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MASTER'S THESIS

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Author: Peng, Guicang	
Faculty supervisor: Professor. Jayantha Prasanna Liyanage Company Thesis Advisor: Anne Siri. Birkeland Carlson (DNV GL)	
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Finally, I would like to thank my family and friends who have believe in me and support me with whatever "crazy" decisions I've made. With your love and supporting, I do not feel lonely wherever and whenever I am actually alone.

After 18 years full time studies as a student, one statement currently popular in China can finally apply to me at this moment as rewarding:

"Mom won't worry about my study anymore"

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Abbreviations

AI - Artificial Intelligent

CBM – Condition Based Maintenance

DFU - Major hazard precursor

EU - European Union

EUDG - EU Director General Energy

EUOAG - EU Offshore Authorities Group

FMEA – Failure Mode Effects Analysis

FMECA – Failure Mode Effects and Criticality Analysis

HC- Hydrocarbon

IRF - International regulators Forum

MBS - Maintenance Baseline Study

MEDA - Maintenance Errors Decision Assistant

MMM - Maintenance Management Model

MODU - Mobile Offshore Drilling Units

NCS - Norwegian Continental Shelf

NPD - Norwegian Petroleum Directorate

NSOAF - North Sea Offshore Safety Authorities Forum

OEM – Original Equipment Manufacture

OIM - Offshore Installation Manager

OTS -Operational Condition Safety

PPE - Personal Protect Equipment

PSA - Petroleum Safety Authority

RBM – Reliability Based Maintenance

RCFA – Root Cause Failure Analysis

RCM – Reliability Centred Maintenance

SCEs - Safety Critical Equipment

SHE - Safety Health Environment

UK - Unite Kingdom

UKCS - Unite Kingdom Continental Shelf

CHAPTER 1. INTRODUCTION

As defined by European Standard EN 13306: *Maintenance is the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function.* For Norwegian Petroleum Industry, Maintenance, particularly maintenance of safety critical system and equipment, has always been addressed as important means to prevent major accidents meanwhile improving operational performance:

'Maintenance is indissolubly linked with safety in a number of ways. Errors in planning, executing or checking maintenance could cause system faults. Inadequate or erroneous maintenance may also mean that existing failure or degradation is not discovered and corrected – and thereby contributes to production shut-downs, work accidents and/or major incidents.' -The Petroleum Safety Authority (PSA)

Good maintenance management and practise is critical to enhance system reliability while reduce vulnerability, therefore is no less important compare to any other facets of companies daily does and should be emphasised with strategic importance as always.

1.1. MAJOR ACCIDENTS CAUSED BY MAINTENANCE ERRORS

Maintenance has always been recognized as core competence with strategic importance, not only because well-functioning maintenance program are critical for increasing assets available time, reducing operational and maintenance costs, building up industrial reputations among competitors etc., but also because faulty maintenance activities had been identified as major causes or escalating factors for large numbers of catastrophic accidents. This is particularly the truth for Aviation Industry, whereas according to Federal Aviation Administration (USA), since 1949, Maintenance errors have been documented as the major causes for more than 24 catastrophic commercial flights accidents, the fatalities distributed by years are showing below:

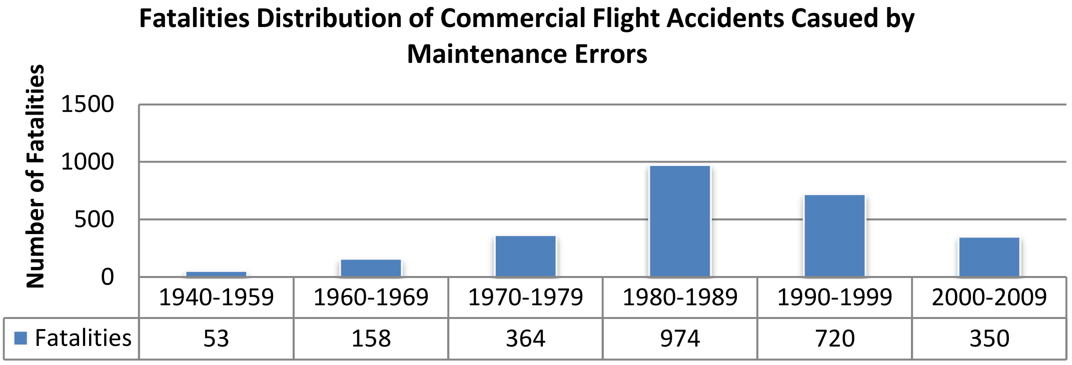


Table 1 Fatalities Distribution of Aviation accidents related to maintenance errors

Comparing to Aviation Industry during similar time interval, Chemical, Oil and Gas Sectors have generally less accidents and fatalities rates caused by maintenance errors, but still some of the most devastating accidents were pointed out to be directly or indirectly associated with maintenance problems as showing below:

Year	Facilities	Accidents Facts
2005	Texas City Refinery	Explosion killing 15 workers and injuring other 170
2004	Stockline Plastics	Explosion killing 9 workers and injuring other 40
2003	DSM Chemical Plant	Explosion Killing 3 workers
1992	Sodegaura Refinery	Explosion and fire killing 10 workers and injuring other 7
1989	USA Phillips 66	Explosion and fire killing 23 workers and injuring 130-300
1988	Piper Alpha	Explosion and fire killing 167
1984	Bhopal Chemical	Released Toxic Gas killing 4000 and injured other 500,000
1974	Flixborough Plant	Explosion Killing 28 and injured other 36

Table 2 Accidents associated with Maintenance Problems in Chemical, Oil&Gas industry

1.2. HYDROCARBON LEAKS CAUSED BY MAINTENANCE ERRORS ON NCS

Hydrocarbon (HC) leaks has been used as the major hazard precursor (DFUs) for "Major Accidents" at NCS by PSA. A study of HC leaks at NCS from 2002-2005 by a Norwegian group(Aven et al., 2006) had indicated that approximately 53% HC leaks were caused by maintenance errors as shown below:

- **Latent errors (44%)**: releases result from latent failures of equipment after human intervention (maintenance).
- **Immediate Errors (9%):** releases during intervention (maintenance)
- **Process (11%):** releases result from process control errors.
- **Design (5%):** leaks caused by deign errors
- **Technical (31%):** technical failures (erosion, corrosion, vibration).

Also at 2006, Statoil Norway had initiated a so called OTS Project (OTS is the Norwegian abbreviation for Operational Condition Safety) to develop or method to measure human and organizational factors with regarding to major accidents based on the above results. A later study conducted at year 2010 by Jan Erik Vinnem et al. at University of Stavanger. Norway had found that 60% of HC leaks due to human interventions as showing below(Vinnem, 2010):

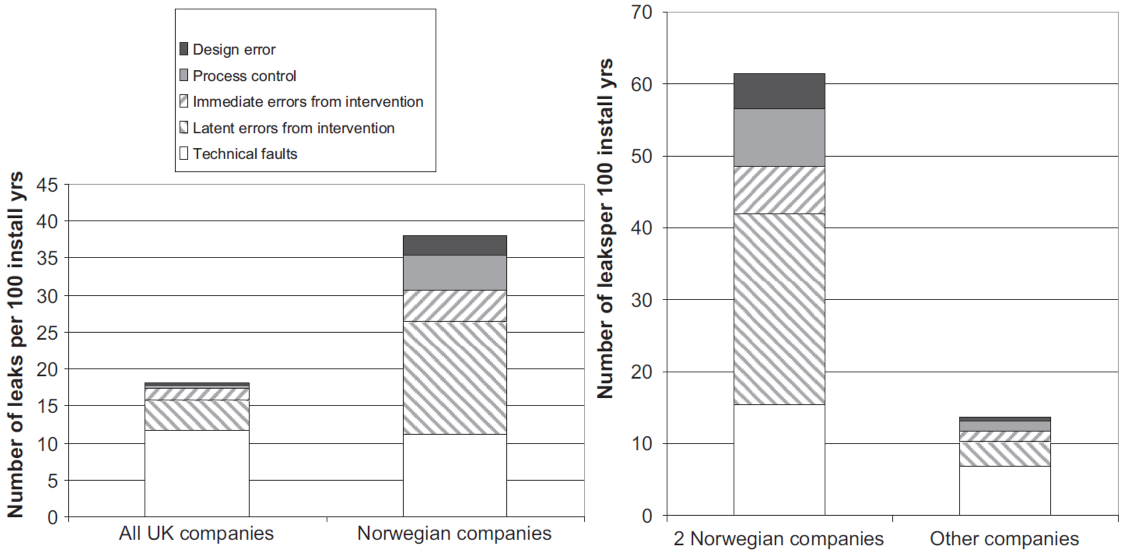


Figure 1 HC leaks causal factors analysis and comparison(Vinnem et al., 2010)

Among the 60% leaks due to human intervention, major casual factors are:

1) Failure to check pre-work isolations, and
2) Failure to check isolations & integrity after re-instatement.

The data above shows that Human intervention (maintenance errors caused by human errors), are the major casual factors for HC leaks and the relevant potential incidents & accidents on NCS.

1.3. MAJOR CHALLENGES OF MAINTENANCE – RISKS OF HUMAN ERRORS

As Dr. Paul Davies (Chief Scientist and Head of Hazardous Installations Directorate, HSE UK) had addressed: *Overall, the general accident trend in the United Kingdom (UK) is downwards but the role of maintenance error as a root or major contributory cause to major accidents has increased. We have seen many examples, in the UK and worldwide, eg the disasters at Piper Alpha, Bhopal, and Clapham Junction and more recently in a number of high-profile aviation accidents.*(MErgS and EurErg, 2002).

Maintenance activities require closet interaction between human and machine, we could even conclude that maintenance activities is a simple human operation because human's directly involvement in nearly every step of the maintenance process, according to this, maintenance errors a in large extent could be triggered by human errors.

HSE UK has been aware of the causation relationship of human errors and maintenance failures since the Piper Alpha accident. One report prepared for HSE UK at 2004 shows that more than 60% of all incidents after 2001 are related to human errors in the maintenance process, among them 20% are caused by poor position / postures, and 38% were caused by poor practice (M J Burton, 2004). Within the same report the author had addressed: '*Human Factors, must, be recognized at the strategic level and they must be addressed throughout the implementation of that strategy. A failure to do so ignores the fact that incidents/ accidents resulting from maintenance are more likely to* *stem from a Human Factors – related root cause than an engineering one*' (M J Burton, 2004).

Separate studies have been conducted by HSE in order to reducing human errors in offshore maintenance disciplines, a summary of those publications are listed below:

Name of the publication
Human factors: Maintenance Errors (HSE UK Website Topics)
Human Factors Briefing Note no.6 (HSE UK)
Extract from inspectors human factors toolkit – Identifying human failures (HSE UK)
Common Topic 2: Maintenance Errors (HSE UK Website Topics)
Improving Maintenance – a guide to reducing human error (HSE UK Book)
Human factors guidance for selecting appropriate maintenance strategies for safety in the Offshore oil and gas industry (HSE UK Sponsored Study)

Table 3 HSE UK publications relevant to human errors in maintenance process

From those publications, HSE are intended to develop a systematic way to integrate controls and defence measures in the maintenance management process to reduce rather than eradicate human errors which is never possible(M J Burton, 2004).

Nevertheless unlike HSE UK, PSA Norway has not specifically linked human errors to maintenance performance and publishes specific guidelines or reports to address potential causal relationships thereafter. Instead, as one officer at PSA had explained to the author in email that: '*we continue to focus on maintenance in general, and in particular the properties of the maintenance systems and backlog of maintenance. Human errors - or rather the training and management – of the people working in the industry is a big issue that permeates both our regulation and our supervisory activity..... It is a set of requirements that has to be read and understood as a whole. Hence 'human* *issues' and their role in an SHE perspective is a part of the context in general. There are no specific parts of these covering ONLY human errors' .*

1.4. OBJECTIVE OF THE THESIS

In response to the high risks of human errors faced by maintenance disciplines, the thesis will focus on examining and mitigation of risks of human errors in the maintenance process, particularly human errors control mechanism in the Maintenance management regimes on NCS. At the end of the thesis, the author will be able to answer the following questions:

1) Human error patterns in the maintenance process in general.
2) Influencing factors of Human Errors in maintenance process
3) Good practice and potential improvement of the Norwegian Maintenance Management regimes with regarding to risks of human errors reduction and mitigation.

1.5. METHODOLOGY OF THE STUDY

1.5.1. THESIS STRUCTURE

The second chapter will firstly conduct a status quo of the North Sea Oil&Gas Industry, and then the maintenance management regime from legislation to frontline level at the NCS will be introduced to serve as the basis for further discussion of risks of human errors reduction and mitigation in the Maintenance process.

The third chapter will start with theoretic analysis of human errors, based on which, author will provide a complete human errors classification system, the system will be used thereafter as the framework to identify human errors influencing factors at Chapter 4.

The Fourth Chapter will firstly examine risks of human errors reduction and mitigation measures and efforts made by HSE UK and the Aviation industry in general, based on the results, author will try to present a complete spectrum of influencing factors of human errors.

The fifth chapter will reflect those influencing factors of human errors into the Norwegian maintenance management regimes, through this we will try to identify the good practises as well as potential improvements of maintenance management at NCS with focusing on control and mitigation of the risks of human errors.

The sixth chapter will discuss the research process of the thesis, including what the author had learnt and what can done further based on this study.

The Seventh chapter will offer conclusion of the study, recommendations will be presented and the limitations of the study will be explained.

1.5.2. RESEARCH WORK FLOW

Please refer to the diagram below for the work flow of the thesis.

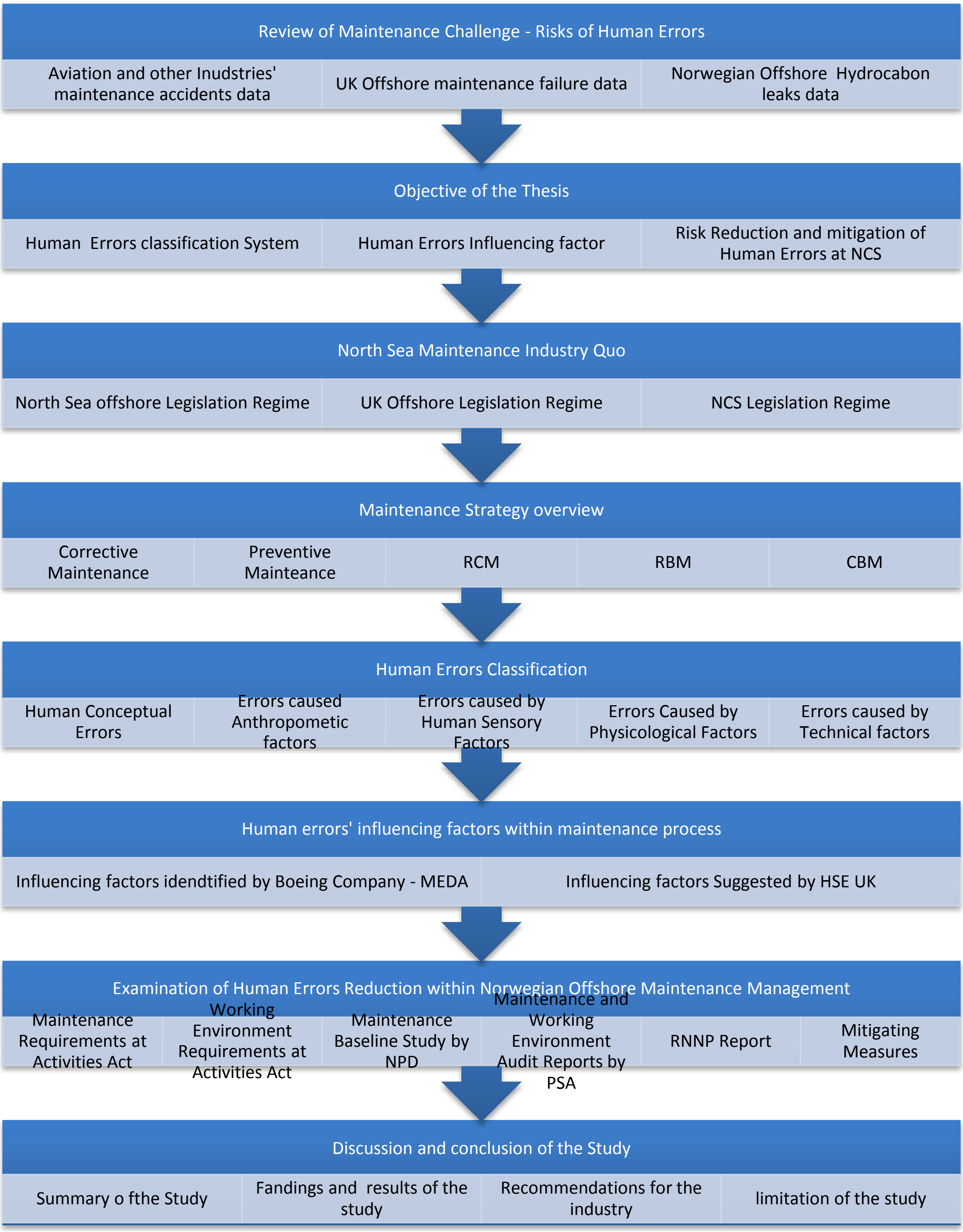


Table 4 Thesis research work flow

1.5.3. DATA RESOURCES

From the research work flow illustrated in Table 5, we can see that four kinds of data have been used by the thesis:

1) Data of human errors within maintenance process at the aviation industry
2) Data of human errors within maintenance process at UK Offshore
3) Data of HC leaks and causation factors at NCS
4) PSA Audit Report for Maintenance and Working Environment management

1.5.4. ETHICS, VALIDATION AND RELIABILITY OF THE DATA

From the research work flow we can see that all the data being cited by the study are derived from credited literatures, government regulations or credited public data base that are open to everyone to use.

Meanwhile the research process are based more on legislation requirements and industry practice review, it is not data critical but most qualitative and situate at industry overall level, therefore the conclusion and comments is validate and reliable to the industry in general in spite of limitations of the quantitative data being collected from different industries and geologic regions

CHAPTER 2. NORTH SEA ASSET MAINTENANCE MANAGEMENT STATUS

2.1. REVIEW OF MAINTENANCE MANAGEMENT STRATEGIES.

Industry maintenance has over the years gone through many different stages, from post industry revolution until todays date. Up until the 1940s machinery maintenance has remained as a practise of unplanned activities, replacing or fixing equipment whenever it broke down - the so called reactive (or corrective) maintenance strategy.

However, in the 1950s after the Second World War, industry resonance worldwide required higher productivity and stability of the system as well as the equipment components. This meant that the corrective maintenance strategy, no longer was effective enough to keep up the systems availability time. Moreover, rapidly increasing numbers of unpredicted equipment fixing and replacement costs, urged companies to bring maintenance under control. This should be done by planned activities to prevent total system failure and by this, reduce unexpected costs. Because of this way of thinking, a preventative maintenance, fixing it before it is broken approach, emerged and was adopted by the majority of the industry.

The third generation of maintenance strategy, which was driven by even higher requirements of system availability time, safety and cost efficiency, came to the stage in the 1970s. Technology developments enabled companies to plan maintenance activities, not only at a fuzzy time before system failure, but also at the best timing with good balance of productivity and costs for the system as a whole – the so called Predictive Maintenance. The diagram derived from Moubray’ s book RCM 2 has illustrated the above evolution process as below:

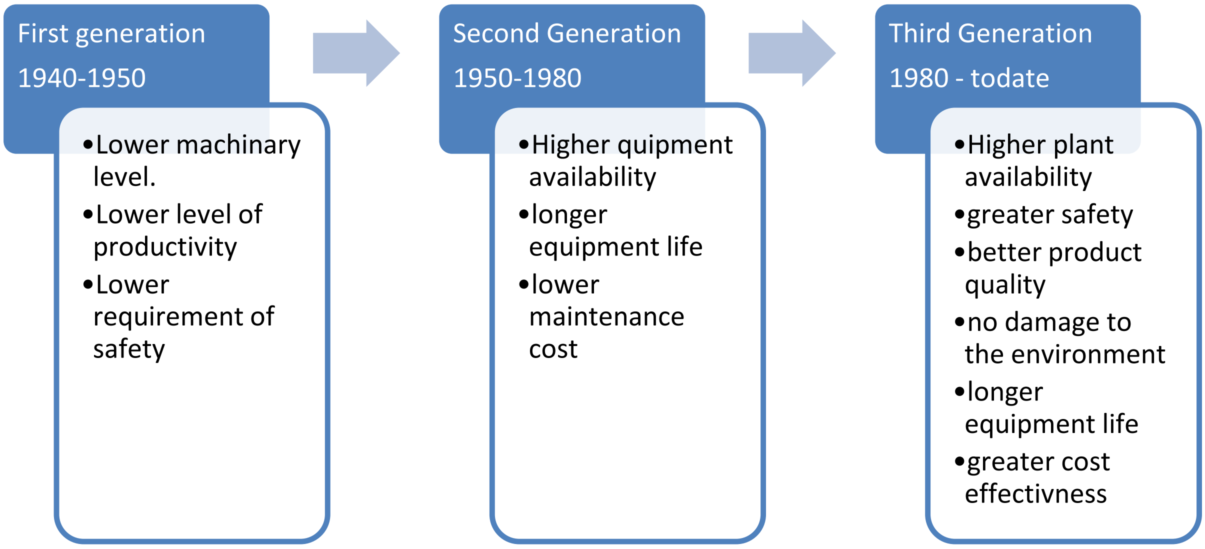


Figure 2 Maintenance Strategy Evolution History

2.1.1. PROACTIVE AND CORRECTIVE MAINTENANCE

Preventive Maintenance and Predictive Maintenance are in general a part of the category of Proactive Maintenance, which is separated from the passive means of corrective maintenance. The instinct difference between the two is the timing of maintenance activities - before or after the system or components' total failure:

- Proactive Maintenance in general is the maintenance activities planned and executed according to the comparative results between systems current performance and integrity level to its minimum acceptable standards (not total failure). Under this main principle, subcategories are preventive maintenance and predictive maintenance.

- Corrective Maintenance is simply repairing, changing or bypassing components whenever it has broken down.

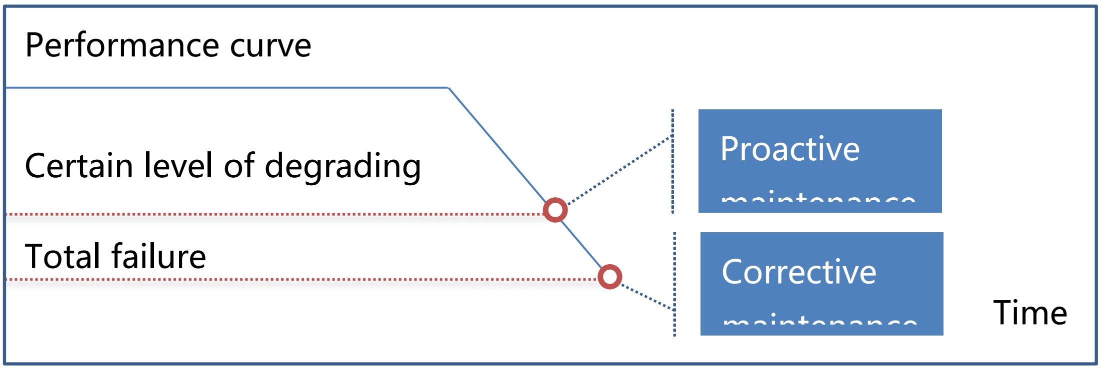


Figure 3 Timing of Proactive and Corrective Maintenance

The detail differences between the above mentioned maintenance strategies are list in the following table.

Maintenance Categories		Timing of Maintenance			Pros and Cons
		System condition	Fixed	Not fixed	
Proactive	Preventive Maintenance	Performance degrading or not	OEM Reco.		High costs
			Ind. Std.		High Reliability
			Co. REQ.		Low downtime
	Predictive Maintenance	Performance degrading		OEM Reco. Ind. Std. Condition Monitoring	Low Maintain costs
					Midrate Reliability
					Low downtime
Corrective	Repair	Mal-function or fail		At the time it fail	Low Maintain. cost
	Replace				Low Reliability
	Bypass				High downtime

Table 5 Comparison of different maintenance categories

2.1.2. RELIABILITY CENTRED MAINTENANCE(RCM)

The pros and cons of the different maintenance strategies are obvious for some simple machinery system, but for a complex industry, a simple strategy will not be enough to cover different challenges as a whole. Instead an integrated framework enable companies to resolve different maintenance challenges with differentiated methodologies is in need. Reliability Centred Maintenance (RCM) is such a process to establish the safe minimum levels of maintenance, a process used to determine the maintenance requirements of any physical asset in its operating context(Moubray, 1997). As defined by the technical standard SAE JA1011, through a qualify RCM, minimal 7 questions listed below should be answered properly:

1) What is the item supposed to do and its associated performance standards?
2) In what ways can it fail to provide the required functions?
3) What are the events that cause each failure?
4) What happens when each failure occurs?
5) In what way does each failure matter?
6) What systematic task can be performed proactively to prevent, or to diminish to a satisfactory degree, the consequences of the failure?
7) What must be done if a suitable preventive task cannot be found?

Basically there are three steps of companies' RCM process to answer the above questions:

Step 1. Identifying all functional groups and their performance standards. RCM focus on maintaining performance standards of certain functional groups instead of single piece of equipment. Therefore functional groups classification at a proper level will at the very beginning reduce complexity and resource consumption of the RCM process.

Step 2. Based on the functional groups classification, the second step focus on Failure Mode identification, including FMECA, RCFA, Deterioration Mechanism, Failure Consequences Analysis etc., through this step, maintenance team should obtain failure mode is of what criticality.

Step3. Based on the failure mode analysis, the third step is the so called RCM Logic process, whereas failure modes have been systematically prioritized depending on their criticalities to Safety, overall and/ or partial Functionality and Cost impact. With different prioritization and the nature of the failure modes themselves, different categories of maintenance activities are assigned to particular failure modes as a package.

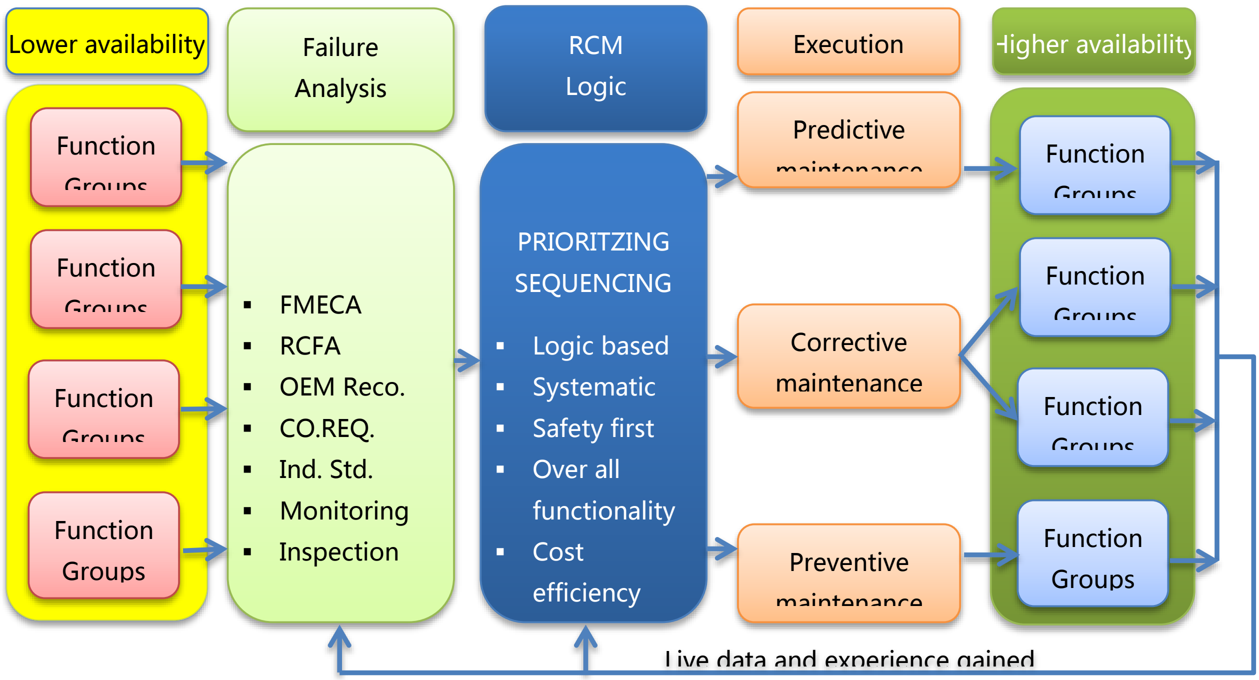


Figure 4 Reliability Cantered Maintenance (RCM)

2.1.3. STREAMLINED RCM

Traditional RCM has been applied within Space and Airline industry and expanded to different industries since 1970s, the major criticism directed against traditional RCM is that it requires systematic mapping of all functional units and maintenance tasks, for complex industries, this is of course a time consuming and resources hungry process. Typically for Oil&Gas industry, 80% of the equipment has either generic, or standardized maintenance program which only need a consistent and simple RCM analysis. Only 20% highly complex functional units need full RCM approach.(Pangawijaya, 2011). To answer this challenge, the maintenance strategy should on one hand, treat the 80% generic and standardised equipment with simple and effective solutions, meanwhile on the other hand, deal the 20% high complicated and critical system with thoroughly RCM analysis – the Streamlined RCM. Comparing to traditional RCM, the major difference of a typical Streamlined RCM is that it start with analysing exist maintenance programs, rather than functional groups defining. Through analysing exist maintenance programs, failure data and history, all failure modes which are not critical enough for further analysing are quickly eliminated, for those failure modes left on the list, a light version RCM analysis will be conducted thereafter to decide their proper maintenance activities depending on their criticality for Safety, Productivities and Costs. The topology below shows a typical Streamlined RCM for USA Aviation industry is attached below:

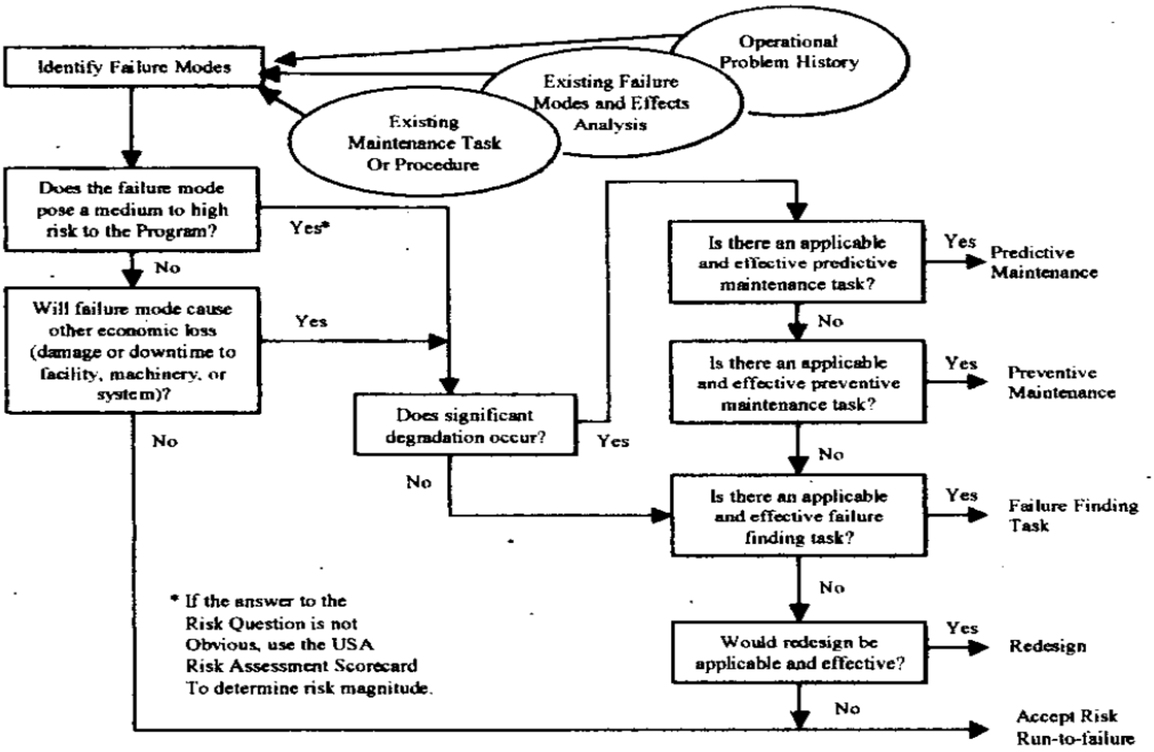


Figure 5 Topology of Streamlined RCM (Hauge and Johnston, 2001)

2.1.4. RISK BASED MAINTENANCE AND CONDITION BASED MAINTENANCE

Risk Based Maintenance

Later after the Streamline RCM, Risk Based Maintenance (RBM) has further reduced the resources required by RCM process, The process will start with risk evaluation based on historical data of a certain equipment, risks will be ranked to different level, depended on which a certain maintenance strategy will be assigned, for instance, if the risk ranking is high enough, a condition monitoring and inspection based maintenance program will be designed for this equipment in order to mitigate the risks. Major steps of RBM are illustrated below:

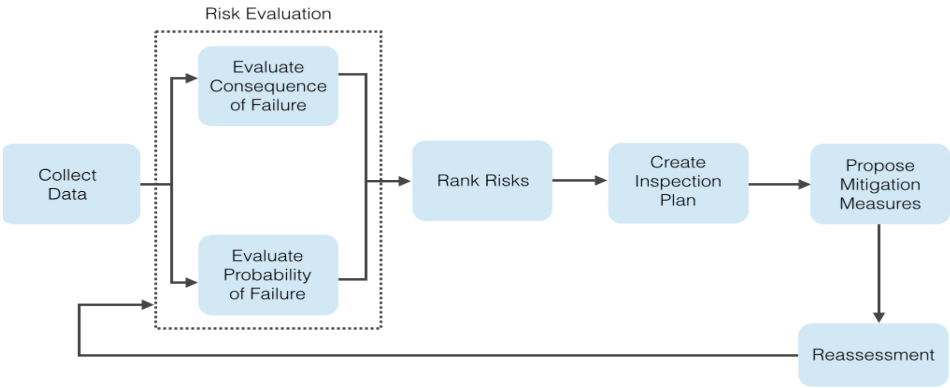


Figure 6 Risk Based Maintenance (Maintenance Assistant Incorporated 2014)

Condition based Maintenance (CBM)

CBM is a 'just in time' maintenance strategy that depends on the results of condition monitoring of the equipment - only maintain it when the data shows that the equipment will fail or the performance is going to reduce to certain acceptable level. Three steps of the CBM are listed below(Maintenance Assistant Incorporated 2014):

1) Condition monitoring of the equipment

2) Data analysis and problem diagnoses based on the results of the condition monitoring

3) Maintenance planning - performing the corrective action based on the results of data analysis and diagnoses

Advanced technology today enables great number of sensitive and accurate instruments being used to collect various data from the equipment on a real-time basis. Moreover artificial intelligence and expertise system allow the data being processed with auto-generated recommendations and alerts – the so-called Intelligent Watchdog Technologies, which has more than ever, facilitate maintainers to decide when and how to maintain the equipment with best-cost efficiencies.

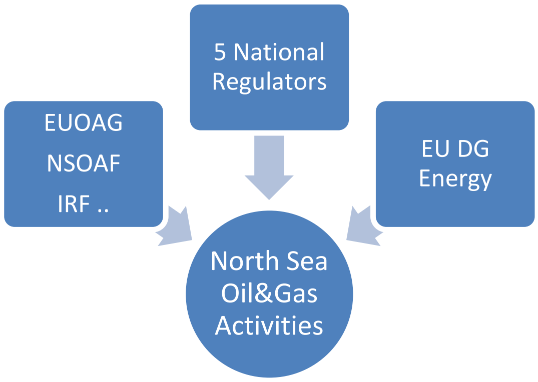
Nevertheless, even the maintenance cost might drop largely, the upfront costs for the CBM are quite high due to large investment for infrastructures building up. Therefore for Oil&Gas industry, CBM are mainly focus on vibration monitoring of critical rotation equipment besides various other parameters. Moreover CBM are best for newly- built facilities whereas it can be easily fit into the system, this is usually not that easy for old and aging facilities

2.2. MAINTENANCE MANAGEMENT REGIMES OF NORTH SEA

Since maintenance management is critical for safety, almost all regulators have addressed maintenance management, particularly maintenance management for safety critical equipment, as part of Safety Management as a whole. Therefore, to examine maintenance management regimes has to begin with reviewing different safety management regimes.

2.2.1. SAFETY MANAGEMENT REGIMES AT NORTH SEA OIL&GAS SECTOR

North Sea has approximately 575,000 km^2 in acreage. On the coast there are six states namely Norway, Denmark, Netherlands, United Kingdom, Germany, Belgium, among which only Belgium are not into Oil&Gas E&P activities. Therefore five national legislation regimes together with EU have to be taken into consideration for legislation compliance purpose. North Sea legislation structure are showing in the topology below:



5 Nations	Norway, Denmark, Netherlands, United Kingdom, Germany
EU DG Energy	EU Commission Director General Energy
EUOAG	EU Offshore Authorities Group
NSOAF	North Sea Offshore Safety Authorities Forum
IRF	International regulators Forum

Figure 7 North Sea Legislation Structure

2.2.2. EU COMMISSION, DG ENERGY AND EUROAG.

Director General Energy (DG Energy) – Directorate B3: Retail Markets; Coal&Oil, is the major regulatory body in EU Commission whose focus is offshore safety management from EU level. Three kind of legislation are issued by EU Commission in General:

- Regulations applied to all EU member states with same force as national laws.
- Directive need to be transferred into national law by each states' own means
- Decisions only relevant to particular issues.

For instance, after the tragic accident of Deep Water Horizon, EU DG Energy B3 had enforced EU Directive 2013/30/EU besides the former EU OSH Framework Directive and EU Drilling Safety Directive (92/91/EEC) to prevent occurrences of offshore major accidents. Meanwhile a decision has been issued by EU Commission to set up the EU Offshore Authorities Group (EUROAG) as an expert and advisory organization, EUROAG as the EU/EEA regulators' forum is chaired and coordinated by DG Energy, its main functions are listed below:

- Advise EU Commission regarding to offshore safety issues.
- Identifies and exchanges best practises among industries and authorities
- Promote rapid data and information exchanging and transparency.
- Facilitate and promote developing and applying high safety standards legislation in North Sea offshore oil and gas industry.

2.2.3. NORTH SEA OFFSHORE SAFETY AUTHORITIES FORUM

North Sea Offshore Safety Authorities Forum (NSOAF) as the North Sea inter-governmental organization is the most important partner of EUOAG to coordinate pragmatically with North Sea member States and their regulatory authorities. The member states and their relevant authorities are listed below:

States	Regulatory Authorities	States	Regulatory Authorities
Denmark	Denmark Energy Authorities	Norway	Norwegian Petroleum Safety Authority
Faroe Islands	Jarðfeingi	Sweden	Swedish Geological Survey
Netherlands	Staatstoezicht up the Mijnen	Germany	Landesbergamt Für Bergbau, Geologie und Energie, Clausthal-Zellerfeld
Ireland	The Commission for Energy Regulation	UK	Health & Safety Executive

Table 6 Member States of NSOAF

NOSAF are operated through different working groups with presidencies by different countries elected by the member states each year:

1) The Working Group on Health, Safety and Environment chaired by Netherlands

Main functions of this group is contributing to a continuous improvement in health, safety and environment protection. Meanwhile this group has been facilitated knowledge and experience transferring among the member states and harmonisation process of regulatory requirements/ reduction in administrative burdens. This group has also acted as the organizer for meetings between NSOAF and E&P industry associations. Five subordinate working focus on coordinated by different countries as below:

Working focus	Coordinating Countries
Worksite supervision	Netherlands
Asset integrity of fixed and mobile facilities	UK
Aging workforce	Denmark
Lifting operations and equipment	Norway
Leading and lagging key performance indicators	Netherlands

Table 7 Working Focus Distribution of NOSAF

2) The safety training working group chaired by Denmark

Major efforts of this group is to achieve mutual acceptance for the basic safety and emergency preparedness training across countries.

3) The working group on drilling and well control chaired by Norway

Fundamental functions for this group is to encourage continuously improvement for safety, environment protection in all Well operations. Meanwhile, it is also this group to facilitate the mutual understanding and acceptance for Well operation requirements and standards(PSA Norway, 2013).

4) Working Group on the European Union (EU Working Group) chaired by Norway

EU Working Group is to 'exchange views and experiences concerning EU directives and directive proposals' (Danish Enrgy, 2014)

2.2.4. INTERNATIONAL REGULATORS FORUM(IRF)

IRF is a group of eleven regulators of health and safety in the offshore upstream oil and gas industry. It exists to drive forward improvements in health and safety in the sector through collaboration in joint programmes, and through sharing information' (International Regulators' Forum, 2010). The 11 member states are:

1) *Australia National Offshore Petroleum Safety and Environmental Management Authority*
2) *Brazil National Agency of Oil, Gas and Biofuels (ANP)*
3) *Canada Canada-Newfoundland and Labrador Offshore Petroleum Board; Canada-Nova Scotia Offshore Petroleum Board; and the National Energy Board*
4) *Denmark Danish Energy Agency (DEA)*
5) *Mexico National Hydrocarbons Commission (CNH)*
6) *Netherlands State Supervision of Mines*
7) *New Zealand Department of Labour*
8) *Norway The Petroleum Safety Authority*
9) *United Kingdom Health and Safety Executive*
10) *United States Bureau of Safety and Environmental Enforcement*

As showing above, 4 member states of IRF as UK, Norway, Denmark, and Netherlands are also member states of NSOAF, Naturally IRF has great influence on legislation environment on North Sea.

2.3. MAINTENANCE MANAGEMENT REGIMES OF UK.

After the tragedy accident of Piper Alpha at July 1988, fundamental changes took place and formed nowadays offshore safety legislation regimes at UKCS. Major changes at that time are listed below(Steve Walker, 2013):

1) Separating licensing authorities and safety management authorities, safety supervision responsibility since then has been shifted to HSE.
2) Set up Safety Case as the major supervision regime to manage offshore safety from legislation level.
3) Shifting from prescriptive requirements to performance based requirements (Goal Setting).

2.3.1. UK OFFSHORE HEALTH AND SAFETY LEGISLATION STRUCTURE IN GENERAL

As coordinating country for the subsidiary group of Asset Integrity Of Fixed And Mobile Facilities of the Working Group on Health, Safety and Environment at NSOAF, UK has set up an example for Maintenance Management among the member states. Again before review the maintenance management status, let us first let us firstly review the HSE legislation framework at the UKCS:

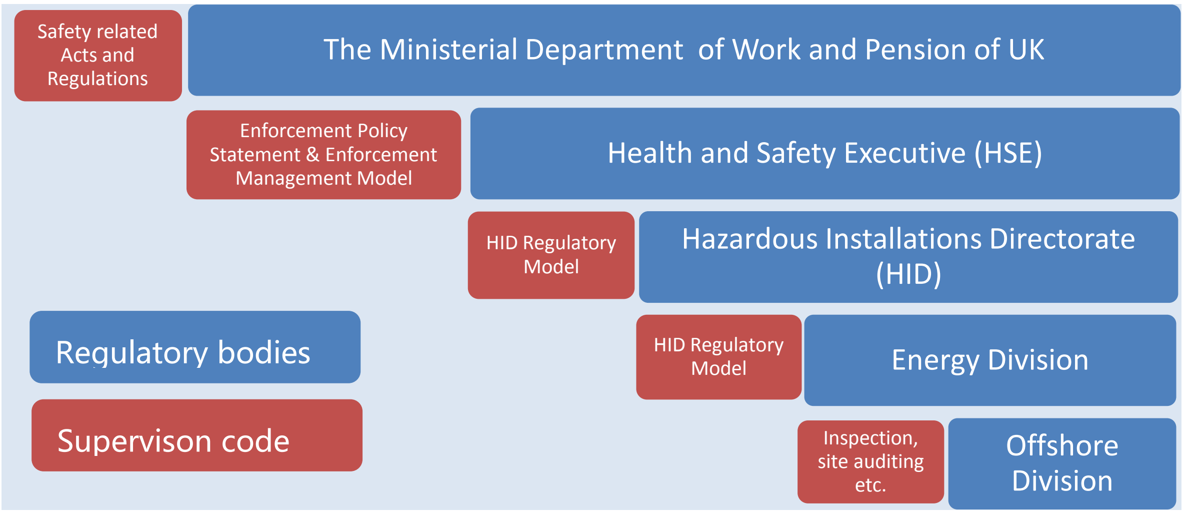


Figure 8 UK Offshore Safety Management

Safety Acts and regulations related to maintenance management:

1) Health and Safety at Work etc. Act 1974
2) Offshore Safety Act 1992(2)
3) The Offshore Installations (Safety Case) Regulations 2005

Safety Case regime demonstrate all the mandatory safety requirements at operation and management level to offshore industry based on relevant safety and health requirements from different UK national Acts and Regulations. Therefore it is the most important regulations on the top level to ensure offshore industries' safety. UK offshore safety regulations structure are illustrated below:

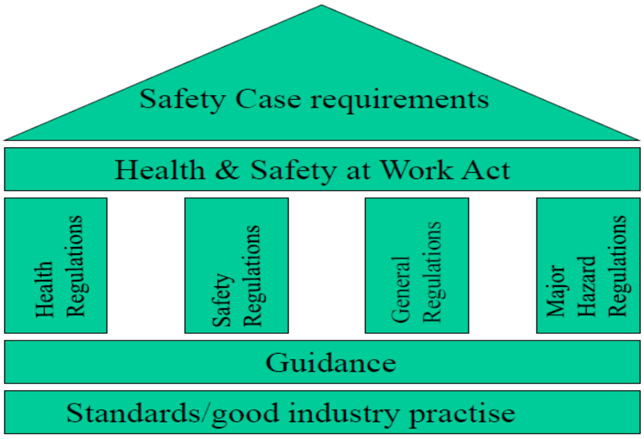


Figure 9 Safety Case Regime(Steve Walker, 2013)

2.3.2. LEGISLATION REQUIREMENTS REGARDING TO OFFSHORE MAINTENANCE

Under a goal setting legislation environment at UK, there is no prescriptive requirement for the industry to follow regarding to maintenance management. However as being addressed on HSE website, *the maintenance of asset integrity and control of the significant risk to asset integrity presented by ageing processes is a key priority for HSE*`. Offshore Division under HSE have launched 2 key programs related to offshore maintenance since 2004, they are Key Program 3 (KP3) and Key Program 4(KP4):

KP3 was initiated at 2004 and involved almost 100 inspections during 3 years, main objective for this program was to ensure that offshore duty holders adequately maintained safety critical elements (SCEs) of their installations.

KP4 was initiated at 2010 to date, with the objective to *determine the extent to which asset integrity risks associated with ageing and life extension are being managed effectively by duty holders.* The program launched both onshore and offshore inspections in more than 30 companies' assets

Both of the two programs had set up regulator's expectations, and promoted good practises from the industry with regarding to maintenance management.

2.4. MAINTENANCE MANAGEMENT REGIMES OF NORWAY.

2.4.1. REGULATION STRUCTURE OF NCS

The Petroleum Safety Authority (PSA) is the *government regulator with responsibility for safety, emergency preparedness and the working environment in the Norwegian petroleum industry.'* PSA is subordinated to the Ministry of Labour and Social Affairs of Norway. Safety related legislative work for the Oil&Gas industry is one of the most important responsibilities for PSA, again under a goal setting legislation regime, no particular Norwegian Regulations and Acts have only focused on maintenance issues, but rather than mention it in different occasions when it is critical to safety. The framework of safety related regulation is illustrated as below:

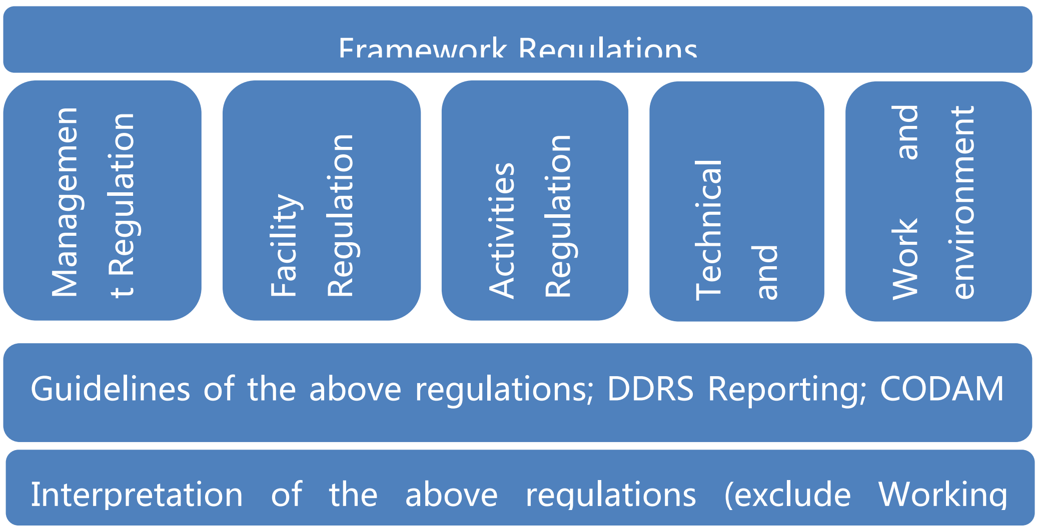


Figure 10 Norwegian Petroleum Safety Regulations

2.4.2. THE MAINTENANCE BASELINE STUDY ON NCS

Similar to UK, without national regulations only for maintenance, the Norwegian Regulator (Norwegian Petroleum Director at the time) had launched a examine project at year 1996 to demonstrate regulator' s expectations and requirements in detail to the industry – Maintenance Baseline Study. Since then The Maintenance Baseline Study has served as a systematic self- assessment method, as well as a tool for continuous improvement for the companies' maintenance system. The base line study based on the Maintenance Management Model below:

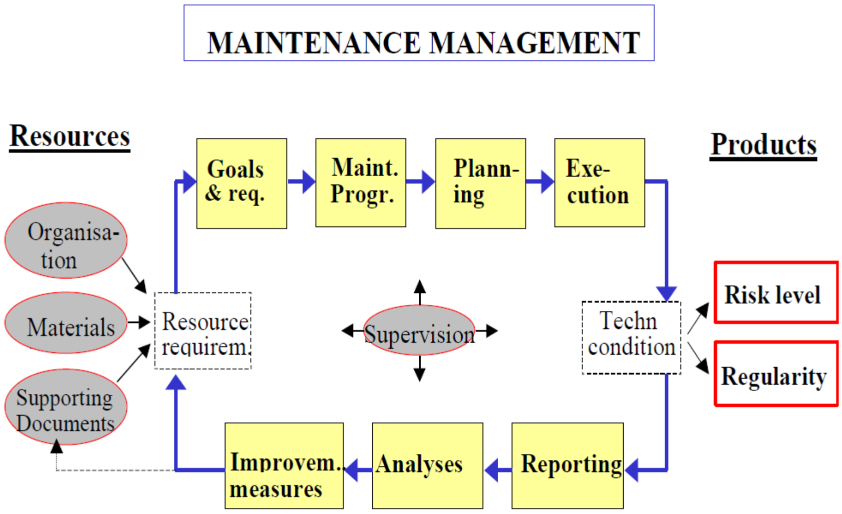


Figure 11 Maintenance Management Model

Each consecutive subject in the yellow square at the above diagram has been assigned a chapter with important questions and concerns raised based NPD' s requirements and the current challenges faced by the industry. Those aspects reflected by the questions and concerns, together with the management framework itself found the basis for the Maintenance Management of the Norwegian Petroleum sector.

2.4.3. COMPANY MAINTENANCE ORGANIZATION AT NCS

A typical MODU maintenance organization at NCS including Offshore Maintenance Team and Onshore Support Team.

Offshore Maintenance Team is headed by Technical Section Leader and Assistant Technical Section Leader (work at night shift), below there are technicians and engineers from function units as Subsea, Electronic, Motor Room, Hydraulic and Mechanics, Warehouse.

Onshore line management of the rig are responsible for maintenance management of the rig, besides supporting units as Technical Supporting Team and Maintenance Supporting team are responsible for providing technical supporting, system and program building, maintenance data and documentations maintain etc. Typical Maintenance Reporting line is illustrated below:

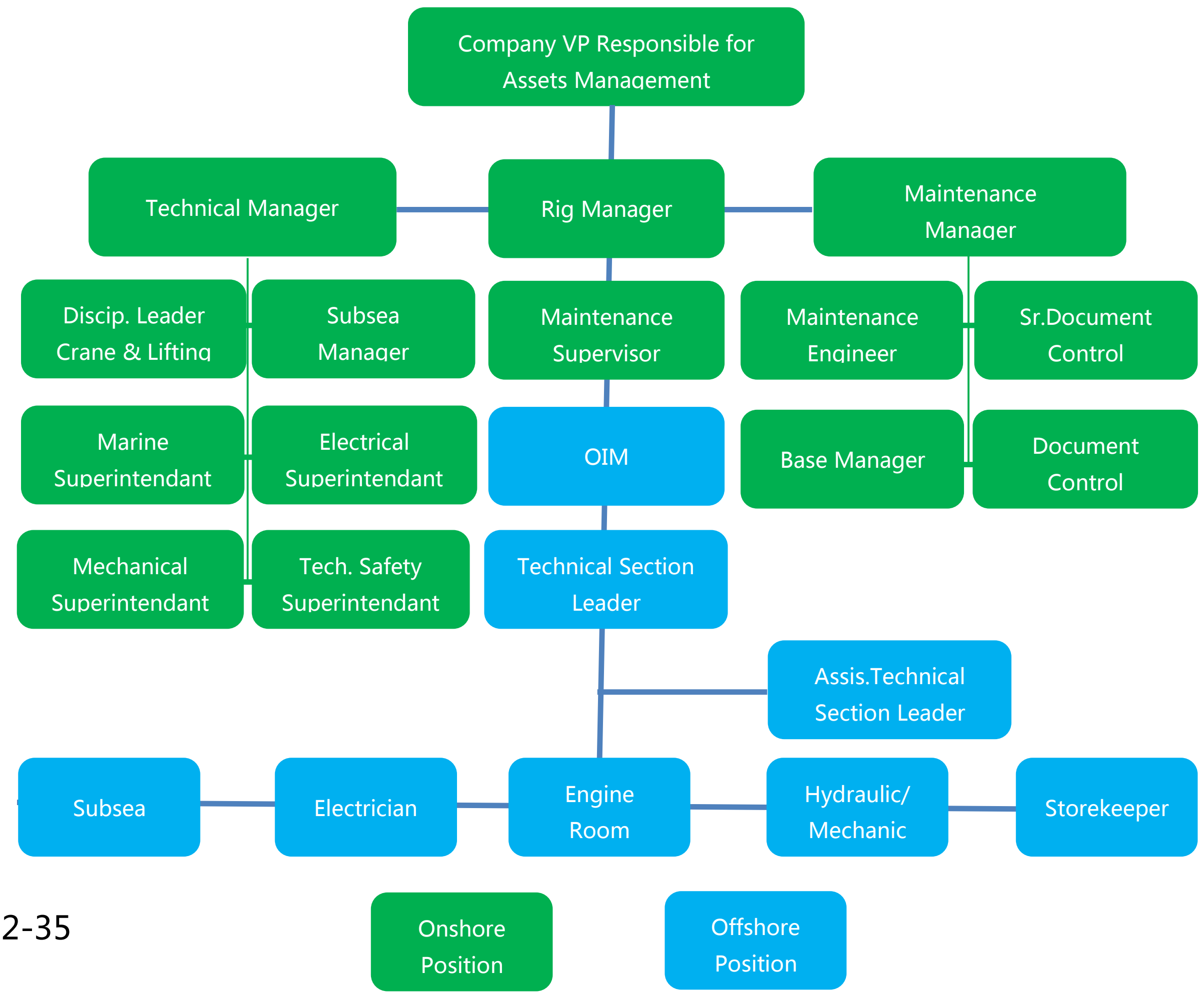


Figure 12 MODU Maintenance Organization

CHAPTER 3. HUMAN ERRORS WITHIN MAINTENANCE PROCESS

From the discussion in Chapter 2, it is obvious to see that all major players at North Sea Offshore Oil & Gas Industry as UK and Norway have been aware that Maintenance errors were the critical causal factors for many incidents and accidents. Moreover human errors as the major causal factors for maintenance errors, are consecutively the major threatens for offshore health, safety and environment. Therefore to control the risks of human errors within maintenance process can be beneficial not only for maintenance itself, but also for health, safety and environment as a whole.

To err is human, this well-known proverb has been used as excuses for many human errors for a long time, it is in recent centuries, high risk associate industries has started to notice that they have paid more and more for that excuse - That part of human nature, along with considerable amplification of increasingly more sophisticated and powerful technical system has gradually become the common cause behind catastrophic accidents, resulting in loss of human life, as well as damage to the environment and properties.

According to Reason’ s analysis of 122 maintenance lapses occurring within a major airline over a three year period, in which maintenance errors are classified to the following categories:

1) Omissions (56%)
2) Incorrect installations (30%)
3) Wrong parts (8%)
4) Other (6%)

To understand the nature behind those human errors is the first step to effectively control them.

3.1. HUMAN CONCEPTUAL ERRORS

Among different classification theories, the most well-known one is Jams Reason’ s classification to define human errors into four categories as skill based errors, rule based errors, knowledge based errors and violations (Reason, 1990):

1) Skill based mistakes - Slips and Lapses

Basic skills that founding the basis of human behaviour, are subconsciously and automatically proceed which has no obvious decision making process, such as walk and talk. Besides, pure manual and physical tasks transferred into automatic and subconscious reaction through numerous repeating in similar conditions are also counted as automatic human behaviour. Errors generated by this kind of behaviours are mainly slips and lapses of intended actions, which happened to everyone on a daily basis.

2) Rule–Based mistakes

Rule - Based behaviours are proceeded only according to comparative judgements of current situations against pre-set rules and conditions, alternatives of decisions are multiple but all under expectations. People making false judgement then applying impropriate rules are the most common error types in every industry.

3) Knowledge – Based mistakes

Knowledge based behaviours need comparative judgements as well, but unlike rule-based behaviour, current situations are unexpected, pre-set rules are not applied in such conditions, rational judgement therefore can only be made according to people’ s knowledge of the past and real time analysis and calculation of the risk pictures of future. Again false judgements are common due to limitation of knowledge base, inaccurate risk perception of the future etc.

4) Violations

Deliberate individual or collective breaking of pre-set rules and regulations usually have different reasons, among which probably the most important one is that the rules and regulations are malfunctioned, in this case, violations can be prevented from organizational and managerial perspective. However violations as randomly or planned sabotages are difficult to discuss here because it involves broadened context with contradictive social valuation and personal believes, which is not usually belong to engineering, organizational and managerial thinking context within civil industry. Therefore in this thesis, deliberate sabotages will not be discussed as human errors.

Human conceptual errors are illustrated below:

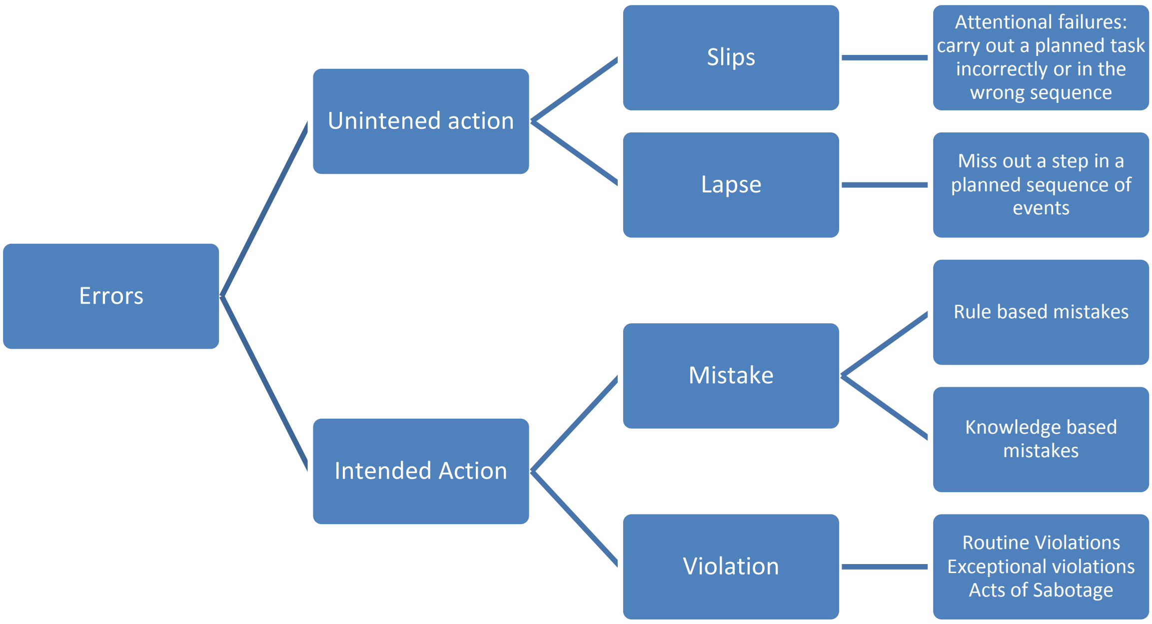


Figure 13 Human Error Classification(Reason, 1990)

3.2. HUMAN ERRORS TRIGGERED BY EXTERNAL FACTORS

Reason' s human errors classification is situated at conceptual level and under the assumption that all external factors are function correctly. For those human errors which triggered by external factors, a more comprehensive classification is needed.

Blanchard et al. had introduced such classification system at 1995 in their book **MAINTAINABILITY,** instead of directly classifying human errors into different categories, Blanchard alternatively classified human errors influencing factors into four categories as Anthropometric Factors, Human sensory factors, Physiological factors, Psychological factors. Among them Psychological factors is more or less equal to Reason’ s conceptual classification system thus will not be introduce here(Blanchard et al., 1995):

1) Anthropometric Factors:

Anthropometric factors represent the sizes, spaces, distances available for maintainers to finish the task. If all or part of those factors are not suitable for a normal size person. Errors might occur when maintainer try to finish their jobs with a poor position, awkward posture or compromise of maintenance quality. According to a report, awkward posture and poor positions in the maintenance process were the root causes for 20% of incidents after 2001 at UKCS(M J Burton, 2004).

Human errors in the maintenance process roots in anthropometric factors, in some cases, have nothing can be controlled within the operation phase, not only because sometimes it’ s impossible to make changes of the physical states of the facilities, and also because the nature of maintenance is not try to redesign but restore the original function states of the equipment, rather in the facility design phase, design – in features to improve the maintainability of the equipment based on ergonomic studies will effectively reduce human errors triggered by anthropometric factors, therefore it is important to take the maintainability of the facilities into account during design, construction, commission and modification process.

However, even in the operation phase, it is still good to understand and control the actual status of anthropometric factors through FMEA and FMECA studies during RCM or RBM analysis. For instance, what failure modes can be triggered due to lower maintainability of which equipment with what criticality? Based on such conclusions, measures such as minor scale modification of the equipment, specifically designed maintenance procedures can be engaged in order to reduce the human errors.

2) Human sensory factors:

Human sensory factors include issues which could affect human’s ability of information accessing and perception etc.

For instance, visibility and background noise level, as well as placards, signs, indicators, gauges and all Human - Machine interface in general will influence of human sensory abilities. Among them the most important issue which has been continuously emphasized by the offshore maintenance process is the background noise level. Generally People believe that noise up to certain level have negative impacts of human’s ability of concentration and accuracies, as one reports from Norwegian side had found out that noise level had positive correlation with HC leaks on NCS. Hypothesis for this positive correlation, as the author of the report had pointed out, could be(Vinnem et al., 2010):

1) Higher noise level wear out people easier, and cause people made more mistakes compare to lower noise level.
2) Higher noise level imply higher vibration and fiction inside the mechanic system, again this can be a signature for lower assets integrity with poor maintenance performance achieved by maintainers.

This is the reason that on NCS, noise level has been monitored and controlled continuously by PSA with high priority.

3) Physiological factors:

Physiological factors share some commons with human sensory factors, but refer more to environmental impacts on human capabilities, such as temperature, humidity, vibration etc. it also include stressing impacts of human thinking and behavior patterns which come from social, organization and work levels, for instance, pressures come from family matters or tensions between team members, mental tiredness due to work monotonous etc.

Similar to anthropometric factors, physiological factors has more to be controlled rather in the design and modification process instead of operation phase. Environmental factors such as temperature, ventilation, vibration etc. can be largely improved by relevant design – in features. Companies should design and modify their facilities in order to provide better physiological environment for human operations.

A typical example for this is the winterization of drilling facilities at extreme cold environment: Not only operation capacity of the equipment itself have been modified to adapted colder weather, but also human physical and psychology reaction to the extreme weather - from personal protection equipment (PPE) to rig wind wall - have been upgraded accordingly.

Figure 14 COSL Drilling Europe As Winterized Rig

The above three external influencing factors need to be taken into consideration besides human errors under Reason' s Conceptual Classification, because they were the root causes for many human errors, yet it is much simpler to work on those factors rather than human themselves in order to reduce the risks of human errors.

3.3. HUMAN ERRORS TRIGGERED BY TECHNICAL INFLUENCING FACTORS

Typical maintenance system including four interacting components that are operators, equipment, documentation and task. This four components interact continuously under technical and organizational environment (Latorella and Prabhu 2000), from which operators (human) is the one to line up all the other three to fulfil the functional requirements, therefore we can conclude that maintenance is in large extent a human activity but proceeded with the influencing from tremendous technical and organization factors. Therefore to improve maintenance performance by reducing human errors need to have clear understandings of the interaction between human errors and technology and organization factors.

3.3.1. FAITH FOR TECHNOLOGY ADVANCEMENT

To reduce human errors by technology advancement has been the focus for industries as always, and many do believe that as technology advanced, human errors has also been effectively reduced:

1) Better engineering design has in great extent improved the maintainability of the facilities to reduce external influencing factors. Development of Ergonomics and its prevalence has benefit maintainers with physically suitable work environment, much less noise and better Human-Machine interface. In a way that external influencing factors as anthropometric, physiology and human sensory errors are not as common as before.
2) Human-errors preventing design has reduced the possibilities for slips and lapses, for instance, if the installation sequence was wrong or omissions occurred, the left components would not be able to install at all, this has in some way improve maintenance performance by reduction of human errors as slips and lapses.
3) Artificial Intelligence development with advanced data collection and computing technology has given the birth to namely Expert System to help maintainers with decision making, errors diagnoses and risk assessment etc., which in some way benefit reduction of rule based and knowledge based human errors.

3.3.2. LIMITATIONS OF TECHNICAL SYSTEM

It’s reasonable to say that human errors are inevitable in any human behaviour categories. Nevertheless are technical system able to be mistake – free? The answer is no. Even though technical system has much lower possibility of malfunctioning comparing to human in the same time interval, the technical system is still artificial physical object and therefore subject to limitations as the following:

1) Physical deterioration: As physical subjects, technical components as well as the system as a whole are subjected to wearing, fatigue, aging and all the other kinds of physical deterioration process until failures occurs.
2) Reflection of human intellectual shortages: Technical systems mainly operated by Artificial Intelligent (AI) Systems and Experience Based Logic which designed based on human knowledge and experience in the past are in any case insufficient to predict and react to all scenarios occurred in the future properly.
3) Either over or lack of human involvement in the technical system can be problematic, in each end of the situation, System venerability will be high:

   Line-up defects to break through the Swiss Chess Model: No matter how well designed the independent barriers are to control risks from pure technical perspective, human controls at the sharp end of each barrier and the entire system are capable to cause failures of different barriers simultaneously. Typically this is how some technical systems with most advanced safety barriers can fail **Highly Automated Systems is not the answer**: Besides inherited deficiencies from the design faces, highly automated systems has typically the following defects with regarding to control mechanism that could increase systems vulnerabilities. As Reason described in his book at 1997: highly automated system only offered a ‘keyhole view of a limitless virtual space’ (Reason, 1997), then it is difficult to understand and interfere when something goes wrong ; System demanding memories more than rational analysis and judgement from operator side, as time goes by, operators are tend to remember how to push the bottoms more than understand the actual process and logic lay behind. This degrading of capability increases operators` difficulties to react to the abnormal situations properly.

3.4. HUMAN ERRORS TRIGGERED BY ORGANIZATIONAL FACTORS

From the discussion above, it is reasonable to say that neither human nor technical system is perfect and mistakes – free, therefore organisational and managerial factors as the third aspect would play an important role to either exacerbate or restrain risks of human errors and technical failures – whereas either human and technical system are running complementarily to cover each other' s shortages in a way that system resilience is gained, or in other extreme, human and technical system are running contradictorily with significantly increased system vulnerability.

The way human contributed is the most crucial factors when build an industry organization. Referring to previous classification of human behaviour in general, there are two categories: human contribution following prescriptive rules and procedures; Knowledge and experience based human contribution to achieve Performance Based Requirements.

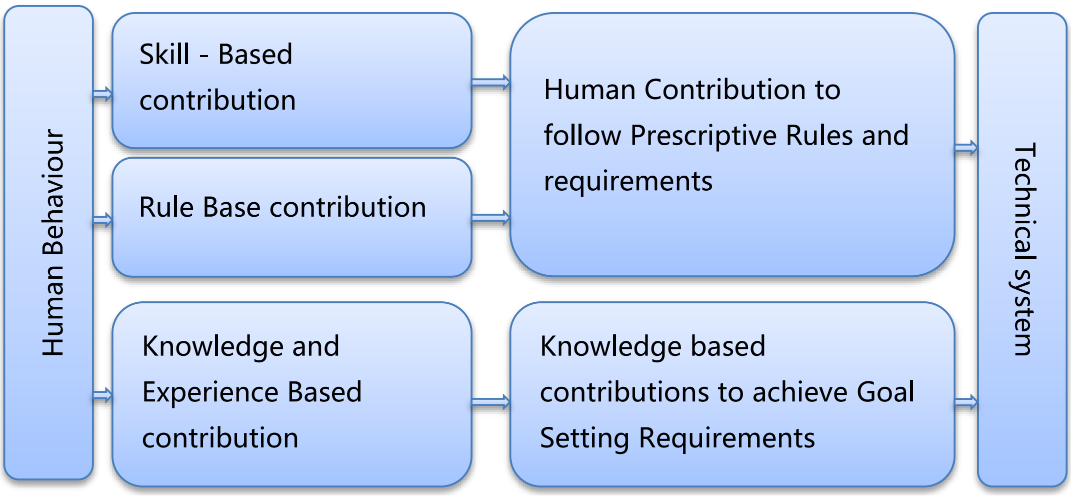


Figure 15 Human' s contribution to the system

Managerial and control structures are vary depending on the nature of the business and the type of human contribution in the process. Mainly there are two types of managerial and control structures in industry organization(Reason, 1997):

1) For business mainly regulated by prescriptive requirements meanwhile with relatively less changes and unexpected situations, for instance manufactures for mature products, the managerial and control structure is illustrated below:

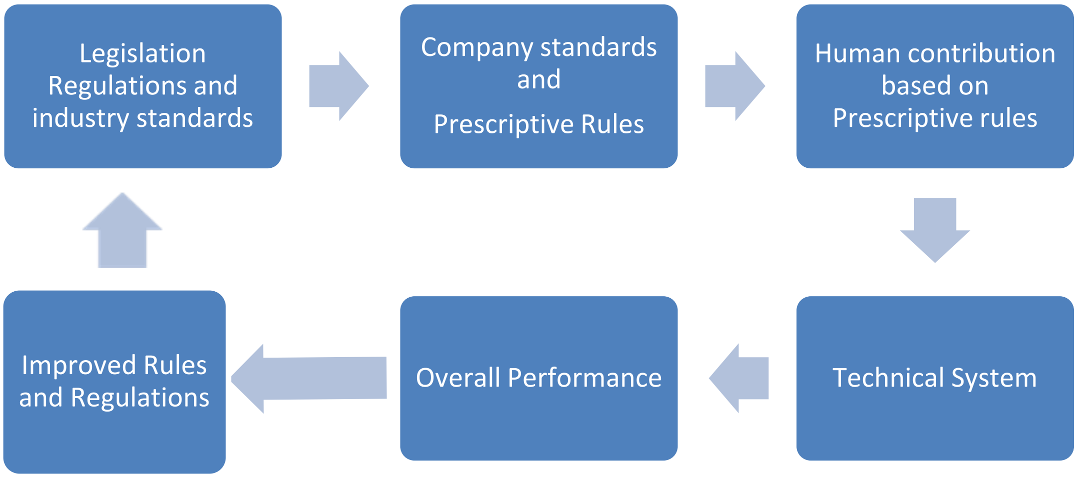


Figure 16 Managerial Structure – Prescriptive requirements oriented

2) For business without mature technology in an unstable or unfamiliar environment, for instance, explorative operations, scientific research project etc. goals and objectives, performance requirements might be exist but without prescriptive operation procedures, actual operations are mainly depending on operators' experience and knowledge also estimations of future situations. The managerial structure are illustrated below:

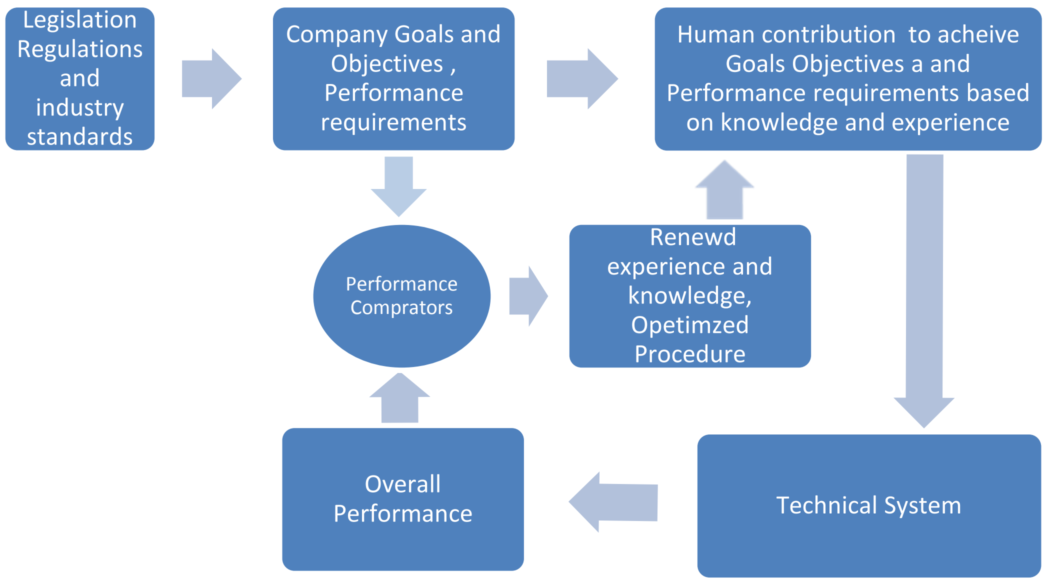


Figure 17 Managerial and Control Structure –Performance requirements

Apparently for most of the complex industries, both goal setting and prescriptive requirement and its corresponding organisation structures are exist. Clear and effective prescriptive requirements are essential to reduce human errors as slips and lapses, as well as some rule based errors. Meanwhile clear defined and practical goal setting requirements on the other hand grant the operators not only clear direction but also flexibilities to make decisions based on their own experience and knowledge.

Nevertheless both the two kinds of requirements have the possibilities to trigger human errors, for instance, strict prescriptive requirements will limit human's ability to alter actions in order to deal with unexpected scenarios with the best judgement, sometimes this cause fatal mistakes, one of the saddest case is that most of the crew who had followed the rule to assemble at the safe points on Piper Alpha were dead, however some of those who used their own judgment are survived. This dilemma has caused particular challenges for the Oil & Gas industry nowadays, whereas on one hand strict regulatory requirements and usually disastrous consequences of accidents have urged companies to apply more and more prescriptive regulations as detail as possible in the hope to enhance risks controls of human errors and technical failure. On the other hand, organisations luck of prescriptive requirements of the day to day operations are always seems both risky and ineffective. Typically goal setting requirements such as ALARP show in large extent of weakness to control individual or even collective violations due to Risk Management´s nature of incapable to dichotomize daily or unexpected situation to a 'yes or no' decisions on real time basis, thus many find that, particularly for frontline workers, goal setting requirements affect little in the decision making process, workers need consolidate rules and standards to make decisions more than a serials of independent risk calculation and assessment to reach the goals.

From the above discussion, one can easily understand that perfect organization and management schemes which could completely eliminate human errors are not exist, similar to technical advancement, organization always face challenges to control the risks of human errors within the maintenance process. Therefore it is important to take organizational and managerial influencing factors into consideration when develop methodologies to reduce human errors. It is proper to refer to HSE UK's Elements of Health and Safety Management Model to identify the major organizational and managerial influencing factors of the human errors as the following(Books HSE, 2000):

1) Policy and organising
2) Planning and implementing
3) Measuring performance audit and review

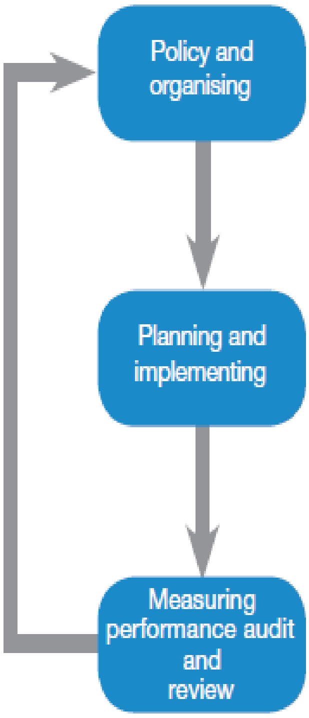


Figure 18 Elements of Health and Safety Management HSE. UK

CHAPTER 4. HUMAN ERRORS INFLUENCING FACTORS AND REDUCTION EFFORTS

From the previous discussion, we know that to develop human errors reduction methodologies within the maintenance process has to take all the following categories of influencing factors into consideration:

1) Anthropometric factors
2) Human sensory factors
3) Physiological factors
4) Technical factors
5) Organizational and Managerial factors

We will firstly review the human errors reduction methodologies within Aviation industry, then conduct the same review within UKCS Oil&Gas industries. After the review completed, a cross comparing between Aviation industry and UKCS Oil&Gas industry will be conducted, based on which the completed spectrum of human errors influencing factors within the maintenance process will be proposed and used as reference to examine human errors reduction process at Oil&Gas industry on NCS.

4.1.1. HUMAN ERRORS REDUCTION IN AVIATION INDUSTRY

Due to the high possibilities of maintenance errors triggered by human errors meanwhile catastrophic consequences of those errors, Aviation industry is the forerunner and founder of maintenance management systems as well as human errors reduction methodologies among different industries. One can always find developing leads of different maintenance management methodologies pioneered by aviation industry.

For instance the developing process of RCM, Streamlined RCM and RBM etc. are all started at aviation industry and applied by other thereafter, meanwhile Aviation industry has the most mature systems to collect, analysis data of human errors, as well as the most comprehensive theoretical researching and authentic applications of human errors reduction methodologies. Therefore aviation maintenance standards and practises are always to be recognized as the frontier among other industries. To look into human errors reduction mechanism within it should be essential prior to examination of the same concerns of the Offshore Oil&Gas industry. In the aviation industry, Human errors reporting systems are the foundations to develop errors management strategy, whereas human errors generating mechanism and contributory factors, as well as relevant control measures etc. are identified. One dominate errors reporting system applied in Aviation industry is the Maintenance Errors Decision Aid (MEDA) developed mainly by Boeing (Latorella and Prabhu, 2000). MEDA is a retroactive measured whereas errors reporting are conducted based on accidents, incidents investigation and /or failure data available, human errors are identified by comparison of pre-set performance standards and actual human behavior being identified in the investigation or data analysis process. Investigation process of MEDA is illustrated in the figure as below(Rankin, 2000):

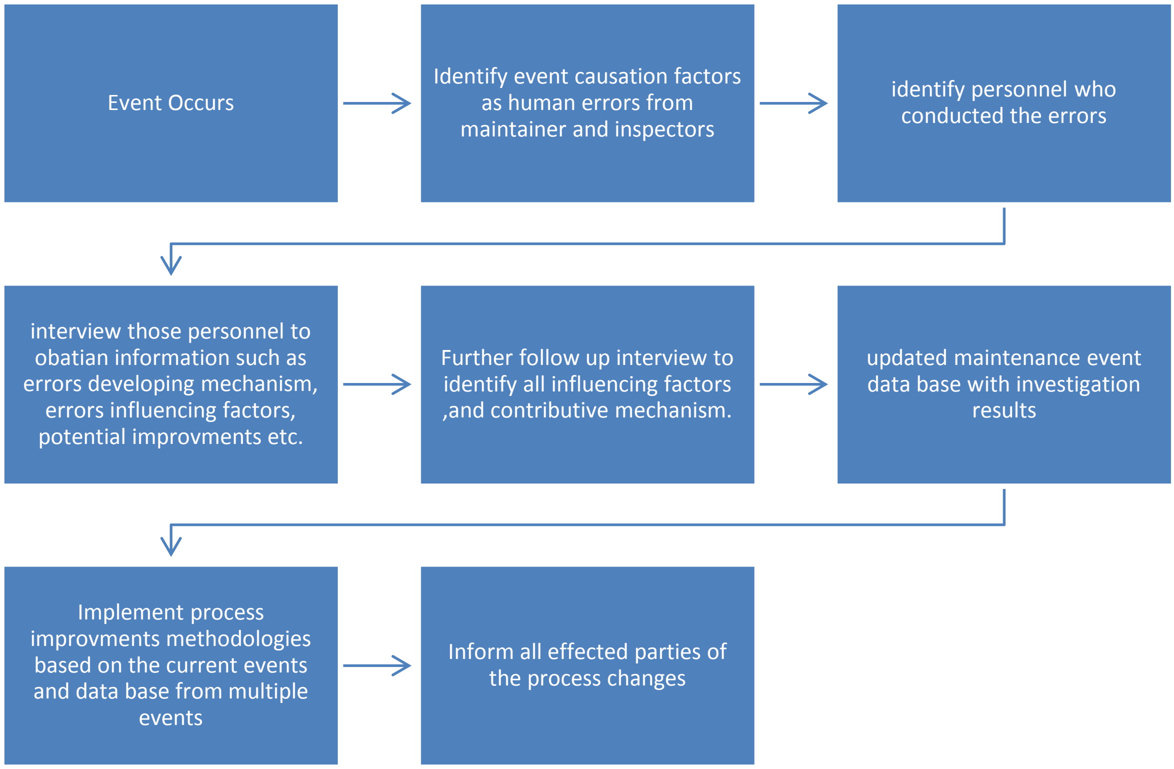


Figure 19 MEDA investigation process(Rankin, 2000)

During this investigation process, one Contributing Factors Checklist is employed to identify human errors influencing factors within maintenance process under 10 top categories listed as follows:

1) Information
2) Equipment, tools and safety equipment
3) Aircraft design, configuration and parts
4) The job or task
5) Technical knowledge and skills
6) Individual factors
7) Environment and facilities
8) Organizational factors
9) Leadership and supervision
10) Communications

Under each of the 10 top category, Boeing had suggested approximately 70 subordinate categories with 320 detail check points to pinpoint particular influencing factors in detail level , an example can be found below(The Boeing Company, 2008):

Table 8 MEDA Top Category 1: Information

Subordinate categories	Check points in detail
Not understandable information	Unfamiliar words or acronyms
	Unusual or non-standard format
	Poor or insufficient illustrations
	Not enough detail or missing steps
	Poorly written procedures
Unavailable information	Procedures does not exist
	Not located in correct or usual place
	Not located near worksite
Incorrect information	Missing pages or revisions
	Does not match aircraft configuration
	Transferred from source document incorrectly
	Steps out of sequence
	Not the most current revision
	Procedure does not work
……..	…………

The complete subordinated categories derived from Boeing MEDA User Guide can be find in **Attachment1: MEDA Influencing factors checklist**. Not all of the influencing factors on that checklist can be used for cross comparison with Oil&Gas industry due to differentiate levels of details, Organizational and technical specialities of Aviation Industry etc. Therefore we have screened out all the irrelevant ones and regrouped the left items as following with heading MEDA Group 1-5:

Table 9 MEDA Group 1. Anthropometric factors

Maintenance Area inaccessible	Components or area to be maintained is surrounded by structure
	No access doors exist in the maintenance area
	Area lacks footing space or hand-holds
	Small or odd-shaped area
Required abnormal Body size and strength	Abnormal reach, unusual fit, or unusual strength required
	Inability to access confined spaces
Inappropriate maintenance tools and equipment/ cannot be used in intended environment	Standard hand tools used for leverage
	Not capable of handling weights, forces, or pressures
	Connections or grips not the right size
	Not enough space to operate tool
	Requires level surface where one is not available

Table 10 MEDA Group 2. Human sensory factors

Higher noise level	High noise impacts the communication necessary to perform a task
	Noise covers up system feedback during a test
Poor visibility	Easy to read wrong display or use wrong control
	requires too many simultaneous readings
	Components too small to read or control
	Not clear Labelling and marking of components

Table 11 MEDA Group 3. Physiological factors

Environmental factors	noise level , Hot, Cold, Humidity, Rain, Snow , lighting , winds , vibrations , cleanliness, hazardous / toxic substances, Inadequate ventilation, Markings.
	Noise covers up system feedback during a test
Work fatigue	Significant increase in work hours or change in conditions
	Excessive length of work day
	Excessive time spent on one task
	Chronic overloading
	Task saturation (e.g., inspecting rows of rivets)

Table 12 MEDA Group 4. Technical factors

Complexity of the equipment	Fault isolation on the system or component is difficult
	Installation of components is confusing, long, or error prone
	Multiple similar connections exist on the system or component (electrical, hydraulic, pneumatic, etc.)
	Installation tests for the component are extensive and confusing
	Different sized fasteners can be installed in multiple locations
	Similar parts on different models are installed differently
Easily to install wrongly	Can be easily installed with wrong orientation
	No orientation indicators (e.g., arrow, colours)
	Connections identical in size, colour or length
Complexity of maintenance tasks	Multiple other tasks are required during this task
	Multiple steps required at the same time by different maintenance technicians
	Long procedure with step sequences critical
	System interacts with other systems during testing or fault isolation
	Multiple electrical checks are required
	Task requires exceptional mental or physical effort

Table 13 MEDA Group 5. Organisational and managerial factors

leadership supervision	planning organization of tasks
	prioritization of Work
	delegation of tasks
	unrealistic attitude / Expectations
	amount of supervision
Organizational Factors	quality of support from technical organizations
	company policies
	Maintenance manning
	corporate change/ Restructuring
	Union Action
	work process/ Procedure
Communication	between departments
	between mechanics
	Between Shits

	between maintenance crew and lead
	between lead and management
	between operation and maintenance crew
Competency management (technical knowledge and skills)	maintenance skills
	task knowledge
	task planning
	Maintenance process knowledge
	Facility system knowledge
	Language proficiency
	Competency monitoring
Maintenance tasks planning	task Monotonous
	New task and task change
	different from other similar tasks
Information	not understandable information
	Unavailable information
	Incorrect information
	Too much information

4.1.2. HUMAN ERRORS REDUCTION AT UKCS OIL&GAS INDUSTRY

As facilitating State for the subsidiary group of Asset integrity of fixed and mobile facilities of the Working Group on Health, Safety and Environment at NSOAF, UK has taken the leads of human errors reduction methodologies developing and application within offshore industry. With close collaboration with Human Factor in Reliability Group (HFRG) as an expert forum for industry, regulatory and academics. HSE UK had initiated several representative projects and published number of successful Joint HSE/HFRG publications with regarding to human errors reduction in the maintenance process. Among them the publication – Improving Maintenance, a guide to reduce human errors will be used as the foundation of our discussion to draw out human errors influencing factors defined within offshore industry at UKCS.

Improving Maintenance, a guide to reduce human errors

First published at year 2000, this HSE/HFRG joint publication was aim to send the key message to the industry that human errors is critical to maintenance related accidents and incidents , thereafter should be tracked structurally and proactively within the maintenance process. Meanwhile this guidance was aim to introduce a systematic solution to reduce human errors in the maintenance process.(Books HSE, 2000)

The guidance following Successful Health and Safety Management System had defined three major elements for maintenance management as:

1) Maintenance policy making and organization set up
2) Maintenance activities planning and implementing
3) Maintenance performance auditing and reviewing

Under each of the three elements, subordinate topics are drawn out to highlight the critical facets as follows:

Table 14 HSE UK Human Errors' Influencing Factors

Major Elements	Subordinate Topics
Policy making and organization set up	Policy
	Resources allocation
	Roles, Responsibilities and accountabilities
	Formal communications
	Management of Changes
	Organisational learning
Planning and implementing	Procedures and permits
	Procedures(presentation, understanding, usability)
	Work design
	Crew/shift (handover and shift work)
	Individual capabilities
	Competence (technical and interpersonal skills)
	Teamwork
	Supervisor effectiveness
	Environmental factors
	Plant and equipment
Measuring performance Audit and review	Routine checking of maintenance performance
	Review maintenance performance

For each subordinate topic, discussion, guidance and underline causes have been made to address the critical influencing factors. A complete underline causes list can be found at **Attachment 2: Underline causes of maintenance – related accidents.** An example is listed below:

Table 15 Example of Underline Causes of Maintenance - Related Accidents

Major Topic	Sub. Topics	Underline causes
Policy and Organization	Policy	Policy Maintenance policy unclear
		Policy gave inadequate support to safety or equipment reliability
		Policy not communicated to staff
		Policy not supported by actions of senior managers
	…….	……..

Among the 18 subordinate topics, Individual Capabilities and Team Work are found not comparable under the thesis context due to the following reasons:

Individual Capabilities:

Major Topic	Sub. Topics	Underline causes
Planning and implementing	Individual Capabilities	Lack of care or self-checking during task
		Failure to obtain assistance when required
		Failure to use required procedures, equipment or personal protective equipment (PPE)
		Failure to report maintenance problems or inspection/calibration results

From the table above, it is obvious to see that all the 'underline causes' are more like human errors itself instead of the causation factors for it. For instance Lack of care or self-checking during task is rather a human errors which could be caused by lack of training or supervision as managerial influencing factors than an underline causes or influencing factor. Therefore we will not include this subordinate topic into further discussion.

Team Work

Major Topic	Sub. Topics	Underline causes

Planning and implementing	Team Work	Poor teamwork with temporary work teams
		Poor communication within and between teams 4 4
		Poor support from other team members (eg of same craft discipline)
		Team members not promoting good practices and not criticising poor ones

Teamwork as a prevalent phrase has been used in many occasions, however poor teamwork is more equivalent to a general surface problem caused by root causes as organizational or managerial deficiencies rather than the causation factors for it. Since the thesis is try to identify root causes or influencing factors for human errors, thus Teamwork is not necessary to discuss in the thesis any further.

Again in order to compare to Aviation industry and Oil&Gas Industry at NCS, all the underlined causes were regrouped as following with the heading HSE UK Group 1-5:

HSE UK Group 1: Anthropometric factors

Underline causes

- Poor access to plant and equipment for maintenance design

HSE UK Group 2: Human sensory factors

Underline causes

- Poor labelling of equipment/components or test/calibration points

HSE UK Group 3: Physiological factors

Underline causes

- Inadequate lighting or poor ventilation
- Excessive high or low working temperatures
- Excessive noise or vibration

- Inadequate provision of PPE

HSE UK Group 4: Technical factors

Underline causes

- Poor plant and equipment maintainability, eg parts able to be fitted incorrectly

HSE UK Group 5: Organizational and Managerial factors

Sub. Topics:

- Policy
- Resources allocation
- Roles, Responsibilities and accountabilities
- Formal communications
- Management of Changes
- Organisational learning
- Procedures and permits
- Procedures (presentation, understanding, usability)
- Work design
- Crew/shift (handover and shift work)
- Competence (technical and interpersonal skills)
- Supervisor effectiveness
- Routine checking of maintenance performance
- Review maintenance performance

Underline causes

52 underline causes in total (please review attachment 2 for details)

4.1.3. COMPARISON BETWEEN MEDA GROUP AND HSE UK GROUP

Details of the Comparison between MEDA and HSE UK' s human errors influencing factors groups can be found in the table below:

Table 16 Comparison between MEDA and HSE UK

Group heading	Number of Influencing Factors				
	Anthropometric	Human Sensory	Physiologic	Technical	Organizational & Managerial
MEDA	3 sub. Topics, 11 check points	2 sub. Topics, 6 check points	2 sub. Topics, 7 check points	3 sub. Topics, 15 check points	6 sub. Topics, 31 check points
HSE UK	1 underline causes	1 underline causes	4 underline causes	1 underline causes	14 sub. Topics. 52 underline causes

From the table above, we can see that both MEDA and HSE UK group headings have coved all the five categories but put more attentions on organizational and managerial factors than the other four. Nevertheless, the different focus between MEDA and HSE UK group heading are still obvious as follows:

MEDA Group

MEDA Group do put more attentions on Anthropometric, Human sensory, Physiology and Technology influencing factors compare to HSE UK Group, and generally have better balance of the five categories, the reason for this is probably because Aviation industry is technology intense and require intricate and meticulous technical operation under confined spaces and chambers, in this case high maintainability from craft hanger to a single bolt is required, therefore equal or even more attention has been put on anthropometric, sensory, physiology and technology influencing factors compare to managerial and organizational influencing factors. However, as we see MEDA Group has not identified managerial and organizational influencing factors systemically based on complete quality control loop.

HSE UK Group

It is obvious that HSE UK Group heading has put more efforts on managerial and organizational influencing factors, which seems will be more effective to control human conceptual errors rather than external influencing factors such as anthropometric, sensory, physiology and technic influencing factors. At least from HSE UK' s understanding: *incidents/ accidents resulting from* *maintenance are more likely to stem from a Human Factors – related root cause than an engineering one*' (M J Burton, 2004). In some extent this is true due to that offshore Oil&Gas industry is less technology intense compare to aviation industry, and generally has 'bigger' operation space that require less maintainability rather organizational and managerial efficiency. Thus HSE UK has systematically identified organizational and managerial influencing factors based on HSE's Effective Health and Safety Management Model.

4.1.4. COMPLETE SPECTRUM OF HUMAN ERRORS INFLUENCING FACTORS

After compares MEDA user guide and HSE UK's publication with regarding to human errors reduction within maintenance process, we noted that HSE UK has better coverage of managerial and organizational influencing factors, but generally address less on external influencing factors. However, as one had addressed, two of the most technology advanced Industry of the 21st Century are up into the outer space and descend into the deepest ocean – the aviation and offshore industry have represented highest civil industry technology level and the developing are still ongoing, therefore Offshore Oil&Gas industry which has been pushing frontier to Deepwater and extreme environment conditions should control risks of human error without underestimate any forms of influencing factors. A comprehensive spectrum of human errors influencing factors therefore should combine both the external influencing factors and organizational and managerial factors together. Based on MEDA Group and HSE UK Group classification, we present a comprehensive spectrum of human errors influencing factors within the maintenance process named as Thesis Group 1-5 as follows:

Table 17 Human Errors influencing factors

Group 1 Anthropometric influencing factors	
	Confined space without designed access.

Maintenance Area accessibility	Abnormal fit in size, reach distance, less than enough operating space
	Inadequate standing or holding points, require constant awkward postures.
Maintenance tools adeptness	Tools with abnormal size cannot be operated in the maintenance space
	Tools require extra strength, or over-meticulous operations
	Tools always need to get by with more or less compromise of sizes.
Group 2 Human Sensory factors	
Visibility/ Information presenting	Not clear or no labeling or placards, instruction diagrams on site.
	Confuse instructive text and diagram, easy to misunderstand.
	Require too many simultaneous reading and interpretation.
	Poor Human- Machine interface for data presenting and feedback
	Less than enough visual inspection and monitoring access.
Noise level	Background noise effect echo or acoustic based test or inspection
	High noise level effect verb communication during maintaining process
Group 3 Physiologic factors	
Environmental stressing factors	Temperature
	Lighting condition
	Vibration
	Ventilation
	Noise
Working stressing factors	Significant changes of work conditions. Eg. Work hours, shift, patterns
	Chronic overloading

	Monotonous due to repetitive works
	Prolong time with the same task.
Social stressing factors	Family matters
	Peer pressure
	Bad company culture
Group 4 Technical factors	
Complexity of equipment	Installation sequence is confusing, long and error problematic
	Difficult system fault isolation
	Similar parts on different models are installed differently
Human errors inductive features	Components can be installed in wrong orders
	No component orientation indicators
	Different connections or components identical in size, color or length
excessive compact and integrated design	Release little information of the equipment
	Difficult to understand the deterioration mechanism
	Not convenient for emergency responding
Group 5 Organizational and Managerial factors	
Maintenance strategy and policy	Strategy and policy unclear , not relate to company business objectives
	Strategy and policy not formally communicated to staff
	Management has not shown their commitments to the strategy and policy
Maintenance Performance Standard	Performance standards not clear, practical and effectively link to strategy
	KPI not clear, practical and effectively link to strategy
	Performance standards has not communicated to staff
Resources allocation	Inadequate system and standards for work planning and prioritizing

	Resources allocation planning has not coordinate to strategy and performance standards
	Inadequate provision of resources to achieve scheduled maintenance. Eg. Parts, equipment and working hours.
Organization efficiency and work process	Not efficient organization hierarchy onshore and offshore, Vague reporting lines from maintenance crew to leads, leads to onshore units
	Poorly defined responsibilities and accountabilities of personnel and units, some work responsibility overlaps between units while some are belong to no one
	Work process and procedure inefficient.
	Poorly collaboration between maintenance and other functional units. Eg. Technical supporting units.
Maintenance work planning	No criteria for maintainers for work prioritization
	Assigning wrong person to carry out the work
	Inconsistency or lack of processes for delegating tasks
	Giving the same task to the same person consistently
	Uneven workloads distribution
Maintenance work execution	Work order has wrong format and error prone
	Work order luck of essential information, eg. Work criticality, performance requirements, safety precautions, isolation requirements etc.
	Work permit system is not effectively implemented or in a wrong manner
	Crew / Shift handover procedure is problematic, eg. Luck of information exchange between to shifts. Bad recording and logging, poorly shift patterns caused physical and mentally fatigue.
Changes Management	No considerations and plans for changes
	Changes inadequately monitored

	Changes not updated into the system after occurrence.
Communication	Inadequate system of informing staff about maintenance and safety requirements and priorities
	Inadequate system of team briefing to promote safety and reliability
	Inadequate system for staff to report maintenance problems
	Adequacy of communication channels not monitored or reinforced
	Overlook the language issues, eg. Difficulties with Foreign language and professional terminologies.
Competence management	Inadequate training for maintenance skills
	Inadequate training for maintenance work process and procedures
	Inadequate training for knowledge of facility and equipment
	Inadequate training for task planning and prioritizing
	Inadequate training for team work and interpersonal skills
	Inadequate monitoring and improving of competence gaps
Supervision and continuous improvement	Inadequate monitoring or over involved of work practices by supervisors
	Supervisor did not correct poor practice and encourage the good one
	Unrealistic expectations, zero tolerance for errors.
	Maintenance failure data has not been systematically collected
	Maintenance failure has not been systematically analyzed
	Maintenance data entry has no quality ensuring mechanism.

	Good and bad practices (not personnel) have not been formally documented and communicated to the organization

CHAPTER 5. HUMAN ERRORS REDUCTION ON NCS

Based on the Thesis Group 1-5 presented at Chapter 4, this chapter will try to examine the status of Norwegian maintenance management regime with regarding to the concern of human errors risks reductions

As concluded by the email communication between one PSA official and thesis author, there are no regulations, guidelines or studies issued by PSA to address only on human errors within the maintenance process. Norwegian Regulator’ s requirements and expectations of human errors reduction within (the maintenance process require comprehensive understanding of bunch of regulations and supervisory activities together.

Therefore to examine the status of human errors reduction within the maintenance process on NCS need to look into Safety and Maintenance Management requirements as a whole, that includes regulations, guidelines, PSA´s audit reports etc.

5.1. HUMAN ERROR REDUCTION REQUIRED BY ACTIVITIES REGULATION

Activity Regulation and Management Regulation declared specific requirements with regarding to company maintenance management. Typically in Chapter IX of Activity Regulation, requirements for maintenance management are listed as the follows:

1) *Equipment and system should be classified with regarding to their impacts on health, safety and environment consequences for potential failures, this classification are the basis for developing maintenance program*
2) *Maintenance Program shall systematically prevent failure modes that could lead to health , safety or environment risks*

3) *Criteria shall be available for prioritizing maintenance activities and set deadlines for each maintenance task.*
4) *Maintenance effectiveness should be continuously monitored and improved*

Each of those principle requirements together with relevant guidelines and interpretations formed the basis of the legislation requirements of maintenance management, nevertheless no particular concerns has been addressed to any human reliability issues within the maintenance process.

However Chapter VIII – Work Environment Factors has declared regulator’s requirements regarding to environment factors including the following:

1) *Ergonomic aspects*
2) *Psychosocial aspects*
3) *Chemical health hazard*
4) *Radiation*
5) *Noise*
6) *Vibrations*
7) *Safety signs and singling in the workplace*
8) *Personal protective equipment*

We can see that all those requirements apply to all activities occurred on the facilities including maintenance, and cover the human errors’ external influencing factors presented at Chapter 4 very well. Therefore, we can conclude that from the legislation level, human errors’ external influencing factors within the maintenance process, such as Anthropometric, Human sensory, physiology factors, have been taken into consideration already under general requirements of working environment conditions by the Activities Regulations, probably this is the reason that regulators and industries here at NCS do not examine those factors within the Maintenance Management, rather those factors will be examined in anther discipline as Working Environment management.

5.2. HUMAN ERRORS REDUCTION REQUIRED BY MBS

As described in previous chapters, one of the most representative guidelines issued by Norwegian Regulators with regarding to maintenance management is the MAINTENANCE BASELINE STUDY(MBS), as a project initiated by the Norwegian Petroleum Directorate (NPD) at 1996 and ended at 1998, MBS was aim to develop a method for a systematic and comprehensive assessment of the company's own maintenance management system, meanwhile this project had addressed more on safety – related maintenance and tried to provide a better explanation to the industries of NPD’ s expectations and requirements in this area(The Norwegian Petroleum Directorate, 1998).

Until now MBS is still the principle document used by both companies and regulators when comes to maintenance related activities. Regulators use MBS more on safety related maintenance, while companies generally apply it to all maintenance activities. Therefore to have a thoroughly review of this document can grant the author to a good basis for further comprising and discussion.

5.2.1. MAINTENANCE MANAGEMENT MODEL

MBS firstly established the Maintenance Management Model (MMM) as a frame work to organize the study. Later MMM has been adapted by the industry as the company maintenance management framework to organize all maintenance activities.

Tropology of the MMM are shown as below:

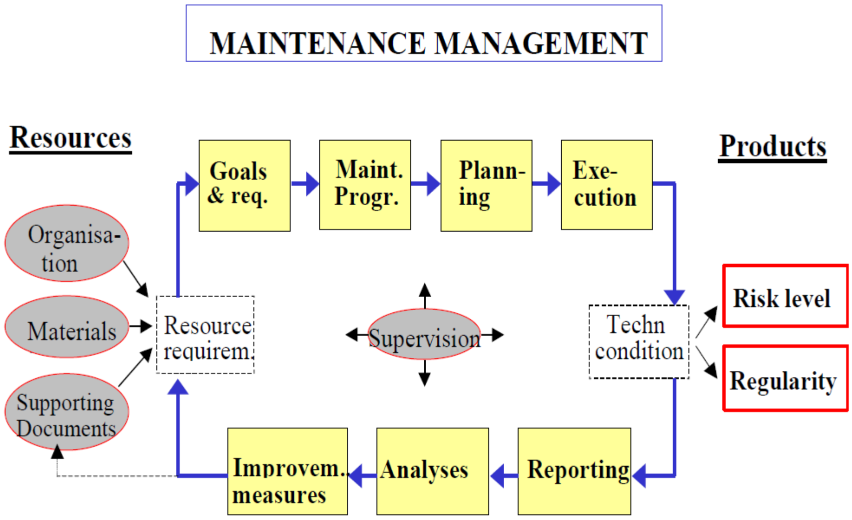


Figure 20 Maintenance Management Model(The Norwegian Petroleum Directorate, 1998)

A single Chapter had been assigned to each module listed above on the MBS report, whereas NPD firstly made comments of the current industry status of the discussed concerns, thereafter drawn out typical management and technical concerns by asking relevant questions both at surface and detail level. An example can be found below(The Norwegian Petroleum Directorate, 1998):

NOTE: Could you elaborate if there are any specific actions being highlighted as measures to reduce Human error (perhaps as a part of Safety integrity level) ?, if so, highlight them briefly under each 'module' ...

MBS Module 1: Objectives and Requirements

Sub. Topic 1: Overall, safety-related objectives and management parameters

Comments:

It is the NPD's experience that the companies' overall objectives and requirements relating to safety are only to a limited degree broken down to an operational level which makes it possible to use these to develop measuring and management parameters related to the maintenance function.

Concerning points:

1) *Has the company a set of clear, safety-related, maintenance objectives (long term, annual)?*
2) *Which management parameters/indicators have been developed to follow up these objectives?*
3) *Are results measured against the overall objectives?*
4) *How do you handle deviations between objectives and actually achieved results?*

Sub. Topic 2: Requirements relating to outstanding maintenance

………………

Sub. Topic 3: Technical and operational requirements based on risk analyses

………………

From the example and explanation above, we can see that MBS is a systematic management process which cover every major consecutive steps of the maintenance management and quality control loop. Therefore is no less effective compare to HSE UK' s Effective Health and Safety Management system to provide a complete overview of safety related concerns within the maintenance process.

However even no typical risks of human errors had been discussed and pinpoint out, some sub topics and/ or concerning points are in one or other way relevant to human errors reduction issues but never specifically addressed it.

This is typically true for organizational and managerial influencing factors, For instance from the spectrum of human errors influencing factors presented at chapter 4, under the 5th group managerial and organizational influencing factors, we have 10 sub. Topics as:

1) Maintenance strategy and policy
2) Maintenance Performance Standard
3) Resources allocation
4) Organization efficiency and work process
5) Maintenance work planning
6) Maintenance work execution

7) Changes Management
8) Communication
9) Competence management
10) Supervision and continuous improvement

All the above topics are covered by MBS very well, but the discussion within each topic are most related to operational risk rather than risks or human errors, even on the topic of Supervision Activities, the focus are still put on maintenance systems, methods, equipment, etc. thus human involvement here in the MBS are more referred as safety barrier rather than risk resources in the following occasions:

1) To ensure quality and continuous improvement of the process and procedures
2) To ensure quality of maintenance operations, data registration etc.
3) To verify risk assumptions in the risk assessment process

MBS is a good methodology that can be used to assess companies' maintenance management system and accordingly provide improvement methods. However, MBS simply has not taken human errors into consideration when mapping different risks associated in the maintenance process. Since most of the industries apply the MBS as principle guideline to their maintenance activities, we also assume that for most of the companies on NCS, human errors within the maintenance process are also not particular addressed.

5.3. HUMAN ERRORS REDUCTION REQUIRED BY PSA AUDITS

PSA has conducted regular audits upon Oil&Gas players on NCS with different focus, all the audit reports are made public for information transparency purpose. Those audit reports can provide good examples of PSA's expectations and requirements as well as the industries performance of maintenance management.

The Author has reviewed two categories of audit reports as Maintenance Management (46 reports) and Working Environment (55 reports). From the audit reports of Maintenance Management we confirmed our finding from section 5.1and 5.2 that PSA have not particularly addressed human errors within the maintenance process, instead most of those audit focus were technical and operational aspects in general. From audit reports of working environment, we confirm the conclusion from section 5.1 that all the ergonomic, psychosocial and environmental factors, which could trigger human errors, are addressed in the audit process in general.

5.4. TRENDS IN RISK LEVEL IN THE PETROLEUM ACTIVITIES (RNNP)

RNNP as a program with annual occurrences is initiated by PSA with the aim to measure various risks level of the Norwegian Oil&Gas Industry. Two methods are applied complementarily to fulfil these targets:

1) Measuring predefined persecutors of major accidents (DFUs), as well as various risks influencing factors of the SHE performance – Most of the DFUs are quantitative measurements.
2) Interviews, surveys, fieldwork and other studies being used as qualitative measurements.

Maintenance has firstly been mentioned in the RNNP questionnaire survey delivered to all employees work in the Norwegian offshore Oil&Gas Industry every year as below "deficient maintenance has led to poor safety ". Secondly, under Barrier against major accidents, indicators of maintenance management have been monitored as Maintenance Backlog and Outstanding, tagging of the equipment (include safety critical equipment). Moreover, in the RNNP questionnaire and Risk indicators monitoring, working environment issues such as ergonomic, cognitive, social factors has been extensively surveyed independently without specific focus on maintenance management.

5.5. SPECIFIC MITIGATING MEASURES OF THE RISKS OF HUMAN ERRORS.

We have went through the Activities Regulations, MBS, PSA audit activities, RNNP Projects and found that Norwegian Offshore Oil&Gas industry do not recognize human errors specifically as critical risks of maintenance performance. Instead human factors have been addressed more in working environment management. This is not enough according to our previous analysis and comparison with other industries and regions, as long as human errors within the maintenance process are the major casual factors for HC leaks on NCS, it is the risk for SHE that has to be specifically reduced and mitigated.

According to the human influencing factors presented at Table 17 in chapter 4, the following influencing factors groups have to be addressed in order to reduce and mitigate risks of human errors on NCS.

1) Anthropometric factors
2) Human sensory factors
3) Physiological factors
4) Technical factors
5) Organizational and managerial factors

5.5.1. ANTHROPOMETRIC FACTORS

Current PSA audits focusing on work environment issues have covered most of the anthropometric factors, but without specific concern of maintenance issues. Therefore during audits of maintenance management, experts and auditors should examine the anthropometric factors from maintenance perspective, for instance, specifically check the following influencing factors:

1) Confined space without designed access for maintenance.
2) Abnormal fit in size, reach distance, less than enough operating space for maintenance.

3) Inadequate standing or holding points, require constant awkward postures during maintenance.
4) Maintenance Tools with abnormal size cannot be operated in the space
5) Maintenance Tools require extra strength, or over-meticulous operations
6) Maintenance Tools always need to get by with more or less compromise of quality.

5.5.2. HUMAN SENSORY FACTORS:

Current focus during maintenance audits has been put into labelling and tagging of equipment, meanwhile noise level has also been monitored continuously onsite. All of the three focuses are parts of human sensory factors. More efforts can be put into the following aspects:

1) Confuse instructive text and diagram for maintainers, easy to misunderstand.
2) Require too many simultaneous reading and interpretation for the maintainers.
3) Poor Human- Machine interface for data presenting and feedback during the maintenance process
4) Less than enough visual inspection and monitoring access for maintainers.

5.5.3. PHYSIOLOGICAL FACTORS

Physiological factors including environmental stressing factors, working stressing factors and social stressing factors that could induce human errors, of which environmental stressing factors have been covered by working environment audits such as temperature, lighting, vibration, ventilation, noise level etc. more efforts should put into work stressing factors and social stressing factors as the follows:

1) Changes management of the maintainers´ work conditions, for instance, working hours, shifts and patterns.

2) Are there enough resources to avoid chronic work overloading of the maintainers?
3) Do they have the mechanism to plan the maintenance work in a challenge way, so that maintainers could avoid monotonous due to repetitive works all the time.
4) Do they set up suitable work scope, so that each maintenance task will not last for a prolong time.
5) Does the team maintain health culture and atmosphere ， have the maintainers´ social and psychological needs been taken cared.

5.5.4. TECHNICAL FACTORS

Technical factors that could induce human errors have not been regularly verified by the audit process or the companies themselves, this is because to identify these induce factors require multiskilling personnel. Usually this verification process can be organized in any FMECA analysis. The following aspects need to be taken into consideration:

1) **Excessive complex equipment**:
- Is the Installation sequence confusing, long and error problematic
- Is the system difficult to conduct fault isolation during maintenance
- Does the system have similar parts on different models are installed differently

2) **Human errors inductive features**:
- System has components can be installed in wrong orders
- No orientation indicators of the components
- Different connections or components identical in size, color or length

3) Excessive compact and integrated design
- Release little information of the equipment
- Difficult to monitor and understand the deterioration mechanism
- Not convenient for emergency fixing and isolation.

5.5.5. ORGANIZATIONAL AND MANAGERIAL FACTORS:

From the author´s view, MBS has covered most of organization and managerial factors that could induce human errors very well. If companies have applied MMM correctly, most of the organizational and managerial inductive factors can be managed. Besides MMM, the following issues has to be clearly emphasized:

1) Leadership commitments

As discussed before, on NCS, human errors has not been recognized as the critical threat of maintenance performance, authorities´ major focuses are always put into the timing of maintenance – backlog and outstanding tasks, as well as what should be maintained - tagging of equipment, regarding to faulty maintenance, there is no tracking and overall supervision. Therefore, to mitigate and reduce risks of human errors within the maintenance process should firstly start with leadership commitments. Human errors reduction should be emphasized during maintenance strategizing, planning, implementing, evolution and continue improving process. Particularly during FMEA, FMECA process, human errors can be discussed as a failure model in each system.

2) Be aware of Language problems

Due to the fact that official working language on NCS is Norwegian, possibilities of communication problems between Norwegians and foreign workers who does not know the language are still exist. Meanwhile according to the author´s own experience, professional phrase and terminologies are sometimes has no precise Norwegian translations, therefore, in companies´ documents or online registering system, readers can easily found mixtures of Norwegian and English, and this again will cause confusion and misunderstanding that could induce human errors not only in the maintenance process. Therefore it is important that the operators being aware of the language problems and provide essential language trainings for foreign workers on NCS. Moreover, since the Norwegian Sea has been the international arena for Oil&Gas industry since the very beginning, multinational companies are operated all over the continental shelf whereas the writing language should be unified as English so that everybody could read and understand correctly.

CHAPTER 6. DISCUSSION

6.1. SUMMARY OF THIS STUDY

In this thesis, we have firstly reviewed the maintenance management evolution process, meanwhile depends on relevant data and conclusions from other literatures, we found that in general human errors are the causation factors for large number of maintenance failures and the accidents and incidents thereafter, thus human errors become one of the biggest challenges faced by the industry. With the finding we establish the research objectives of the thesis as to firstly identify general patterns of human errors by establishing human error classification system, then try to identify human errors influencing factors of those human errors occurred in the maintenance process, Finally try to examine the management status of those influencing factors in the Norwegian Maintenance management regimes.

We have set our discussion scope mainly on North Sea Oil&Gas Industry; therefore we firstly conducted a survey of North Sea legislation regimes, then legislation regimes of UK and Norway consequently as a background for further discussion. Then we started a theoretical discussion of the natures of human errors, and combined several different human errors classification theories adapted by aviation maintenance industry in order to have complete human errors categories as:

Human conceptual errors: Under this category, we assume that, all the external factors except human themselves are functioning normally, in this circumstance human errors such as slips and lapses, rule based mistakes, knowledge based mistakes and violations are conceptual, and in many case cannot be eliminated due to human nature.

Human errors triggered by external factors: we find that some errors which were directly conducted by a person or a group of people, are actually triggered or induced by external factors, such as environmental factors, technical and organizational factors etc. in other words, if we manage those external factors in the right or better way at the beginning, the human could avoid those mistakes.

Based on the errors classification, we further presented a complete spectrum of human errors' influencing factors within the maintenance process by complementarily utilization of Boeing' s MEDA and HSE UK' s relevant suggesting as shown at **Table 17 Thesis Human Errors influencing factors.** Finally we tried to reflect those human errors influencing factors into the maintenance management regime on NCS through reviewing of the Activities Regulations, MBS as well as Audit Reports and RNNP reports issued by PSA.

Potential mitigation measures for Human errors on NCS has been suggested by the author according to the framework of **Table 17 thesis human errors influencing factors**.

6.2. WHAT THE AUTHOR HAD LEARNT

With the broaden coverage of the research topics being went through, the author had obtained theoretical knowledge and practical methodologies mainly as the follows:

1) North Sea Oil&Gas legislation regimes: this including multinational legislation framework such as EU Commission, NSOFA, IRF etc. As well as Safety Management regime in UK and Norwegian in general.
2) Maintenance strategy such as Corrective maintenance, Proactive Maintenance RCM, Streamlined RCM, RBM, CBM etc.
3) UK legislation guidelines and requirements regarding to human risks mitigation and reduction within the maintenance management
4) Aviation industry theories and practices regarding to human risks mitigation and reduction within the maintenance process.
5) Classic human errors classification theories presented by James Reason.

6) Human errors influencing factors classification recommended by UK HSE and Boeing Company.
7) Author had gone through Norwegian Activities Regulations, MBS, PSA Audit reports and RNNP reports, thereafter obtained comprehensive understanding of the Norwegian offshore safety and maintenance management regimes.

6.3. WHAT CAN BE DONE FURTHER OF THIS STUDY

At the end of this study, author had believed that in the Norwegian sector, more attentions should be addressed specifically to human errors within the maintenance process in order to reduce the possibilities of major accidents. Therefore further studies could be conduct to find out how to actually do that particularly under Norwegian legislation regimes and industrial practises.

Through the data collection process, the author had found that there is no specific database has been created to only collect and analysis the risk level of human errors on NCS. RNNP has created different risk indicators but ignored the act that overall quantity of human errors and their differentiate natures could be very good indicators to show the overall competence level of employees, as well as the organizational performance such as training, supervision, communication and continue improving etc. on NCS. Thus author suggest that Norwegian Regulators start to collect data of human errors regularly.

Barrier Management has been adapted by NCS as the core instrument for SHE management, mainly there are technical barrier, organizational barrier and operational barrier, how to mitigate and reduce risks of human errors through those Barriers systematically and effectively could be a meaningful topics for further study.

6.4. CHALLENGES FACED DURING THE THESIS WRITING PROCESS

Major challenges are the following:

1) Human errors are in large extent random behaviours, therefore it is very hard for the author to collect first hand reliable data to calculate the probabilities under normal risk assessment methodologies. Moreover on NCS, there is no public database that has collected data of human errors systematically.
2) Maintenance as a technical discipline consist most of practical experiences and skills instead of theoretical knowledge. Therefore study of maintenance should be conducted through more case studies directly from industry such as interviews, surveys and audits, of which the author had struggling a lot to get the opportunities but without success.
3) Basically this thesis has covered human factors, maintenance management and safety management, moreover data and reference were collected from aviation industry, UK and Norway Offshore Oil&Gas industry, this wide coverage has actually somehow challenged author with his limited knowledge and experience.

CHAPTER 7. CONCLUSIONS

7.1. FINDINGS AND CONCLUSIONS OF THIS STUDY

From the discussion in the previous chapters, we found that Norwegian legislation and industries hold different perspectives and apply different methodologies with regarding to human errors with in the maintenance process compare to UK legislation and Aviation industry in general, major findings and conclusions are listed below:

1) Human errors within the maintenance process are the major causation factors for large number of accidents and incidents occurred cross industries and regions.
2) Industries such as Aviation and Offshore UK have been aware of the SHE risks induced by human errors within the maintenance process for a long time, and have developed some well-known theories and effective practices to reduce the risks of human errors.
3) Norwegian Offshore Legislation and Industries have not addressed the risks of human errors within maintenance process as an independent threat for SHE performance, rather risk of human errors are managed by requirements scattered into different regulations, guidelines and supervisory activities initiated by the regulators

7.2. RECOMMENDATIONS FOR OFFSHORE INDUSTRY ON NCS

Be aware risks of human errors within the maintenance process

From the research we understand that at the Norwegian side, Human errors within the maintenance process are not recognized as a major threat for SHE issues, and NCS do achieved remarkable SHE performance during the last decades. But through our literature review, we found that Human intervention are still the biggest causation factors for HC leaks on NCS, that means human errors with in the maintenance process still can be the direct causes for catastrophic accidents, and the possibility for that is bigger than the other, thus we believe that it is very important for the offshore legislation and industries to firstly be aware of this threats then put more efforts to confront it.

To improve human errors reduction within maintenance process on NCS

Employee training is not always the single cure to reduce human errors because *to simply tell or teach someone not to do something they are not basically intended to do is not effective at the first place*(Latorella and Prabhu, 2000). Management should have an overview of human errors influencing factors within the maintenance process then take actions accordingly. Great many strategies and methodologies has been developed by peer industries and regulators for this concerns, for NCS, it is still necessary to initiate such research projects and develop methodologies based on local legislation regimes to address this problem in order to least the risks for catastrophic accidents and raise the SHE performance to an even higher level

7.3. LIMITATION OF THIS STUDY

Limitations of this study are listed below:

1) The study has not been able to get first hand data directly from offshore Oil&Gas industry due to the data collection is a resources consuming process which the author is not capable to do it. Therefore only second hand data and references from other literatures have been used.
2) The study has not addressed risks of human errors as Violations because that involve much larger research context which is out of the author’s capability.
3) The study and presentation of the Maintenance management regimes of different industries and regions are not 100% comprehensive and accurate due to that is a resources hungry process and require better knowledge and professional experience which the author doesn't have enough.

4) The study has not stepped further to develop risks reduction and mitigation methodologies for human errors based on Barrier Management perspective systematically, but recommended several suggesting according to authors own theoretical system.

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ATTACHMENTS

MEDA INFLUENCING FACTORS CHECKLIST

Sources of the table: THE BOEING COMPANY 2008. *MEDA User Guide*

MEDA Top Category	MEDA Subordinate category	MEDA Influencing factors in detail
Information	not understandable information	Unfamiliar words or acronyms
		Unusual or non-standard format
		Poor or insufficient illustrations
		Not enough detail or missing steps
	Unavailable information	Poorly written procedures
		Procedures does not exist
		Not located in correct or usual place
		Not located near worksite
	Incorrect information	Missing pages or revisions
		Does not match aircraft configuration
		Transferred from source document incorrectly
		Steps out of sequence
		Not the most current revision
		Procedure does not work
	too much and conflicting information	Similar procedures in different resources do not agree
		Too many references to other documents
		Configurations shown in different resources do not agree
	updated process is too long complicated	Requested revisions have not been incorporated yet
		Configurations changed by service bulletins or engineering orders have not been updated in applicable maintenance procedures
		Document change requests are not submitted, lost, or incorrectly filled out
	incorrect modified manufactures MM	Intent of manufacture's procedure is not met
		Non-standard practices or steps are added
		Format does not match rest of procedure or other procedures

	information not used	Not using technical documentation is potentially a violation, if the technician should have used the documentation, but did not , find out why
		Procedure available but the technician did not have enough time to get it
		Technician thought that he did not need the procedure because he had done the task many times before
Equipment / Tool / Safety Equipment	unsafe equipment Tool Safety Equipment	Platform moves and is unstable
		brakes or safety devices inoperative
		non-skid material worn or missing
		a lock-out mechanism is missing or faulty
		placards are missing or faded
		sharp edges are exposed or personal protective devices are missing
		Power sources are not labelled or protected
	unreliable equipment	Intermittent or fluctuating readings on dials or indicators
		Damaged or worn out
		Expired use limits
		History of defects
	layout of controls or displays	Easy to read wrong display or use wrong control
		Awkward locations, hard to reach
		Too small to read or control
		Directional control of knobs or dials is not clear
	mis-calibrated	Tool out of calibration from the start of use
		Wrong specifications used during calibration procedure
	unavailable equipment	Is not owned or in stock
		Not available for procurement
	inappropriate tools and equipment	Standard hand tools used for leverage
		Not capable of handling weights, forces, or pressures required for the task
		Connections or grips not the right size
	cannot be used in intended environment	Not enough space to operate tool
		Requires level surface where one is not available
	no instruction	Instructional placards missing or faded
		Directional markings missing
		Tool usage instructions not available

	too complicated	Tool usage requires too many simultaneous movements and/or readings
		Fault isolation or testing is too complex
	incorrectly labelled	Hand marked labelling or operating instructions are incorrect
		Tool has incorrect scale readings
	not used	Equipment/tool/part is available but not used.
	incorrectly used	Safety equipment not appropriate for the hazard
		Personal protective equipment not properly worn
	safety equipment	System protection devices on tools/equipment not available
Aircraft Design / Configuration / parts	complexity of the equipment	Fault isolation on the system or component is difficult
		Installation of components is confusing, long, or error prone
		Multiple similar connections exist on the system or component (electrical, hydraulic, pneumatic, etc.)
		Installation tests for the component are extensive and confusing
		Different sized fasteners can be installed in multiple locations
	inaccessible	Components or area to be maintained is surrounded by structure
		No access doors exist in the maintenance area
		Area lacks footing space or hand-holds
		Small or odd-shaped area
	configuration variability	Similar parts on different models are installed differently
		Aircraft modifications have changed installation or other maintenance procedures between aircraft
	parts unavailable	Part not owned or in stock
		Not available for procurement
	Parts incorrectly labelled	Hand marked labelling incorrect
		Wrong part number on part
	very easy to install incorrectly	Can be easily installed with wrong orientation
		No orientation indicators (e.g., arrow, colours)
		Connections identical in size, colour or length
	parts not used	Correct part was available to use, but technician did not use it and used a different (non-interchangeable) part instead
		Correct part was unavailable, so technician used a different (non-interchangeable) part
	parts not used	Components are too heavy for easy removal/installation
		Lack of feedback provided by component or system
		Direction of flow indicators do not exist

tasks and Jobs	task Monotonous	Similar steps are performed over and over (opening and closing circuit breakers during a long test)
		The same task performed many times in multiple locations (removing seats)
	task complexity and confusing	Multiple other tasks are required during this task
		Multiple steps required at the same time by different maintenance technicians
		Long procedure with step sequences critical
		System interacts with other systems during testing or fault isolation
		Multiple electrical checks are required
		Task requires exceptional mental or physical effort
	New task and task change	New maintenance requirement or component
		Revision to a procedure
		Engineering modification to existing fleet
		New aircraft model
	different from other similar tasks	Same procedure on different models is slightly different
		Recent change to aircraft configuration has slightly changed task
		Same job at different worksites is performed slightly different
technical knowledge and skills	maintenance skills	Safety wiring
		Rigging of controls
		Using calibrated equipment
		Carrying out a fault isolation task
	task knowledge	Slow task completion
		Technician change of maintenance responsibilities
		Task performed by maintenance technician for the first time
		Task performed in wrong sequence
	task planning	Frequent work interruptions to get tools or parts
		Failure to perform preparation tasks first
		Too many tasks scheduled for limited time period
		Task necessary for safety not performed first
	Airline process knowledge	If the technician knows the correct airline process to follow, but does not do so, then this could be a violation. If the technician did not follow the process correctly, find out why (i.e., what the contributing factors to not following the then this could be a violation. If the technician did not follow the process correctly, find out why (i.e., what the contributing factors to not following the airline process)
		Failure to acquire parts on time
		Technician new to airline or to type of work (from line to hangar, etc.)

		Airline processes not documented or stressed in training
	Aircraft system knowledge	Technician changes aircraft types or major systems
		Fault isolation takes too much time or is incomplete
	English Language proficiency	Technician made mistake because they could not read English technical documentation well enough
		Technician made mistake because they could not understand spoken English well enough
	skill and performance monitoring	Technician performance/skills not accurately tracked/measured
individual factors	physical health	Sensory acuity (e.g. vision loss, hearing loss, touch)
		Failure to wear corrective lenses
		Failure to use hearing aids or ear plugs
		Restricted field of vision due to protective eye equipment
		Pre-existing disease
		Personal injury
		Chronic pain limiting range of movement
		Nutritional factors (missed meals, poor diet)
		Adverse affects of medication
		Drug or alcohol use
		Complaints of frequent muscle/soft tissue injury
		Chronic joint pain in hands/arms/knees
	fatigue	Lack of sleep
		Emotional stress (e.g. tension, anxiety, depression)
		Judgment errors
		Inadequate vigilance, attention span, alertness
		Inability to concentrate
		Slow reaction time
		Significant increase in work hours or change in conditions
		Excessive length of work day
		Excessive time spent on one task
		Chronic overloading
		Task saturation (e.g., inspecting rows of rivets)
	time constraints	Constant fast-paced environment
		Multiple tasks to be performed by one person in a limited time
		Increase in workload without an increase in staff

		Too much emphasis on schedule without proper planning
		Perceived pressure to finish a task more quickly than needed in order to release the aircraft from the gate
	peer pressure	Unwillingness to use written information because it is seen as a lack of technical skills/knowledge
		Lack of individual confidence
		Not questioning other's processes
		Not following safe operating procedures because others don't follow them
	complacency	Hazardous attitudes (invulnerability, arrogance, over-confidence)
		Task repetition leads to loss of mental sharpness or efficiency
	body size/ Strength	Abnormal reach, unusual fit, or unusual strength required for the task
		Inability to access confined spaces
	Personal Event	Death of a family member
		Marital difficulties
		Change in health of a family member
		Change in work responsibilities/assignment
		Change in living conditions
	workplace distractions/interruptions	Confusion or disorientation about where one is in a task
		Missed steps in a multi-step task
		Not completing a task
		Working environment is too dynamic
	Memory Lapse	Forgot
	Visual perception	Misread dial/display because of parallax issues
		Misjudged distance
		Could not easily tell whether airplane was following marking into hangar because
	other personal issues	of visual angle
		Absenteeism
		Vacations
		Medical leave
		Risk-taking behaviour
Environmental facilities	noise level	High noise impacts the communication necessary to perform a task
		Extended exposure to noise reduces ability to concentrate and makes one tired
		Noise covers up system feedback during a test
	Hot	Work area is too hot so the task is carried out quickly

		Extremely high temperatures cause fatigue
		Long exposure to direct sunlight
		Exterior components or structure too hot for maintenance technicians to physically handle or work on
	Cold	Work area is too cold so the task is carried out quickly
		Long exposure to low temperature decreases sense of touch and smell
	Humidity	High humidity creates moisture on aircraft, part and tool surfaces
		Humidity contributes to fatigue
	Rain	Causes obscured visibility
		Causes slippery or unsafe conditions
	Snow	Causes obscured visibility
		Causes slippery or unsafe conditions
	lighting	Protective gear makes grasping, movement difficult
		Insufficient for reading instructions, placards, etc.
		Insufficient for visual inspections
		Insufficient for general maintenance activity
	winds	Excessive - creates glare, reflection, or eye spotting
		Interferes with ability to hear and communicate
		Moves stands and other equipment (creates instability)
		Blows debris into eyes, ears, nose or throat
	vibrations	Makes using written material difficult
		Use of power tools fatigues hands and arms
		Makes standing on surfaces difficult
	cleanliness	Makes instrument reading difficult
		Loss of footing/grip due to dirt, grease or fluids on parts/surfaces
		Clutter reduces available/usable work space
	hazardous / toxic substances	Inhibits ability to perform visual inspection tasks
		Reduces sensory acuity (e.g. smell, vision)
		Exposure causes headaches, nausea, dizziness
		Exposure causes burning, itching, general pain
		Personal protective equipment limits motion or reach
		Exposure causes general or sudden fatigue
		Exposure causes general concern about long term effect on health
	Power sources	Not labelled with caution or warning

		Guarding devices missing or damaged
		Power left on inappropriately
		Circuit protection devices not utilized or damaged
		Cords chafed, split, or frayed
	Inadequate ventilation	Strong odor present
		Burning or itching eyes
		Shortness of breath
		Sudden fatigue
	Markings	White guide lines into hangar not painted
		White guide lines into hangar faded/chipped and hard to see
		Stop lines in hangar not painted or hard to see
	others	Area(s) not organized efficiently (difficult to find parts, work cards, etc.)
		Area too crowded with maintenance technicians and/or other personnel
Organizational Factors	quality of support from technical organizations	Inconsistent quality of support information
		Late or missing support information
		Poor or unrealistic maintenance plans
		Lack of feedback on change requests
		Reluctance to make technical decisions
		Frequent changes in company procedures and maintenance programs
	company policies	Unfair or inconsistent application of company policies
		Standard policies do not exist or are not emphasized
		Standard error prevention strategies don't exist or are not applied
		Inflexibility in considering special circumstances
		Lack of ability to change or update policies
	not enough staff	Not enough trained personnel
		Not enough trained personnel at the time
	corporate change/ Restructuring	Layoffs are occurring
		Early retirement programs drain experience
		Reorganizations, consolidations and transfers cause more people to be in new jobs
		Demotions and pay cuts
		Frequent management changes
	Union Action	Contract negotiations create distractions
		Historical management/labor relations are not good

		Positive or negative communication from union leadership
		Strike, work slowdown, or other labor action creates a disruption
	work process/ Procedure	Standard operating procedures (SOPs) incorrect
		General maintenance manuals outdated
		Inadequate inspection allowed
		Process/procedure does not obtain the desired outcome
	work process/ Procedure not followed	Skipped operational check
		Required protective equipment not used
		Did not use ”parts removed” tag
	work process / Procedure not documented	No procedure for radio check before towing operation
		No inspection criteria
		No procedure for proper use of safety equipment
	work group normal practice Norm	Documented procedure—most people in the same situation do not follow the process or procedure
		Undocumented procedure—most people do the procedure like the technician did.
	other	Company is acquired by another company
		Work previously accomplished in-house is contracted out
		Overall inadequate staffing levels
leadership supervision	planning organization of tasks	Excessive downtime between tasks
		Not enough time between tasks
		Paperwork is disorganized
		Tasks are not in a logical sequence
	prioritization of Work	Technicians not told which tasks to carry out first
		Important or safety related tasks are scheduled last
		Fault isolation is not performed with the most likely causes checked first
	delegation of tasks	Assigning the wrong person to carry out a task
		Inconsistency or lack of processes for delegating tasks
		Giving the same task to the same person consistently
		Wide variance in workload among maintenance technicians or departments
	unrealistic attitude / Expectations	Frequent dissatisfaction, anger, and arguments between a supervisor and a
		technician about how to do a task or how quickly a task should be finished
		Pressure on maintenance technicians to finish tasks sooner than possible or reasonable

		Berating individuals, especially in front of others
		Zero tolerance for errors
		No overall performance expectations of maintenance staff based on management vision
	amount of supervision	Look over the shoulder management style
		Frequent questioning of decisions made
		Failure to involve employees in decision-making
	other	Meetings do not have purpose or agendas
		Supervisor does not have confidence in group's abilities
		Management doesn't "walk the talk" and thereby sets poor work standards for maintenance staff
Commu nication	between departments	Written communication incomplete or vague
		Information not routed to the correct groups
		Department responsibilities not clearly defined or communicated
		Personality conflicts create barriers to communication between departments
		Information not provided at all or not in time to use
	between mechanics	Failure to communicate important information
		Misinterpretation of words, intent or tone of voice
		Language barriers
		Use of slang or unfamiliar terms
		Use of unfamiliar acronyms
		Failure to question actions when necessary
		Failure to offer ideas or process improvement proposals
		Personality differences
	Between Shits	Work turnover not accomplished or done poorly or quickly
		Inadequate record of work accomplished
		Processes not documented for all shifts to use
		Job boards or check-off lists not kept up to date
	between maintenance crew and lead	Lead fails to communicate important information to crew
		Poor verbal turnover or job assignment at the beginning of a shift
		Unclear roles and responsibilities
		Lead does not provide feedback to crew on performance
		Crew fails to report problems and opportunities for improvement to lead person
		Communication tools (written, phones, radios, etc.) not used Little or no communication exists

	between lead and management	Goals and plans not discussed regularly
		No feedback from management to lead on performance
		Lead does not report problems and opportunities for improvement to management
		Management fails to communicate important information to lead
	between flight crew and maintenance	Late notification of defect
		ACARS/data downlink not used
		MEL/DDG interpretation problem
		Logbook write-up vague or unclear
	other	Computer or network malfunctions lead to loss of information
		E-mail not used or ignored

UNDERLINE CAUSES OF MAINTENANCE – RELATED ACCIDENTS

Sources: BOOKS HSE 2000. Improving maintenance a guide to reducing human error

Category	Underline Causes
Policy	Policy Maintenance policy unclear
	Policy gave inadequate support to safety or equipment reliability
	Policy not communicated to staff
	Policy not supported by actions of senior managers
Resource allocation	Inadequate system for work planning and prioritisation
	Inadequate provision of resources to achieve scheduled maintenance, e.g. people, parts, equipment and time
	Failure to schedule necessary maintenance due to resource constraints
	Inadequate system of recording and prioritising equipment defects 4
Roles, responsibilities,	Poorly-defined responsibilities for maintenance staff and accountabilities
	Responsibilities of maintenance staff unclear to them
	Poorly-defined responsibilities of non-maintenance staff
	Responsibilities of non-maintenance staff unclear to them
Formal communications	Inadequate system of informing staff about maintenance and safety requirements and priorities
	Inadequate system of team briefing to promote safety and reliability
	Inadequate system for staff to report maintenance problems
	Adequacy of communication channels not monitored or reinforced
Management of change	Lack of consideration given to changes in plant or organisation
	Poor planning of changes
	Procedures and training not updated to reflect changes

	Changes inadequately monitored
Organisational learning	Inadequate priority and resources to implement improvement actions
	Management show lack of visible commitment to improvement
	Staff uninvolved and uncommitted to improvements
	Lack of willingness to learn from national and international best practices
Procedure(contents)	Procedures contain technical errors (contents)
	Procedures contain inadequate information on task requirements 9 9
	Permits-to-work not completed correctly
	Errors in procedures and permits not reported
Procedures (presentation/understanding and usability)	Task misunderstood because format of procedures is poor
	Procedures incorrectly followed due to poor format
	Procedures not used because difficult to use
	Procedures not readily available at place of work
Work design	Job beyond physical capability of person
	Job routine and repetitive causing lack of attention
	Poor use of skills causing loss of competence
	Excessive tiredness because of excessive overtime
Crew/shift handover	Inadequate exchange of verbal information during shift handover and shift work
	Errors or deficiencies in equipment records and logs 4
	Excessive tiredness because of poor shift patterns
	Allocation of intricate tasks to night shift rather than day shift
Individual capabilities	Lack of care or self-checking during task
	Failure to obtain assistance when required 1 1
	Failure to use required procedures, equipment or personal protective equipment (PPE)
	Failure to report maintenance problems or inspection/calibration results
Competence (technical and interpersonal skills)	Inadequate technical training for task
	Inadequate training in personnel skills, e.g. teamwork
	Inadequate training of supervisors in line-management skills
	Inadequate training of maintenance managers in leadership skills
Teamwork	Poor teamwork with temporary work teams
	Poor communication within and between teams 4 4
	Poor support from other team members (e.g. of same craft discipline)
	Team members not promoting good practices and not criticising poor ones
Supervisor effectiveness	Inadequate monitoring of work practices by supervisor
	Poor example set by supervisor
	Supervisor did not correct poor practices
	Supervisor did not encourage good practices
Environmental factors	Inadequate lighting or poor ventilation
	Excessive high or low working temperatures
	Excessive noise or vibration

	Inadequate provision of PPE
Plant and equipment	Poor access to plant and equipment for maintenance design
	Poor labelling of equipment/components or test/calibration points
	Poorly designed or maintained tools or calibration equipment, etc.
	Poor plant and equipment maintainability, e.g. parts able to be fitted incorrectly