categorised. Learning process should stem from what is frequent (i.e. positive situations, successes) as well as from what is are (i.e. failures, accidents). Identify the required qualifications and profile types of participants and launch program training with specialised organisms in collaboration with human resources departments	3	Maintenance department coordination throughout the organisation		
4.2 The learning activity is a continuous process and built throughout the entire organisation for time pressure issues	The learning process is not continuous and all opportunities are not used	2	There is an absolute necessity to make the learning process continuous within the organisation regarding time pressure issue. Provide management support to train specialist and provide coaching to remedy the situation.	3	The maintenance department Maintenance department coordination throughout the organisation		
4.3 The organisation allocates necessary resources to investigate, analyse, disseminate results, and learn from time pressure issues	Do not exist	1	There is an absolute necessity to identify and allocate appropriate competences and resources to the investigation, analysis, and results dissemination in collaboration with human resources departments	3	The maintenance department Maintenance department coordination throughout the organisation		

Atelier Time Pressure, ability to learn (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
4.4 The delay between event reporting, analysis, and learning are the shortest possible for time pressure issues	Do not exist	1	There is an absolute necessity to shorten the delay between reporting an event, the analysis, and learning	3	The maintenance department Maintenance department coordination throughout the organisation		
4.5 The outcomes of these analyses are rapidly communicated inside and outside the organisation for time pressure issues	Do not exist	1	There is an absolute necessity to communicate rapidly inside and outside the company the results of analysis. The learning process should take part at all levels (individual, collective, and the entire organisation). A person should be assigned the responsibility to compile experiences so that lessons are learnt. In every plant, results should be communicated to the section “communication” and should propose the best ways to implement learnt lessons (through regulations, procedures, standards, training, instructions, redesign, etc.)	3	The maintenance department Maintenance department coordination throughout the organisation		
4.6 There are means in place to verify that the intended learning is taking place for time pressure issues	Do not exist	1	There is an absolute necessity to put in place means to verify or confirm that learning has taken place. A “learning factor” should be included by human resources departments to appreciate performance of personnel	3	The maintenance department Maintenance department coordination throughout the organisation		

Atelier Time Pressure, ability to learn (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
4.7 There are means in place to maintain what has been learned for time pressure issues	Do not exist	1	There is an absolute necessity to put in place means to maintain what has been learnt. A “learning factor” should be included by human resources departments to appreciate performance of personnel	3	The maintenance department Maintenance department coordination throughout the organisation		

Table 1-49 Atelier coordination/supervision, ability to respond

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
1.1 Before each management review, the department assesses coordination/supervision issues	Meetings are held to discuss raised issues. Comments on supervision/coordination issues are limited	2	A preparation of meetings/briefings should be done by the planning section first. Hold daily/weekly evaluation of such issues in the different sections of the maintenance department and monthly meetings at director and maintenance departments dedicated to supervision/coordination issues. These meetings should be done according to preventive maintenance planning where priority should be given to vulnerable equipment. Contractors' experience should be used to contribute to such actions. Systematically evaluate value added by these meetings.	3	The maintenance department		
1.2 The department has prepared responses to coordination/supervision issues	There are limited responses to solve supervision/coordination issues.	1	Specific training, selective recruitments, new recruits backing through training, coaching, etc. may achieve it. A personal development plan is required for every worker.	2	Decisions should be taken at corporate level		
1.3 The department applies threshold criteria for activating a response to coordination/supervision issues	There are no threshold criteria	1	It may be achieved by an adequate human resources policy; if a personal development plan (PDP) is established for every employee, threshold criteria can be defined from these PDP's. The study of the PI's developed in the following section (2.2) will be very instructive.	2	The maintenance department Decisions should be taken at corporate level		

Atelier coordination/supervision, ability to respond (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
1.4 The department systematically evaluates and testes on site the responses to coordination/supervision issues	Do not exist	1	The evaluation of training and coaching for instance may allow know whether the responses are appropriate or not. Elements to look for include required time that makes a response effective, the celerity to establish a total response, necessary time to maintain a response effective, the rapidity to reconstruct the resources. These could be considered as proactive PI's	2	The maintenance department Decisions should be taken at corporate level		
1.5 The department provides sufficient resources (competent personnel, time, etc.) to respond to coordination/supervision issues	To some extent	2	It may be achieved by checking complaints during and after maintenance intervention, controlling maintenance planning and safe return back to service of facilities. Pi's could be assigned to these controls and analysis performed on regular basis (e.g. annually after equipment overhaul)	3	The maintenance department		
1.6 The department maintains readiness to respond to coordination/supervision issues	See 1.2 above. In addition, there is a lack of appropriate documentation for supervisors, lack of experts, and lack of spare parts.	1	Define the resources that must be kept exclusively to prepared responses and the criteria that allow returning to normal situation.	3	The maintenance department		

Table 1-50 Atelier coordination/supervision, ability to monitor

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
2.1 The monitoring of coordination/supervision issues is of great importance in the maintenance department	Each team tracks only its own personnel; there is limited communication between teams/sections/departments	2	There is an opportunity to carry out the monitoring of supervision/coordination issues through the CMMS (statistic studies, maintenance intervention reports) but this is unfortunately under exploited. It is of great importance to put in place appropriate PI's and support teams to perform the monitoring of supervision/coordination issues. The person responsible of the operation and the zone planner may carry out this monitoring before (for preventive maintenance activities) and during actions (interventions while there is an imminent danger).	3	The maintenance department		

Atelier coordination/supervision, ability to monitor (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
2.2 There are Performance Indicators (PI) allowing the monitoring of coordination/supervision issues	There are PI's devoted to the monitoring of supervision/coordination issues by means of the CMMS (intervention time man/days, thresholds that mustn't be exceeded, quality of work performed, discipline, absenteeism, compliance to procedures, reporting)	2	CMMS is underexploited. Based on the measure of the frequency of occurrence, examples of PI's that should be taken into consideration in addition to those proposed in table 7.9 could be: • Feeling that there is some limitation of knowledge or experience to perform an assigned task • Correcting an error done by someone else without documenting what has been done • Feeling that a defect has not been properly corrected before a system or a component was returned to service • Certifying that someone's work was correct without checking it • Starting a task while someone has already begun to perform it • Task supposed to be done but found after it was not the case • Receiving wrong information about a task, etc. In addition, the participants recommended the following: • Review regularly this list in collaboration with other departments • Appoint someone to review the list • Perform the measures on a regular basis before the management review	3	The maintenance department		

Atelier coordination/supervision, ability to monitor (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
2.3 There is an appropriate choice for types of PI (leading, current, and lagging) related to coordination/supervision issues	The choice is appropriate for current and reactive PI's	2	A study and review of existing PI's and those proposed in this workshop is important in order to determine a model allowing an appropriate choice for the types of PI's as well as their validity and reliability.	3	The maintenance department		
2.4 There are PI's for monitoring shrinking safety margins for coordination/supervision issues	Do not exist	1	It can be achieved by employee medical follow-up, adequate training, compliance to work regulations (in terms of number of hours worked), mental and physical workload risk assessment on a regular basis and recommendations implemented with no delay.	3	The maintenance department Decisions should be taken at corporate level		
2.5 PI list is regularly updated based on Indicator's pertinence for coordination/supervision issues	Do not exist	1	Review and update regularly before each management review and Health and Safety Committee. Put in place focus groups to discuss these issues annually.	3	The maintenance department Decisions should be taken at corporate level		
2.6 PI measurements are reliable for coordination/supervision issues	They are reliable for the existing PI's	2	Optimal exploitation of the CMMS is required in addition to audits and systematic control on site.	3	The maintenance department		

Table 1-51 Atelier coordination/supervision, ability to anticipate

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
3.1 There is a vulnerability (fragility, weakness) model within the organisation clearly formulated for coordination/supervision issues	To some extent, there is a model in human resources direction (carrier planning) at corporate level but with limited implementation	2	It is worth noting that at department level, there is an assessment of the situation (retirement of experts, training on time to face new technology, resignation and transfer out, etc.); information is communicated but there is limited feedback. Implement the mid-term Company plan that consists of resources planning communicated by every facility. Accelerate the pace of selection of candidates and recruitments	3			
3.2 The organisation uses the necessary expertise to investigate the future (analyses trends) for coordination/supervision issues	There is no available expertise to investigate the future	1	The level of awareness regarding states where things go right should be increased at all levels. There is an absolute necessity to develop internal competence and use external expertise to remedy the situation	3	The maintenance department Maintenance department coordination throughout the organisation		
3.3 The organisation possesses tools to analyse and predict outcomes caused by coordination/supervision issues	Do not exist	1	It may be achieved by a better exploitation of the CMMS, maintenance intervention reports, and on site controls and audits	3	The maintenance department		

Atelier coordination/supervision, ability to anticipate (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
3.4 The organisation analyses long term effects and develops strategic planning for coordination/supervision issues	Do not exist	1	Encourage the emergence of internal expertise; encourage the coaching of new recruits; create technology watch units to adapt human resources to new technologies. Future threats and opportunities should be evaluated at least once per year. The nature of supposed future threats is expressed through routine, drop of level of vigilance, overconfidence (complacency), self-satisfaction, fatigue, etc. These develop through absence of control, successive good results, and repeated tasks for a long period of time in the same place, lack of mobility intra-branches, etc. It is worth therefore, seeking and monitoring all these factors. The nature of supposed future opportunities lies in the detection of competence and expertise, and the assurance to retain those recognised staff, the transfer of good practices and knowledge, the capitalisation of knowledge and know-how, etc. It is worth therefore, seeking and monitoring all these factors	3	The maintenance department Maintenance department coordination throughout the organisation		

Atelier coordination/supervision, ability to anticipate (continued)

Items	**Current situation**	**Score**	**Actions**	**Expected score**	**Carried out by**	**Debut**	**End of task**
3.5 The department assesses absence of failures, hazards, and accidents to anticipate coordination/supervision issues	Do not exist	1	There is limited awareness regarding states where there is absence of failures, accidents, etc. Raise awareness of personnel/managers to assess such situations. Establish within the organisational culture an explicit recognition of acceptable and non-acceptable risk; the risk awareness is not part of the organisational culture but remains individual efforts. Same as above (3.4) for the future opportunities/threats.	2	The maintenance department Maintenance department coordination throughout the organisation		
3.6 Information exchange within the department is a continuous and spontaneous flux that constitutes a basis to locate signs of trouble stemming from coordination/supervision issues	Do not exist	1	Communicate and share within the organisation expectations regarding the future throughout forums; this is achieved by developing means of horizontal and vertical communication and generalising the use of the CMMS.	3	Maintenance department coordination throughout the organisation		
3.7 There is a regular diagnosis of safety/production trade-off within the organisation for coordination/supervision issues	Production is favoured in comparison to safety except when there is an imminent danger	2	The trade-off safety/production might be addressed by: • Simulating near-misses risk scenarios along with a study of the impact on production • Respecting maintenance tasks schedules as planned • Increasing the levels of vigilance of workers based on company's event logs • Requesting production staff to increase awareness and vigilance in following up and tracking production parameters	3	The maintenance department Maintenance department coordination throughout the organisation		

Atelier coordination/supervision, ability to anticipate (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
3.8 The organisation assesses the impact of resource reduction on safety margins stemming from coordination/supervision issues	Performed by the maintenance department	3	The impact of resources reduction on safety margins might be assessed by measuring: • The frequency of updating the schedules, and staff performing urgent tasks • The impact of such actions on deadlines and quality of maintenance	4	The maintenance department		
3.9 Data collected are immediately analysed, the results disseminated, and the recommendations implemented throughout the organisation for coordination/supervision issues	Do not exist	1	The implementation of the previous recommendations may remedy.	3	The maintenance department		

Table 1-52 Atelier coordination/supervision, ability to learn

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
4.1 The organisation supports and trains staff to collect data, analyse, and learn from coordination/supervision issues	Do not exist	1	The events are described in intervention reports. The data are not collected, categorised, and analysed. Some events are investigated because accidents have occurred, it is the only criterion used. The learning process concerns only negative events i.e. rare events (failures, accidents, etc.). There is an urgent need to learn also from positive events i.e. successes. Reports will be published within the entire organisation by means of a monthly bulletin. In addition, it is worth reactivating the one-year induction to the new recruits.	3	The maintenance department Maintenance department coordination throughout the organisation		
4.2 The learning activity is a continuous process and built throughout the entire organisation for coordination/supervision issues	The learning is event oriented and not a continuous activity.	2	The use of all opportunities of learning is emphasised. It is worth training management regarding empowerment and coaching. Encourage learning from what is frequent (successes, things that go right) as well as what is rare (failures, things that go right) as well as rare events (things that go wrong)	3	The maintenance department Maintenance department coordination throughout the organisation		

Atelier coordination/supervision, ability to learn (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
4.3 The organisation allocates necessary resources to investigate, analyse, disseminate results, and learn from coordination/supervision issues	Limited; human resources departments make statistics. There are limited resources allocated to the investigation, analysis and dissemination of results, and learning for positives situations.	2	A steering committee should be put in place at corporate level to analyse and investigate annually the situation	3	Maintenance department coordination throughout the organisation		
4.4 The delay between event reporting, analysis, and learning are the shortest possible for coordination/supervision issues	Do not exist	1	Make someone responsible to compile experiences Assign responsibility to a multidisciplinary team to make optimum exploitation of the CMMS	3	The maintenance department		

Atelier coordination/supervision, ability to learn (continued)

Items	Current situation	Score	Actions	Expected score	Carried out by	Debut	End of task
4.5 The outcomes of these analyses are rapidly communicated inside and outside the organisation for coordination/supervision issues	Reports on negative situations are communicated to the different authorities	2	No one is responsible for compiling experiences to learn from them. It is therefore worth designating a person by department to perform this action. Lessons learnt should be implemented through top management directives for execution, application notes, etc. Before any implementation, it is important to launch sensitising campaigns.	3	The maintenance department Maintenance department coordination throughout the organisation		
4.6 There are means in place to verify that the intended learning is taking place for coordination/supervision issues	Do not exist	1	Create an audit/follow-up unit to check that learning has taken place	3	Maintenance department coordination throughout the organisation		
4.7 There are means in place to maintain what has been learned for coordination/supervision issues	Do not exist	1	Create an audit/follow-up unit to verify that means to maintain this learning is in place. Consider coaching the new recruits by personnel close to retirement to transfer the capital experience at least during the 5 last years of work; carry out sensitising campaigns to increase the level of knowledge within the organisation; use the communication means that exist within the company to encourage training delivered by internal competences to ensure transfer of capital experience; select pertinent information and associate PI’s to ensure follow-up, etc.	3	Maintenance department coordination throughout the organisation		

7.3.2. Maintenance System Abilities: Results and Analysis

The maintenance system profiles that include the four abilities and the department profile by atelier are shown in the following figures from figure 7.2 to 7.15. The profiles in blue colour represent the system abilities before drawing any recommendation whereas those in red colour represent the targeted profiles after recommendations. R stands for "ability to respond", M for "ability to monitor", A for "ability to anticipate", and L for "ability to learn". S1, S2, etc. represent the respective statements for each of the four abilities. Tables 7.13 to 7.16 give the meaning of each statement.

Table 1-53 The meaning of statements for the ability to respond

Items (statements)	Meaning
Respond S1	Before each management review, the department assesses…
Respond S2	The department has prepared responses to…
Respond S3	The department applies threshold criteria for activating a response to...
Respond S4	The department systematically evaluates and testes on site the responses to...
Respond S5	The department provides sufficient resources (competent personnel, time, etc.) to respond to...
Respond S6	The department maintains readiness to respond to …

Table 1-54 The meaning of statements for the ability to monitor

Items (statements)	Meaning
Mon-S1	The monitoring of …issues is of great importance in the maintenance department
Mon-S2	There are Performance Indicators (PI) allowing the monitoring of ...
Mon-S3	There is an appropriate choice for types of PI (leading, current, and lagging) related to…
Mon-S4	There are PI's for monitoring shrinking safety margins for …
Mon-S5	PI list is regularly updated based on Indicator's pertinence for...
Mon-S6	PI measurements are reliable for ...

Table 1-55 The meaning of statements for the ability to anticipate

Items (statements)	Meaning
Ant-S1	There is a vulnerability (fragility, weakness) model within the organisation clearly formulated for...
Ant-S2	The organisation uses the necessary expertise to investigate the future (analyses trends) for...
Ant-S3	The organisation possesses tools to analyse and predict outcomes caused by ...
Ant-S4	The organisation analyses long term effects and develops strategic planning for ...
Ant-S5	The department assesses absence of failures, hazards, and accidents to anticipate ...
Ant-S6	Information exchange within the department is a continuous and spontaneous flux that constitutes a basis to locate signs of trouble stemming from ...
Ant-S7	There is a regular diagnosis of safety/production trade-off within the organisation for...
Ant-S8	The organisation assesses the impact of resource reduction on safety margins stemming from…
Ant-S9	Data collected are immediately analysed, the results disseminated, and the recommendations implemented throughout the organisation for…

Table 1-56 : The meaning of statements for the ability to learn

Items (statements)	Meaning
Learn S1	The organisation supports and trains staff to collect data, analyse, and learn from...
Learn S2	The learning activity is a continuous process and built throughout the entire organisation for ...
Learn S3	The organisation allocates necessary resources to investigate, analyse, disseminate results, and learn from...
Learn S4	The delay between event reporting, analysis, and learning are the shortest possible for...
Learn S5	The outcomes of these analyses are rapidly communicated inside and outside the organisation for...
Learn S6	There are means in place to verify that the intended learning is taking place for ...
Learn S7	There are means in place to maintain what has been learned for ...

In the following section, the maintenance system resilience as well as strategies for improvements at both department and corporate levels are discussed based on the results that stem from the three ateliers. The current maintenance system performance and the targeted one are detailed by studying the different profiles and reviewing the corresponding items (statements) for each of the four abilities.

7.3.2.1. Ability to respond

i. Resources Factor Resilience Profile for the ability to respond

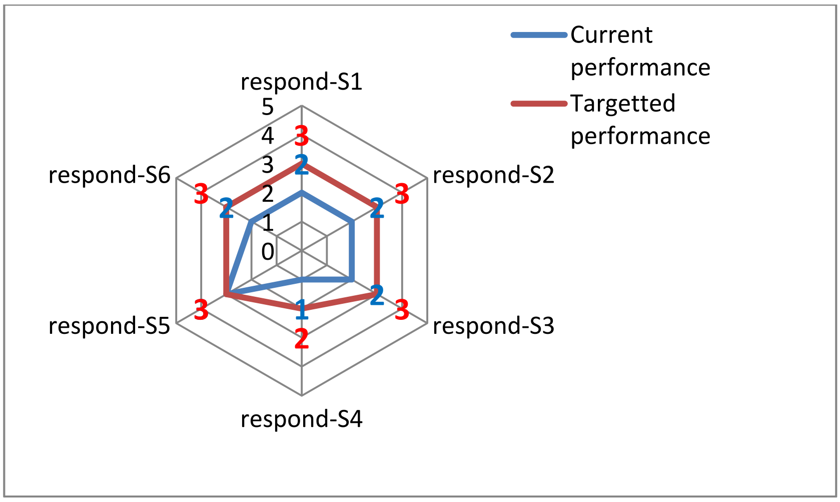

Figure 1-27: Resources Factor Resilience Profile for the ability to respond

From this profile, for the majority of items (statements) the score is 2 meaning that the system performs under performance requirements. Items S4 and S5 show respectively score 1 and 3 which denotes that the system does not systematically evaluates and testes on site the responses (item S4) whereas item S5 meets minimum requirements. The targeted performance is mainly meeting minimum item requirements.

ii. Time-pressure Factor Resilience Profile for the ability to respond

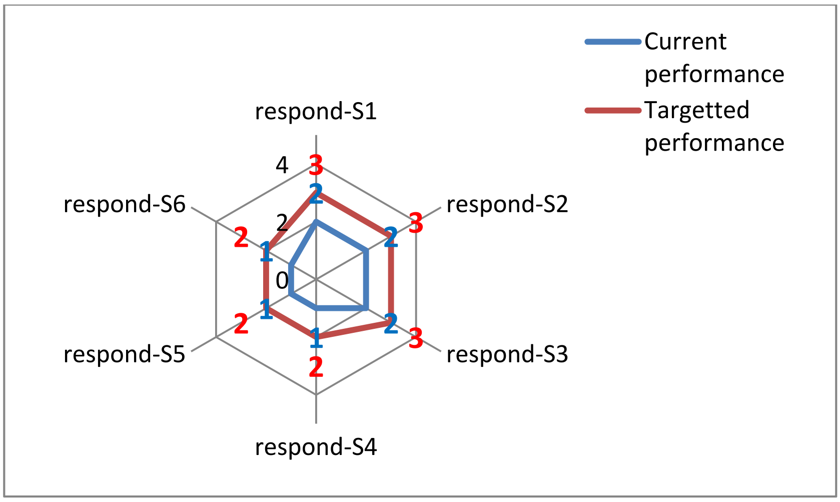

Figure 1-28: Time-pressure Factor Resilience Profile for the ability to respond

Items S4, S5, and S6 are nor addressed. There is neither systematic evaluation nor responses testing on site as well as resources provision and readiness to respond. With regard to the remaining items, the system performs under minimum requirements. The targeted performance is to make the system meet minimum requirements for item S1, S2, and S3 while the remaining items should be at least addressed.

iii. Supervision/coordination Factor Resilience Profile for the ability to respond

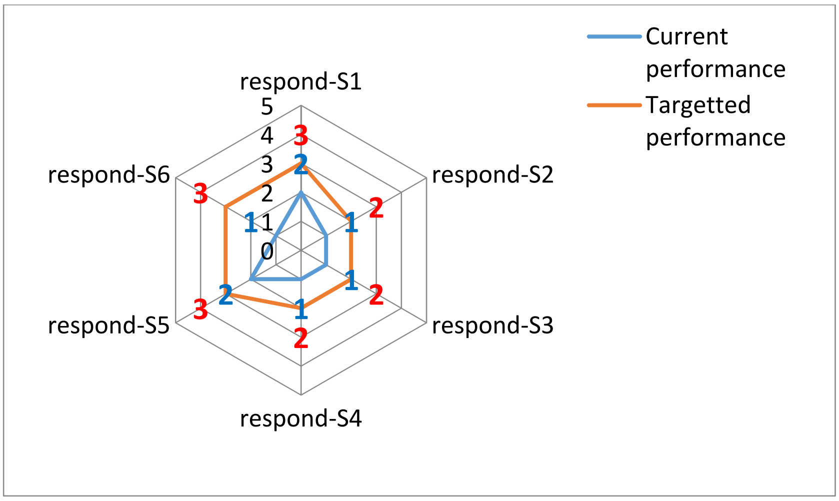

Figure 1-29: Supervision/coordination Factor Resilience Profile for the ability to respond

Majority of items are not addressed, only items S1 and S5 are tackled to some extent (meetings are held to discuss raised issues without any particular emphasis on supervision/coordination issues). The targeted performance is to address these items and meet for S1, S5, and S6 minimum requirements.

iv. Discussion

Management reviews were not performed systematically. There have been neither a model to respond to the studied issues nor prepared responses especially for the lack of spare parts within maintenance departments. Responses have been generated when the constraint impacted the performance (for instance production and safety) or when it was required by line management. Criteria used have been performance disturbance and accidents. Since there have been no prepared responses, testing and evaluation of such responses have been missing. Besides, “time pressure” and “supervision/coordination” issues were generally not addressed; therefore, resources to cope with these factors were not allocated.

As a result, participants recommended holding meetings at department level monthly to discuss these issues to evaluate preventive maintenance, study the compliance of personnel to the maintenance schedule, introduce the prioritisation of vulnerable equipment, and define the resources dedicated exclusively to prepared responses and criteria to return to a normal situation. These meetings should also:

- Address the studied issues by analysing PI's measurement (see list of PI's for each issue in the following sections)
- Define appropriate resources to respond to such problems
- Establish indicators so that management can control/monitor continuously these issues
- Establish/update a Personal Development Plan (PDP) for every worker
- Assess training, coaching, and back to back activities to determine appropriate responses
- Define resources to be exclusively allocated to prepared responses
- Help front line managers in terms of strategy definition

The following elements might constitute proactive PI's. It has been found of great importance to search:

- The appropriate time to trigger an effective response
- The promptness to establish a full response ability
- The necessary time to maintain an effective response
- The rapidity to reconstitute the resources
- The number of claims during or after any maintenance tasks

At corporate level, participants highlighted the need for the harmonisation of the existing CMMS and the optimisation of its exploitation as well as the creation of joint ventures for spare parts provisions. On the other hand, the obsolescence of some spare parts and the disappearance of spare parts suppliers were particularly emphasised. Thus, it has been recommended to create technology watch units and internal audits to follow up maintenance activities issues. One of the most important recommendations was to establish a mutual response assistance plan at corporate level regarding all kind of resources linked to maintenance activities.

In addition, at corporate level, it has been recommended to:

- Define frequency to assess these issues
- Define threshold criteria that allow trigger responses based on proposed PI's
- Develop models to assess and test responses on site
- Establish/update the necessity to develop for every member of staff a PDP

Resources availability is an important issue; hence, a kind of "fear" to see the facilities stop working exists. Actually, this led to increase the ability to adapt to any condition but there a model dedicated to remedy the situation has been found still lacking. Every issue was solved in daily manner i.e. a day-to-day action was carried out when problems were faced. The vulnerability issues might be defined by the assessment of actual state. Examples include spare parts obsolescence, exclusive resources for safety margins, and watch monitoring centres units (see ability to anticipate). Many examples of positive actions to respond and adapt to changing conditions have been collected by means of storytelling. Engineers and other members of staff at the shop floor generally take these actions. To illustrate, an engineer and his team fabricated spares in the workshop of a facility that are not made up so far by the constructor.

7.3.2.2. Ability monitor

i. Resources Factor Resilience Profile for the ability to monitor

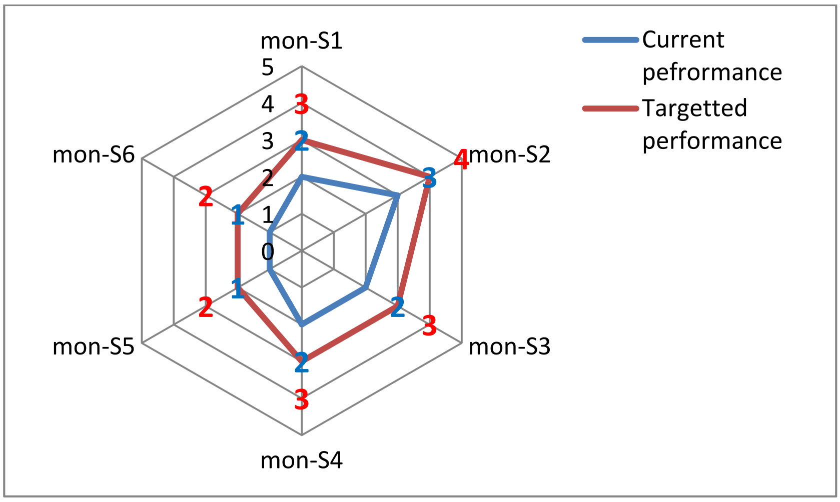

Figure 1-30: Resources Factor Resilience Profile for the ability to monitor

Items S5 and S6 are not addressed for the ability to monitor profile; this means that existing PI's are not updated and their reliability is not evaluated. S2 meets the minimum requirement since PI's for resources issues exist in the CMMS. For the remainder items, the system performs under performance requirements. The targeted performance is increasing the number of PI's, updated existing ones, and evaluating their reliability.

ii. Time-pressure Factor Resilience Profile for the ability to monitor

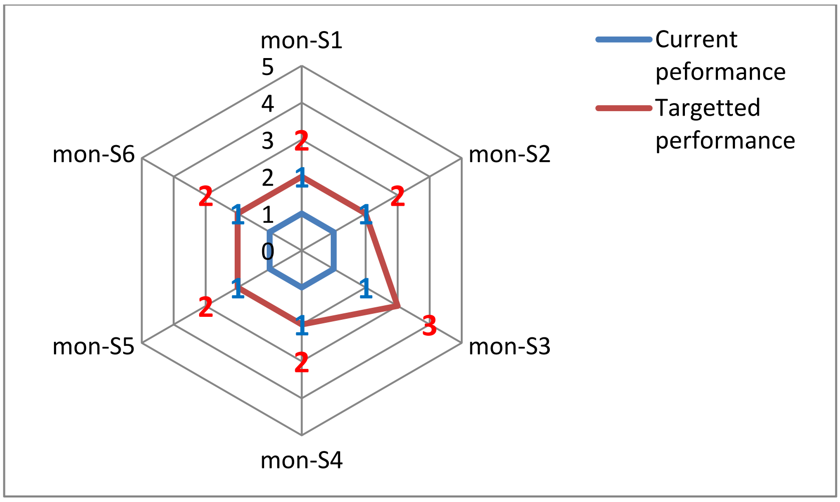

Figure 1-31: Time-pressure Factor Resilience Profile for the ability to monitor

In this case, the profile shows that all items are not addressed. The targeted performance is to make the system meet at least minimum requirements

iii. Supervision/coordination Factor Resilience Profile for the ability to monitor

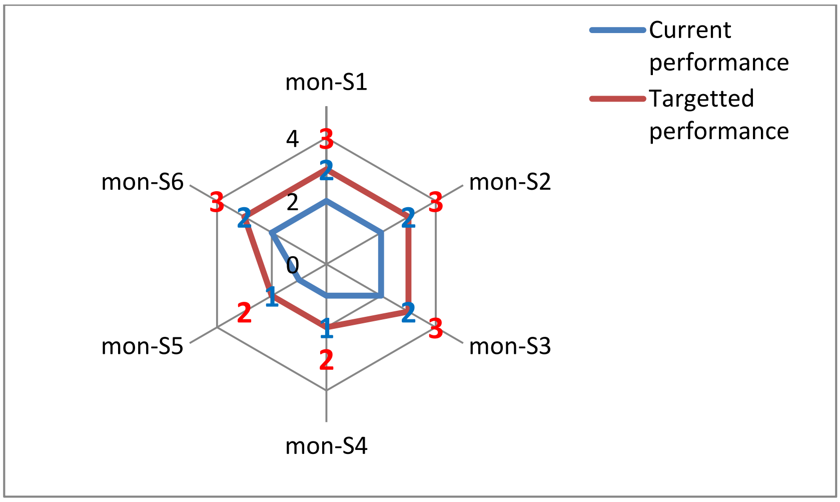

Figure 1-32: supervision/coordination Factor Resilience Profile for the ability to monitor

In this case, the system performs under minimum requirements even though there are PI's devoted to the monitoring of supervision/coordination issues by means of the CMMS. Items S4 (PI's for monitoring shrinking safety margins) and S5 (PI's regular update based on Indicator's pertinence) are not tackled. The targeted performance is to address these items (S4 and S5) and meet minimum requirements for the remaining ones.

iv. Discussion

The participants highlighted that the CMMS has been used to monitor some resources and supervision/coordination issues such as time to perform tasks (h/days), quality of work, attendance of personnel, compliance to tasks and procedures. The PI's were found appropriate with respect to reactive and current PI's; unfortunately, the list of PI's has not been updated and has been found underexploited. However, this remained insufficient. The indicators have not been updated based on their relevance; their reliability has not been assessed, and there has been limited analysis of collected data to disseminate and implement recommendations. It should be noted that the coding system has not been unified across the Company branches of activity. There have been no PI's to monitor the diminution of safety margins. Besides, support to monitor "time pressure" issues have been limited. Consequently, PI's have not been allocated to monitor this factor ("time pressure").

At department level, the introduction of appropriate performance indicators (PI) has been found of great importance. The absolute necessity to support monitoring such problems was highlighted. Examples of PI's that should be taken into consideration, based on a study of the maintenance environment and on the measure of the frequency of occurrence (adapted from Hobbs' MEQ), are given in tables 7.17, 7.18, and 7.19. These PI's may enhance the system's ability to respond.

Table 1-57: Table Examples of PI's for "resources" factor

How many times a member (or a team) within the department	Was unable to find a tool or an item of maintenance equipment
	Has delayed a task because a consumable part is missing
	Has delayed a task because a major part is missing
	Has used an unserviceable equipment
	Has performed a task without the appropriate tool/equipment
	Has performed a task without the appropriate documentation, etc.

Table 1-58: Examples of PI's for "time-pressure" factor

Frequency of	Lack of time to read adequately documentation before starting a task
	Rushing an inspection
	Cut shorting a functional check
	Signing for a task before it is completed
	Being asked to hurry a task
	Interrupting a task to perform a more urgent one, etc.

Table 1-59: Examples of PI's for "supervision/coordination" factor

Frequency of	Feeling that there is some limitation of knowledge or experience to perform an assigned task
	Correction of an error done by someone else without documenting what has been done
	Feeling that a defect has not been properly corrected before a system or a component was returned to service
	Certification of someone's work was correct without checking it
	Starting a task while someone has already begun to perform it
	Task supposed to be done but found after it was not the case
	Receiving wrong information about a task, etc.

In addition to this non-exhaustive list, it has been recommended to:

- Perform the measures on a regular basis before the management review
- Review regularly this list in collaboration with other departments
- Check PI's reliability by performing audits
- Assign the monitoring of safety margin diminution to statistics and CMMS specialists
- Put in place a unit for follow-up under the responsibility of the plant
- Appoint someone to review the list
- Analyse, interpret, communicate, and implement the results immediately through reporting and discussions during management review
- Perform mental and physical workload risk assessment

At the same time, it has been also recommended to identify and analyse actions that have been carried out to overcome situations characterised by lacks to achieve assigned goals. It has been suggested to measure how many times for instance, a member (or a team) within the department has overcome lack of (1) time, (2) competence, (3) knowledge, and (4) resources, particularly how these actions have occurred. This might allow the identification of actions that could go right as well as those that could go wrong. Following this research work, a study to collect such data is currently undergone within the Company.

At corporate level, it has been recommended to:

- Evaluate the maintenance system; continuously evaluate and harmonise PI's, and integrate them within the system in order to determine appropriate PI's types (proactive, current, and reactive) as well as PI validity and reliability
- Support and generalise the monitoring of the studied issues and safety margin diminution
- Establish a schedule for regular inspection and audits

- Disseminate the results within the organisation
- Put in place panels of experts (internal and external to the company) to reflect on, evaluate PI's, and assess these issues

The harmonisation, the use, and the full exploitation of existing CMMS was judged a great opportunity. A module was developed and added to one of the maintenance management systems that are used currently in a branch of the Company. This module allows all maintenance departments within this branch to have access to unused spare parts that can be found in any facility. It might be generalised to all branches by harmonising the CMMS

A PI list to monitor resources issues exists but needs to be updated. In addition to what already exists, it has been recommended to update the PI list so that current conditions would be monitored in order to identify trends and develop a vulnerability model. This action should be based on resilience engineering approach. Besides, the need to coordinate actions between sections of a maintenance department, other departments within a facility, and other facilities has been emphasised.

The need to evaluate PI's is highlighted. The procedure of managing maintenance exists since 1970's. Its existence was considered a good thing but its periodical evaluation and update has been thought a crucial opportunity to allow the Company have a larger view of the maintenance process.

7.3.2.3. Ability to anticipate

i. Resources Factor Resilience Profile for the ability to anticipate

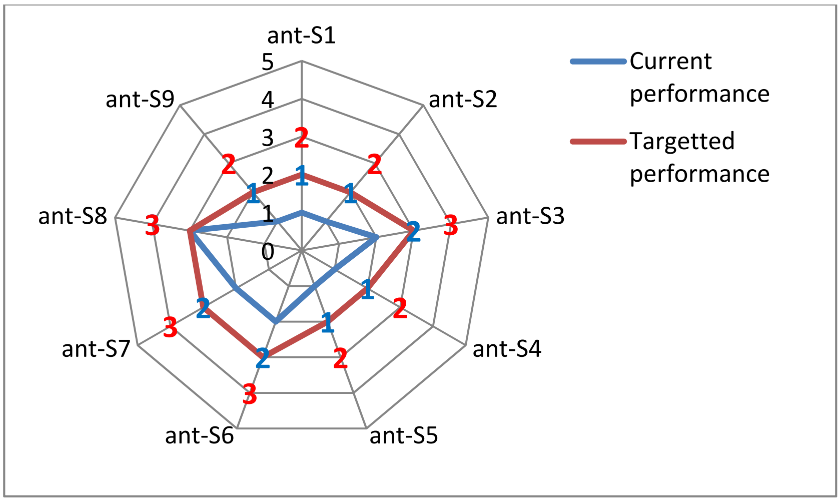

Figure 1-33: Resources Factor Resilience Profile for the ability to anticipate

In this case, the profile shows that only few items are addressed. Only S8 item meets the minimum requirements since the impact of resource reduction on safety margins is assessed within the organisation (production driven culture). For three (03) items over nine (9), the system performs under performance requirements. The targeted performance is to make the system perform at least under minimum requirements.

ii. Time-pressure Factor Resilience Profile for the ability to anticipate

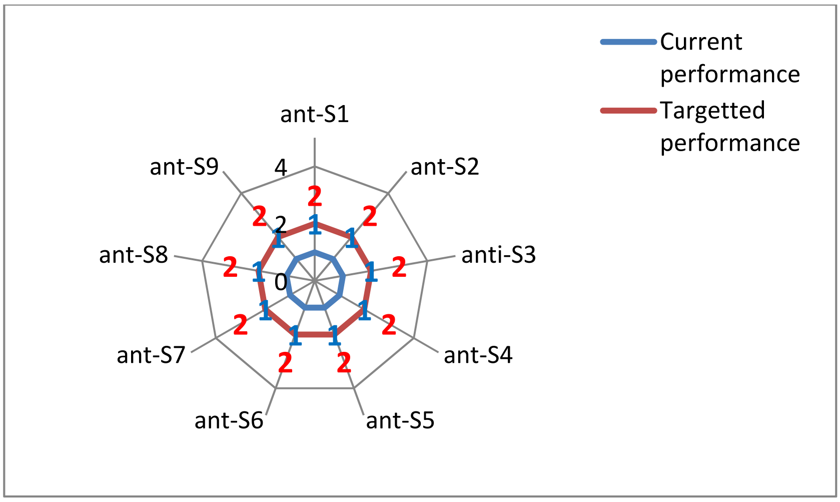

Figure 1-34: Time-pressure Factor Resilience Profile for the ability to anticipate

The profile shows that all items are not addressed. This means that the ability to anticipate time-pressure issues is missing. The targeted performance is to make the system meet minimum requirements.

iii. Supervision/coordination Factor Resilience Profile for the ability to anticipate

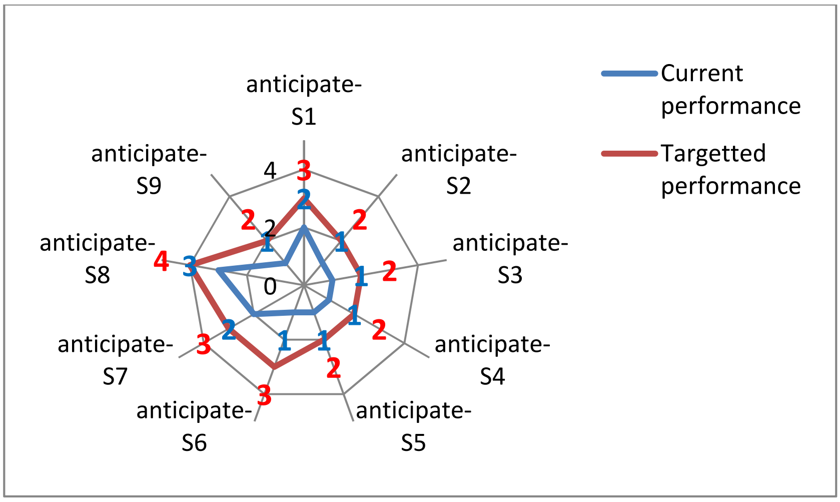

Figure 1-35: supervision/coordination Factor Resilience Profile for the ability to anticipate

With respect to ability to anticipate, the profile shows that majority of items are not addressed. However, a model of carrier planning exists at corporate level with a limited implementation (S1). When a diagnosis of safety/production trade-off is carried out, production is favoured (S7). Besides, the maintenance department assesses the impact of resource reduction on safety margins stemming from supervision/coordination issues. The targeted performance is to meet realistic item requirements for item S8, minimum requirements for items S1, S6, and S7 and address the remaining ones.

iv. Discussion

The participants highlighted the absence of vulnerability model clearly formulated for these issues. It has been shown that the required expertise to investigate the future assuredly exists within the Company but not used as expected. Vulnerability has been dealt with solely throughout individual experience and expertise. There has been limited analysis of long term effects within the organisation and limited development of strategic plans regarding these issues. CMMS was found the only tool used however its limitations included the ignorance of the analysis of situations where things went (go) right in order to investigate the future. The exchange of information flux that might constitute a basis to identify signs of trouble has not judged spontaneous and continuous because of high departmentalisation. Production was generally favoured except when there was an imminent danger. There has been limited feedback regarding sent reports despite a regular diagnosis. Besides, it is worth noting that departments have regularly assessed the impact of resource reduction on safety margins regarding resources issues; participants judged this highly positive.

At department level, it has been recommended to:

- Encourage the development of internal expertise from the monitoring aforementioned and use external expertise to investigate the future
- Update database to optimise exploitation
- Review/analyse past maintenance reports to extract trends and include, in the future, trend analysis in the reports
- Introduce proposed PI’s (see ability to monitor) and analyse data collected
- Assess future threats/opportunities on a regular basis e.g. at least once per year to make a projection in the future at corporate level
- Alert about retirement/leaving of key staff
- Alert on time about training to face new technologies and process

- Perform a continuous training for new recruits
- Encourage the coaching of new recruits

The trade-off safety/production might be addressed by:

- Simulating near-misses risk scenarios along with a study of the impact on production using systemic methods such as the FRAM method
- Respecting maintenance task schedules as planned and or as adjusted
- Increasing the vigilance levels of workers based on company's event logs
- Requesting production staff to increase awareness and vigilance in following up and tracking production parameters

The impact of resources reduction on safety margins might be assessed by measuring:

- The frequency of updating the schedules, and staff performing urgent tasks
- The impact of such actions on deadlines and quality of maintenance

At corporate level, it has been recommended to:

- Develop a vulnerability model clearly formulated for the future
- Develop tools to predict dangers stemming from these issues by an optimum exploitation of maintenance reports and CMMS tools
- Encourage the development of analysis tools to investigate the future
- Associate maintenance/production experts to define strategic plans
- Clearly establish an explicit recognition of acceptable/non acceptable risks
- Search (and monitor) factors throughout future threats; this might be expressed, particularly by disappearance of spare parts suppliers in order to be prepared to
- Improve communication and share future expectations/events within the organisation throughout for instance forums
- Make the nature of future threats/opportunities widely known within the organisation (which they are and how they develop)
- Establish a projection in the future of the company maintenance culture and procedures
- Raise awareness of personnel/managers to assess situations where things go right.
- Create technology watch and monitoring units to adapt human resources to new technologies

The nature of supposed future threats was expressed through routine, drop of level of vigilance, overconfidence (complacency), self-satisfaction, fatigue, etc. These might develop through absence of control, successive good results, and repeated tasks for a long period in the same place, lack of mobility intra-branches among others; therefore, these factors have been found worth seeking and monitoring. On the other hand, the nature of supposed future opportunities lied in the detection of competence and expertise and the assurance to retain those recognised staff, the transfer and sharing of good practices and knowledge, the capitalisation of knowledge and know-how, etc.; therefore, these factors have been judged worth seeking and monitoring too.

As claimed by the participants, this was actually the weakest ability within the organisation. Many propositions have been adopted to remedy the situation. The need to elaborate a vulnerability model recognised and clearly formulated as well as to include trend analysis in future maintenance reports has been highlighted. It is worth putting a stress on the high number of experienced people in the maintenance departments (more than 20 years of experience). Taking benefit of these workers before retiring and even after (some of these persons should be utilised to train both new recruits and other staff) was another opportunity.

The ateliers recommended also identifying future threats as well as opportunities through annual meetings to make a projection in the future of the organisation and elaborate strategic plans. Many stories have been told regarding things that went right. By means of storytelling method, a study is being carried out to remedy the lack of documented things that go right (work as performed) as explained above.

7.3.2.4. Ability to learn

i. Resources Factor Resilience Profile for the ability to learn

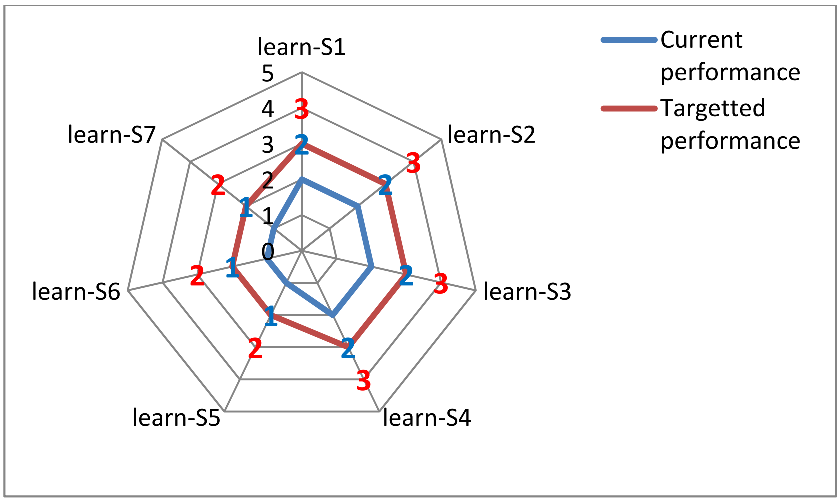

Figure 1-36: Resources Factor Resilience Profile for the ability to learn

Four (04) items over seven (07) show that the system performs under minimum requirements whereas the reminders are not addressed by the system. The targeted performance is to make the system meet minimum requirements for the former and at least address the latter.

ii. Time-pressure Factor Resilience Profile for the ability to learn

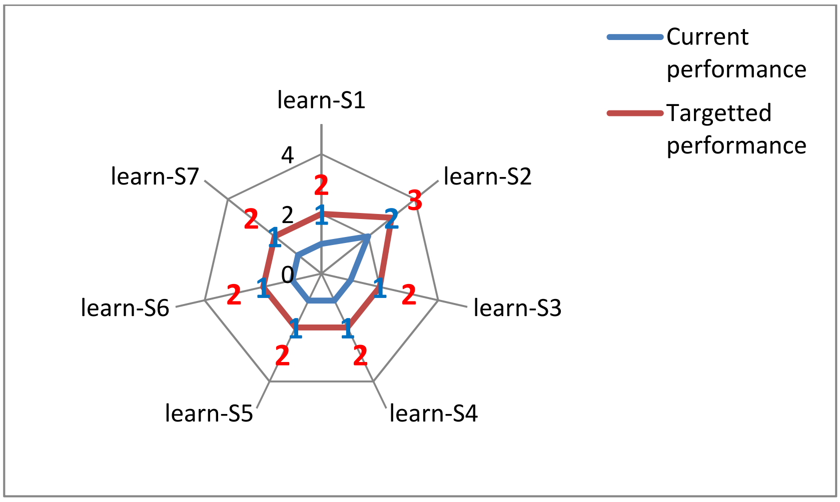

Figure 1-37: Time-pressure Factor Resilience Profile for the ability to learn

It can be seen in this profile that the system does not address the items except item S2 (the learning activity is a continuous process and is built throughout the entire organisation) showing the system performs under minimum requirements. The targeted performance is to make the system meet minimum requirements for item S2 and address the remaining items.

iii. Supervision/coordination Factor Resilience Profile for the ability to learn

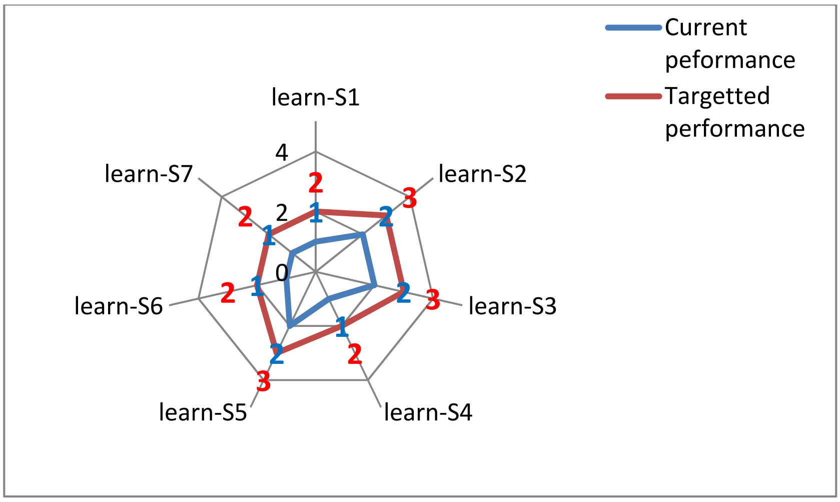

Figure 1-38: supervision/coordination Factor Resilience Profile for the ability to learn

For the ability to learn, some items are not addressed (organisation support to collect data, analyse, and learn from coordination/supervision issues; shortest delay between event reporting, analysis, and learning; means in place to verify and maintain learning). For the remaining items, the system performs under minimum requirements. The targeted performance is to meet minimum requirements for items S2, S3, and S5 and address the remaining ones.

iv. Discussion

The participants found the learning process quite missing or learning was event oriented and was not a continuous activity for the studied factors. Support and training of personnel to collect, analyse, and learn with respect to these issues were not totally considered within the organisation as well as required resources allocation to investigate, analyse, and disseminate results and learning inherent to such issues. The allocation of necessary resources (particularly when things go right) to investigate, analyse, disseminate, and learn was found limited. The results of analysis were not immediately communicated. The necessary means to verify and maintain what was learnt were not in place. There were limited plans with respect to staff carrier plan.

At department level, it has been recommended to:

- Establish/update and implement staff carrier plans
- Encourage learning from what is frequent (successes, things that go right) as well as what is rare (failures, things that go wrong)
- Use all opportunities to learn; in particular assign responsibility to a multidisciplinary team to make optimum exploitation of the CMMS

- Put in place anonymous storytelling process to collect, categorise, and analyse all data (what is frequent as well as what is rare); a person should be responsible for experiences compilation in order to extract lessons to share knowledge
- Implement learned lessons throughout application notes, top management directives, etc.
- Publish reports monthly to allow a large diffusion.
- Mentor (coach) new recruits by experienced personnel near to retirement
- Communicate results to "communication units" and propose the better ways to implement lessons learned (regulations, procedures, standards, training, instructions, redesign, reorganisation, etc.)
- Introduce means to verify or confirm that learning has taken place throughout evaluation (formative and summative)
- Introduce means to maintain what has been learned

At corporate level, it has been recommended to:

- Reactivate the one-year induction for new recruits
- Review management training and resources allocated to allow a continuous improvement and give more importance to statistics/methods/analysis services
- Harmonise maintenance reports
- Organise workshops
- Encourage internal training
- Select relevant information and allocate PI's to ensure follow-up
- Identify competences within the organisation and allocate appropriate resources to investigate, analyse, and disseminate results and learning in collaboration with Human resources departments
- Make learning a continuous process within the organisation through coaching, training of specialists, and management support
- Include the learning factor in the new Company's performance management system
- Elaborate a template for event description and how to collect and categorise data
- Communicate rapidly result analysis inside and outside the organisation
- Create an audit/follow-up unit to check that learning has taken place and verify that means to maintain this learning is in place
- Establish a return on investment model to determine learning outputs

7.3.2.5. Department profiles

The following figures (7.13, 7.14, and 7.15) present the department profiles regarding the three studied factors.

i. Resources Factor Department Resilience Profile

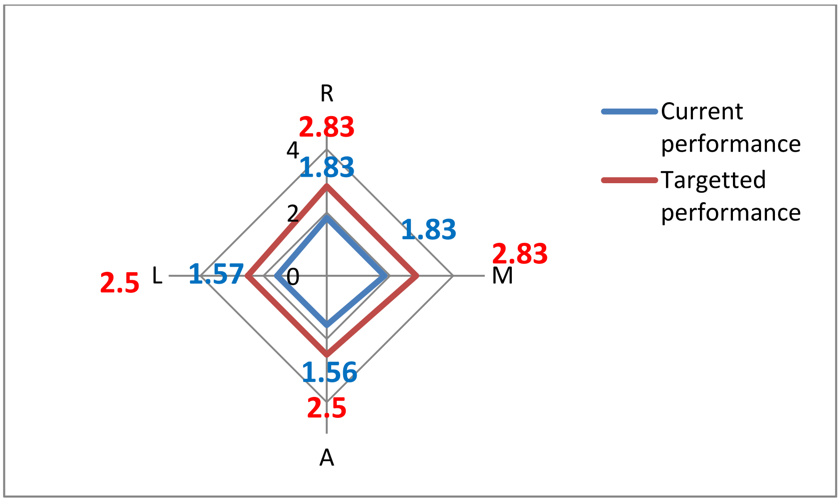

Figure 1-39: Resources Factor Department Resilience Profile

With respect to the resources factor, the maintenance department profile shows lower ability to anticipate and learn while ability to respond and monitor is slightly higher. In any case, the maturity level is MAL2 (see chapter 6, table 6.15); this implies that the system does not meet minimum requirements. The targeted performance is to move from MAL2 to MAL3

ii. Time-pressure Factor Maintenance Resilience Profile

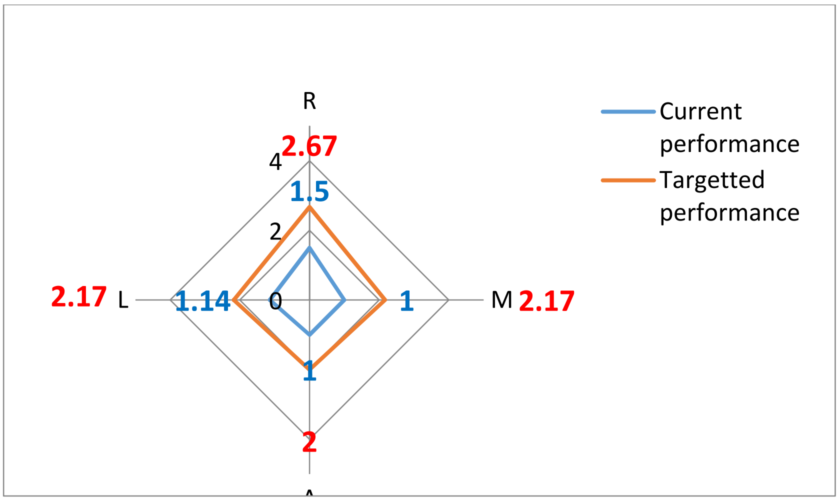

Figure 1-40: Time-pressure Factor Maintenance Resilience Profile

With respect to time-pressure factor, the maintenance department profile shows very low ability to anticipate, to monitor, and to learn while the ability to respond is slightly higher. In any case, the maturity level is MAL1 (see chapter 6, table 6.15); this implies that the system does not address the items. The targeted performance is to move from MAL1 to MAL3

iii. Supervision/coordination Factor Maintenance Resilience Profile

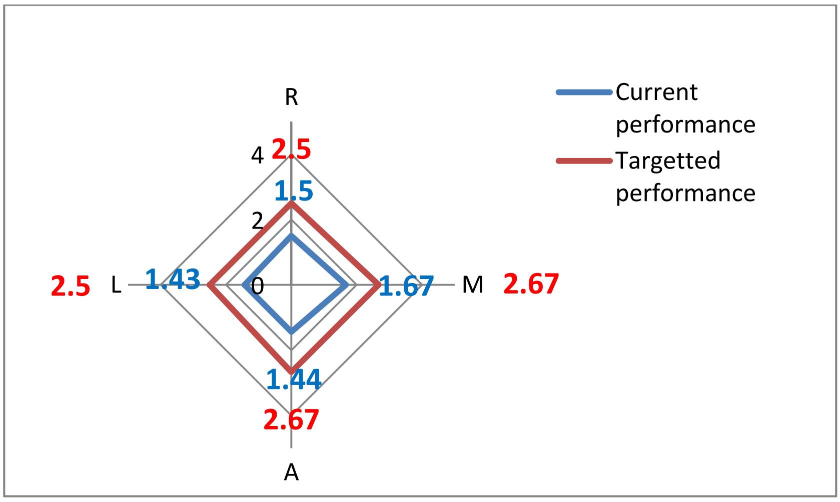

Figure 1-41: supervision/coordination Factor Maintenance Resilience Profile

With respect to the coordination/supervision factor, the maintenance department show low ability to anticipate, learn, and respond while ability to monitor is slightly higher. In any case, the maturity level is MAL2 (see chapter 6, table 6.15); this implies that the system does not meet minimum requirements. The targeted performance is to move from MAL2 to MAL3.

7.3.2.6. The System's Performance

The analysis of the above results shows that current system performance is reactive with respect to the studied factors. As stated in chapter 3 (section 3.3) and chapter 5 (section 5.5), the four cornerstones of resilience engineering representing the system performance had to be addressed; none of them had to be left out to make the system AHRAP. In particular, the ability to monitor the system performance and the environment should be the centre of actions regarding the others during the long and endless journey that makes the system AHRAP. Therefore, the ability of the system to transform its performance from current to targeted one should be based on the enhancement of the monitoring aspect. This will assuredly increase the other abilities.

Such an approach has been taken into account in this study. For the three factors (resources, time-pressure, and supervision/coordination), actions that might enhance the system abilities were linked to developing the ability to monitor. For instance, to increase the system ability to respond from 1.61 to 2.67, the ability to anticipate from 1.33 to 2.33, and the ability to learn from 1.38 to 2.37, the system ability to monitor should be improved from 1.5 to 2.56. (figure 7.16; in this figure, axis X stands for the four abilities that is, R for ability to respond, M for ability to monitor, A for ability to anticipate, and L for ability to learn; whereas Y axis stands for the score of each ability). This would take the system from MAL2 to MAL3 that is, from system performing under nominal criteria to system performance that meets minimum (nominal) criteria required by items.

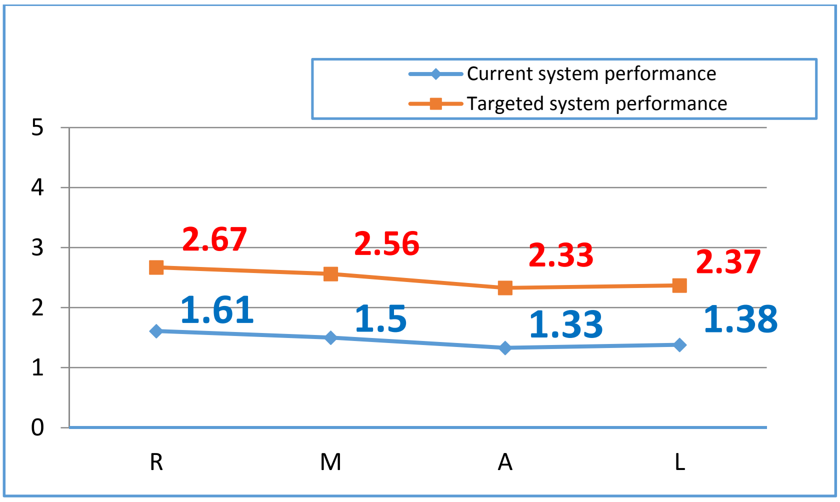

Figure 1-42: Evolution of the system's performance.

7.3.3. Recommendations to Top Management

The last objective of the workshop was to make recommendations to the top management of the Company. In the above section related to workshop results, the latter were presented in terms of actions that might be implemented at department level and others that might require top management commitment. The results that came up from the three ateliers were synthesised and communicated to the audience for approval in a final presentation in presence of IAP managers. The audience adopted the list of recommendations in order to be sent to the top managers of the Company.

The main recommendations issued from the workshop to be implemented at corporate level are summed up in the following:

- Establish at corporate level mutual response assistance plan regarding all kind of resources linked to maintenance activities
- Harmonise and exploit and make an optimum use of the computerised maintenance management system (CMMS)
- Update the organisation maintenance system
- Revive and reenergise methods and statistics sections in the maintenance department to analyse trends in order to anticipate threats/opportunities
- Put in place a suitable support for information exchange and/or forums between the different branches of the company
- Create technology watch units and internal audits to follow up maintenance activities issues
- Create joint-ventures for local manufacture of spare parts and maintenance with potential suppliers

A detailed report of the workshop encompassing the results given in this section was sent to all participants and managers. These recommendations are presented in more details in the following. First, it is worth highlighting existing opportunities within the maintenance departments. They are characterised by a motivated personnel, but many of them are close to retirement; this may benefit the Company. In addition, all the departments have a computerised maintenance management system that is underutilised. The maintenance system that has been in place for years requires an evaluation and revision according to the participants. Besides, the participants agreed to raise the necessity to elaborate an organisation vulnerability model clearly formulated regarding the three studied factors. The participants required specific care to the investigation of the future and the development of strategic plans to anticipate any development. To do so, it has been advised to include trend analysis. This might create the opportunity of emergence of expertise within the organisation and the valorisation of work preparation and statistics departments in the maintenance system. A technological watch, monitor, and follow-up of trends related to the obsolescence of spare parts and/or the disappearance of spare parts suppliers have been found of great importance. It has been recommended to perform audits to study such issues. A solution could be the creation of joint ventures particularly for spare parts or for the maintenance of facilities in general.

A computerised maintenance management system (CMMS) is used within the maintenance departments but each branch of the Company has tailored its own system. These tools are underutilised. It has been recommended to harmonise these CMMS in order to create a unique database (a unique codification) within the organisation and to explore the options that might enable its optimal and effective exploitation. This might reduce maintenance costs from 20 to 50% according to benchmarks (Le Caz, 2005).

The different areas of activities of the Company have mutual response assistance plan with respect to safety. The establishment of a mutual response assistance plan at corporate level regarding all kind of resources linked to maintenance has been recommended; this could begin with spare parts assistance between all branches of the Company.

The limited support and training regarding data collection, analysis and learning with respect to the studied factors has been noted. The identification of skills and profiles in order to launch the related training has been recommended.

The need to provide a forum for information exchange between all branches of activities of the Company has been also highlighted. This would improve the flow of information, particularly those stemming from expert meetings within the Company.

It is worth noting that like most of the companies in the world (Hollnagel, 2010a), situations where things go right are not assessed. Their assessment would allow identify the cases where there could be a drift towards hazardous situations (requiring barriers) as well as those where things might go right (needing to be known, encouraged, and boosted).

To sum up, experts from maintenance departments of the Company met and debated about the prevailing situation to determine maintenance system current performance and targeted one and exchanged experiences. Particularly, the resilience of the maintenance system has been evaluated for the first time by means of MASRAT. It resulted that the system did not meet the nominal criteria addressed by the specific items particularly for the ability to anticipate. Improvement strategies have been formulated by means of strategies that might be studied within each department to determine the appropriate mechanisms of implementation.

7.4. Workshop Evaluation

The evaluation is carried out to examine whether the intended goals of the action were achieved. It allows identify areas of improvement and way ahead. It consists of collecting and analysing feedback of the actors. Data collection was performed by: (1) getting an immediate feedback from the participants just at the end of the workshop before they go back home; (2) sending questionnaires to the participants as well as the facilitators; and (3) performing interviews with facilitators after the analysis of questionnaires. These are discussed in the following subsections.

7.4.1. Immediate Feedback from Participants

At the end of the workshop, discussions have been conducted with participants to give their immediate comments. All were delighted to attend the workshop, to meet people from other departments and exchange information and opinion about their concerns. They were happy with the recommendations raised during the workshop. They found that the time allocated to the workshop was too short. The experience was very interesting since it allowed them have a better understanding of their working environment. The new approach was difficult to grasp at the beginning. Participants were not used to such a way of thinking and the relevance of the items. For some participants a number of items were difficult to capture first instance particularly regarding the ability to monitor aspect. It was also recommended to make the scoring system more flexible by adding “halves” for each score that is, the scale will change from 1, 2… 5 to 1, 1.5, 2, 2.5, and so forth. To sum up, the need to train people to the use of MASRAT has been highlighted.

7.4.2. Questionnaire to Participants

A questionnaire was sent to the participants to evaluate the activity (see Appendix 6). It consisted of four (04) themes, for each theme a set of statements has been proposed to the participants. They were asked to say to what extent they agree or disagree with a particular statement, the scale ranged from 1 that is strongly disagree to 5 i.e. strongly agree. Theme 1 related to the presentation of MASRAT to the audience and the following debate, four (04) statements. Theme 2 concerned the facilitators, three (03) statements. Theme 3 regarded the efficiency of the workshop, five (05) statements. Eventually, theme 4 dealt with MASRAT, four (04) statements.

Theme 1, Participants Answers Regarding the Introduction

This theme related to the presentation given by the author to introduce MASRAT and explain the underlying theoretical background. During this presentation, workshop objectives have been communicated as well as the planned activities. Table 7.20 shows the mean value, standard deviation, minimum, and maximum scores ranging from 1 to 5, that have been attributed by respondents regarding the introduction.

Table 1-60: Participants answers regarding the introduction

Statements	Mean	SD	Min	Max
A. The information was clearly given by the presenter	4.46	0.66	3	5
B. The presenter attracted audience attention	4.16	0.80	3	5
C. The presentation was well-structured	4.31	0.63	3	5
D. The presenter answered appropriately to the questions	4.38	0.77	3	5

As can be seen from the table given above, the participants' answers can be summed up as follows. More than 90% of the participants found the information clearly given by the presenter (a mean value of 4.46). The presenter attracted the audience attention for 75% (a mean value of 4.16), the presentation was well structured according to more than 90% (a mean value of 4.38), and the presenter answered appropriately the questions for more than 80% (a mean value of 4.38).

Theme 2, Participants Answers Regarding the Facilitation

Theme 2 related to the facilitation of the workshop. It concerned the contribution of the facilitators to help achieve workshop objectives in time and content. Table 7.21 shows the mean value, standard deviation, minimum, and maximum scores ranging from 1 to 5, attributed by respondents regarding the facilitation of the workshop activity.

Table 1-61: Participants answers regarding facilitators

Statements	Mean	SD	Min	Max
A. The information was clearly given by the facilitator	3.92	0.64	3	5
B. The facilitator attracted audience attention	3.77	0.83	3	5
C. The facilitator helped achieve workshop objectives in time and content	3.92	0.86	3	5

With respect to the facilitation of the workshop, table 7.21 above shows that 75% of participants (a mean value of 3.92) have found the information clearly given by the facilitator but only 50% of them (a mean value of 3.77) said the presenter attracted the audience. For more than 50% (a mean value of 3.92), the facilitator helped achieve the workshop objectives in time and content. An interview of the facilitators was decided to analyse these values in addition to the comments of some participants who gave a score fewer than 4 (section 7.3.3).

Theme 3, Participants Answers Regarding the Workshop

Theme 3 concerned the relevance and significance of the workshop for the participants. Table 7.22 shows the mean value, standard deviation, minimum, and maximum scores ranging from 1 to 5, attributed by respondents regarding this concern.

Table 1-62: Participants answers regarding the relevance and significance of the workshop

Statements	Mean	SD	Min	Max
A. The workshop was relevant for me	4.16	0.89	2	5
B. The workshop was interesting	4.38	0.65	3	5
C. The workshop content was significant for me	4.31	0.75	3	5
D. The workshop pushed me to reflect on my own actions	4.46	0.66	3	5
E. The workshop motivated me to take actions.	4.08	1.04	2	5

From table 7.22, majority of the participants found the workshop

- Relevant for them (more than 80%, a mean value of 4.16),
- Interesting (more than 90%, a mean value of 4.38),
- The content significant for them (more than 80%, a mean value of 4.31),
- Pushing them to reflect on their own actions (more than 90%, a mean value of 4.46),
- Motivating to take actions (more than 70%, a mean value of 4.08).

It is worth noting that 7.7% of participants did not find the workshop relevant and 7.7% not motivating to take actions.

Theme 4, Participants Answers Regarding MASRAT

The last set of questions addressed MASRAT; that is its usefulness and ease of use and understanding. Table 7.23 shows the mean value, standard deviation, minimum, and maximum scores ranging from 1 to 5, attributed by respondents regarding this set of questions.

Table 1-63: Participants answers regarding MASRAT

Statements	Mean	SD	Min	Max
A. MASRAT was easy to understand and use and followed a logical order	3.46	0.97	1	5
B. MASRAT is designed for maintenance system	3.77	0.83	2	5
C. The use of MASRAT generated a debate among participants	4.15	0.69	3	5
D. The workshop made recommendations et realistic actions	4.15	0.81	3	5

It can be noted that more than 55% of participants (a mean value of 3.46) found MASRAT easy to understand, use, and follow a logical order whereas 7.7% of them strongly disagree with the affirmation. Approximately 70% of them (a mean value of 3.77) said it is designed for the maintenance system. For quite 85% of them (a mean value of 4.15), the use of MASRAT generated a debate among participants and more than 77% (a mean value of 4.15) said the workshop made recommendations and realistic actions. As per facilitation theme, section 7.3.3 addresses the low scores given by participants.

7.4.3. Participant Comments When the Score Is Fewer than 4

Some participants who have given a score fewer than 4 (score 4 is for agree and 5 is for strongly agree) commented on and made recommendations. The comments received from these participants are given in the following.

7.4.3.1. Respondent one

Theme 2, question C: “time allocated to the workshop was very short. It was not sufficient to become familiar with MASRAT in order to use it in the maintenance system. The situation necessitated long debate hence more time even though the facilitator contributed to clarify things”.

Theme 3, question E: “the problem is not to take action and initiatives but to have the necessary resources available to perform required tasks. These resources are considered as barriers; they can be spare-part, documentation, diagrams, or may be to perform a more urgent task, etc. The inexistence of databases regarding all the maintenance tasks performed in the department prevents a real evaluation and analysis of the situation. It doesn’t encourage us to take initiatives and actions”.

Theme 4, questions A and B: “it depends actually on the implementation of majors recommendations made to top management. A multi-disciplinary team (production, technique, maintenance, safety, etc.) may put in place recommendations at department level to achieve objectives of the plant”.

7.4.3.2. Respondent six

Theme 2, general comments: “I think the facilitator should be more involved in the workshop. This is not obvious, particularly regarding time allocated. I recommend giving time for the facilitator to prepare the activity, understand the objectives so that he can find the best way to transmit them to the participants”. “The workshop was an excellent opportunity to step back from our daily work and analyse our situation. It allowed us to reflect on the work in a maintenance department. It should be held at least annually”.

7.4.3.3. Respondent seven

General comment: “In my point of view, a successful maintenance system necessitates motivating and sensitising those who are responsible directly or indirectly within the system”

7.4.3.4. Comments

With respect to theme 1, the presentation was acceptable and it helped both the participants and facilitators to achieve workshop goals and objectives. For theme 2 relating to the facilitation of the workshop, the scores attributed by the participants called to discuss deeply with the facilitators in order to understand why some scores were fewer than 4 (neither strongly agree nor agree). To begin with, it is worth noting that many participants gave a high score i.e. strongly agree (respectively quite 17% and 34% for questions B and C); this is why the mean value is somewhat high. According to the participants who commented on, the main issue lies within the time allocated to the workshop. This was not sufficient to allow facilitators do the facilitation as expected.

Theme 3 dealt with the answers regarding the relevance and significance of the workshop for the participants. One participant disagreed with the fact that the workshop was relevant for him and said he is not motivated to take action. As stated earlier, their own directions chose some participants; therefore, the motivation could be missing. It is worth noting that the majority of the actors found the workshop interesting, motivating, and very significant for them.

7.4.4. Questionnaire to Facilitators

Each of the three facilitators directed this activity in his respective atelier. They all knew how easy or difficult it was to conduct the action. They were responsible for achieving the objectives of the workshop in terms of time and content. Hence, their evaluation and comments were judged of great importance. They have been asked to evaluate (1) the preparation of the workshop, (2) the quality of the preliminary presentation, (3) the difficulties encountered during the facilitation, and (4) MASRAT usability. The questionnaire is given in appendix 7.

With respect to the first question, that is the preparation of the workshop, they said they were satisfied in terms of organisational aspects whereas they found that the time allocated to this preparation insufficient, it was very short. The facilitators appreciated very positively the preliminary presentation. According to them, the information has been clearly communicated to the audience and the presentation attracted the participants. On the other hand, it fairly helped the facilitators.

Regarding the difficulties encountered during the facilitation, the facilitators could not achieve easily the objectives in terms of time. As stated in the interview of facilitators in the next section, the approach was new; it generated therefore large debate among participants to understand better what each item of the tool meant. Hence, it was not easy to achieve workshop objectives in terms of time and content. It is worth noting that participants and facilitators did a great job to overcome these difficulties.

For the usability of MASRAT, they agreed to say that the tool was designed for maintenance system and generated a large debate among participants. Eventually, realistic recommendations were made.

7.4.4.1. Comments

For the facilitators, the main explanation was that in general the participants were not used to such a new and difficult approach to grasp at the beginning, in addition to the fact that some of the used jargon seemed ambiguous for them. This might explain why some of the allocated time has been used to clarify what looked confusing. Besides, there has been a translation (from English to French) issue particularly for the phrase “time pressure”. The translation given first instance has been changed during the workshop to a more convenient and relevant one.

7.4.5. Interview of facilitators

The three facilitators were solicited individually to comment on the workshop by means of a semi-structured interview in order to better explain their responses to the questionnaire (table

7.24). Facilitators F1, F2, and F3 were respectively facilitating atelier 1 “resources”, atelier 2 “time pressure”, and atelier 3 “supervision/coordination”.

Table 1-64: Facilitators’ interview

Questions	Facilitators answers
Q1: How did you find the presentation?	F1: in the future, it would be better if the presentation is based on a simple case study depicting MASRAT calculation and implementation leading to the results rather than giving the state-of-the art underlying theory of MASRAT F2: the presentation was precise. Underlying theory and objectives of ateliers were well explained F3: excellent, very clear
Q2: Did the presenter communicate clearly the information?	F1: yes F2: yes, the presentation and the program were properly linked F3: yes
Q3: Did the presentation help you perform the facilitation?	F1: yes F2: certainly. In my atelier, there was a problem of terminology regarding the translation of “time pressure” to French. F3: yes
Q4: Is MASRAT easy use?	F1: yes, but performing another case study will be helpful F2: yes F3: some items were ambiguous at the beginning for the participants. A deep discussion was engaged to clarify them and sometimes we were obliged to call the presenter to explain what was expected from participants.
Q5: What difficulties did you find to perform the facilitation in your atelier?	F1: there were some difficulties with respect to group background. F2: there were difficulties regarding to the time allocated to achieve all stated objectives. F3: it was difficult to distinguish between some items
Q6: Did MASRAT help participants to better understand their environment and find ways to improve current situation?	F1: yes, after several attempts F2: yes. Everything looked complex and difficult at the beginning. Since there is no tool to address such issues this way, the presentation and the use of MASRAT helped simplify the complexity. F3: I don’t know; they have tried to answer for the 28 items

Facilitators' interview (continued)

Questions	Facilitators answers
Q7: Was it easy to achieve workshop objectives in terms of time and content?	F1: the work speed augmented at the end of the workshop due to deadline in order to achieve goals and go through all the items (28) F2: no. this is due to the time allocated to the workshop. Actually, it depends on the facilitator and the participants. F3: it was difficult due to the time allocated; some items were difficult to understand first instance; this is also may be due to the participants' background
Q8: Was MASRAT easy to understand and use? Does it follow a logical order?	F1: yes. F2: easy to understand for some of the participants. It is worth noting that some efforts have been made to distinguish between items in order not to make confusion. This is due to the fact that it is a new way of thinking based on a novel approach for the participants. Much more time has been taken to ensure everyone in the atelier has understood the items and objectives. I think, after having used MASRAT a couple of times, everything will be fine. Participants are not used to such a way of reasoning. F3: no.
Q9: Is MASRAT designed to maintenance system?	F1: it will be useful if it has some links to maintenance system of the Company F2: yes. F3: yes.
Q10: Did the use of MASRAT generate a debate among participants?	F1: yes. F2: yes. Some items did more than others did. F3: yes.
Q11: Did the workshop make realistic recommendations and actions?	F1: yes. Mainly to the actual situation where a lot of works should be done F2: yes. F3: yes.
Q12: Did MASRAT allow measure maintenance system resilience?	F1: yes. F2: yes. F3: yes.

Facilitators' interview (continued)

Questions	Facilitators answers
Q13: Did MASRAT permit to collect necessary data to respond to the objectives of the study?	F1: it depends on the maturity of the participants' knowledge. F2: yes. F3: yes.
Q14: How many persons attended your atelier?	F1: 09 persons F2: 08 persons F3: 07 persons

7.4.5.1. Comments

The facilitators added the following comment. With respect to items, the second aspect (ability to monitor) raised issues. People were generally not used to the word monitoring which was difficult to understand. For the third aspect (ability to anticipate), the term vulnerability was only linked to HSE matters. Some participants did not make the difference between strategies and tactics. They had also a better understanding of the word "means" than "resources" (see the fourth aspect i.e. ability to learn). There was nothing to say regarding the first aspect (ability to respond), easier to understand.

7.4.6. Barriers

There have been many barriers to overcome. First barrier identified was the time allocated by management to perform the workshop. Only one day and half were devoted including the presentation, the debate, and the summary of the workshop results. Second barrier identified was the difference regarding the backgrounds of the participants. Some participants were selected during the validation phase whereas others were chosen by their organisation. This difference led to slow down sometimes the work in the ateliers.

7.4.7. MASRAT Improvements

For some participants a number of items were difficult to capture first instance particularly regarding the ability to monitor and anticipate aspects. The item 3.5 "the department assesses absence of failures, hazards, and accidents to anticipate … issues" has been reworded accordingly and become "the department assesses situations that went (and go) right". As a result, many examples of maintenance intervention to make things go right have been identified. It was also recommended to make the scoring system more flexible by adding "halves" for each score so that the scale will change from 1, 2,…, 5 to 1, 1.5, 2, 2.5, etc.

7.5. Chapter Summary

This chapter addressed the last phase of this piece of research, that is instrument testing that consisted of applying the tool to measure the system's resilience, identify strategies for improvement, and make recommendations to manage safety proactively in the maintenance system so that the system becomes AHRAP, objective 4 of this research work. The testing phase included a panel expert testing through a workshop held in the Algerian Petroleum Institute. It was organised in three ateliers according to the three factors (resources, time pressure, and coordination/supervision). Experts from maintenance departments were invited and asked to use MASRAT.

It can be seen from what was given previously that the specific objectives hereafter recalled have been attained. First, the usability of MASRAT has been tested in the workshop with a panel of experts from maintenance departments and found usable even though all participants deemed the time allocated to perform such an activity very short. Second, MASRAT has been used to measure the resilience of the maintenance department of the Company and the maturity level was found MAL 2. Third, strategies that might lead the system from current level of maturity to excellence have been identified. Eventually, recommendations have been made to management to be implemented both at corporate and department levels. These recommendations have received a great attention from top management of the company since IAP has been asked to write a draft directive to implement these recommendations.

MASRAT tool is based on resilience engineering approach. Therefore, there has been no search for « errors » or “failures” within the system whatsoever. Quite the contrary, the approach has been directed towards understanding what actually characterised the system, how work was actually performed by the maintenance staff rather than searching deviations from work as imagined. This study dealt with a novel approach that analysed actual situation with a different view. It looked to find out what the abilities of a system were instead of studying contributing factors that might lead to “errors” to be corrected and avoided. The actions were reversed. The elements that represented actual conditions of work were viewed differently. According to the first view, these elements had to be seen “dirty” necessitating clearance. For the new approach on which this research work was based, the view was completely different. It focused on things that went (go) right as well as those that went (go) wrong. The solution lied in the fact that increasing those that went (go) right will necessarily decrease the number of those that went (go) wrong. This view did not emphasise on compliance with standards, operating procedures and so forth, but it put a stress on adapting them to match actual conditions to achieve goals. When it looked at compliance to schedules, procedures, it searched to understand why personnel complied or used shortcuts.

As explained hitherto, some data were not sorted out by other methods such as MEQ (chapter 5) but might be used in complement to each other. This study highlighted the different system’s abilities and identified strategies for improvement as shown in the subsections above. Department's profiles for the four (04) aspects together or individually and the profilers of the three (03) factors together or individually as well have been determined by means of MASRAT. A maturity level (MAL) has also been obtained for each of the three (03) factors and the department. According to a scale ranging from MAL1 to 5 i.e. MEL (maturity excellence level), the level obtained for the maintenance department as well as for each factor was MAL2. This meant that the system did not meet the nominal criteria as required. From the maintenance department profiles, the ability of the system to anticipate has been found limited. "Time pressure" factor received the lowest scores in comparison to "Resources" factor.

Based on these profiles and maturity levels, the assessment permitted identifying improvement strategies at both department and corporate levels (section 7.3.2). Besides, the workshop results witnessed that MASRAT provided a great amount of information that was very useful to analyse to deliver strategies for improvement and to increase system's resilience hence system's abilities. This allowed make the system as high resilient as possible, AHRAP (section 3.3).

One of the limitations of this research work that may arise concerned the follow-up of the recommendations. Such an action requires a long period of time that goes beyond the objectives of this thesis. It can be suggested as further work or way ahead of this piece of research to follow-up the recommendations issued during this activity and deeply explore the monitoring aspect of the resilience precepts as a central aspect in relation to the other ones. In this chapter, the results of the workshop have been presented as well as an evaluation of this activity. The objectives set for the workshop were achieved.

CHAPTER 8. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1. Summary

The first part of this thesis dealt with a review of the relevant literature and theoretical background covering the key important issues of this research work that have been tackled by some researchers. This addressed objective 1 of this research work. The second part, concentrated on the empirical study including the exploration of the maintenance working environment of the Company (objective 2), the design of a strategy based on resilience engineering to achieve safety excellence (objective 3), and the outlining, testing and validation of the tool that measures the resilience of Oil and Gas maintenance systems, MASRAT (objective 4). These objectives are reviewed in the following.

8.1.1. The Literature Review

The first main objective concerned the review of the relevant literature covering the areas of this research. Systems have become nowadays more complex than ever; they are characterised by conditions where time, resources, knowledge, and competence are finite. Besides, people and organisations usually work under pressure to achieve corporate goals. This leads the elements of the system, particularly the human part, to make continuously adaptations/adjustments to fill in the gap between "what should be done" and "what could be done". Maintenance system consists of activities that are labour intensive, hence accidents prone. The impact of human factors in maintenance activities on safety within industrial facilities has received more or less attention from a sector to another one. In particular, the inherent human factors that lead to accidents are difficult to identify. A critical review of the relevant literature related to this area has been carried out to identify ways to address this issue. In the following, the main findings are summed up.

First, the conventional approach to managing safety has been critically reviewed.

- Definitions of key words related to this research work have been revisited. It has been shown that these definitions are based actually on the conventional approach to the management of safety (see chapter 2 for more details)

- A critical review of this conventional approach has shown that hazardous situations as well as unwanted events, their causes and consequences can be identified methodologically by means of techniques such as PHA, FMEA, HAZOP, etc. (called tabular techniques) or FTA, ETA, etc. (known as pictorial techniques). The outcomes of risk assessments using such techniques can be used as a means of communication to decision makers on the risks incurred. The techniques may complement each other. However, these techniques present limitations as shown in chapter 2.
- This approach is based on a supposition that the underlying principles applied to equipment/component failures (failures, causes, consequences, probability of occurrence, and so forth) may be used to characterise the human intervention by the search of for instance "human errors", a taxonomy of "human errors", a probability of "human errors". However, the human intervention is rather considered as an asset (chapter 3).

With respect to the impact of maintenance activities, the main findings are given in the following.

- It has been found that the maintenance activities have a tremendous impact on safety.
- Despite the accident records, the impact of human factors in these activities on safety has been thoroughly studied in other industries, particularly in aviation and nuclear in comparison to oil and gas sector.
- However, the works presented in chapter 2 are based on the conventional approach to safety management where the search for failures and/or "human errors" (critically discussed in chapters 2 and 3) is the leitmotiv; only lacks have been reported as if there have been only negative behaviours or simply positive actions are judged normal and taken for granted.

Afterwards, resilience engineering concepts and precepts have been examined. The approach has been thoroughly studied from the different uses of the concept, followed by the evolution of its use, and ending by the search for relevant definitions.

- The concept of "human error" has been discussed and found meaningless and elusive and hinders the examination of various conditions, pressures, conflicting goals, trade-offs in decision making, etc. that may lead to an outcome.

- It has been found that most resilience definitions refer to the ability of a system to face some threats, changes, or unexpected situations expecting as a result a positive outcome (recover, regain a stable state, maintain, persist, achieve goals, etc.).
- Performance variability has been addressed. It has been shown that systems are underspecified due to a combination of multiple factors (more details needed, incompletely known modes of operations, or tight couplings among functions, fast system changes, etc.) implying approximate adjustments based on trade-offs made in daily activities leading to system performance variability seen inevitable and necessary.
- It has also been shown that systems can be characterised by abilities to perform daily work (what an organisation does) to achieve objectives that make them resilient, namely the ability to respond, monitor, anticipate, and to learn at which the ability to transform is added. Knowing and increasing these abilities will make a system more resilient.
- Eventually, the necessity to move from following the principle of As Low As Reasonably Practicable (ALARP) to adopt the principle of As High Resilient As Possible (AHRAP) has been highlighted.

Based on the resilience engineering approach,

- Safety is seen as "a state where the performance variability produced by a system under conditions that are variable prevents the drift towards hazardous situation".
- Definitions of resilience and resilience engineering have then been proposed. They are respectively the "intrinsic ability of a system to successfully cope with the variability of its performance under expected and unexpected conditions" and "the approach that engineers (plan for, design, and build) practices to identify and implement strategies that make a system AHRAP".

8.1.2. Exploring the Maintenance Working Environment of the Company

To achieve the second objective, the maintenance working environment of the Company has been explored by means of three methods that complement each other (see chapter 5). The main findings are summarised in the following.

First, a survey of the maintenance system was carried out by means of the Maintenance Environment Questionnaire (MEQ). The results are as follows:

- This survey came up with a snapshot of daily activities and identified the human factors in the maintenance system of the Company and their probable impact on the system's safety.
- The conclusion of this survey showed that the three most significant factors that affect safety were resources, time pressure, and supervision/coordination.
- These factors have been selected to measure the resilience of the maintenance system and identify strategies for improvement.
- The limitations of the MEQ to respond alone to the framework requirements (as developed in chapter 6) have been highlighted.

Then, the FRAM was used.

- The FRAM method was used to describe the couplings of functions in the maintenance system and show how the elements of the system interact to illustrate the complexity of the system.
- This study contributed to better understand the maintenance system.
- The elements of the system have been found tightly coupled, hence the system complex.

Storytelling was afterwards used to complement the two others methods.

- As expected, the daily activities of maintenance staff and staff from other departments have been found plenty of stories describing the continuous adaptations of people to achieve assigned objectives.
- The method allowed collect stories particularly positive actions (things that went right) and let people tell their experiences and share them with others

Eventually, the need to measure the four cornerstones of resilience engineering has been shown.

8.1.3. A Strategy Based on Resilience Engineering to Achieve Safety Excellence

The third objective concerned the design of a strategy to achieve safety excellence. The main findings are summarised in the following.

- First, a framework that consisted of performing a gap analysis using the appropriate tools and doing the correct assessment of current situation to identify strategies for improvement has been outlined.
- This entailed carrying out a diagnosis of the situation with respect to the four aspects of resilience to establish a maturity level (MAL) and identify strategies that might lead a

system from a given level of maturity to maturity excellence level (MEL) for each of the three factors already identified.

- It required the development of a management tool that would assess the resilience of the maintenance system.

The developed tool, MASRAT, which consisted of 32 statements (items), has aimed at measuring the resilience of the maintenance system of an Oil and Gas Company through the measurement of the four cornerstones of resilience engineering (the ability to respond to threats/opportunities, the ability to monitor, the ability to anticipate developments, and the ability to learn from past experiences). This has been followed by a validation phase that has been thoroughly described in chapter 6. It concerned a content and reliability validation.

MASRAT has been designed to carry out the analysis by measuring the resilience of the system i.e. measuring the four cornerstones (aspects) of resilience engineering. The measures have been related to the three most significant factors that have been identified by the survey (see chapter 5): resources availability, time pressure, and supervision/coordination. It allowed determining profiles of the system, in our case the maintenance system. MASRAT permitted determining:

- The maintenance department profile for the four aspects i.e. the MAintenance Resilience Profile (MARP)
- The maintenance department profile for the four aspects for each factor i.e. the Factor Resilience Profile (FRP), and
- The maintenance department profile for each aspect and each factor i.e. the Aspect Resilience Profile (ARP)

From these profiles, a MAturity Level (MAL) which ranged from MAL1 to Maturity Excellence Level (MEL) was then determined. A SWOT analysis of these profiles was carried out to identify strategies for improvement.

8.1.4. Testing and Validating the Tool that Measures the Resilience of Oil and Gas Maintenance Systems

Last step was testing the usability of MASRAT (see chapter 7 for more details). The main findings are given in the following.

- First, the usability of MASRAT has been tested in a workshop with a panel of experts from maintenance departments and found usable even though all participants deemed the time allocated to perform such an activity very short.
- Second, MASRAT was used to measure the resilience of the maintenance department of the Company.
- Third, strategies that may lead the system from current level of maturity to excellence have been identified.
- Eventually, recommendations have been made to management to be implemented at both corporate and department levels.
- These recommendations have received a great attention from top management of the company since IAP has been asked to write a draft for a directive to implement these recommendations.

On the other hand, it has been noted that the follow-up of the recommendations issued from this workshop require a long period of time which goes beyond the objectives of this thesis.

8.2. Conclusions

The main conclusions that may be drawn from this research work are given in the following.

- The traditional risk assessment techniques as well accident causation models presented limitations that principally lied within the fact that they could not handle systems that have become very complex and socio-technique. As a consequence, this kind of techniques could not be used to provide reliable results; hence more powerful techniques were required.
- The concept of ‘human errors’ has been found meaningless. Therefore, the appropriate way to deal with complex socio-technical systems and understand what actually happened in real world was to use the concept of performance variability where variability was mainly due to the human intervention, considered as an asset.
- Since systems resilience might be characterised by four (04) abilities to perform daily work, it has been found necessary to measure these abilities.

With respect to the exploration of the maintenance-working environment, three methods have been used to survey this system. The main conclusions are summarised in the following.

- MEQ was found an interesting tool to collect data from the working environment but did not help identify strategies for improvement as sought by the framework (chapter 6).
- Because it focused on the identification and modification of error-shaping factors in the workplace in order to avoid accidents occurrence, it might look at things that went right but with the eye of seeking “errors”. It was actually not the case of resilience engineering that considered the performance variability as an asset. Hence, performance variability might be used rather than “human errors”
- The FRAM was not a method used to perform a gap analysis as required by the framework, it was found a good one to explore a system by finding how functions were linked together and how they interacted to identify the variability of the outputs of these functions; in fine, how they might resonate.
- Alike the other methods, storytelling was not intended to carry out a gap analysis. It was rather used to complement the other data collection methods since it studied things that went right and was appropriate for complex safety critical systems such as the oil and gas industry.
- The three methods can actually complement each other to explore a studied system. However, they cannot be used to perform a gap analysis as required by the framework developed in chapter 6.

MASRAT was developed and validated to perform the gap analysis. Regarding the validation of MASRAT, the index of item-objective congruence, principal component analysis, and Cronbach’s alpha analyses were carried out.

- This ended with the validation of MASRAT after taking into account the results of these analyses.
- The 32 items were reduced to 28 out of which 2 were reworded whereas one was moved from an aspect to another one (see chapter 6)

The usability of MASRAT has been demonstrated during the workshop. An evaluation of this action has been carried out. It has been found that the objectives set for this workshop were achieved (see chapter 7).

In addition to what was given previously, this thesis contributed to the theory and practice of resilience engineering precepts.

8.3. Original Contribution

From the key questions stemming from the problem statement, it has been shown that the resilience engineering approach was the appropriate solution to managing safety in complex socio-technical systems. It has also been highlighted that implementing such an approach implied identifying ways that make a system As High Resilient As Possible (AHRAP). The research work that has been carried out within the Algerian Oil and Gas Company came up with some contributions that are given in the following.

It highlighted the benefits of using a novel approach based on resilience engineering concepts along with the need to fill in the gap between resilience engineering theory and practice. For the first time, resilience engineering approach has been implemented in the Company. A framework based on a gap analysis study has been outlined; it proposed a way to implement resilience engineering and AHRAP concepts in practice by tackling particular issues in the maintenance system of oil and gas assets. This has been achieved by developing a tool, MASRAT, tailored to the maintenance system of oil and gas assets. MASRAT was based on the four cornerstones (abilities) of resilience and maturity levels. If these abilities were known and increased, this would make the system more resilient. MASRAT has been validated and tested. It allowed:

- Measure the system resilience for the first time with respect to three most significant human factors within the Company
- Engineer practices that identify strategies for improvement to increase system's resilience hence system's abilities which make the system AHRAP
- Provide a great amount of information that is very useful to analyse and create a database that may serve the Company and further research

Moreover, MASRAT permitted the assessment of the resilience of the system, the identification of maturity levels and strategies for improvement. Its utilisation during the workshop showed its usability and particularly the opportunity to make realistic recommendations to management in order to manage safety proactively in the maintenance system. MASRAT has been tested for three factors (resources, time pressure, and supervision/coordination) and found reproducible; hence, it has been found flexible and might be extended to any of the 16 identified factors (chapter 6).

Besides, the research work contributed to remedy the limited research in the area of human factors within the maintenance systems of oil and gas industries. It has been achieved by exploring the maintenance working environment of the Algerian National Oil and Gas Company providing a better knowledge of the maintenance working environment and human factors impact on safety and by profiles determination and improvement strategies identification. This study allowed exploring the maintenance system of the Company. By means of the MEQ, the maintenance working environment has been surveyed. The use of the FRAM has showed the complexity of the maintenance system. Storytelling allowed collecting stories about what actually maintenance personnel do to achieve objectives under conditions characterised by finite resources and knowledge.

To sum up, this research work contributed by

- Exploring the maintenance working environment of an oil and gas company and studying the impact of human factors in the maintenance activities on safety,
- Measuring the resilience of the maintenance system of the company,
- Determining profiles and identifying strategies for improvement, and
- Eventually contributing to the theory and practice of resilience engineering.

8.4. Recommendations for Future Work, the Way Ahead

This research work has highlighted the need to base the management of safety on resilience engineering since traditional risk assessment techniques as well as accident causation models have failed to handle complex socio-technical systems. It has contributed to the development of theory and practice of resilience engineering precepts by introducing MASRAT a management tool that has measured the resilience of the maintenance system of an Oil and Gas company.

In spite of the practical advantages that stem from the approach used in this research work, there are some points that need deeper exploration and may suggest axes of research. They are summarised in the following.

8.4.1. MASRAT

To begin with, actually, each of the 28 proposed items constituting MASRAT could be a research topic itself.

- MASRAT is a management tool, therefore, the monitoring of the resilience of the system needs developing a web page based application. This may ease its use, monitoring, and decision-making and follow-up.
- Since MASRAT is flexible enough, it is worth going beyond the maintenance system and exploring the organisation as a system, or the production, or any other system within the organisation.
- Investigating the relationship between the four cornerstones of resilience engineering precepts to find how the deficiencies of one aspect may influence the others is another axis of research. This may be, for instance, the exploration of the monitoring aspect by developing performance indicators for the examined system or the development of a model of vulnerability. The latter is one of the important elements of the anticipation aspect that requires a deeper examination.

8.4.2. Resilience Engineering

The concepts of resilience engineering may enhance the implementation of any HSE management system. It is of great importance to find a way to introduce these precepts since companies have troubles to implement such systems. This action has already begun during training sessions of steering committees that will implement the Company's HSE MS by using the FRAM unit (see chapter 1) to characterise recommended activities/actions (functions).

It has been shown that traditional risk assessment techniques as well as accident causation models cannot handle complex socio-technical systems; it is therefore an interesting research axis. The use of FRAM during this research work has raised the need to the development of a way to measure the variability of the performance. The exploration of the use of fuzzy cognitive maps (MCP) could be an axis of development.

Eventually, in this thesis, the concept of AHRAP has been introduced without any development. A study showing the need to make the shift from the concept of ALARP to the concept of AHRAP is of great importance too.

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Appendix 1 Relevant Definitions of Resilience

Table A-1.1 : Relevant definitions of resilience

System feature	In front of	Definition	Author
Ability to absorb and persist	Changes and disturbances	A measure of the ability of the systems to absorb changes of state variables, driving variables, and parameters, and still persist. A measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables	Holling (1973)
Speed to turn back to initial state (stability)		A measure as the speed with which a system returns to its original shape	Pimm (1984)
Ability to withstand	Stress	The ability of a system to withstand stresses 'environmental loading…It is a fundamental quality found in individuals, groups, organisations, and systems as a whole	Horn and Orr (1998) in Vugrin et al (2010)
Capacity to adapt resources and skills	New situations	The capacity to adapt existing resources and skills to new situations and operating conditions	Comfort, 1999, in Vugrin et al (2010)
Ability to cope with	External stresses and disturbances	Ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change	Adger (2000) in Vugrin et al (2010)
Ability to absorb Ability to use resources Ability to rebound	Strain and adversity	Ability to absorb strain and preserve or improve functioning despite the presence of adversity Continuing ability to use internal and external resources successfully to resolve issues Capacity to rebound from adversity strengthened and more resourceful	Sutcliffe and Vogus (2003)
Capacity to cope with Capacity to learn bounce back	Unanticipated dangers	Capacity to cope with unanticipated dangers after they have become manifest, learning to bounce back	Widalvsky (2004)
Capability to maintain functions and structures	Changes	Capability of a system to maintain its functions and structure in the face of internal and external change	Allenby (2005) in Vugrin et al (2010)
Ability to absorb	Disturbance	Ability of a system to absorb disturbance and still retain its basic function and structure	Walker and Salt (2006)
Ability to steer activities	Close to dangerous areas	Ability to steer the activities of the organisation so that it may sail close to the area where accidents will happen but always staying out of the dangerous area	Hale and Heijer (2006)

Relevant definitions of resilience (continued)

System feature	In front of	Definition	Author
Ability to prevent or adapt to	Changing conditions	Ability of systems to prevent or adapt to changing conditions in order to maintain (control over) a system property	Leveson et al (2006)
Potential abilities used to the utmost	Expected and unexpected situations	Utilisation of system's potential abilities (engineered features or acquired adaptive abilities) to the utmost extent and in a controlled manner, both in expected and unexpected situations	Fujita (2006)
Ability to efficiently adjust to Intrinsic ability to react to and recover	Harmful influences Disturbances	Ability of an organisation to efficiently adjust to harmful influences rather than to shun or resist them Intrinsic ability of a system to react to and recover from disturbances at an early stage, with minimal effect on its dynamic stability	Hollnagel (2006)
Ability to prevent or recover	Something bad	Ability to prevent something bad from happening, from becoming worse, or to recover from it once it has happened	Westrum (2006)
Ability to keep or recover quickly to a stable state Ability to have appropriate levels of resources	Major mishap or in presence of stress Sudden increasing challenges or onset of a major hazard	Ability of an organisation (system) to keep, or recover quickly to, a stable state, allowing it to continue operations during and after a major mishap or in the presence of continuous significant stresses Ability to have appropriate levels of resources (particularly reserves) that can react to sudden increasing challenges or onset of a major hazard	Wreathall (2006)
To cope with	Complexity under pressure	A paradigm for safety management that focuses on how to help people cope with complexity under pressure to achieve success	Woods and Hollnagel (2006)
Ability to achieve core objectives	Adversity	A resilient organisation is able to achieve its core objectives in the face of adversity.	Seville et al. (2006)
Ability to absorb and retaining basic functions	Disturbance	Ability of a system to absorb disturbance and still retain its basic function and structure	Walker and Salt (2006)
Capability to Recognise, adapt to, and cope with	The unexpected	Resilience refers to the capability of recognising, adapting to, and coping with the unexpected.	Woods, (2006)
Intrinsic ability to maintain or regain a dynamically stable state	Major mishap or in presence of significant stress	Intrinsic ability of an organisation (system) to maintain or regain a dynamically stable state, which allows it to continue operations after a major mishap or in the presence of continuous significant stresses	Weick and Sutcliffe (2007)

Relevant definitions of resilience (continued)

System feature	In front of	Definition	Author
Ability to reduce efficiently magnitude and duration of deviation	Deviation	The ability to efficiently reduce both the magnitude and duration of the deviation from targeted system performance levels.	Vugrin et al (2010)
Intrinsic ability to adjust functioning	Prior to, during or following changes and disturbances	The intrinsic ability of a system to adjust its functioning prior to, during or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions	Hollnagel (2011)
Intrinsic ability to adjust functioning	Prior to, during or following events (changes, disturbances, or opportunities)	A system is resilient if it can adjust its functioning before, during, or following events (changes, disturbances, or opportunities) and thereby sustain required operations under both expected and unexpected conditions.	Fairbanks et al (2014)

Appendix 2 FRAM of the Turbo-compressor

Table A-2.1: Characterisation of the foreground and background functions by the six parameters

Functions	Type	Who	Input	Output	Preconditions	Controls	Resources	Time
Isolate equipment	B	Production	Work planned and scheduled	Equipment isolated	Equipment available	Isolation procedures Permits to work and associated certificates issued HSE department	Operators	01 day
Drain equipment	B	Production, HSE, maintenance	Work planned and scheduled	Equipment drained	Equipment isolated	Explosion/fire tests Permits to work and associated certificates issued HSE department	Technicians operators	01 day
Inspect equipment to identify nature of breakdown	B	Inspection and technical department	Inspection request	Equipment inspected Nature of breakdown identified	Equipment isolated blind flange	Competence and experience	Inspectors	01 day (may take several days
Request inspection of equipment	B	Production	Breakdown	Inspection of equipment requested		Production procedures	Operators	01 day

Characterisation of the foreground and background functions by the six parameters (continued)

Functions	Type	Who	Input	Output	Preconditions	Controls	Resources	Time
Report breakdown	B	Production	Recommendations after inspection	Breakdown reported		Production procedures	Operators	
Issue work demands	B	Production		Work demands issued		Production procedures	Operators	01 h
Prepare work orders	B	Maintenance preparation section	Work demands	Work orders prepared Required resources defined Required human resources defined Estimation of man/h defined	Equipment outage	Maintenance system procedures	Assistants Technicians	01 h
Issue work permits	B	Maintenance	Work orders	Permits to work and associated certificates issued	Permits Certificates	Permit to work system (PTWS)	Technicians	01 h
Schedule activities	B	Maintenance planning/ scheduling section	Work orders Permits to work and associated certificates	Work planned and scheduled Performance/costs measured	Attendance sheet Spares Tools Equipment	Maintenance system procedures	Planners	01 day
Dismantle instruments, piping, probes, etc.	F	Maintenance crafts (instrumentation, logistics, electricity, mechanics)	Work planned and scheduled	Instruments, piping, probes, etc. dismantled	Permits to work and associated certificates issued Equipment drained Equipment isolated	Manufacturer procedures/ instructions HSE department Competence/ experience	Crafts	02 days

Characterisation of the foreground and background functions by the six parameters (continued)

Functions	Type	Who	Input	Output	Preconditions	Controls	Resources	Time
Open equipment	F	Maintenance crafts (logistics, mechanics)	Work planned and scheduled	Equipment opened	Permits to work and associated certificates issued Equipment drained Equipment isolated	Manufacturer procedures/ instructions HSE department Competence/ experience	Crafts Tools Equipment	01 day
Clean components	F	Maintenance crafts (logistics, mechanics)	Work planned and scheduled	Components cleaned	Equipment drained Equipment isolated	Manufacturer procedures/ instructions HSE department Competence/ experience	Crafts	01 day
Make recommendations	B	Inspection and technical department		Recommendations made after inspection		Competence/ experience	Inspectors	04 h
Repair identified issues	F	Maintenance crafts (instrumentation, logistics, electricity, mechanics),	Work planned and scheduled	Identified issues repaired	Permits to work and associated certificates issued Equipment drained Equipment isolated	Manufacturer procedures/ instructions HSE department Competence/ experience	Crafts	04 h Depends on spare availability

Characterisation of the foreground and background functions by the six parameters (continued)

Functions	Type	Who	Input	Output	Preconditions	Controls	Resources	Time
Lift components	B	Maintenance crafts (instrumentation, logistics, electricity, mechanics)	Work planned and scheduled	Components lifted			Logistics Tools Equipment	04 h
Overhaul auxiliary equipment	F	Maintenance crafts (instrumentation, logistics, electricity, mechanics)	Work planned and scheduled	Auxiliary equipment overhauled	Permits to work and associated certificates issued Equipment drained Equipment isolated	Manufacturer procedures/ instructions HSE department Competence/ experience	Crafts	
Grease auxiliary equipment	F	Maintenance crafts (instrumentation, logistics, electricity, mechanics)	Preventive maintenance schedule Work planned and scheduled	Auxiliary equipment greased	Permits to work and associated certificates issued Equipment drained Equipment isolated	Manufacturer procedures/ instructions HSE department Competence/ experience	Crafts	03 h
Replace failed components (pumps, hoses, etc.)	F	Maintenance crafts (instrumentation, logistics, electricity, mechanics)	New components Work planned and scheduled	Failed components (pumps, hoses, etc. replaced	PTW and associated certificates issued Equipment drained Equipment isolated	Manufacturer procedures/ instructions HSE department Competence/ experience	Crafts Spares Tools Equipment	04 h

Characterisation of the foreground and background functions by the six parameters (continued)

Functions	Type	Who	Input	Output	Preconditions	Controls	Resources	Time
Lubricate components	F	Maintenance crafts (instrumentation, logistics, electricity, mechanics)	Preventive maintenance schedule Work planned and scheduled	Components lubricated	Permits to work and associated certificates issued Equipmentdrained Equipment isolated	Manufacturer procedures/ instructions HSE department Competence/ experience	Crafts	02 h
Align equipment	B	Maintenance crafts (instrumentation, logistics, electricity, mechanics)		Equipment aligned		Manufacturer procedures/ instructions HSE department Competence/ experience	Crafts Operators Technicians	02 h
Mount instruments, piping, probes, etc.	F	Maintenance crafts (instrumentation, logistics, electricity, mechanics)	Work planned and scheduled	Instruments, piping, probes, etc. mounted	Permits to work and associated certificates issued Equipment drained Equipment isolated	Manufacturer procedures/ instructions HSE department Competence/ experience	Crafts	2 days

Characterisation of the foreground and background functions by the six parameters (continued)

Functions	Type	Who	Input	Output	Preconditions	Controls	Resources	Time
Test equipment	B	All departments present	Equipment aligned	Equipment tested	Permits to work/ certificates completed and signed-off	Manufacturer procedures/ instructions HSE department Competence/ experience	Crafts Operators Technicians	04 h
Complete and sign-off permits to work and associated certificates	B	Maintenance, production, and HSE	Equipment de-isolated Equipment inspected Components cleaned Identified issues repaired Auxiliary equipment overhauled Auxiliary equipment greased Failed components (pumps, hoses, etc. replaced Components lubricated Equipment aligned Instruments, piping, probes, etc. mounted	Permits to work and associated certificates completed and signed-off		PTWS		04 h
Manage competence	B			Training, experience available				

Characterisation of the foreground and background functions by the six parameters (continued)

Functions	Type	Who	Input	Output	Preconditions	Controls	Resources	Time
Manage procedures	B			Procedures made available				
Manage resources	B	Planning scheduling Logistics	Maintenance personnel Spare parts Tools Equipment needs	Required personnel assigned Required spares made available Required equipment tools made available				
Inspect opened equipment	B	Inspection and technical department	Work planned and scheduled	Opened equipment inspected Recommendations made	Permits to work and associated certificates issued Equipment drained Equipment isolated	Competence/ experience	Inspectors Technicians	04 h
Start equipment	B	All departments present	Permits to work and certificates completed and signed-off	Equipment started	Equipment aligned	PTWS Manufacturer procedures/ instructions HSE department Competence/ experience	Crafts Operators Technicians	04 h

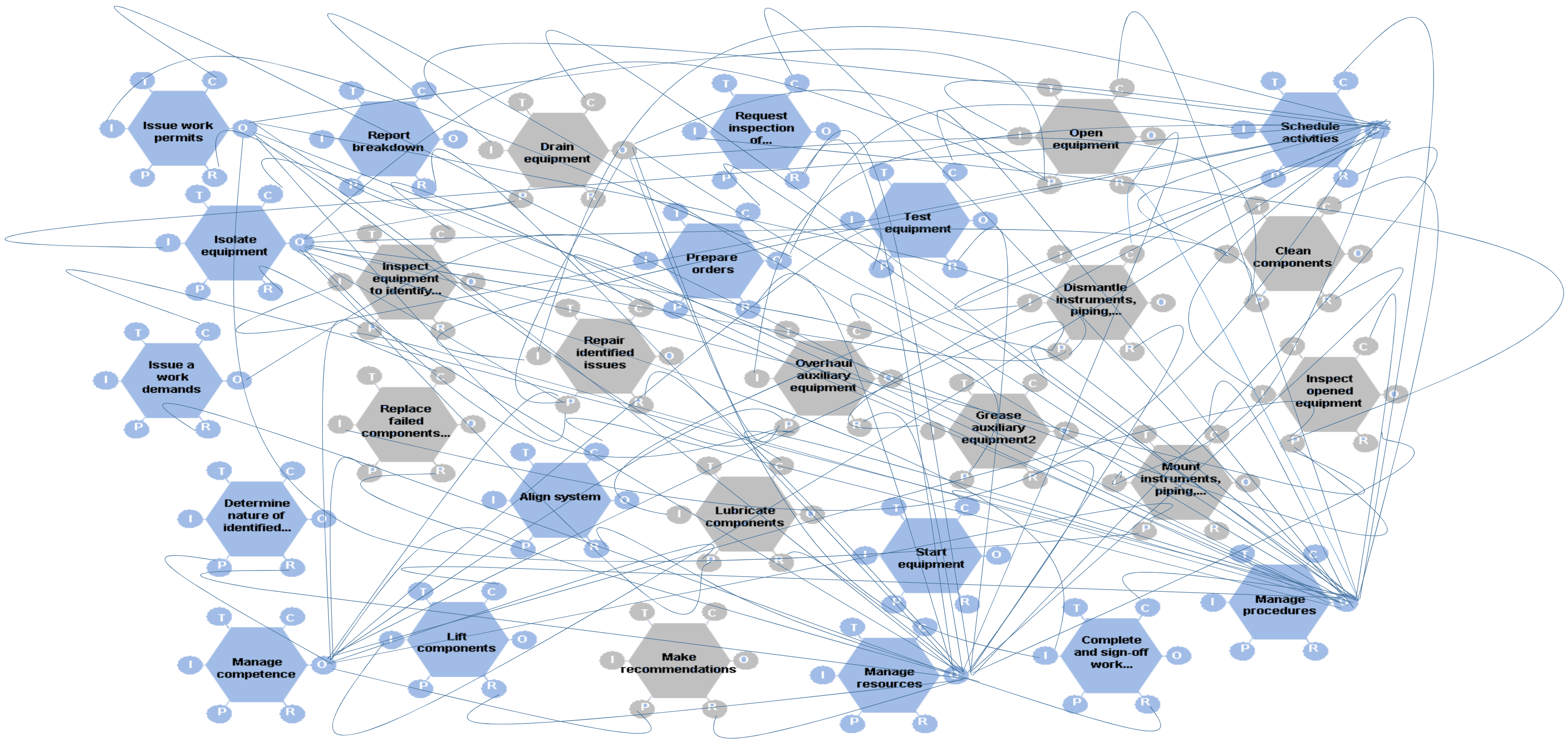

Figure A-2.1: Links for the outputs of the considered functions

Note: the background functions are in blue colour

Appendix 3 Experts comments on MASRAT

Example of messages sent to the experts

To the attention of Professor Sydney Dekker,

Dear professor,

I am Said Ameziane, part-time PhD student in Robert Gordon University. I had the honour to read your contributions particularly managing safety by resilience engineering. I am working in the area of human factors and my research deals with finding a strategy to enable the optimisation of human factors in maintenance and achieve safety excellence. I have already designed an instrument which measures the resilience of a system based on issues identified by means of a survey in the maintenance environment, interviews of maintenance staff, observations, and literature review on the one hand, and on generic probing questions proposed by Professor Hollnagel.

At the beginning, 25 items were identified to be analysed at organisational level. The organisational assessment tool was then adapted to fit the maintenance system, object of our study. 16 items were identified to do so.

Since it is quite impossible to address all the 16 items during the research project, the list was reduced to only 3 highlighted issues that received the most frequent rating for a situation that occurred at least once in six months or more frequently by maintenance staff and interviews of maintenance specialists: equipment i.e. resources availability, coordination/supervision, and time pressure (operational constraints).

The instrument is intended to be used in an Algerian company, so there are 2 versions: English and French. It necessitates a validation process. As an expert in the field of resilience engineering, I would be very grateful if you can be among the expert panellist who will assess the content validity of the instrument in question. Your comments/feedback are very welcome. Thank you indeed.

I am attaching the Excel file for rating if you agree. Thank you very much

My Very Best Regards

Said

Response from Professor Sydney Dekker

Sidney Dekker <s.dekker@griffith.edu.au>
Mon 24/09/2012 05:36
Inbox
To:
SAID AMEZIANE (0410925);
You replied on 24/09/2012 14:48.
Dear Said,

Sorry for the delay. I have had a chance to look at your survey. I generally commend you for trying to operationalize resilience like this, and to probe an organization with it. Generally, the content is fine and seems to be a fair reflection of what the resilience literature has been trying to do (or at least one part of that literature).

Your questions vary from very specific (e.g. "6. The department estimates best response duration...") to much more high-level and unspecific (e.g. questions 18 and 19 about the "learning process"). This may not be a problem, of course, but perhaps worth looking at once more.

Also, it seems as if for each question, 4 answers need to be given (for all 4 resilience markers). Is that right? If so, I am not looking at 32 questions, but rather at 128, which may induce a bit of survey fatigue among your informants. Perhaps there are ways in which you can better collapse some of the questions, so as to end up with even fewer ones?

Hope this works for you,
Best wishes,
Sidney Dekker

Professor Sidney W. A. Dekker, PhD
School of Humanities
Griffith University
Macrossan Building, N16_2.22, Nathan Campus
QLD 4111, Australia
+61 - (0)7 - 373 54842

Response from Professor Erik Hollnagel

Erik Hollnagel <hollnagel.erik@gmail.com>
Sun 19/08/2012 16:24
Inbox
To:
SAID AMEZIANE (0410925);
You replied on 24/08/2012 17:32.
Bonjour Said
Sorry to take so long in replying, but such is life.
I have looked through your descriptions, and also the spreadsheet. It looks quite interesting, and I think that the questions are quite sensible. I am involved in a similar project but in healthcare (starting next year, in fact), so it would be interesting to keep track of your results. As you say, there are quite a number of questions to be asked, but I think that experiecne can help in finding the most informative ones.
So do keep me informed about how this work develops.

With kind regards,
Erik Hollnagel
Professor Erik Hollnagel

Appendix 4 Explanatory introduction to participants to the validation phase

The following is the explicative note given to the survey participants during the validation phase of MASRAT.

Introduction

The following survey is a part of a PhD research to develop a tool which measures the intrinsic ability of a system or an organisation to its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions (Hollnagel, 2010a). By means of a questionnaire, the ability of a system to respond (1) to threats/opportunities, to flexibly monitor (2), to anticipate (3) any development, and to learn (4) from past experiences is measured. The system considered is the maintenance department within an Oil and Gas organisation. For the 4 aspects given above, 3 items are examined through 28 statements in order to obtain a profile of the system in question and determine a level of maturity using a scale from level "1" to "excellence". The respondents are asked to tick the relevant box from "1" to "M" to confirm or invalidate the statement. For example, "5" for "The department often assesses...resource availability" means fully agree with the statement i.e. the system on the whole exceeds the criteria addressed by the specific item that is assessment is made on a regular basis using the last available techniques, etc.

Category assessment

Table A-4.1: Scores and meanings (adapted from Hollnagel, 2010a)

Fully agree "5"	The item can be addressed and the system exceeds item requirements
Agree "4"	The item can be addressed but the system meets realistic item requirements
Somewhat agree "3"	The item can be addressed but the system meets the minimum item requirements
Disagree"2"	The item can be addressed but the system performs under the minimum item requirements
Fully disagree "1"	The item can be addressed but the system does not address it
Missing "M"	The system cannot address the item whatever the condition are

The following are some guidelines to help understand what is meant by each of the three factors

Maintenance activities are labour intensive: they are accidents prone. Human factors are most times difficult to identify and research in this area within the oil and gas industry is limited. Organisations, particularly the human part of the system make adjustments continuously to adapt system resources to multiple objectives. Safety research has focused so far, on accidents that occurred. There is an urgent need to develop something different that takes into account the interaction of the elements of a system. This may be achieved by measuring the system's resilience i.e. the intrinsic ability of a system or an organisation to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions (Hollnagel, 2010a). A resilient system is one which is able to: a) Respond to threats, (know what to do), b) Flexibly monitor, (know what to look for), c) Anticipate any developments, (know what to expect), and d) Learn from experience (known to learn).

Resources

The lack of resources is one of the most important factors influencing system performance. By resources it is meant any kind of resources human and material so that objectives are achieved. Examples of non-exhaustive points to consider:

- Been unable to obtain a special tool or item of maintenance equipment
- Been delayed on a task because you could not obtain a consumable part (for example, an 'O' ring)
- Used an unserviceable piece of maintenance equipment (for example, a broke ladder)
- Been delayed on a task because you could not obtain a major part (for example, a wheel or pump)
- Done a task without the correct tools or equipment
- Had to do a task without the appropriate documentation, etc.

Time pressure

Examples of non-exhaustive points to consider:

- Not had enough time to adequately read the documentation before starting a task
- Had to rush an inspection
- Had to cut short a functional check
- Been interrupted part-way through a task to perform another more urgent task.
- Been asked to hurry a task
- Had to skip a required functional check, etc.

Supervision/Coordination

Examples of non-exhaustive points to consider:

- Felt that you did not have enough knowledge or experience to do an assigned task
- Not been aware of maintenance activities done previously, when you needed to know.
- Corrected an error made by someone else, without documenting what you had done

- Signed off a task before it was completed
- Left out a task step because you did not know it needed to be done
- Been given wrong information about a task
- Assumed that work had been done by someone else, but found out later that it had not been done
- Felt that a defect had not been rectified adequately before a system or component was returned to service
- Certified that someone's work was correct without checking it
- Found that somebody else had already started a task you were about to do, etc.

Appendix 5 Explanatory introduction to workshop participants

Towards a proactive management of safety in the maintenance of industrial assets

1. Introduction

Maintenance activities are actually labour intensive and maintenance staff often works under pressure to finish tasks as rapidly as possible, and sometimes lack the necessary knowledge to perform certain tasks as required (Ameziane et al, 2011). Thus, they are accidents prone.
The job, the organisation, and the individual are the three interacting aspects, called human factors that influence human behaviour at work and can affect health and safety as defined by HSE (2005). Human factors inherent in such accidents are most times difficult to identify. Research in this area within the oil and gas industry in maintenance management is limited in comparison with aviation and nuclear industries.

In such systems, organisations are often working under pressure. They face situations requiring the management of unexpected events. To achieve success, they must adapt their functioning and make correct adjustments. They have to rely on the capability of humans to make these adjustments fill in the gap between “what should be done” and “what could be done” using available resources, time, knowledge, and competence. Actually, these adjustments may lead to success or to increase risks.

Instead of focussing only on why accidents happen, it is worth orienting the work toward understanding also why things go right within systems. The solution lies within using more powerful and non-linear methods/models based on systems theory and resilience engineering precepts.

Systems have become more complex, there is an urgent need to develop something different that take into account the interaction of the elements of the system, more powerful than traditional accident causation models and risk assessment techniques that have shown their limits to handle such systems. Resilience engineering is the solution. In other words, measuring the resilience of a system i.e. its intrinsic ability to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions (Hollnagel, 2010b).
The main objective of this workshop is testing the usability and implementing of a tool designed to measure the resilience of a system, in our case the maintenance system of the Company

2. A management and measurement tool

Research in safety has been recently oriented towards the use of resilience engineering particularly in the aviation and Aerospatiale industry whereas it is very limited in the oil and gas sector. To date there is no recognised tool that measures the resilience of a system,

This study is a part of a research to develop and validate a tool to measure a system's resilience. A resilient system is one which is able to respond to threats/opportunities 9know what to do), flexibly monitor its performance and the performance of the surrounding environment (know what to look for), anticipate any development (know what to expect), and learn from past experiences (know what to learn).

This tool has been developed for the maintenance system of SONATRACH with respect to three factors that impact activities i.e. resources, time pressure, and supervision/coordination (see below meanings of each factor). This may be extended to 16 factors and adapted to other systems such "production" and "the organisation", in this case 18 factors are considered. The tool allows identify system's profiles and define a maturity level; it searches strategies for improvement that take the system from the current maturity level to excellence. The tool is called **MA**intenance **S**ystem **R**esilience **A**ssessment **T**ool (MASRAT)

Workshop objectives

The objectives set for this workshop are as follows:

- Communicate and study the data collected during the action of validation,
- Assess the resilience of the maintenance system and determine the different profiles and maturity levels,
- Identify strategies for improvement, and
- Make recommendations to top management.

The workshop is organised in three ateliers with respect to the three studied factors.

Theme of atelier 1: Resources

The lack of resources is one of the most important factors influencing system performance. By resources it is meant any kind of resources human and material so that objectives are achieved. Examples of non-exhaustive points to consider:

- Been unable to obtain a special tool or item of maintenance equipment
- Been delayed on a task because you could not obtain a consumable part (for example, an 'O' ring)
- Used an unserviceable piece of maintenance equipment (for example, a broke ladder)

- Been delayed on a task because you could not obtain a major part (for example, a wheel or pump)
- Done a task without the correct tools or equipment
- Had to do a task without the appropriate documentation, etc.

Theme of atelier 2: Time pressure

Examples of non-exhaustive points to consider:

- Not had enough time to adequately read the documentation before starting a task
- Had to rush an inspection
- Had to cut short a functional check
- Been interrupted part-way through a task to perform another more urgent task.
- Been asked to hurry a task
- Had to skip a required functional check, etc.

Theme of atelier 3: Supervision/Coordination

Examples of non-exhaustive points to consider:

- Felt that you did not have enough knowledge or experience to do an assigned task
- Not been aware of maintenance activities done previously, when you needed to know.
- Corrected an error made by someone else, without documenting what you had done
- Signed off a task before it was completed
- Left out a task step because you did not know it needed to be done
- Been given wrong information about a task
- Assumed that work had been done by someone else, but found out later that it had not been done
- Felt that a defect had not been rectified adequately before a system or component was returned to service
- Certified that someone’s work was correct without checking it
- Found that somebody else had already started a task you were about to do, etc.

Appendix 6 Questionnaire to participants

Questions regarding the introduction

Would you please say to what extent you agree or disagree with the following statements 1 means you completely disagree (CD) and 5 completely agree (CA)?

Table A-6.1: Questions regarding the introduction

Theme 1	CD				CA
	1	2	3	4	5
The information was clearly given by the presenter					
The presenter attracted audience attention					
The presentation was well-structured					
The presenter answered appropriately to the questions					

Questions regarding facilitators

Would you please say to what extent you agree or disagree with the following statements 1 means you completely disagree (CD) and 5 completely agree (CA)?

Table A-6 2: Questions regarding the facilitators

Theme 2	SD				SA
	1	2	3	4	5
The information was clearly given by the facilitator					
The facilitator attracted audience attention					
The facilitator helped achieve workshop objectives in time and content					

Questions regarding the efficiency of the workshop

Would you please say to what extent you agree or disagree with the following statements 1 means you completely disagree (CD) and 5 completely agree (CA)?

Table A-6 3: Questions regarding the efficiency of the workshop

Theme 3	SD				SA
	1	2	3	4	5
The workshop was relevant for me					
The workshop was interesting					
The workshop content was significant for me					
The workshop pushed me to reflect on my own actions					
The workshop motivated me to take actions.					

Questions regarding MASRAT

Would you please say to what extent you agree or disagree with the following statements 1 means you completely disagree (CD) and 5 completely agree (CA)?

Table A-6.4: Questions regarding MASRAT

Theme 4	SD				SA
	1	2	3	4	5
MASRAT was easy to understand and use and followed a logical order					
MASRAT is designed for maintenance system					
The use of MASRAT generated a debate among participants					
The workshop made recommendations et realistic actions					

If you have given a score under “4”, would you please use this space to comment on.

Appendix 7 Questionnaire to facilitators

Questions regarding workshop preparation

Would you please say to what extent you agree or disagree with the following statements 1 means you completely disagree (CD) and 5 completely agree (CA)?

Table A-7.1: Questions regarding workshop preparation

Theme 1	CD				CA
	1	2	3	4	5
The workshop preparation (resources) was satisfactory					
The workshop preparation (time and content) was satisfactory					

Questions regarding the introduction

Would you please say to what extent you agree or disagree with the following statements 1 means you completely disagree (CD) and 5 completely agree (CA)?

Table A-7.2: Questions regarding the introduction

Theme 2	CD				CA
	1	2	3	4	5
The information was clearly given by the presenter					
The presenter attracted audience attention					
The presentation was well-structured					
The presenter answered appropriately to the questions					
The presentation helped me facilitate the workshop					

Questions regarding workshop facilitation

Would you please say to what extent you agree or disagree with the following statements 1 means you completely disagree (CD) and 5 completely agree (CA)?

Table A-7.3: Questions regarding workshop facilitation

Theme 3	SD				SA
	1	2	3	4	5
Participants were interested by the workshop					
Workshop objectives (content) were easily achieved					
Workshop objectives (time) were easily achieved					
There have been no difficulty to facilitate the workshop					

Questions regarding MASRAT

Would you please say to what extent you agree or disagree with the following statements 1 means you completely disagree (CD) and 5 completely agree (CA)?

Table A-7.4: Questions regarding MASRAT

Theme 4	SD				SA
	1	2	3	4	5
MASRAT was easy to understand and use and followed a logical order					
MASRAT is designed for maintenance system					
The use of MASRAT generated a debate among participants					
The workshop made recommendations et realistic actions					

If you have given a score under “4”, would you please use this space to comment on.