
# DEPARTMENT OF MANAGEMENT SCIENCE

## FORMULATION OF A CONCEPTUAL FRAMEWORK FOR MAINTENANCE STRATEGIES

A CASE STUDY ON UK NORTH SEA OIL AND GAS INDUSTRIES

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A thesis presented in fulfilment of the requirements of the Degree of Master of Philosophy

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# DECLARATION

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.



Name:

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# ABSTRACT

Maintenance has been linked with costs and plant downtime, which makes it thought of as being a necessary evil. In recent times, reliability, availability, and safety in plant production have been more emphasized, particularly in hazardous working environments. Companies are now increasingly replacing fire-fighting maintenance approaches with more proactive maintenance strategies, such as predictive and preventive maintenance, in order to attain world-class performance with huge plant efficiency and high safety performance.

This master thesis aims to investigate what the issues are that are hindering North Sea Oil and Gas Companies from achieving a more proactive maintenance approach. The common maintenance strategy in today's North Sea Oil and Gas is a reactive approach, where events and failures dictate pace, although there have been on-going changes that have been put in place to adopt a more preventive and proactive maintenance approach. This master's thesis would serve as a foundation for developing North Sea Oil and Gas' maintenance strategy, which will guide oil and gas companies toward a preventive and proactive maintenance environment.

Different research methods have been used in this thesis. These include an extensive literature study, a systematic review of literature, interviews with maintenance personnel, and a review of a case study examining companies' documentation and benchmarking practices. In order to perform an accurate comparison between companies, a benchmarking tool was developed. The tool is called Maintenance Section Review (MSR). The MSR consists of questions within the areas of: maintenance structure, maintenance training programs, work orders, planning and scheduling, preventive maintenance (PM), spares inventory & purchasing, computerized maintenance management system (CMMS), operation, maintenance reporting, predictive maintenance, reliability & breakdown, maintenance – key performance indicators (KPIs), and financial planning. All questions generated are justified according to the published literature.

This thesis provides results showing that highly reactive approaches are common in the maintenance department. This is evidenced by the average score from the MSR on predictive maintenance, with a value of 1.2. Some other key aspects identified as lacking

or behind include planning and scheduling, maintenance reporting, inventory and purchasing, reliability and breakdown, and maintenance structure. There is also room for improvements in cooperation and communication between the maintenance department and production department, which would contribute to a more proactive working environment. The maintenance department is often left out of projects and is seen as a separate supporting function. The benchmarking has shown that successful companies need to change their approach in communication between departments and should focus on an integrated approach. These findings later formed the basis of the Shareholder Focused Model which has been developed to guide North Sea Oil and Gas in developing a maintenance strategy.

The Shareholder Focused Model has been developed as part of this thesis. This is mainly based on the research findings relating to the factors that are impeding the maintenance department from maximizing their productivity. This model was developed as a form of guidance to maximize productivity.

**Keywords**: Maintenance strategy, benchmarking, oil and gas, North Sea

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# ABBREVIATIONS

| | |
|---|---|
| BCM | Business Centered Model |
| CM | Corrective Maintenance |
| CMMS | Computerized maintenance management system |
| FMEA | Failure Mode and Effects Analysis |
| KPI | Key Performance Indicator |
| LCC | Life Cycle Cost |
| LCP | Life Cycle Profit |
| MSR | Maintenance department analysis |
| MTBF | Mean time between failures |
| MTTF | Mean time to failure |
| OEE | Overall equipment efficiency |
| PDCA | Plan-Do-Check-Act |
| PdM | Predictive Maintenance |
| PM | Preventive maintenance |
| RCA | Root-cause analysis |
| RCM | Reliability Centred maintenance |
| ROI | Return on investment |
| SFM | Shareholder Focused Model |
| TPM | Total productive maintenance |

# 1.0 BACKGROUND

This chapter is intended to give the reader an understanding of why this research will be relevant to both industry and academia. This chapter presents the objectives and the expected results of the conducted research, and the outline of this research.

Today's plant's systems are expected to perform at very high standards throughout their operational phase (Nahmias & Olsen, 2015). This is because the cost associated with unavailability of these systems is very high, especially with oil and gas plants this could add up to millions of pounds. Therefore many oil and gas companies are now recognizing how important the need for effective maintenance of production facilities and systems. (Chan & Prakash, 2012).

A significant amount of the annual plant operational costs are attributed to maintenance costs (Jardine & Tsang, 2013). An effective and efficient maintenance strategy would help achieve plants operational objectives successfully, but this is becoming increasingly difficult given the growing complexity of plant systems with the advancement of technology (Zaim et al, 2012). One of the biggest operational challenges faced by a plant manager is to reduce maintenance costs, capital investment in maintenance resources and redundant capacity without reducing system reliability/availability. The question plant manager always face is what section of the plant maintenance budget can be cut?

In the United Kingdom North Sea Oil & Gas (O&G) industry, due to the steady decline in production over the decade, unit operating costs continue to rise, and indeed total operating expenditure rose by 15.5% during 2013 'to an all-time record of £8.9bn.That over a period when production has halved, operating costs have more than doubled (since 2002). It now costs on the average £17 to extract a barrel of oil in the North Sea. These rising costs influence operators decisions on what are deemed 'recoverable reserves', as higher costs make some reserves less economically to exploit. Maintenance activities account for on an average 28% of the total cost of increase in total operating expenditure due to late life of plant equipment and obsolesces (Greig, 2014).

In order to cope with the new oil and gas price challenges, O&G companies need to look for ways to reduce the operating cost which maintenance cost over 20% (Greig, 2014). O&G companies therefore have to develop their maintenance on a strategic level. Several researchers have argued the importance of maintenance strategies; these include Walker (2005) who argued that once maintenance issues are higher on companies' priorities that is seen as a key business-driver, the ability for the company to make profit will improve.

Despite the obvious importance of maintenance strategies, a survey conducted by Alsyouf (2009) indicated that the true proportion of companies with full maintenance strategy is less than 48%.The importance of the maintenance has become greater majorly because of its role improving availability, improving efficiency, environment requirement, safety requirements and overall plant productivity. Therefore a rising awareness of maintenance and its effect for both industrial enterprises and society as a whole can be recognised. Many researchers and practitioners have highlighted the total losses due to maintenance omission or ineffectiveness (Karuppuswamy, 2014).

Nevertheless, maintenance is still considered as a cost center has researchers had not done much to highlight the impact of the maintenance department on the overall plant performance, i.e. productivity and profitability (Christer, 2014).

In the O&G industry, the maintenance task is becoming increasingly more complex due to the changes in the production and the challenging environment (Ratnayake, 2012). These changes can be described by factors such as the level of automation of production, increase globalization, organization reform, downsizing policies, downturn in price, dynamic organization structures, personnel competence development and the difficulty of assessing a measure of causality between maintenance and company's profitability (Christer, 2014). A typical O&G production system consists mechanical components, electronic, hydraulic, electromechanical elements, software and human beings. Therefore disturbances and deviations in the production process may occur due to different factors which include failure of important components of equipment, the quality of purchased material and spare parts, design, process control, management systems and human errors

(Mohammadfam et al, 2013).

Maintenance decision issues could be categorized with respect to the time scale involved (Costa et al., 2013).That is, it starts early in the design phase of systems; the type of equipment, the level of redundancy, and the accessibility that strongly affects the maintainability. Furthermore, a very critical decision should be made regarding which event (e.g. failure, the passing of time, etc.) triggers what type of maintenance, i.e. inspection, repair or replacement. The main maintenance objective is to reduce failures of industrial plant, machinery and equipment/component, therefore increasing the plant productivity through uptime and availability.

Maintenance decision maker attempts to select from all the possible maintenance approaches an approach for each equipment or component in a plant. However, the existing practices in plant and equipment maintenance and replacement decisions are commonly based on expert opinions such as using the original equipment manufacturer's recommendations, or subjective replies to common conditions such as responding to a critical component failure by introducing a company-wide programme for doing preventive based replacement or condition based replacement of such components (Fraser, 2014). However, even though such procedures for establishing a maintenance programme may improve plant uptime / availability, it doesn't guaranteed to provide the most cost effective solution (Jardine & Tsang, 2013). The identification and application of the appropriate maintenance approach will enable managers to avoid unnecessary replacement costs, maintain production uptime capabilities and control the deterioration of the system / its component parts. This means that industry could improve its performance if it implements the proper maintenance approach for eliminating the causes of production uptime fluctuation (Ni & Jin, 2012).

## 1.1 RESEARCH PROBLEM

Based on the described background, motivations for the improvement of maintenance performance have been identified particularly to the Oil and Gas (O&G) industry. However, there are still reduced interests for structured maintenance improvement work O&G industry (Mearn & Yule, 2008). This is due to the following;

- Many proposed concepts for maintenance improvements are resource-demanding which makes them less attractive to any company (Sherwin, 2000). This may be an issue that may be related to low interest in participating in research project in his area (Dey et al, 2004).
- Secondly, O&G companies rarely recognize the potential financial contribution of their maintenance activities. This is because the financial metrics for maintenance activities still focus on direct maintenance cost and neglect costs induced by poor or inadequate maintenance strategies implementation (Liyanage & Kumar, 2003).

## 1.2 OBJECTIVE

The main objective of this research is to develop a simple and cost effective framework aimed to formulate and implement maintenance strategies for O&G companies.

Our focus on the oil and gas plants is for two reasons. First, oil and gas plants work with high capital investments which translate to large expenses for production downtime, unavailability and unreliability. This therefore puts pressure on the maintenance function and causes the need for optimum maintenance decisions (Jardine et al., 2013). Secondly, empirical research in this area is limited to date (Bettis et al., 2015).

As part of this research, maintenance strategies used in different oil and gas companies will be investigated and how these policies influence industrial success will be analysed. Maintenance practices in this study will include activities such as planned maintenance, unplanned maintenance, technical analysis, personnel training, planning systems / controlling work, expert systems, multitasking and team work. The degree of usage of these activities influences the business performance outcomes.

Normally, various maintenance actions are used to reduce failures of industrial plant, machinery and equipment and the cost assigned to their failure consequences. These

actions can take several forms such as corrective maintenance (or Failure based maintenance), preventive maintenance (PM), i.e. replacing components at a pre-specified time using statistical models which are based on historical failure data, or condition based maintenance (CBM). In all cases, the decision maker, however, needs to select from all the applicable maintenance strategies the most cost effective for each component, module or equipment.

## 1.3. RESEARCH QUESTIONS

To summarize the previously mentioned purpose, this research ought to do through a few techniques; including literature review, benchmarking and report on North Sea O&G organization's present state, build up develop a model that form the premise for the formulation of the maintenance department's future methodology. With a specific end goal to build up the model, three research questions have been defined. These three inquiries are gone for getting a handle on the key destinations of the postulation furthermore to work as direction along the method for building up the model.

In order to fulfil the research objective, the following research questions have been formulated;

**Research Question 1 – What is the current state of maintenance departments North Sea O&G industries and what is the anticipated state?**

**Research Question 2 – Where do case study companies stand in comparison with other, and what can they learn from others?**

**Research Question 3 – Which factors influence the achieving the anticipated state?**

Majority of the O&G industry views maintenance as a cost driver, rather than a contributor to competitiveness or profitability. This is mainly due to the lack of well balance financial performance. Therefore this research is to understand the present

state at O&G industries maintenance department In O&G industry, maintenance is usually an integrated part of operations. Hence, maintenance strategy is an essential part of production strategy as well as over-all companies' business strategy.

However, O&G companies often lack the strategy to guide maintenance work. In order to facilitate the strategic management of production maintenance, a process for the formulation of maintenance strategies will be developed.

The implementation of maintenance strategies are a form of change management, therefore, companies' management of change procedure should apply to implementation of maintenance strategies. However, it is fair to assume that some other factors hinder implementation of maintenance strategies. Therefore, this research will identify these factors specifically to O&G companies in order to know how to implement and operationalize maintenance strategies.

## 1.4 THESIS OUTLINE

This thesis comprises of eight chapters including introductory chapter. Chapter 3, "Literature Review", provides a comprehensive review why strategic maintenance development is important in oil and gas industry. Chapter 4, "Theoretical framework" introduces the basic elements of maintenance and maintenance strategy, and link them to formation and implementation of maintenance strategy. Chapter 5, "Benchmarking" introduces the approach for establishing operating goal and present a tool developed as part of this research to perform maintenance department benchmarking for north sea oil and gas companies. Chapter 6, "Findings" contains details of the findings from the data collected from case study companies to facilitate discussion on how to formulate maintenance strategy. Chapter 7, "Discussion" contains how the findings are used to formulate maintenance strategy model. Chapter 8, "Conclusion", summarizes the major conclusions from this research. It also shed light on different aspect of maintenance strategy which are considered to require more focus, and also related to continuous improvement for future research in this area.

# 2.0 RESEARCH METHOD

The method used in this research aims at understanding maintenance from a strategic perspective, to understand the present state at O&G industries maintenance department. Then, a model for formulation of a maintenance strategy for O&G companies will be presented. This research is intended to generate useful discussion about issues faced by O&G companies' maintenance department. Hence, the authors have continuously moved between performing literature studies of theoretical framework and documentation of their own observations, respectively collection of opinions from maintenance employees' within the industry. These had been completed so as to gather a strong foundation of knowledge to present a broad and useful result and discussion.

In other to select the research method to be adopted, the researcher had to select a suitable research paradigm. To overcome such a challenge, particular questions were raised by the researcher:

1. What is the core of the social phenomena under investigation?
2. Are human minds creating the social phenomena or is it part of reality and objective in nature?
3. What forms the basis of knowledge that corresponds to social reality and how best to capture and disseminate such knowledge?
4. What is the correlation between an individual and their environment?

From the abovementioned questions, the researcher was able to identify if the research questions and/or propositions relate to the positivism paradigm, interpretive paradigm or critical theory. Once ascertained, the particular paradigm aligned with an appropriate research approach.

The research is doing an in-depth explanation of a social behavior for North Sea O&G industries maintenance department. These can be linked back to the research questions stated in section 1.3.

This Chapter covers the theoretical underpinning on which this research is based. Here the philosophical and theoretical issues that have shaped this research are presented. The adopted philosophical stance will be explained and related to decisions made regarding method of inquiry. This will be followed by an elaboration of the theoretical frameworks upon which this study is built. Prior to concluding the chapter, we will present the conceptual framework that guided this research.

Section 2.1 shows a brief discussion of the various paradigms and perspectives within the management sciences. This sets the scene for a discussion of the nature of the phenomena of interest in this research. Some methodological challenges concerning ontological and epistemological issues will be identified prior to providing an explication of the subsequent research process. Following identification of the research questions addressed by this thesis, an account will be given of the research strategy.

# 2.1 RESEARCH PARADIGMS

Management sciences are characterised by a variety of paradigms and perspectives which stretch across academic disciplines and the full range of social science areas of study and topics of interest. A paradigm, or interpretive framework, has been defined as “a basic set of beliefs that guide action” which support “the researcher’s epistemological, ontological and methodological premises” (Tuli, 2011). Paradigms are therefore axiological, incorporating the ethical and moral frameworks which support the researcher’s world view and the ways in which s/he thinks that world may be known. Perspectives are somewhat different from paradigms, in that they are not as solidified, nor as well unified, although a perspective may share many elements with a paradigm – for example, a common set of methodological assumptions or a particular epistemology (Tuli, 2011). This presents a series of challenges for management science researchers in terms of making methodological choices and decisions about their projects, which are not as evident in the natural sciences where debates tend to focus on the methods used, but rarely debate the ontological and epistemological aspects of research (Easterby-Smith el at, 2012). In the management sciences these issues are more complex than the

somewhat simplistic, if commonly held, quantitative/qualitative view would suggest (Bryman, 2007). This relatively common view is neither entirely relevant to, nor accurately descriptive of, this field of academic endeavour. It is not entirely relevant because its emphasis tends to be erroneously and narrowly focused on research techniques or methods; it is not accurately descriptive, because both the quantitative or qualitative approaches may be evident within the same social science discipline, and even within a single research project (Easterby-Smith et al., 2012).

Paradigms and the perspectives they encompass may be complementary or competitive (Tronvoll et al., 2011). Those situated at either end of the continuum are generally held to be mutually exclusive and competitive, whilst those situated along the continuum may be complementary to a greater or lesser extent. Most management science research projects fall towards the "alternative" end of the spectrum within those paradigms regarded as interpretivist (Tuli, 2011) rather than positivist. However, despite claims of their reduced application, positivist and post-positivist paradigms do still feature in some management science studies (Wahyuni, 2012). A summary of paradigms is set out in table 2.1

| **ISSUE** | **POSITIVISM** | **POSTPOSITIVISM** | **CRITICAL THEORIES** | **CONSTRUCTIVISM** | **PARTICIPATORY** |
|---|---|---|---|---|---|
| Nature of knowledge | Verified hypotheses established as facts or laws | Nonfalsified hypotheses, probable facts or laws | Structural/ historical insights | Individual and collective reconstructions sometimes coalescing around consensus | Extended epistemology: primacy of practical knowing; critical subjectivity; living knowledge |
| Knowledge accumulation | Accretion – adding to "edifice of knowledge"; generalisations & cause/effect linkages | As for Positivism | Historical revisionism; generalisation by similarity | More informed & sophisticated reconstructions; vicarious experience | In communities of inquiry embedded in communities of practice |
| Goodness or quality criteria | Conventional benchmarks of "rigor": internal & external validity, reliability, objectivity | Conventional benchmarks of "rigor": internal & external validity, reliability, objectivity | Historical situatedness; erosion of ignorance and misapprehensions; action stimulus | Trustworthiness and authenticity including catalyst for action | Congruence of experiential, presentational, propositional, practical knowing; leads to action to transform the world in the service of human flourishing |
| Values | Excluded – influence | Excluded – influence | Included – Formative | Included – formative | Included – formative |

| | | | | | |
|---|---|---|---|---|---|
| | denied | denied | | | |
| Ethics | Extrinsic | Extrinsic | Intrinsic | Intrinsic | Intrinsic |
| Inquirer posture | "Disinterested scientist" as informer of decision/ policy makers and change agents | As for Positivism | "Transformative intellectual" as advocate and activist | "Passionate participant" as facilitator of multivoice reconstruction | Primary voice manifest through aware self-reflexive action; secondary voices in illuminating theory, narrative, other presentational forms |
| Training | Technical and quantitative; substantive theories | Technical; quantitative & qualitative; substantive theories | Resocialisation; qualitative and quantitative; history; values of altruism, empowerment & liberation | As for critical theories | Co-researchers are initiated into the inquiry process by facilitator/researcher and learn through active engagement in the process; facilitator/researcher requires emotional competence, democratic personality and skills |

**TABLE 2.1: PARADIGM POSITIONS (ADAPTED FROM MERTENS, 2014)**

Each paradigm has its relative merits and difficulties. These may only become evident when considered in relation to the questions to which the research project is addressed. These philosophical issues may seem somewhat unclear initially. However, their importance lies in the nature of research itself, in that it concerns the study of both abstract and physical entities.

Wahyuni (2012) suggests researchers ask themselves five "difficult questions" concerning the ethical/moral, ontological, epistemological and methodological issues them face, regardless of the (qualitative or/and quantitative) methods they eventually adopt, to meet this requirement:

1. What is the nature of the phenomena, or entities, or social 'reality', which I wish to investigate? (Ontological issues)
2. What might represent knowledge or evidence of the entities or social 'reality' which I wish to investigate? (Epistemological issues, related to1.)
3. What topic, or broad substantive area, is the research concerned with? (Methodological issues, related to 1 & 2.)
4. What is the intellectual puzzle? What do I wish to explain? What are my

research questions? (Connects what you wish to research with how you are going to research it, consistent with and related to 1, 2 & 3.)

5. What is the purpose of my research? What am I doing it for? (Axiological issue and academic contribution, relates to paradigm positioning and encapsulates 1, 2, 3 & 4.)

These questions enable the researcher to think about the paradigm and perspective which best suits their particular research project. This facilitates the construction of a coherent research design which retains a necessary degree of flexibility to allow alterations to be made in light of what is learned when conducting the research whilst ensuring it remains focused and the questions are addressed.

## 2.3 RESEARCH CONCEPTS

The central issue for any research project is to address the research questions posted. Each step in that research process involves choices and decisions relating to the issues encapsulated by Wahyuni (2012) five questions as outlined above. In management sciences, the process is closely related to the researcher's favoured paradigm, and within that, Wahyuni (2012) preferred perspective on the phenomena of interest. These preferences are rigorous, with informed choices which display the skills necessary to conduct research. They also relate to a key quality indicator in research projects: how appropriate is the design for studying the phenomena under scrutiny, and does the methods used fits the question(s) asked.

Research conducted within the positivist or post-positivist paradigm is based on deductive logic and seeks to test a priori propositions or hypotheses to either confirm or disprove them. This type of research is potentially useful when the topic relates to material, measurable objects and the questions relate to questions such as what those things are, how frequently they are encountered, or how two or more of them relate to one another (or do not). Social scientists are often interested in abstract concepts mainly related to human interactions and their questions focus on why certain processes occur (or do not) and how they happen (Wahyuni, 2012).This means that the field of research is not static and frequently the focus is not on

material objects. Therefore, the positivist and post-positivist paradigms are used less often in the social sciences. When they are used, researchers need to ensure they relate openly and appropriately to the phenomena of interest and enable the research questions to be addressed. Topics of interest to social scientists may often be better served by the application of inductive logic (Wahyuni, 2012).This allows the researcher to use data from the "real world" he or she is studying to inform the course of the research, enable new insights to be gleaned, new themes to emerge, and to form the basis for analysis and findings. Although there are methodologies which seek to be entirely inductive, for example some purist forms of grounded theory (Johnson & Onwuegbuzie, 2004) where everything begins with and stems from the data generated, this is not usually the case in practice. Most people do not conduct their research knowing nothing about their topic of interest. In most instances they draw upon various informative sources prior to commencing data gathering, including their own prior experience or "pre-understanding".

Charmaz, (2014) gathered from the findings of previous research about their topic, and by familiarising themselves with potentially relevant areas of theory. The process involves moving back and forth, both mentally and physically, in an iterative and inductive fashion: mentally, they move between what is already understood and what is emerging through the process of conducting the research which creates new insights; physically, they move between their field of research and their own research base. This iterative-inductive process allows the researcher to identify and address their research questions and also focused on coherent research strategy devised at the outset when addressing the "five difficult questions" Wahyuni (2012) from within their preferred paradigm and perspective.

## 2.4 THESIS METHOD

It is important to have a clear standpoint regarding the methodology of a research study. The selected methodology affects the validity, the reliability and research results. Therefore we illustrate how we have selected and design the research methodology.

The methodological problem can be worked out by creating best fit between three concepts, which are the basic assumptions, methodological approaches, and researched problem (Tarone et al, 2013).

Researcher's view of the social world and the approach in which it should be investigated is use to explain how the researcher looks at reality, ideals, etc. The researchers' assumptions, as suggested by Seidman (2013), could be grouped using the subjective-objective dimension as "objectivist" approach or "subjectivist" approach.

The researcher may view reality as objective, that is the reality is independent of the researcher, but can be measured using various instruments e.g. questionnaire. Researcher also view reality as being constructed by the individual involved in the research therefore multiple realities exist in any given situation.

When researchers want to arrive at any assumptions about grounds of knowledge, researcher would define his position on the issue by confirming if knowledge / reality is something that can be acquired, or something that had to be experienced by the researcher. Therefore, the "Objectivist" approach implies that the researcher will be independent of what is being researched e.g. Surveys and experiments, but researchers will have to control for bias by using systematic sample and being objective. While in subjectivist standpoint, researchers interact with what they study, by living with or observing over a prolonged period of time, or by actual collaboration.

For this research, an "Objectivist" approach was taken because of his scientific/ engineering background. This means that the author views reality as objectively accessible, independent and measurable objectively. Knowledge can be acquired, and the researcher should remain distant and independent of what is researched. However, since what could be considered as objective by a certain social setting could be considered subjective by other community's viewpoint, therefore I emphasise that this thesis focuses specifically on a community of researchers within management science and people within a plant or a business management setting.

Operative paradigm in business and management sense describes the relationship

between the methodological approach and the under study scope. It is determined in terms of the methodological procedures used to capture data, analyse, and draw conclusions. Easterby-Smith et al. (2012) stated that the research and solving techniques are either of an empirical or conceptual (theoretical) nature. Sartori & Ceschi (2013) used the terms Nomothetic (general laws and procedures for exact science) and Idiographic (the understanding of particular cases) to represent the quantitative and qualitative research methodologies, respectively. And the characteristics of the Nomothetic and Idiographic approaches in addition to the case survey methodology.

The Idiographic approach is established on a process oriented case study method that highlights qualitative multi-aspects and few in-depth studies, often covering a long period of time with the aim of explaining and understanding. It aims to provide rich descriptions and to make theoretical generalizations. This is in contrast with the nomothetic approach, which deals with quantitative analyses of a few aspects across large samples in order to test hypotheses and make statistical generalizations using systematic and quantitative methods to describe and explain causality.

Nomothetic (quantitative) studies have the advantage of providing rigorous and statistically general cross-sectional analyses of patterns across large samples, but the context of the studied is usually limited. Idiographic (qualitative) studies have the advantage of providing relevant, detailed analyses of complex organizational processes, both in time and in context. They contribute by providing new unexpected insights and by building new theories and concepts (Sartori & Ceschi 2013). Case-survey methodology bridges the Nomothetic- Idiographic research gap. It enhances the relevant findings of prior empirical studies through a systematic analysis of pattern across cases. It overcomes the problem of generalization from a single case study and at the same time provides more in-depth analysis of complex organizational phenomena than questionnaire surveys. But it requires a long time and great efforts in addition to the availability of prior empirical studies (Jurisch et al. 2013)

In this thesis both the Idiographic (qualitative) and Nomothetic (quantitative)

approaches would be used with different research questions and in different periods of research study.

This research use several methods; including literature review, interviews, benchmarking and a status report on O&G companies present state, and develop a model that form the basis for the formulation of the maintenance department's future maintenance strategy. In order to develop the model, research questions have been formulated. These questions are aimed at grasping the key objectives of the research and also to function as guidance along the way of developing the model.

The research method used in this research is a case study approach, which aimed at gaining knowledge about the field of maintenance from a strategic perspective specifically in the oil and gas (O&G) company. This enable researcher to understand the present state at O&G companies' maintenance department, then to finally present a model for the formulation of a maintenance strategy. This research is intended to generate results and useful discussion for O&G plants maintenance department. Therefore, the researcher continuously move between performing literature studies of existing maintenance theoretical framework and documentation of observations, and collection of opinions from maintenance department employees' within the O&G industry. Therefore, gathering a solid background of knowledge so as to present a comprehensive result and useful discussion.

The main approach in collection of data in this research consisted mainly of interviews and observations, i.e. a qualitative methodology. An extensive literature review and benchmarking process was developed and performed in order to collect data and to create an understanding of the subject of study.

This research problem is characterized by different factors. Therefore, to explain and understand the importance of this problem a qualitative method will be used. This follows the research design model presented by Maxwell (2005). Qualitative research approaches emphasize words rather than numbers when data are collected and analyzed compared to quantitative approaches, and are intended to clarify the properties of a phenomena or problem rather than determining quantities (Bryman

and Bell, 2003).

This study has used case study as a research strategy to explore Maintenance practices in oil and gas. The choice of a case study research strategy had been attributed to a number of reasons. Case study has a distinctive advantage over other research strategies when “how” or “why” questions are being posed to discover a current phenomenon and when the researcher has little or no control over the events (Yin, 2003). It offers the opportunity to “explain why certain outcomes may happen – more than just find out what those outcomes are” (Denscombe, 1998:31). This is actually very important for the present study to identify why oil and gas companies are lacking behind in the maintenance strategy propoer implementation. Gray (2004) confirmed that a case study approach is particularly useful in revealing the casual relationships between the phenomenon and the context in which it takes place.

Moreover, the case study enables the researcher to use multiple sources of data and a variety of research methods to explore the research questions which, in turn, foster the validation of data through triangulation (Denscombe, 1998). Thus, any findings or conclusions are likely to be more compelling and accurate (Yin, 2003). This has also supported the use of case study as a research strategy for the current study. The case study strategy is best for gaining a deeper understanding of the research being investigated (Morris and Wood, 1991).

Maxwell (2005) interactive research design model is intended to facilitate the understanding of the actual structure of the research, and also to plan and perform the research. According to Maxwell, (2005) to design a qualitative research, a logical approach cannot be developed in advance and then devotedly be implemented. That is, qualitative research is a continual process rather than a sequential process which as a fixed sequence of steps. Therefore, the research design components interactions with other components demands the design to be changed and adjusted so that the research realizes what it is intended to (Maxwell, 2005).

The interactive model of research design different parts form an interacting and integrating whole and each component is tied closely to several others. The most important connections among the five components (goals, conceptual framework, research questions, methods and validity) included in the model presented in (Maxwell,

2005) can be obtained from Figure 2.1 below.

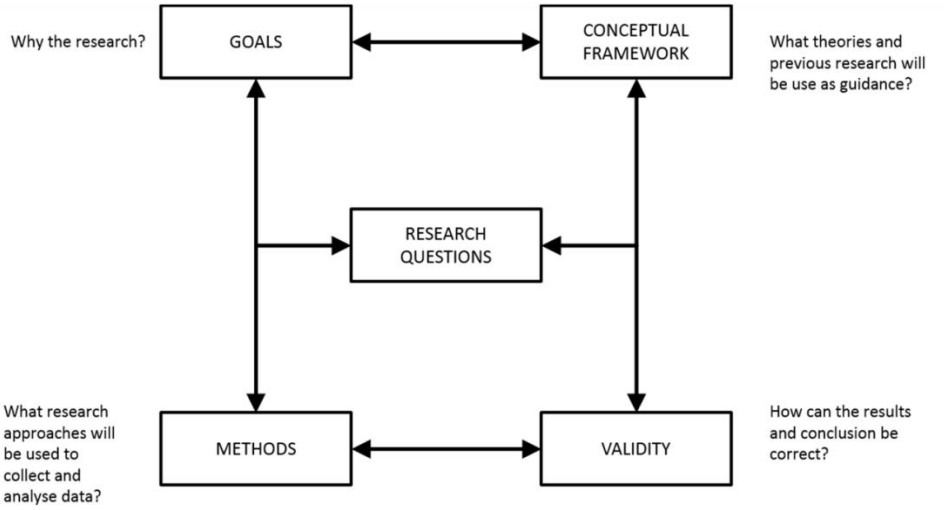



**FIGURE 2.1: AN INTERACTIVE MODEL FOR RESEARCH DESIGN (MAXWELL 2005)**

1. Aims: Why is your study worth doing? What issues do we want it to clarify, and what practices and policies do we want it to influence? Why do we want to conduct this study, and why should we care about the results? Refer to section 1.2.
2. Conceptual framework: What do we think is going on with the issues, settings, or people we plan to study? What theories, beliefs, and prior research findings will guide or inform our research and what literature, preliminary studies, and personal experiences are we drawing on for understanding the people or issues we are studying?
3. Research questions: What, specifically, do we want to learn or understand by doing this study? What do we not know about the things we are studying that we want to learn? What questions do our research attempt to answer, and how are these questions related to one another? Refer to section 1.3.
4. Methods: What are we actually doing in conducting this study? What approaches and techniques are we using to collect and analyze your data, and how do these constitute an integrated strategy? Refer to section 2.0.
5. Validity: How might our results and conclusions be wrong? What are the plausible alternative interpretations and validity threats to these, and how do we deal with these? How can the data that we have, or that you could potentially collect, support or challenge our ideas about what's going on? Why should we believe your results? Refer to section 7.6.

The research to be performed has been structured in accordance with design research methodology as suggested by Blessing and Chakrabarti (2009). The methodology aim to link research questions together and addresses them in a systematic way. The methodology is based on a framework shown below;

| METHODS | STAGES | EXPECTED OUTCOMES |
|---|---|---|
| Literature analysis | Research clarification | The need for strategic maintenance development |
| Empirical data Analysis - Benchmarking | Study 1 | The industry's view on strategic maintenance development / analyse the maintenance strategy and types and to understand the applications in real maintenance day to day work. |
| Assumption Experience Synthesis | Study 2 | Formulation of maintenance strategies |

**TABLE 2.2: THE RESEARCH TO BE PREFORMED, STRUCTURED IN ACCORDANCE WITH THE DESIGN RESEARCH METHODOLOGY FRAMEWORK, ADAPTED FROM BLESSING AND CHAKRABARITI (2009)**

The research performed has been structured as show in the table 2.2 above. This structure is based on the design research methodology, which is its basic form, consists of four main stages, each having its basic means for creating knowledge and its outcome.

To answer the research question and achieve the overall aim of this research, 3 case studies will be performed. Table 2.3 show the different stages of the research to be performed, in which context they will be performed, what focus each study had and which data source.

| STAGE | COMPANY | | FOCUS OF THE STUDY | DATA SOURCES | MAIN OUTCOME |
|---|---|---|---|---|---|
| Literature Review | N/A | Literature analysis | Why strategic maintenance development - systematic review. | Literature | Critical Analysis of research scope and systematic review |
| Study 1 | A,B,C | Empirical data analysis including Benchmarking | View on strategic maintenance factors, strategically important for maintenance. The use of maintenance performance indicators | Interviews Direct observations Documents | The industry's view on strategic maintenance development / analyze the maintenance strategy and types. |
| Study 2 | ABC | Assumption experience synthesis | Development and test of the process for the formulation of maintenance strategies | Interviews Participant observations | Formulation of maintenance strategies |

**TABLE 2.3: RESEARCH STRUCTURE**

## 2.5 RESEARCH QUALITY

It is unavoidable that the researcher will influence his research. This is particularly true when conducting case studies where element of observations. Furthermore, the researcher's epistemology, ontology, background and pre-exposure to the research area influence the research in various ways. This influence might contribute to the research outcome. These can therefore introduce bias on the research to be performed as well as the research outcome.

The researcher has 15 years working experiences in the O&G industry, of which most of the 15 years was on both practical maintenance and maintenance development. This means that the researcher has vast experience in O&G industry. Such an experience most certainly has given the research a pre- understanding of the research area. The pre-understanding will give researcher advantages in designing and conducting the case studies. For example previous experience had help researcher to be able to identify some of the important issues which include assess to key personnel. However, such a pre-understanding may cause bias in the case studies. In other to avoid / reduce the possible bias, the research started this research completing a thorough literature study that focused on findings studies with various views on strategic maintenance in many industries, in order to challenge some of his pre understanding. The research will be taking active precaution to avoid bias, as well as to avoid biased influence on the industrial participants. Outcome of the case studies will be discussed with industrial participants in order to get verification from industrial experts.

It is important to convince assessor of my work that my results are justifiable and not seriously flawed by subjectivity. In other word I must make my outcomes credible. Credibility of research results is determined by their quality, which in turn, is defined by fulfilling the four criteria (Yin, 2003):

1. Construct validity – which is about establishing correct operational measures to lower the risk of subjective judgments.

2. Internal validity – consisting in establishing clear causal relationships, whereby certain conditions are shown to lead to other conditions as distinguished from spurious relationships.
3. External validity – is concerned with establishing a domain to which a study's findings can be generalized.
4. Reliability – should demonstrate that the operations of a study, mostly the data collection procedures, can be repeated with the same results

To increase probability of obtaining high quality research study by meeting the four criteria Yin (2003) suggested the following set of measures and techniques.

| Criteria | Strategy | Phase |
|---|---|---|
| Construct validity | Use multiple sources of evidence | Data collection |
| | Establish chain of evidence | Data collection |
| | Have key informants review draft case study report | Pre test |
| Internal validity | Do pattern-matching | Data analysis |
| | Do explanation-building | |
| | Address rival explanations | |
| | Use logic models | |
| External validity | Use theory in single-case studies | Research design |
| | Use replication logic in multiple-case studies | |
| Reliability | Use case study protocol | Data collection |
| | Develop case study database | |

**TABLE 2.4: STRATEGIES FOR INCREASING CASE STUDY QUALITY. SOURCE: (YIN, 2003)**

To obtain high construct validity I have used the technique called triangulation. Triangulation is often defined as "a combination of methods used to study the interrelated phenomena from multiple and different angles or perspectives"

(Given, 2008). There are four basic types of triangulation (Stake, 1995):

1. Triangulation of methods of data collection – using different research methods (e.g. interviews, observations, surveys, document analysis) in trying to arrive at the same set of conclusions.
2. Investigator triangulation – different investigators independently collect and analyse data from the same sample to solve identical research problem.
3. Theory triangulation – examining data using different theoretical perspectives (e.g. economics, management science, sociology) to check if they can provide coherent explanations.
4. Triangulation of data sources – drawing evidence from a variety of data sources trying to verify the same set of findings. The sources may include different people knowledgeable about the studied phenomena, documents, public records, personal papers, photograph etc.

In my research I have used multiple sources of evidence to establish convergent lines of inquiry in the process of triangulation of sources of data. In other to achieve a situation in which at least two sources independently confirmed a finding. Therefore I have only consider a finding valid when it can be confirmed by at least two sources of evidence and no source presented contradictory information.

The other strategies I have applied to increase construct validity is establishing chain of evidence. To establish chain of evidence is to give the case study reader a possibility to follow the derivation of any evidence, ranging from initial research questions to ultimate case study conclusions. In the research every step of conducting research study was fully documented. Appendix of dissertation will present results from every company in details. For every finding such an amount of information on application of maintenance strategies and its context are presented so that the reader can draw its own conclusions and see if they matched those of the author.

To further strengthen construct validity I use key reviewers of my draft case study

report. At the end of writing-up case-study report from each company a management-board member was consulted to check the most important findings of the study. When justifiable objections are raised I had corrected the case study report accordingly.

With regard to internal validity I have taken the following steps to maximize its level:

1. Data in each case study were analysed using earlier described pattern matching approach for dependent variables, whereby each hypothesis contained a single, measurable dependent variable
2. To increase contrast between solutions only two dichotomous patterns was used. When there is an increase in benefits or decrease in costs as measured by a variable or lack thereof

I also attempted to achieve the highest external validity with a design where both literal and theoretical replications were used. And finally as a means to increase reliability of the findings I have publish in my dissertation a detailed case study protocol containing the instrument as well as the procedures and the general rules to be followed in conducting case study. In fact most of the sixth chapter of the dissertation will contain elements of case study protocol, including general and probing questions, procedure for collecting data, methods of analysis and templates of tables and charts are used in displaying information.

# 3.0. LITERATURE REVIEW

This section aim to detail knowledge gain about the role of a maintenance organization within an enterprise and the various maintenance concepts presented by researchers. This research work began with an extensive literature study. And areas such as maintenance strategy, maintenance management and change management were studied in order to understand the strategic level of maintenance and the management's role.

The key objective of this chapter 3 is to answer Research Question 1 – What is the current state of maintenance departments North Sea O&G industries and what is the anticipated state?

# 3.1. WHY STRATEGIC MAINTENANCE

A literature study was completed to establish the gaps in empirical studies for maintenance strategies in O&G industry. Furthermore to maintenance strategy, the theoretical aspects of maintenance have been reviewed in literature, as well as management of change theories which were established to affect maintenance strategy implementation in other industries (Salonen & Deleryd, 2011).

In addition to different academic databases, relevant maintenance books, articles and publications has also been reviewed. The articles found was mainly through using google scholar which is a tool that linked up different databases. The search was based on the following main words "maintenance", "implementation", "strategy", "oil" and "gas". Furthermore to the previously mentioned words, these were combined with each other and as well "cost" and "management". The outcome of the study is presented as detail description of terms in this chapter and also a critic of the literature are detailed below.

An exhaustive and systematic search of the literature related to the above terms was conducted. The time frame for this literature review was from 1979 to 2014. This

literature search was conducted using, among others, the following electronic databases: Emerald, Science Direct, Informa World, and Springer Link. In total, 224 articles were reviewed. The reviewed articles were published in 52 journals, between the beginning of 1979 and the middle of 2014. Based on this review, only 26 journals published two or more articles during this period. Of the articles reviewed over 59 percent were published in the following five journals:

1. Reliability Engineering & System Safety - 14.
2. International Journal of Production Economics - 16.
3. International Journal of Operations & Production Management - 19.
4. International Journal of Quality & Reliability Management - 26.
5. Journal of Quality in Maintenance Engineering - 58.

The Journal of Quality in Maintenance Engineering is singled out, as providing the most coverage on the topic investigated in this study during the period under consideration.

On systematic content analysis of the reviewed articles, it was discovered that some articles contained some repetition data. Therefore, 75 percent of articles were selected for further review. Only 7 percent of further reviewed articles did not present maintenance measurement strategies at all. In contrast, 71 percent of the articles, with maintenance measurement strategies, were supported by a model.

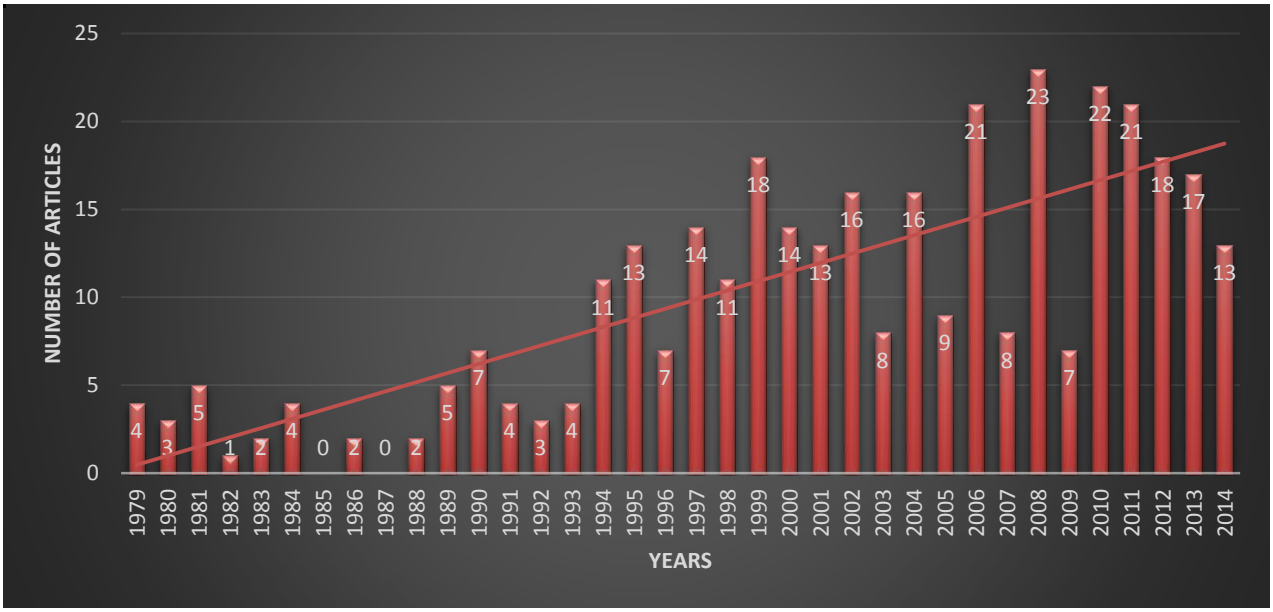



**FIGURE 3.1: NUMBER OF ARTICLES PER YEAR**

As a result of a further literature review, 346 different measures emerged, with a total of 712 occurrences. Figure 3.1 reports the dominant 37 maintenance performance measures, with are observed to have more than two occurrences. Cost is estimated to have about 40 occurrences, which suggest the most used maintenance performance measure and it account for approx. 17 percent of total occurrences. The next most employed measures are safety, economic, technical and human resources. The least employed measures group included training, competences, work incentives, process performance, resources utilization, and maintenance capacity and employee satisfaction. While cost is an important measure, future research would need to also focus on deriving practical performance measures aimed at capturing the human factor of the maintenance performance effort. Which also include the factors that driver or hinder maintenance strategies implementation as this is a function of the maintenance output measurement.

The results of the literature analysis also showed that most of the reviewed research was derived from practical applications. As show on Figure 3.2, 146 case studies related to 25 different industries were reviewed. O&G industry was part of the least represented

industries with less than 2 percent representation in the literature. Future research should attempt to integrate the findings from the case studies into practical implementations methodologies in O&G industry.


**FIGURE 3.2: NUMBER OF ARTICLES PER JOURNALS**

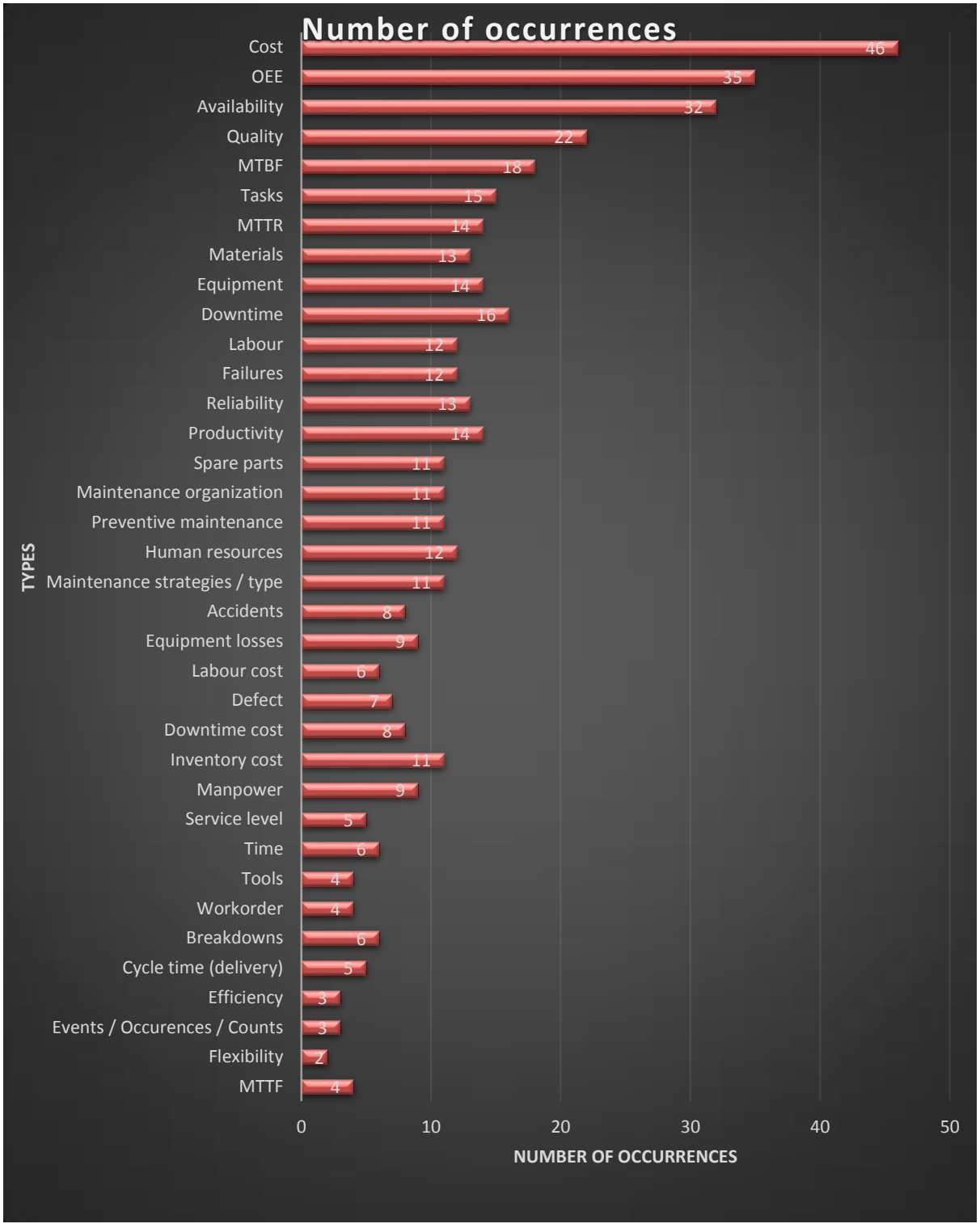



**FIGURE 3.3: NUMBER OF OCCURRENCES PER TYPE**

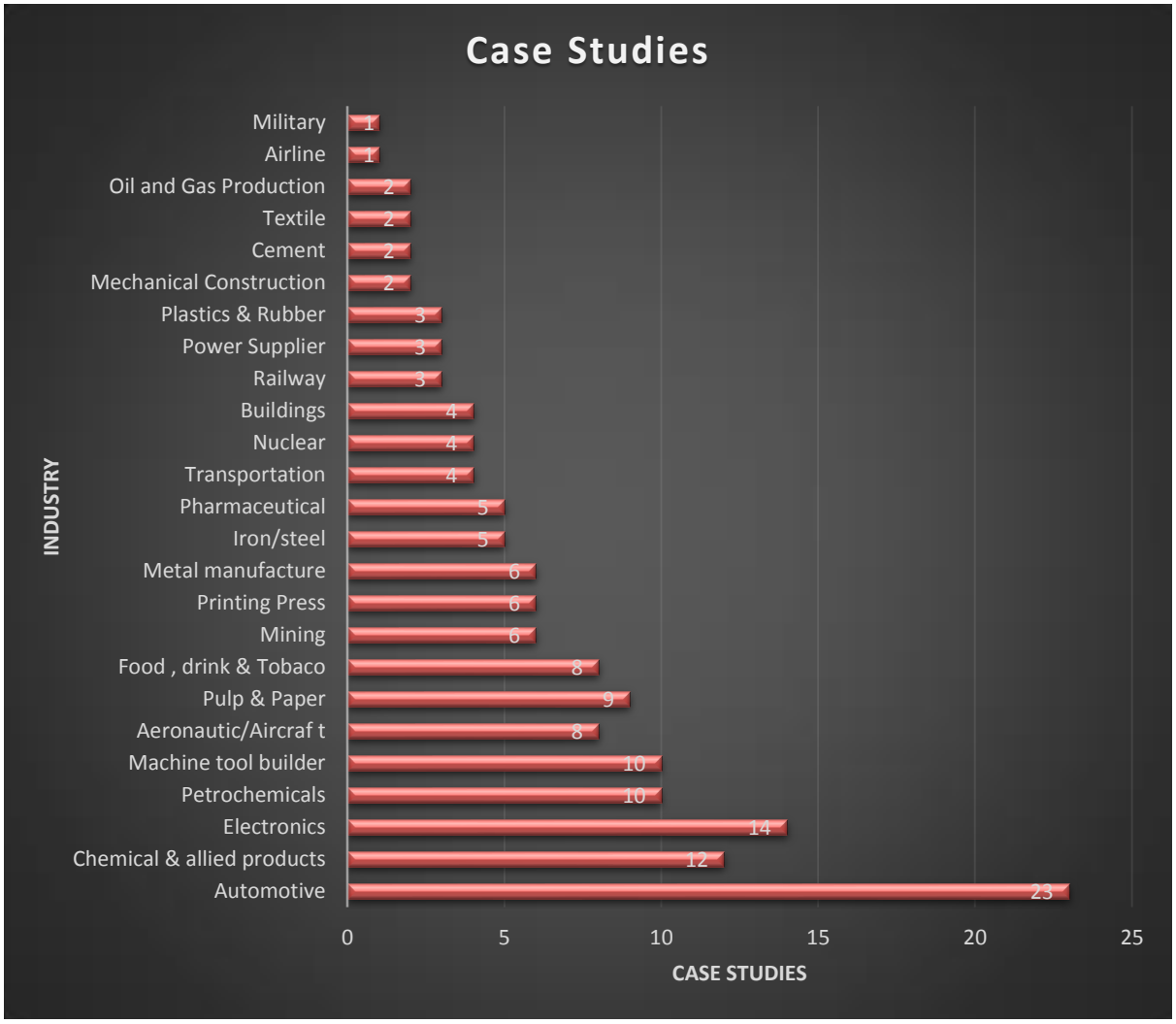



**FIGURE 3.4: NUMBER OF CASE STUDIES PER INDUSTRY**

Further critical review of the selected articles revealed the following findings which are discussed in more details in the next paragraphs.

According to review of maintenance linked literature, it can be concluded that there are no well- defined definitions of maintenance and related terms. In addition, terms like maintenance concept and approaches have no uniform definitions. In the literature, maintenance management only concentration on technical aspect without any link to operation aspects of management. In O&G industry for example, operation and maintenance services are usually a combined organization, this is mainly due to the

nature of dependencies both departments have for production efficiency. (Kennedy, 1993). This relationship between operations and maintenance in the oil industry has always raised more challenges which is yet to be investigated (Simões et al., 2011).

There are numerous financial models from maintenance in literature, they all (in most cases) not have completely differentiate between the costs needed for keeping the established plant reliability and cost that don't add any value to the production department. That is, models in the literature can't be entirely applicable for the optimization of maintenance structure. As discussed in the earlier paragraphs, there are very little empirical researches on maintenance strategies in O&G industry, which explain why no cost model had been formulate or tested on maintenance strategies.

Another very important result discovered from the literature review is the insight that the term maintenance strategy also lacks a common definition among researchers. Possibly, the main reason for this confusion is whether the term should refer to maintenance of a single equipment, or single component of equipment or if it refers to the overall maintenance management. In articles from literature authors had align their ideas to any of the three definitions. For this research however, Pinjala's (2006) definition has been used, which has a holistic view of management strategies. Although there are a number of strategic approaches suggested in literature, some explanations of how to formulate a maintenance strategy which supports the overall company goals does exist in O&G industry as there are not references in literature to suggest it exist. Furthermore, in the instant where maintenance strategies formulation processes are suggested in other industries, they are often rather complex and resource involving, signifying that the process are mainly developed for long time and large investment on maintenance (Van Horenbeek & Pintenlon, 2014).

The outcome from this literature review also include the aspect where researchers emphasize that despite the fact that many companies fail when implementing strategies, the subject of strategy implementation is not been studied to any large degree particularly in O&G industry which has little or no research completed in this

aspect . Similarly, there are very small amount of published works on functional maintenance strategies in general.

According to Tsang & Chan (2000), the factor hindering or driving maintenance strategy implementation are change management, and concepts implementation are more or less the same. They both focus on; Cultural aspect, Vision, Communication Resource Assignment, Leadership, Training and education. Numerous published articles mention a lack of insight as hindrance to successful implementation of strategies and maintenance concepts. Sohal and Terziovski (2000) also argue that companies' management should have adequate training in quality management principles in other to successfully implement maintenance. There is also an argument by Parida & Kumar (2006) that performance measures in general should reflect the overall strategic goals of the company. Also, there is an argument that maintenance performance measure should cover different aspects of the organizations goals, such as cost, productivity, etc. (Parida & Kumar, 2006). In addition to maintenance performance indicators, there is a vast amount of metrics to choose from. In the studied literature, no mentioned performance indicator shows the indirect cost of maintenance.

In addition to literature review, researcher also completed an industrial cross section review specifically to North Sea O&G companies using published data from Noreng (2016). This is summarized in section 3.3

## 3.2. WHY THE INCREASE IN MAINTENANCE COST

In the North Sea UK section, from 2003, the average barrel of oil equivalent development cost has risen by 16% yearly (Noreng, 2016). The high cost has serious implication in the North Sea reservoirs; therefore new development has been half over last 10years. For example between 2011 and 2013, the North Sea O&G industries drilled estimated 121 development wells yearly compared with estimated more than

200 yearly between 2004 and 2005 (Noreng, 2016). Although it can be associated more complex reservoir structure, but also high cost plays a leading role in discouraging reservoirs development. Hence, major reservoirs discovery development had been postponed or cancelled resulting to more than £10 billion investment in the UK Sea of the North Sea and increase in production figures. The high costs include both operating and capital cost, which both contribute the cost of development of a new field. (Covert et al., 2016)

With these rising cost, the UK Section of the North Sea will most likely halt exploration and hence implied future target O&G production figures which will have a major impact on the taxes , companies revenue etc. (Noreng, 2016)

The main factors attributed to the rise of cost in North Sea are mainly age of platform/ plant and the complexity of the reservoirs structure. Other factors include the safety and environmental regulatory bodies. (Robinson et al., 2016)

In a more detailed cost analysis against the sector activities, Mckinsey Company (2004) perform a benchmark which include interview with few North Sea managers and it shows that increase North Sea company expenditure often have cost due to inefficiencies in both OPEX and CAPEX.

Further analysis suggest the annual increase in North Sea cost between 2003 and 2012 is due to the following factors; (Robinson et al., 2016)

1. Increased activity levels
2. Increased input costs per unit of output product which includes service, labour etc.
3. Lower efficiency — i. e., using more resources to complete the same activities

**1. Increased activity levels**

The complexity of the North Sea had increased significantly over the last decade. There are no many platform/plant actively producing oil and gas from various reservoirs. And

majority of these platforms have passed their designed life, hence increased maintenance and integrity inspection required to support productions uptime. This therefore increases OPEX cost, in UK section of the North Sea, platform operators had spent over £1 billion per year to upgrade and extend the life of platform. For example a platform manager confirms that maintenance and integrity activities increase by over 57% yearly between 2009 and 2013.

**2. Increased input costs per unit**

New investments in North Sea O&G development with increase in international opportunities have increased the demand for professionals. Engineers and technicians are in high demand, which had a major effect on the cost of hiring and retaining professional. These therefore drive up OPEX and CAPEX cost.

**3. Lower efficiency**

Lower productivity, increasingly over designed / over engineering activities, and poor supply chain activities practices are the main cause of escalation of costs. Inefficiencies is without a doubt the major contributor to cost escalation in the North Sea O&G industries. Some other inefficiency is due to regulatory changes but majority is down to operator practices and approaches

- Lower productivity: Work productivity has declined UK Section of the North Sea O&G industries. For example data from Noreng (2016) show that in 2012, 179 core personnel travelled offshore per platform. That is 26% increase from 2006. Work productivity was measured using a metric of hours per activity and a decline of over 4% p. a. was observed between 2001 and 2009. One reason could be the fall in the number of weeks a typical worker has to be offshore per year, hence requirement for more personnel to cover platforms.

- Over- design and specification: The increased complexity / customization had exaggerated cost inefficiencies. For example, in the review of CAPEX cost the patterns for design of topside O&G platform was compared with similar platform

with same production capability. It was observed that the work processes have become over-emphasized, which is often driven by health, safety and environmental (HSE) requirements and also due to operator oversight of contractor activities. For instance, at one large platform, a broken flow meter would have been replaced as part of standard maintenance routine in the past but nowadays, it is completed as a brownfield modification, hence process become time-consuming and significant increase in costly.

- Poor purchasing practices. In O&G industry 70% to 80% of all expenditure (CAPEX or OPEX) are on third parties, therefore the O&G industry is deeply dependent on procurement and supply chain practices (Robinson et al., 2016). According to the McKinsey Global Purchasing Excellence survey which was conducted on over 400 organizations in 20 industries, it was noted that O&G sector was ranked as one of the lowest on the index. Some of the factors attributed to this is lack a clarity on contractual strategy which in turn ensure quality in operations and projects

Although the challenge is great, many of these drivers of cost escalation can be tackled by operators. This research address some of the factor highlighted in this section with concentration in maintenance which is a subset of OPEX cost.

## 3.3 STUDY 1 – THE O&G INDUSTRY'S VIEW ON STRATEGIC MAINTENANCE DEVELOPMENT

The first study was performed to compare the view on maintenance strategies in oil and gas companies with and without formulated maintenance strategies. It was performed as a multiple case study. The case study companies were selected in order to reflect a similar maintenance organization structure which includes a maintenance managers, maintenance planners, maintenance engineers and maintenance technicians.

The geographical location had not been considered as a variable as the case studies plants will be consider on the same geographical location.

We will not be considering the difference in maintenance strategies according to geographical location in this research although researcher believe from experience and literature that there geographical location influence maintenance strategies (Pinjala et al., 2006).

Based on the literature review, researcher's experience and interviews which was conducted on three companies in order to find out their view on maintenance management and its strategic implications. When studying a system that depends on human opinions and their resulting decisions, interviews of key people within the model is a valuable data base (Yin, 2009). The respondents were managers responsible for maintenance in the companies, and the interview questions were direct and open. Each interview took about 1 hour. In addition to interviews, observation notes was taken during the company visit .By observing the studied system, the researcher was able to verify or dismiss data obtained through other sources such as interviews and documents (Marshall & Rossman, 2014). Further, additional documentation was requested from these companies. Yin (2009) finds that documents play an explicit role in any case study. Relevant documents provide reliable data as to the formal structures and real outcomes of the system. The collected data was analyzed through pattern matching logic and cross-case analysis.

Pattern matching logic is one of the better analysis methods available for case studies (Yin, 2009). This technique is essentially comparing empirically observed patterns with predicted ones. The predictions was based on result from literature review, as well as the researchers own experiences from the O&G industry.

Cross-case synthesis is an analysis technique in which the researcher aggregates findings from a series of individual studies (Yin, 2009). This technique is particularly relevant when case study consists of more than one case.

As part of the analysis and to understand the strategic level of maintenance in each of the case studied companies, Maintenance Section Review (MSR) benchmarking tool will be developed. The MSR will comprise of questions within areas concerning O&G plant maintenance department. These questions are specific to O&G production industry, which cover areas like asset register, maintenance objectives, maintenance concepts, maintenance organisation, planning & work preparation, workflow management, purchase & inventory management, KPI a& audit, cost & benefits, breakdown analysis and organisation development. Each question was justified by published literature which is detailed on chapter 4. The MSR was developed as a benchmarking tool in order to perform an accurate comparison between case study companies, and then present the results clearly.

This study show how different O&G companies view maintenance as a contributor to the company's overall goals, further, it revealed how companies view maintenance related KPI.The aim of the study was to develop tools and methods for strategic maintenance management and to present a model for formulation of a maintenance strategy. These tools and methods have to be simple and easy to use, so that O&G companies can increase the performance of their maintenance activities with little resources.

## 3.4 STUDY 2 - FORMULATION OF MAINTENANCE STRATEGIES

The study two was developed and tests a work process for the formulation of maintenance strategies in O&G Company. The study was mainly based on workshops and participative studies. Based on the findings from study 1 & literature review, a process will be proposed for the formulation of maintenance strategies.

The participants in this study are the researcher and two people each from each case study company. The participants expected from the companies are people responsible for maintenance. The researcher and company's representative was developed and tested a

work process for the formulation of maintenance strategies. Workshop was organized and the steps of the process were discussed. By researcher participating, he becomes a part of the studied system which provides data otherwise hard to obtain (Yin, 2009). The data was analyzed through pattern matching logic, comparing the outcome of the steps with the predictions based on the team members' experiences and knowledge.

# 4.0. THEORETICAL FRAMEWORK

The theoretical framework created is expected to present maintenance and corresponding methodologies and philosophies within maintenance field. The theoretical framework should also be used as a basis of knowledge within the area of maintenance in order to create a model for the formulation of a maintenance strategy.

# 4.1. MAINTENANCE STRATEGY

Maintenance strategy is a management method used in order to achieve the maintenance objectives (prEN 13306, 1998). The meaning of Maintenance Objectives is the target given to or recognized by the management and maintenance division (Horrenbeek, 2014). These objectives may include availability, cost diminishment, environment safeguarding and safety (Horrenbeek, 2014).

A strategy is the way to achieve the aim which intends to make distinctive strides or performing activities. The general course, an arrangement which depicts the activities to be performed is portrayed by the strategy (Campbell and Reyes-Picknell, 2006).

The content in the maintenance procedure is a blend of methods and/or strategies which relies on upon components, for example, the nature of the plant, the maintenance objectives or the equipment that will be maintained, the workplace and the work process designs (Alsyouf, 2007). In a competitive method the companies' objectives and the methods expected to achieve the objectives joined (Salonen, 2011)

Various maintenance procedures and ideas have been recommended by academics and industrialists and executed by professionals. Distinguishing proof and execution of numerous investigate, repair and replace choices (maintenance activities) are included in the maintenance procedure, and the methodology portrays which occasions (e.g. condition, passing of time, failure) that trigger which sort of maintenance activity. The worry is about planning the plant optimal maintenance plan, furthermore the best life

arrangement for every unit of the plant, which ought to be done in co-ordination with production and other functions (Alsyouf, 2007).

### 4.1.1 THE IMPORTANCE OF A MAINTENANCE STRATEGY

Industry today is compelled to expand production efficiency consistently keeping in mind the end goal to be focused. The maintenance of production equipment is one imperative component of this (Salonen, 2009).

A strategy is constantly taken after, either deliberately or unwittingly. At the point when a system is not expressed, just took after unwittingly, the outcome is regularly an open methodology, which causes events and others to pick the course. In the event that an organization does not work proactive to stay away from failures or the results of failures, then the maintenance is working on a raced to- failure approach (Campbell and Reyes-Picknell, 2006).

In the event that there is a well thought through created maintenance approach which is known to everyone, then new issues rather than old repeat ones will emerge. Strategies are the real activities expected to execute the procedure, which concerns the management of processes, individuals, and physical asset (Campbell and Reyes- Picknell, 2006).

The technique are produced to make a course of how to meet the targets of most extreme accessibility/dependability and increasing careful learning in the specialized frameworks with a simple to utilize and organized methodology (Waeyenbergh and Pintelon, 2002). The goals may have all the earmarks of being intuitive, yet not until they are composed down can the significance of a proactive maintenance and reliability organization of an organization and its assets be highlighted. The adequacy of an organization will dependably be sub-streamlined unless the reliability and maintenance organization works with a proactive rundown of targets. Consequently, reliability and

maintenance is more than a "fix it when it breaks" capacity (Wireman, 2010). The goals must be acknowledged as per safety and environmental controls furthermore in a cost effective way. The mix of machines, men, strategies and means into a very much planned technique requires fundamental managerial capacity (Waeyenbergh and Pintelon, 2002). (Waeyenbergh and Pintelon, 2002) points out three critical success factors:

1. The direct production personnel and the maintenance craftsmen and technicians need thorough knowledge of maintenance technology and competence to prevent disruptions early in the production process.

2. Management skills regarding maintenance planning and control tasks as well as human resources management are of major importance.

3. Flexibility to exploit trends and opportunities.

At the point when building up a sound performance management framework a major stride is to build up a complete reliability and a maintenance organization (Wireman, 2010). Without the business characterized it is not clear what the performance management framework measure, in this way, appropriate assets should be committed to guarantee an all-around characterized and endorsed reliability and maintenance method. Until then, performance indicators for reliability and maintenance business ought not to be produced (Wireman, 2010).

Salonen (2009) performed a case study where the industry's perspective on maintenance technique was examined. Six organizations were incorporated into the study and four of these organizations had no maintenance technique, nor did they utilize measures pertinent to maintenance control. Salonen (2009) has presented another case study where partner inclusion in one organization was tested. One imperative conclusion from this study was that partner involvement may prompt a consistent perspective on the maintenance department anticipated that deliveries would the production department, which may add to higher collaboration between these departments. Along these lines the

organization's efficiency will thus profit by this (Salonen, 2009).

In addition, (Bergman and Klefsjö, 2010) drew attention to that both the inner and outside clients, i.e. all partners, should be fulfilled. For this situation, the maintenance experts and technicians are internal clients, as indicated by (Bergman and Klefsjö, 2010) should be satisfied with in order for them to do a good work. There are a few external clients, one of them is the production department, and who is the client which really uses the service, and should be satisfied by the service given by the maintenance department. Other external clients brought up by (Bergman and Klefsjö, 2010) are the general population who live in the environment that is affected by the organization. As per (Bergman and Klefsjö, 2010) does the client who uses the service frequently assume a dynamic part in making the service.

It is maintained that partners of an organization have the following two characteristics (Salonen, 2009):

1. The ability of an organization to achieve its objectives is affected by them.
2. For helping the organization to achieve its objectives they require something in return.

### 4.1.2 FORMULATION OF MAINTENANCE STRATEGY

In order to formulate a competitive strategy is it of important to consider the following key factors (Salonen, 2009):

1. The company’s strengths and weaknesses
2. The key implementer’s personal values
3. Opportunities and threats from the industry
4. Expectations from the society

Number one and two above are internal to organization while number three and four

are external (Salonen, 2009). The procedure should be upheld by strategic arrangements which must be executed, without strategic arrangements comprising ctivities won't what to do or how to do it, be clear (Campbell and Reyes-Picknell, 2006). Industrials frameworks develop quickly, to stay aware of the changing frameworks and environment the maintenance methodology along these lines should be investigated periodically (Waeyenbergh and Pintelon, 2002). This requires an organized as well as an adaptable maintenance technique which permits input, change and reacts to prerequisite changes (Campbell and Reyes-Picknell, 2006). Besides, the technique ought to be customized, which suggests that it ought to consider every single applicable element of the circumstance on-hand. All things considered, the necessities of the organization will be custom fitted in the maintenance procedure. By that, the maintenance procedure will be one of a kind for every organization except the hidden structure expected to grow such methodology might be exceptionally equivalent. The desires of an organized structure for maintenance idea advancement are extremely equivalent in verging on each case (Waeyenbergh and Pintelon, 2002).

When building a system for maintenance it should be considered as an all- encompassing activity (Waeyenbergh and Pintelon, 2002). If the organization knows the present state, i.e. where the organization is today, then a general vision can be made and a decent approach to do this is by conceptualizing for thoughts on effective practices (Campbell and Reyes-Picknell, 2006). The vision to accomplish is an idealized picture of a future state which is desired for the organization. At the point when the vision is detailed it is imperative to be imaginative and urge the employees to think new and big (Thomas, 2005). When the vision is made then the organization states what to do to accomplish it (Campbell and Reyes-Picknell, 2006). if the present state is not notable it is desirable to perform point by point investigations, an audit of what is done and how it is done, before expressing the vision and the technique (Campbell and Reyes-Picknell, 2006).

Kelly (2006) has displayed a business-focused model (BCM) for the formulation of a maintenance technique, see figure BCM below. The methodology is called business-focused in light of the fact that it is gotten from, and driven by, the business goals

identification, which then are deciphered into maintenance objectives and support the formulation of the maintenance technique (Kelly, 2006). At the point when to define a maintenance methodology it is imperative to see how the plant works, the relationship between the plant and its business sector and the maintenance capacity inside this setting (Kelly, 2006).

As indicated by Kelly (2006) maintenance targets should be built up in connection with the production and business goals, before this is done it should be seen how the maintenance function will be influenced by its dynamic connection with the production function. Setting the targets should be done in conjunction with the production department, because production and maintenance objectives are securely attached (Kelly, 2006). The production and maintenance targets likewise should be good with the business goals which can be gotten in Figure 4.1 below.

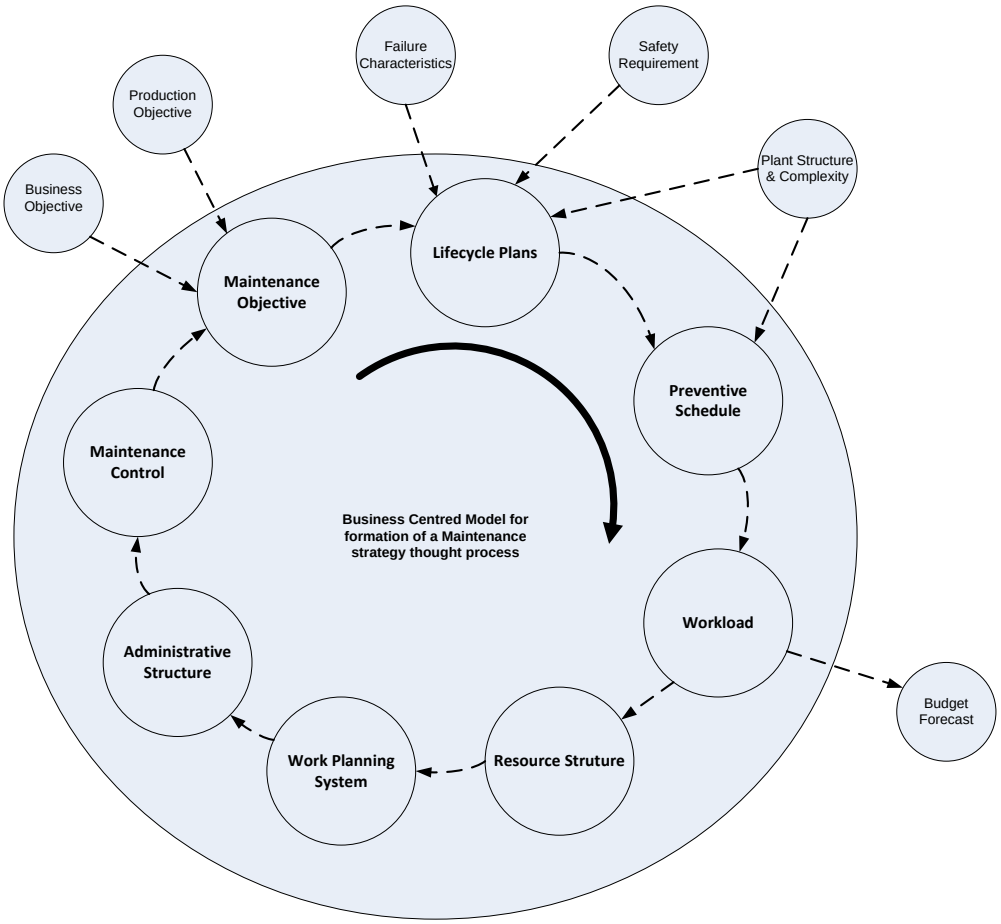


**FIGURE 4.1: A BUSINESS-CENTRED MODEL (BCM) FOR THE FORMULATION OF A MAINTENANCE STRATEGY (KELLY, 2006)**

The big circle in Figure 4.1 above represents the strategic thought process of the maintenance manager which begins with the maintenance goal of the plant (Kelly, 2006). McAllister (1999) has likewise introduced a model for the plan and review of a maintenance procedure. It is brought up that maintenance ought to be considered as an accomplice inside the business with the common general point, that is, to deliver and offer items at a worthy margin of profit. With the goal this should be accomplished it must be comprehended that all functions inside the business adds to profitability. In this manner, the maintenance function ought to adjust to the general business objectives. McAllister (1999) additionally calls attention to that before building up a maintenance methodology the requirement for change ought to be built up. In the maintenance philosophy ought to change be held onto as a noteworthy desire and constituent (McAllister, 1999).

The maintenance system improvement process begins with expressing the maintenance philosophy which is an outflow of the maintenance function's role inside the organization and the picked approach for how to satisfy it. The following steps is to consider the points and goals of the maintenance function. The points can be at corporate, production and maintenance levels and the targets must react to the main driving forces from production. The third step is to survey and assess the maintenance practices and issues. Figure 4.2 below represents the scope of maintenance approach parts and relating practices to consider for this evaluation which, after completion, might be utilized to build up a maintenance program. At that point ought to strategies, for how to incorporate existing practices with new ones, be produced. The last step is to decide the implementation plan (McAllister, 1999).

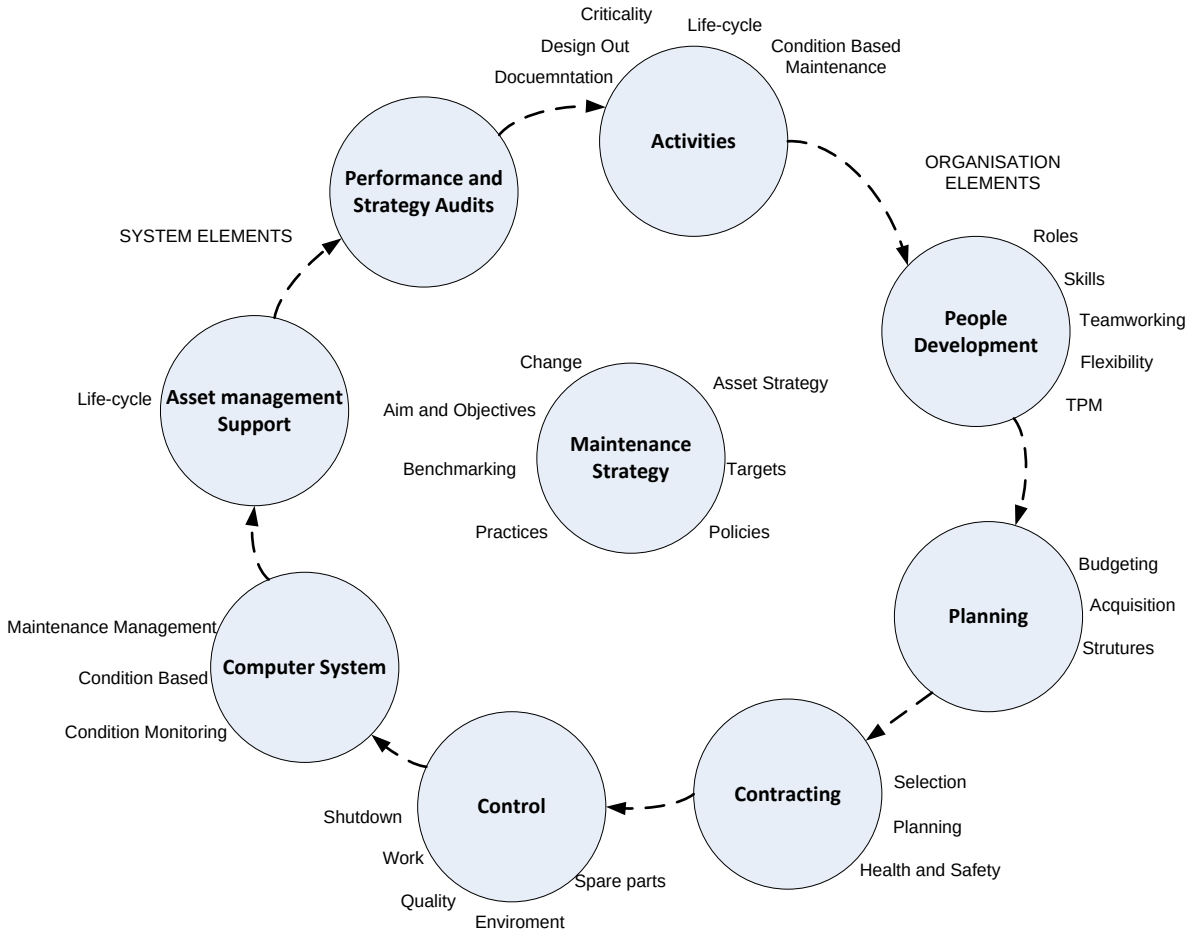



**FIGURE 4.2. THE RANGE OF MAINTENANCE POLICY SECTORS AND CORRESPONDING PRACTICES (MCALLISTER, 1999)**

The factors that shows the general organizational structure, technically define each system to maintain, and also factors that depict interrelations between the diverse frameworks ought to be tended to. The maintenance concept won't achieve its maximum capacity on the off chance that a portion of the required perspectives are excluded in the improvement of the procedure. An indiscreet investigation, lost information or absence of learning may be purposes behind inadequate strategy. Because of the operational effect that maintenance may have on the equipment's performance and the inclusion of high immediate and also indirect cost, for both in-house and outsourcing maintenance, the improvement of the maintenance methodology ought to be done structurally (Waeyenbergh and Pintelon, 2002)

Concerning the formulation of a maintenance strategy a model by Salonen (2009) will likewise be introduced in this thesis. This model is a schematic perspective of the work-process while defining a maintenance technique and is displayed in Figure 4.3 below.

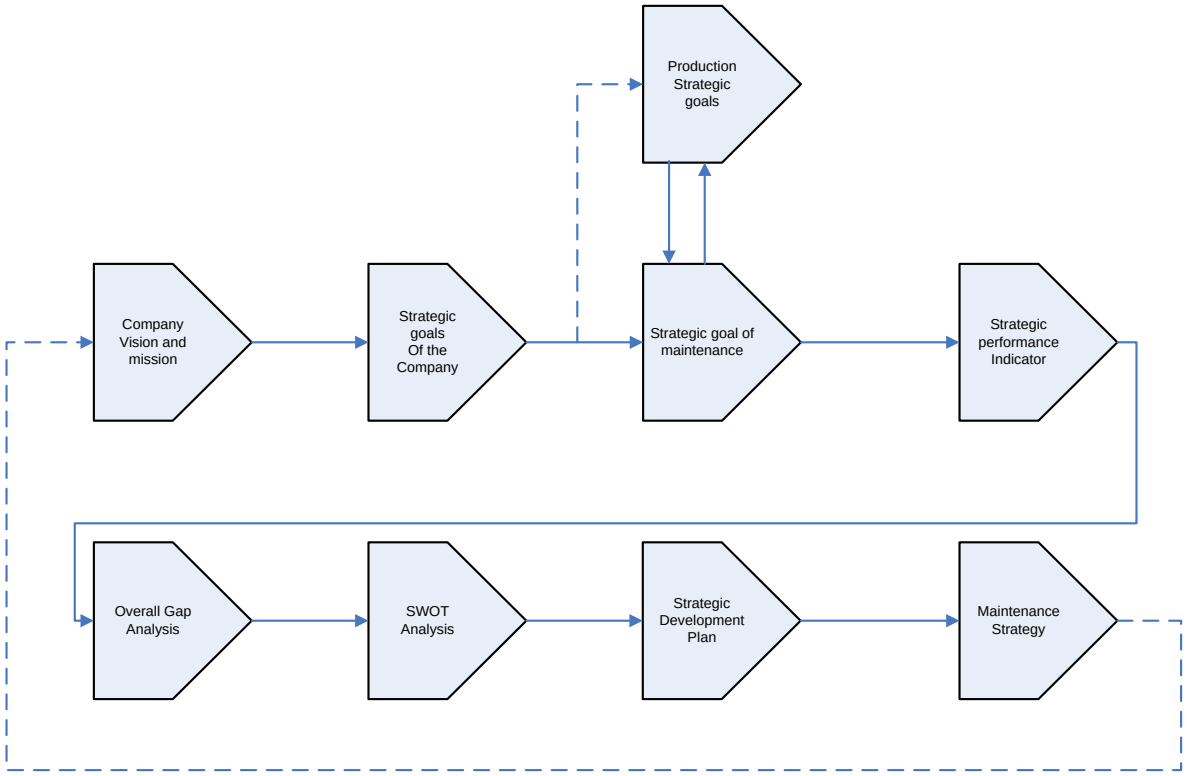



**FIGURE 4.3: A SCHEMATIC VIEW OF THE WORK-PROCESS WHEN FORMULATING A MAINTENANCE STRATEGY (SALONEN, 2009)**

Salonen (2011) describes the different parts within the model as follows:

1. Company vision and mission – The strategy should be based on the company vision and the mission.
2. Formulation of the strategic goals of the company – These goals should be supported by all functional strategies. Regarding the maintenance strategy it is essential to consider not only the overall strategic goals of the company, but also the goals of the production which is the customer to the maintenance organization.

3. Define the strategic goals of maintenance – The strategic goals of both the production department and the company should be considered and the goals should reflect both effectiveness and efficiency. This is, in order to satisfy all stakeholders.
4. Tie the strategic goals to strategic performance indicators – The performance indicators are measured in order to evaluate the fulfilment of the strategic goals. All stakeholders, such as the production department and the owners, should preferably be involved when choosing the performance indicators. The acceptance of the strategy among the stakeholders will with that approach increase. In order to avoid misinterpretations, the indicators need to be well-defined. Responsibilities, data collection methods and sources of data may also be defined in the strategy formulation.
5. Perform the overall GAP – analysis – Address current or potential gaps in maintenance performance and when this is done, identify factors which potentially may influence the gap between current and desired levels.
6. Perform a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis – Address the identified gaps in relation to factors considered strategic for the development of the maintenance function.
7. Determine a strategic development plan – This plan can be set up by prioritizing the actions identified from the SWOT analysis.
8. Formulate the maintenance strategy – When the strategic development plan is in place then maintenance strategy may be formulated (Salonen, 2011).

In order to formulate a maintenance strategy and produce a maintenance plan, following questions need to be answered (Gupta, 2009):

- What should be done?
- Which are the most important items?
- What are the legal requirements to be considered?
- When can the work be performed in order to avoid loss of production?

- In which frequency should surveys, inspections, works and tests be carried out?
- From where does the money come?

Salonen (2011) propose a structure to follow when to formulate the maintenance strategy, see Figure 4.4 below;

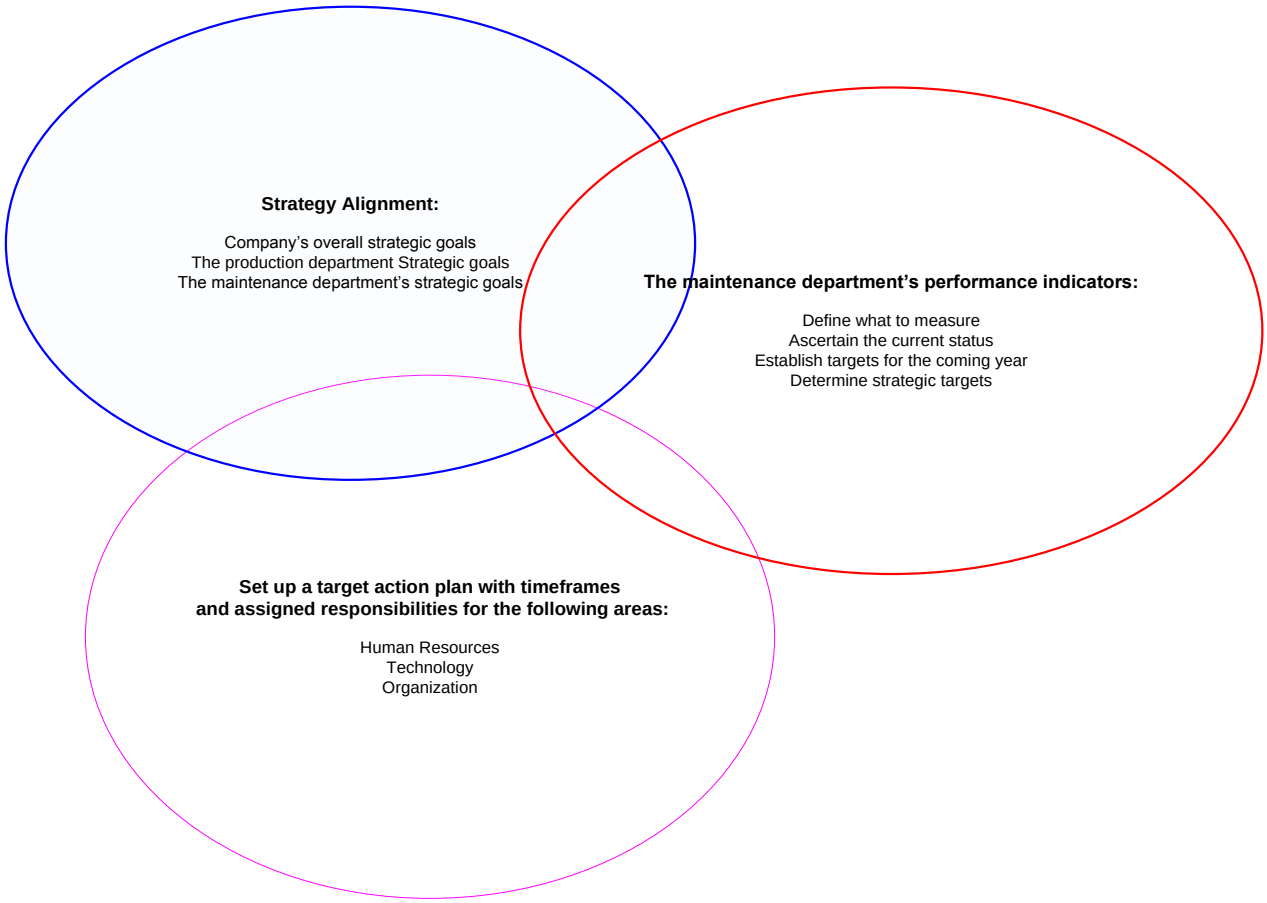



**FIGURE 4.4: A STRUCTURE TO FOLLOW WHEN TO FORMULATE THE MAINTENANCE STRATEGY (SALONEN, 2011)**

A maintenance system ought to work as a guide who permits and incorporates choice; it is not intended to go in only one direction. The maintenance technique must stay adaptable with the end goal it should change with the organization's circumstance. The guide can be made in view of results from benchmarking and from perceptions of the

organization's own best plants and in addition others as of now do. The vision is the portrayal of desired excellence in any case from where the direction starts. The effectively existing practices should be changed on the off chance that they don't coordinate the vision, and this is in any case in the event that it is great or terrible. The arrangements should be pretty much definite reliant on the amount of progress desired (Campbell and Reyes- Picknell, 2006).

### 4.1.3 IMPLEMENTATION OF A MAINTENANCE STRATEGY

There are numerous suppositions on how the system ought to be actualized, yet something that portrays most is that there is no standard for how the implementation to take place. Rubenowitz believe that each organization has its own particular issues and will confront its own issues. The states of which will differ enormously, which makes it hard to utilize standards. The following are some methodologies.

As indicated by Campbell and Reynes-Picknell (2006) the usage on the strategic level depends on the system and the accompanying parts are to be incorporated, see Figure 4.5 beneath:

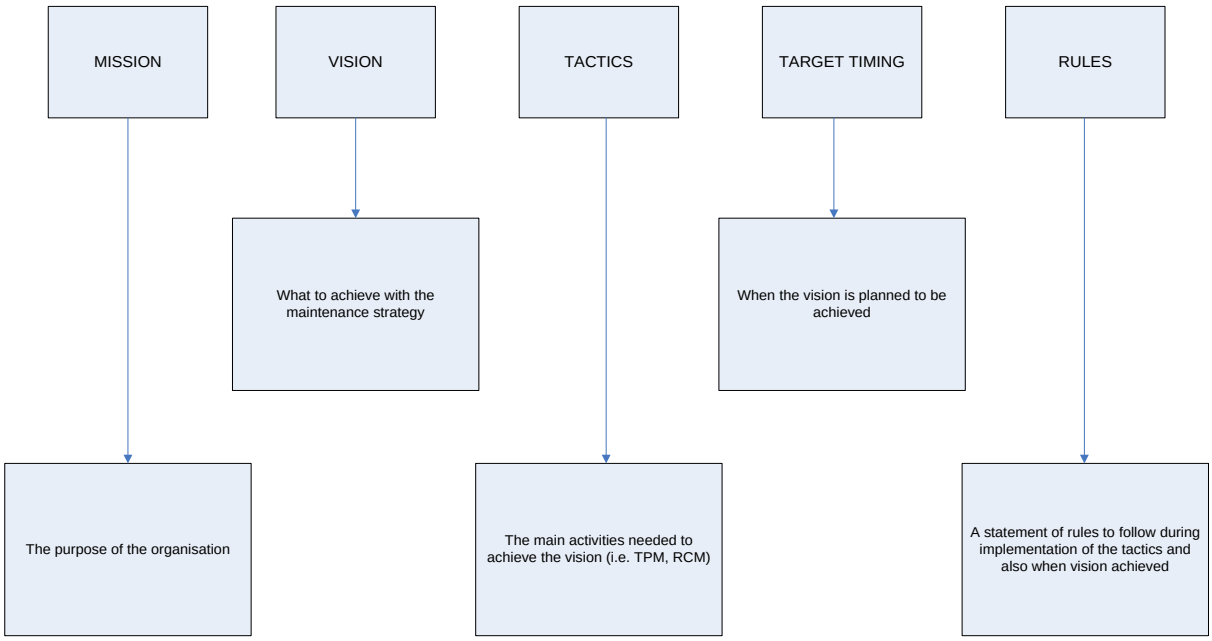



**FIGURE 4.5. COMPONENTS INCLUDED IN THE STRATEGY (CAMPBELL AND REYES-PICKNELL, 2006).**

Supply chain, finance, accounting, training departments, operations, and plant management will all be influenced by the maintenance procedure accordingly, it ought not to just be the maintenance department's in charge of assembling the technique. Consequently, it is collaboration. The subtle elements in the implementation plan don't need to be incorporated into the report or articulation of the procedure, those can be overseen independently, the system ought not to be excessively muddled with unreasonable points of interest – it ought to be straightforward. The definite implementation plans ought to ideally begin to be produced first when the procedure is expressed, and push ahead with the implementation details and execution of them step by step. Figure 4.6 below represents the improvement procedure of the maintenance technique which is exceedingly effective: Plan – Do – Check – Act (PDCA cycle).

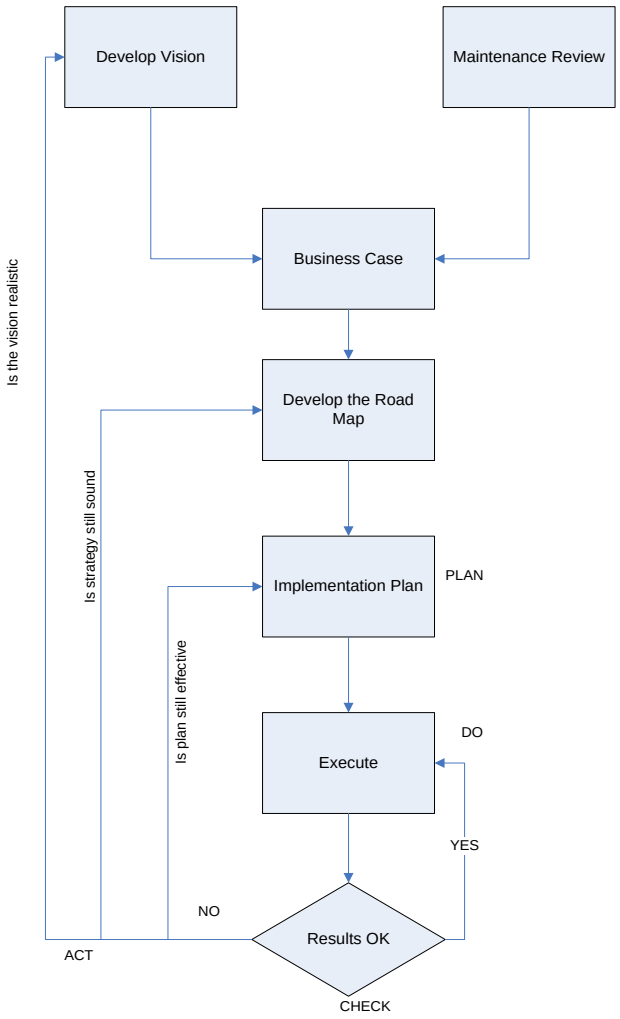



**FIGURE 4.6. STRATEGY DEVELOPMENT PROCESS USING THE PDCA CYCLE (CAMPBELL AND REYES- PICKNELL, 2006).**

The whole evolution to the stage where the desire is reached should be enclosed in the strategy. The execution plan, an account of who will do what in stated time frames, is developed from the road map. From each part of the vision a work stream will be formed (Campbell and Reyes-Picknell, 2006). When developing an implementation plan the following should be considered:

1. The task and its key activities
2. Prioritize the initiatives. If there are several ongoing improvement projects, how much senior management time should be spent on each?

3. Estimate needed resources and level of effort
4. Appoint the “champion” which assignment is to ensure successful completion and the “sponsor” which tasks are to provide the resources
5. Establish start date, completion date, and milestones along the road
6. Define the goal to be achieved on successful completion, and the parameters to measure to determine if the project is on the right track
7. Define and evaluate the challenges along the way that can derail the efforts or cause a lose focus

The implementation of the plans is significantly more than a specialized project. Human change is included, which is the critical step. It is significant not to overlook change management on each level inside the organization (Campbell and Reyes-Picknell, 2006).

As depicted, Rubenowitz (2004) states that there are no standard answers for actualizing an organizational change since all organizations experience the ill effects of issues particular for their organization. However Rubenowitz (2004) additionally expresses that the most important thing while implementing a change in an organization is the level of aspiration. The best changes have been found in circumstance where the underlying step is made in little ranges. A change procedure is a progressing venture and ought to be performed in littler procedures which are then spread over the organization (Rubenowitz, 2004).

Slack and Lewis (2008) views an implementation as all activities equired in making the methodology act as planned. It is supported to utilizes, the five Ps, which are the accompanying: Purpose, Point of entry, Process, Project management and participation. To a vast degree Slack and Lewis (2008) concentrates on operations, and consequently the work won't broadly expound on all steps, be that as it may, a couple of areas are highlighted below.

- Purpose – in this context the purpose covers the strategic context. In which the connection the organizations resource capabilities is linked and fit to the requirements of its market. It also includes the perception of, understanding of,

and cope with risk involved with change. These are all to be included in the implementation plan (Slack and Lewis, 2008). Important aspects here are how to manage risks. Slack and Lewis, describes prevention strategies, where the aim is to prevent a problem arises, mitigating strategies where the event causing the risk is isolated from causing negative consequences. Also, recovery strategies where the operation accepts the consequence from the event happening but actions are undertaken to minimize or compensate them.

- Point of entry – This aspect highlights different organizational structures ability to change, it should be noted however, that each has its strengths and weaknesses and to propose an organizational structure is therefore difficult to do. Further, also it is important to heed the fact that an implementation process can be politically sensitive within the organization or company. For this reason, also support from the hierarchy is central to the success of the change (Slack and Lewis, 2008).

- Process- This step covers the methodology of implementing formulation of the strategy. That is, the means and methods and the approach which are to be taken to formulate the strategy (Slack and Lewis, 2008). This focus area should also take into account the cost of implementation. A change may affect the process negatively in an initial stage, this influence may have economic effect, which Slack and Lewis (2008) categorizes the adjustment cost.

- Project management - implementing a strategy is a big project and need to be treated as such. Slack and Lewis means that it is more of a program than a project. A project has a defined start and end point, a goal and defined resources. A program does not; rather it is an ongoing process. It should include documentation of stakeholders, resource and time planning, controls, communication and reviews. One area that in many cases may need a special focus is just stakeholders, which in some cases have the power to affect change, hence they should never be ignored, and above all they should be kept informed

(Slack and Lewis, 2008), see also Figure 4.7, showing the interest in stakeholders.

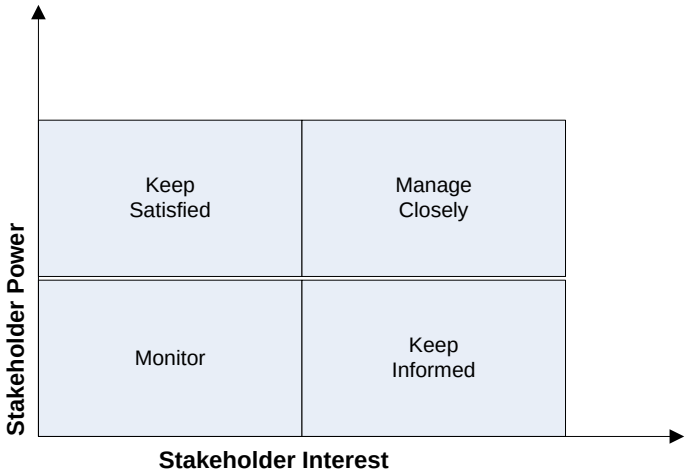



**FIGURE 4.7. STAKEHOLDER INTEREST AND HOW TO INCLUDE THE STAKEHOLDER**

- Participation - Dedicated employees are obtained if those affected by the change also may be part of the process to develop the implementation stage. Bringing in too many staff may however have the effect that the change resemble today's situation too much as many may be limited by current experience.

We have been able to present maintenance and corresponding methodologies and philosophies within maintenance field; this set the foundation for the knowledge within the area of maintenance. Aspects reviewed include maintenance strategy importance, how they are form and implemented.

The next section we will present the development of the method for analyzing the plant maintenance strategy call Benchmarking. Details follow in the next sections.

# 5.0 BENCHMARKING

Benchmarking is a method and procedure developed for analysing internal and / or external process (Southard et al., 2007). Yasin (2002) defines benchmarking as “an approach for establishing operating goals and productivity projects based on best-industry practices”. Its objective is to obtain a better understanding of how others might do the same processing in a more efficient way, and thus increase the likelihood of improving companies own productivity and competitiveness (Bergman and Klefsjö, 2010).

The benchmark exercise can be divided into three fundamental aspects according to the required outcome. First, to know own operation, its strengths and weaknesses. Second, is to know the industry leader, and finally, to incorporate best available methods (Porter, 2008).

Furthermore, benchmarking can be divided into four options; internal, competitor, functional and generic. Internal benchmarking is for example comparing different sections within a company The advantages of this type of benchmarking is data can easily be collected , and hidden factors are also easier to check (Wireman, 2010). Functional benchmarking compares organizations in similar fields. Generic benchmarking involves comparing with best known system that exist (Bergman and Klefsjö, 2010), also called best practices benchmarking (Wireman, 2010).

Various models for benchmarking have been developed. For example Xerox uses a ten-pace plan (Camp, 1993), while Bergman and Klefsjö (2010) presents a benchmarking process that linked the various steps to the PDCA, Plan-Do-Check-Act, and cycle. Benchmarking has become a popular exercise in companies, however it have also received criticism. Wireman (2010) believes that there are some fundamental problems with the method; this is because it is not clear whether a comparison with a company in another industry can really produce significant benefits. The inability to analyze companies and their processes in a more complete way, may lead to companies embracing incorrect methods which might have major impact on productivity. For competitor benchmarking, the

problem with this type of benchmarking is companies will not be willing to support its own competitor. Finally Wireman (2010) is critical about how to adapt to the benchmark values, if the comparison succeeds obtain valuable. What is encouraged is to embrace the best practices, where you will learn how to works according to methods that at well tested work. The problem is that many departments within the same company can be doubtful of solutions they haven't come up by themselves (Wireman, 2010).

Results of the research will consist of a benchmarking exercise whose objective is to compare maintenance strategy between three O&G companies. Since it is difficult to determine or establish the best maintenance system in the O&G industries as there have not been any research done in literature, hence performing a generic benchmarking is impossible, a functional benchmarking will be performed as part of this research. A benchmarking tool will develop, MSR, consisting of questions in different areas of the maintenance organization. In addition, the research work will include visit to three O&G companies and performed on-site analysis according to the MSR.

## 5.1 BENCHMARKING TOOL (MSR)

In order to perform an accurate comparison between companies, a benchmarking tool was developed. The tool, named Maintenance Section Review (MSR) is presented below.

The MSR is developed by the author, also the justifications to the questions. Each question and also the majority of the justifications are based on published literature.

The literatures which have been used are:

Wireman, 2010; Smith, 2004; Stig-Arne Mattson, 2004; UTEK, 2006; European Federation of National Maintenance Societies, 2012; Moubray, 1997; Wireman, 2009; Reliasoft, 2012; http://media.wiley.com/product_data/excerpt/60/04705173/0470517360.pdf, 2012-04-16; NASA, 2008.

The MSR consist of questions within the areas of: maintenance structure,

maintenance training programs, work orders, planning & scheduling, preventive maintenance (PM), spares inventory & purchasing, computerized maintenance management system (CMMS), operation, maintenance reporting, predictive maintenance, reliability & breakdown, maintenance – key performance indicators (KPIs) and financial planning.

All questions generated are justified against published literature. Below are area included in the MSR justified and the corresponding scopes which are addressed in each area.

## 5.2 MAINTENANCE STRUCTURE

Wireman, (2010) suggested that the maintenance organization is either an enabler or disabler to a company plant's success. The developed MSR questions had taken into consideration maintenance department's organizational chart, documentation, communication of work descriptions & responsibilities, document management system and continuous improvements culture.

An up to dated chart of the maintenance department gives a complete view of the department. This aid improvement, reorganization, planning and help in managing change. It is also important that all employee responsibility is clearly stated and expectations are well understand secure with his/hers obligation. Another aspect of maintenance structure is document access during the lifecycle of a plant and its equipment. Waeyenbergh et al., (2002) suggest better documentation which provide the required maintenance support during the equipment lifecycle and should be presented clearly and easy to access. This will aid continuous improvement of plant asset. Continuous improvement is another aspect which employee need to recognize its importance if companies want to secure its long time operation and competitiveness (Ireland and Dale, 2001).

## 5.3 MAINTENANCE TRAINING PROGRAMS

Al-Najjar & Alsyouf (2004) points out that in order for maintenance technicians and engineers to maintain new high-tech equipment, it is important to provide them with proper training so as to achieve the required level of expertise for performing their role and responsibility. Therefore training as we have included as one questions in the MSR is intended to assess area like; training maintenance planners, training frequency to keep up to date with new technology and changes in equipment operations due to legislation and the quality work performed. Maintenance planners for example require training for reporting, project management, inventory management, scheduling techniques and computer basics are essential to achieving the level of proficiency necessary for a successful planning and scheduling program (Wireman, 2010). This ensure planner are able to achieve the required expertise to discharge their responsibilities which include and not limited to Plan, schedule and coordinate maintenance activities, develop weekly schedule, ensure that maintenance related data are complete and updated, and also identify, analyse, and review equipment maintenance problems with maintenance engineering. These also apply to training technician and engineers on new technology. Most companies maintain their competitive edge through innovation and one of the agents of innovation is new technology (Hekkert et al., 2007). Therefore plants are continuously introduced to new technology. In order for the maintenance technicians and engineer to maintain these high-tech equipment it is fundamental to provide training about these new technology. The percentage of workforces that fall behind in technical skills due to the present rate of technology change cannot be confirmed at the point of writing this report as there are no references in literature to suggest data to support any claims (Hekkert et al., 2007). What is apparent is many organizations have aging workforces and the skill level of those entering the workforce lie below the necessary skill standard (Wireman, 2010),particularly in the Oil and Gas industry, 75% of the workforce is over 60 years (Sasson and Blomgren, 2011). It is important to have knowledge about the skill level of one's own workforce. It is also important to maintain and increase one's own workforce .Smith (2004) recommends that each employee receives at least 100 hours per year in education.

## 5.4 WORK ORDERS

Work order systems is use to initiate, track, and record all maintenance activities and to document and track performed maintenance work (Han et al., 2006). True analyses can never be performed and data will be lost if work order is not properly implemented. Work orders are documents or databases which are used to collect necessary maintenance data (Wireman, 2010). Work order system and effective planning and scheduling complement each other, therefore the success or failure of one affect the other. The equipment histories are usually built from the work order databases, budget projections, equipment repair forecasts, labour needs etc. (Han et al., 2006). It is therefore important that all work is covered by work orders, otherwise the equipment analysis will not be completed properly due to have insufficient data.

The measure companies' plant success with work order, MSR will consider the following;

1. The percent of the total amount of work orders processed in the system that are tied to an asset/equipment number.
2. The percent of the total number of maintenance man-hours that are reported to a work order.
3. The percent of the total amount of work carried out that is covered by work orders.
4. The percent of the total amount of work orders that are available for historical data analysis- follow up.
5. The categories covered in a work order.

## 5.5 PLANNING AND SCHEDULING

Maintenance planners are very important in planning and scheduling of maintenance activities (Budai et al., 2006). A planner has a full-time job, where approximately 80 % of their time is expected to be spent on paper and computer work while only about 20 % spent on the plant (looking over equipment parts or spare parts). The planner responsibilities are both important and time-consuming. The planners need to have

good technical skills in order to be efficient in planning work over (Wireman, 2010). Maintenance planners help to controlled work by reducing waste which makes planned work therefore costs less to perform than unplanned work (Budai et al., 2006). Another advantage with planned work is that the practices within inventory and procurement can be optimized if the work is planned several weeks in advance (Labib, 2004). To establish how well or poor the planning and scheduling area in case study companies, MSR will base its question on the total amount of work orders delayed due to poor or incomplete plans, and reporting of work order completed , actual working time, used material, downtime duration etc.

## 5.6 PREVENTIVE MAINTENANCE (PM)

Jardine et al., (2013) confirmed that preventive maintenance (PM) minimize downtime and therefore maximized productivity. PM is key when improving the maintenance process. The amount of reactive maintenance is reduced by proper PM implementation (Wireman, 2010).

How effective a PM is depends on the following;

1. The extent of critical equipment that is covered by the PM.
2. The percent of the PM that is reviewed annually in order to ensure good coverage.
3. Frequency of maintenance tasks in a PM.
4. The percent of the total amount of work orders that have been generated from PM inspections.

## 5.7 INVENTORY AND PURCHASING

The right equipment parts must be provided at the right time. Downtime due to absence of spare parts may cost the company, likewise too much unnecessary spare holding is not economical (Kennedy et al., 2002). Therefore there is a requirement for an upper and lower level of quantity for a spare part, with a reorder point system. By having these levels, the spare parts availability is secured, meanwhile is the

warehousing cost and order costs minimized (Stig-Arne Mattson, 2004). MSR will address the following area:

1. The extent of spare parts to critical equipment available in stock.
2. What department control the inventory of spare parts?
3. The extent of specified minimum and maximum levels for stored materials.

## 5.8 COMPUTERIZED MAINTENANCE MANAGEMENT SYSTEM (CMMS)

The utilization of CMMS database facilitates the collection, processing, and analysis of the maintenance and equipment data. In order to control the maintenance organization properly information about occurring events are needed (Duffuaa, 2015). To gather and analyze data manually requires a tremendous amount of both time and effort. Computerized maintenance management systems (CMMS) are used, they are designed to gather all data related to maintenance and to file it in the history of corresponding asset (Garg and Deshmukh, 2006). To control and manage maintenance tasks is one of the main functions of a maintenance management system (Ylipää and Harlin, 2007). MSR will address the following area:

1. The utilization of CMMS for maintenance operations.
2. The structure and updating of data in the CMMS.
3. Audit of data input into CMMS

## 5.9 OPERATIONS

Typical plants operations technician have good knowledge on the plants equipment which they operate. It will add value to the maintenance process if these operation technicians can generate work orders and perform minor maintenance tasks by themselves (Fernandez et al., 2003). This will save time and decrease the impact of failures on operations and also make them more attentive to any potential breakdown

while operating the equipment (Fernandez et al., 2003).Hence, maintenance department will be able to focus on extensive problems and to develop their knowledge for maintaining and improving equipment strategy. The higher the operators' knowledge is, the less the maintenance have to deal with minor tasks which only are time consuming. Thus, the complexity of equipment and the operators' skills are factors which may decide the extent of operator maintenance (Wireman, 2010). MSR will address the following area:

1. The percent of the total amount of operations personnel that generate work order requests.
2. The tasks which the operators are trained to perform.

## 5.10 MAINTENANCE REPORTING

This report provides maintenance management with information needed to manage and control the maintenance function (Waeyenbergh and Pintelon, 2002). This area focuses on which reports that are in place in order to manage and control the maintenance function, hence MSR will only address reports that are produced for the plants' equipment.

## 5.11 PREDICTIVE MAINTENANCE (PDM)

When performing predictive maintenance, the actual operating condition of equipment and systems are monitored (Zhou et al., 2007). Equipment are used to monitor the condition of other equipment, for example changes in vibration characteristics or changes in temperature, and these techniques are known as condition monitoring (Moubray, 1997). Condition-based monitoring solves or mitigates long-lasting equipment problems (Jardine et al., 2006). If the problems are detected early and even before occurring, the data can be used to improve the asset performance and life cycle of the equipment can be reduced. This will save both time and money due to both fewer failures and less frequent disruption to production. The listed below addresses how MSR present PDM:

1. Does PDM program exist?
2. Does PDM include condition-based monitoring?
3. How many preventive maintenance and corrective maintenance work orders are generated from the PDM?
4. Are the data gained from the PDM used to improve asset performance and asset life expectancy?

## 5.12 RELIABILITY AND BREAKDOWN

Every physical asset/ equipment are commissioned to service because of their specific needs in a plants operation (Moubray, 1997). Reliability focuses on the assets ability to perform this function under certain specified condition during a stated period of time (Gulati and Smith, 2009). Risk analyses should be made in order to reveal possible failures (evaluate the inherent reliability) and predict the effects which the failure will have on the system as a whole plant operation. This is useful in order to pinpoint potential areas for reliability improvement or if not possible, identify possible failures and take action to mitigate the effects before the failure occurs (Reliasoft, 2012);

To find the root causes or causes of a problem is the single most important element of failure or success of any problem-solving method (Monroe, 2010). There are several techniques and tools that can be used to improve the reliability of equipment (Bergman and Klefsjö, 2010). This area address several issues included in reliability engineering in order to find out how reliability and breakdown are managed in an organizations;

1. The extent to which risk analyses are used.
2. Is RCM methodology are used on critical equipment to adjust or refine the PM/PDM.
3. To what extent failures are clearly identified to its root cause.
4. The extent to which the cause of failures accurately can be tracked by work order history.
5. Are failure analyses conducted by the use of an analysis tool such as fishbone, tree, five why's and Pareto diagram to assure accuracy and standardization for each analysis.

6. Are failure frequencies calculated according to “The Six Failure Patterns” included in the RCM methodology?
7. Are any certain software used for calculating failure frequencies and other calculations?

## 5.13 MAINTENANCE – KEY PERFORMANCE INDICATORS

Key performance indicators are to combine metrics and indicators for critical or key processes in order to yield as an assessment, and thus to indicate the maintenance performance (Smith, 2004). This is important because the measurement of process performance is important when comparing with company’s set objective (Bergman and Klefsjö, 2010). Thus, MSR questions were targeted at;

1. The extent to which the equipment efficiency is calculated to monitor the condition of critical equipment.
2. The extent of downtime, due to CM, in relation to total production time for the facility/equipment is known by the company.
3. The percentage of PM costs in relation to the total maintenance costs are known by the company.
4. The proportion of total amount of maintenance man-hours that are devoted to CM are known by the company.

## 5.14 FINANCIAL PLANNING

According to Johansson et al., (2004) maintenance costs can account for as much as 10-40% of the life cycle cost of the plant. It is considered 30% of the maintenance cost consist of unnecessary spending, such as poor planning and overtime (Salonen and Delaryd, 2011). Ahlmann (2002) confirmed that equipment efficiency of 60-80% can lead to economic improvement up to 20% in a typical company. Equipment maintenance also account for 2 to 20 times the initial cost (Barringer, 2003). MSR question will be around the following;

1. Is life cycle cost regarded when initial investments are planned?
2. Classification of the organization's financial knowledge regarding condition determination and classification of assets.

We have been able to present importance of benchmarking and details for the formulation of Maintenance Section review . We have considered questions which are important to the strategic outlook for O&G maintenance strategies.

In the next section we will be reporting finding when this developed (MSR) and other tools were used in the field (case study companies) to collect data. We will also present the analysis of the data collected.

# 6.0 FINDINGS

Below are results from the analyses executed in the work presented. Among other things presented, the current situation of case study maintenance department and the benchmarking where maintenance organizations at other companies are compared is highlighted in this section.

The key objective of this chapter 6 is to answer Research Question 2 – Where do case study companies stand in comparison with other, and what can they learn from others?

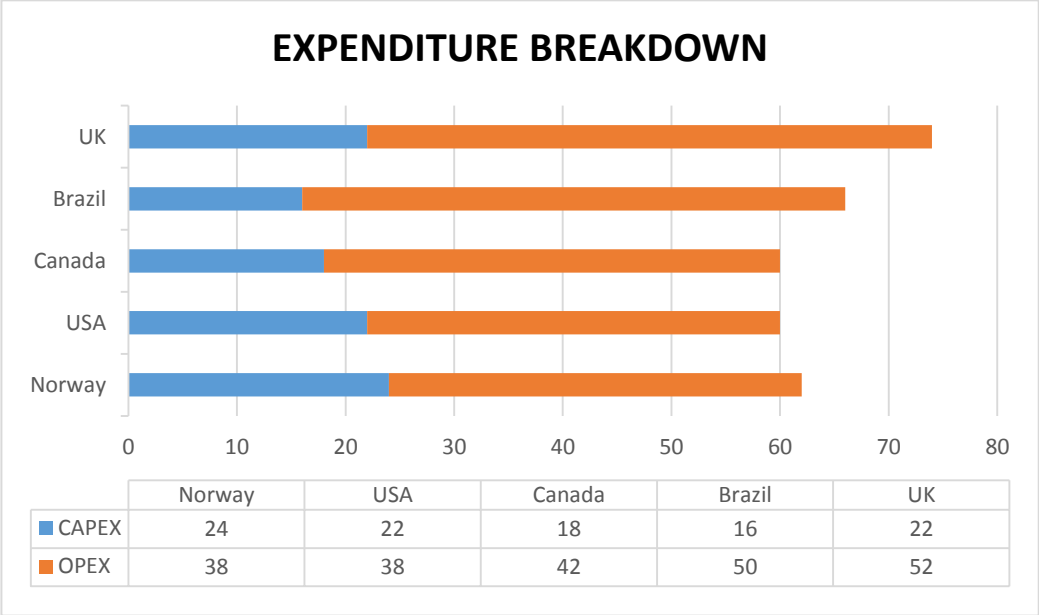
# 6.1 CASE STUDY COMPANIES

Initial discussions with oil and gas companies' maintenance managers had helped to decide on the unit of analysis and in choosing the case companies. We followed some of the advices given by Pettigrew (1990) for selecting case companies, such as looking for companies where the process is transparently observable, where the knowledge and experience about maintenance is substantial or where the perspective on maintenance is different.

We decided to conduct the case studies in UK because the UK has some of the highest costs in the world to produce a barrel of oil. Oil & Gas UK's Business Sentiment Index published in February 2016 showed, unsurprisingly, that optimism across operators and contractors is at its lowest since the index began in 2009. For the sixth consecutive time, sentiment is truly negative with a score of -32 on a -50/+50 scale. In February the oil price dipped below $30 a barrel, which propelled the entire industry into more intensive cut backs in order to survive. But some are in a more precarious position than others, depending on cost of producing oil in their respective countries.

Within the 20 biggest oil producing nations, the UK is the most expensive place to produce a barrel of oil (Refer to the table below). Our CAPEX costs are broadly in line with our peers, but it's our OPEX costs that are the real problem, and are even higher than our '4

on/2 off' neighbors in Norway. This can be explained in part by the age of our assets and infrastructure, which have direct relationship with maintenance.




| | Norway | USA | Canada | Brazil | UK |
|---|---|---|---|---|---|
| CAPEX | 24 | 22 | 18 | 16 | 22 |
| OPEX | 38 | 38 | 42 | 50 | 52 |

**FIGURE 6.1: SOURCE DATA - UCUBE BY RYSTAD ENERGY (FIGURES ARE ESTIMATE IN $/BARREL OF CRUDE OIL)**

In selection of the case companies, a crucial argument from the set of appropriate companies was the previously developed relationship with the company. This way not only was the basis for trust already laid, but the period of orientation for both the members of expert-group and myself was much shorter. The main criteria for choosing the contact people were the following:

1. A person who worked for the company for a long time and knows it well.
2. A person who has day to day involvement in maintenance activities and have a good and extensive working knowledge.
3. A person who can understand my research and be enthusiastic about it.

The following five companies have been chosen for the conduct of the research (the names of the companies are not given due to a confidentiality agreement but their

characteristics are outlined):

Company A is one of the world's largest independent exploration and Production Company, based on proved reserves and production of liquids and natural gas. They explore for, develop, and produce crude oil and natural gas globally. Across our 21 countries of operations, over 15,900 men and women work in a truly integrated way to find and produce oil and natural gas. There technical capabilities, asset quality and scale, and financial strength are unmatched among independent exploration and production companies and uniquely position to compete around the world. Company A has had activities in the United Kingdom. The case study will be conducted with the UK subsidiary of the company.

Company B is an independent global exploration and production company. The Company has reportable operating segments, each of which is organized and managed based primarily upon geographic location and the nature of the products and services it offers. The segments includes the following:

1. North America Exploration and Production (E&P) – explores for, produces and markets crude oil and condensate, natural gas liquids and natural gas in North America.
2. International E&P – explores for, produces and markets crude oil and condensate, natural gas liquids and natural gas outside of North America and produces and markets products manufactured from natural gas, such as liquefied natural gas (LNG) and methanol in Equatorial Guinea.
3. Oil Sands Mining – mines, extracts and transports bitumen from oil sands deposits in Alberta, Canada, and upgrades the bitumen to produce and market synthetic crude oil and vacuum gas oil.

Company B has been producing oil and natural gas in the United Kingdom for more than 30 years. The Company's current holdings in the U.K. include the Company-operated Complex and Field. The case study will be conducted with the UK subsidiary of the

company.

Company C is one of the largest independent crude oil and natural gas producers in the world. Company C have an effective and efficient, diversified combination of assets in North America, the North Sea and Offshore Africa, which enables them to generate significant value, even in challenging economic environments. They have a balanced mix of natural gas, light crude oil, heavy crude oil, bitumen and synthetic crude oil which represents one of the strongest and most diverse asset portfolios of any energy producer in the world.

1. One of the largest independent natural gas producers in Canada.
2. Largest undeveloped land base in the relatively undeveloped, natural gas prone areas of Northeast British Columbia and Northwest Alberta.
3. Diverse portfolio of light, primary heavy, Pelican Lake oil and natural gas liquids.
4. World class opportunity for oil sands mining with 14.4 billion barrels of bitumen initially-in- place (BIIP).
5. Exploitation in the North Sea core and Offshore Africa region.

International operations which include North Sea and Africa remain a strategic part of its business, providing a stable and committed source of light crude oil production. In the North Sea, attention is focused on managing existing infrastructure in a mature basin which leads to field life extension. With a solid inventory of drilling prospects, the North Sea provides significant resource potential in a low- risk environment. The case study will be conducted with the UK subsidiary of the company.

## 6.2. CASE STUDY COMPANIES - MSR

The result from the case study companies are presented below. The case study companies will be discussed in aspects of working procedures and maintenance concepts used. Furthermore a polar diagram was presented showing benchmarking with all case study companies.

The preventive maintenance program is a huge part of the daily maintenance program. All preventive maintenance work is planned in advance to ensure required parts and tools are in stock and to minimize the downtime. Besides the 7 day look ahead planning there is a monthly planning meeting where all preventive maintenance to be perform during the year are discussed. During both plant uptime downtime, each technician involved in a preventive program as a procedure to follow. These procedures are documented in details. With descriptions stating what requires observation and how to observe it are clearly highlighted. The documentation also contains separate sections in which the operator can note that the preventive maintenance program has been followed but also possible problems identified, such as noise and vibration.

During each day, maintenance supervisors to hear whether there have been any problems, and also to audit the preventive program has been followed. This is also done in conjunction with operation managers, maintenance managers as well discipline technical authority.

The maintenance department, besides all other work, has a meeting each week to discuss what PM scope had not been completed. There are not clear route for to suggest maintenance improvements, therefore there are little participation in the maintenance improvement program by the maintenance team. However, the maintenance department, has a high level of understanding for the economic involvement in the maintenance department but also the impact the maintenance department can have on the entire company. The maintenance department is engaged in the start of investment projects as there are clear guidelines, and which must be checked off in order for the project to move on. One of these is, as said, that the maintenance has been consulted and are part of the project.

The Maintenance Section Review (MSR) was taken place in Companies A, B, C Aberdeen office. As part of the MSR, interviews were held and documents were reviewed. Next to this a walk-through session of CMMS (Maximo & SAP) was taken place. This thesis will sequentially describe the approach of the MSR, the results of the scan, and a list of gaps

identified and suggested actions.

The MSR performed at Company A, B, C is a standardized MSR developed in this research. The MSR is based on information retrieved during a 5 day visit to each Company's Aberdeen office. The MSR gives an impression of the current state of the maintenance organization and which gaps there are to the desired situation.

Information are retrieved through interviews with the following position:

| Job titles | Company A | Company B | Company C |
|---|---|---|---|
| Maintenance Superintendent | Yes | | Yes |
| Senior Instrument Engineer | | Yes | Yes |
| Principal Mechanical Engineer | Yes | Yes | Yes |
| Maintenance Optimization Engineer | Yes | Yes | Yes |
| Mechanical Lead Technicians | Yes | Yes | Yes |
| Instrument Lead Technicians | Yes | Yes | Yes |
| Maintenance Supervisor | Yes | Yes | Yes |

**TABLE 6.1: JOB TITLE/POSITION OF INTERVIEWED PERSONNEL**

The MSR is build up out of 13 categories. Each category has a set of standardized questions and answers. These categories and questions are used to structure the interviews and cluster information. Not all categories are discussed with all interviews. The standardized answers are place on scale. Based on the answer the interviewed person gave the research determines the score this question. All scores are made anonymous by averaging the scores of all respondents. If there are any conclusion to be drawn from comments on question or the variation of the answers this will be addressed anonymous. Next to the interviews some documents that were shared by case study companies were reviewed. The following documents were shared:

| Document description | Company A | Company B | Company C |
|---|---|---|---|
| Production Operations SHE Improvement Programme & Targets | Yes | Yes | Yes |
| Asset Strategic Plan | Yes | Yes | Yes |
| Maintenance Management System Manual | Yes | Yes | Yes |
| Maximo – The corrective work process | Yes | | Yes |
| SAP - The corrective and preventive work process | | Yes | |
| Repairs procedure | Yes | Yes | Yes |
| Offshore Planning Procedure | Yes | Yes | Yes |
| Condition Monitoring Procedure | Yes | Yes | Yes |
| Maintenance Planning Procedure | Yes | Yes | Yes |
| Planned Maintenance Workflow Procedure | Yes | Yes | Yes |
| Corrective Maintenance Workflow procedure | Yes | Yes | Yes |

| | | | |
|---|---|---|---|
| Company's Organisation Chart | Yes | Yes | Yes |
| UK Operations report | Yes | Yes | Yes |

**TABLE 6.2: REVIEWED DOCUMENTS**

**MAINTENANCE STRUCTURE**

Findings: The Organogram is not aligned with communication and coordination structure for company C, Engineers formally should communicate and coordinate through maintenance superintendent but in day-to-day activities they communicate directly to offshore technicians and production superintendent. The communication within the maintenance department is good in all the case study companies, but communication with other departments is adequate in most cases. In company, there are no formal meetings in the maintenance department for disciplines to share knowledge or discuss continuous improvements.

Results in: Misalignment of the current organogram and communication structure leads to less control on activities performed by onshore engineers, which are pulled in to day-to-day firefighting mode of the offshore platforms. Also by not clearly stating (i.e. in job description or job title) what effort should be put in pro-actively managing the assets the focus of the organization is completely focused on corrective maintenance.

Identified gaps;

1. Organogram doesn't align with actual coordination structure.
2. Task / job responsibilities and job descriptions doesn't match Assets Management processes.
3. There are no uniformity between jobs across different platforms/plants.

**MAINTENANCE TRAINING PROGRAM**

Findings: In all the 3 case study companies, there are no clear steer by management for maintenance training program direction. There are no structural attention for

developing the organization to support this (no personal development plans, competency matrices etc.) “Firefighting” is rewarded for somebody who fixes a problem get attention, somebody who prevents a problem doesn’t get the same attention). Meetings between engineers are mostly informal and therefore lot of information and coordination are done on a personal base.

Results in: The overall consensus is that there is a firefighting culture in all case study companies. This might be due to positive incentives given for fixing a failure and not for preventing a failure. As a result the change management procedure were bypassed or underestimated.

Identified

gaps;

1. Incorporate the notion that expertise and competencies for PM and continuous improvement are different to CM.
2. Formalize meetings by using agenda’s and action & decision-logs.
3. Set up competency matrix to match roles and required competencies.
4. Manage the development of strategy, procedures, systems, management, employees and culture in cohesion.
5. Develop the organization by using personal development plans to guide employees in developing.

**WORK ORDERS**

Findings: Corrective workflow is captured in procedures and these procedures are being executed in all the case study companies. There are quality checks to confirm whether the CM’s are put correct in CMMS (Maximo and SAP). Corrective Maintenance is being prioritized based on an approved method in coordination with operation department. CMMS (Maximo and SAP) are used to supports this process as required. There is no formal escalation path for solving breakdowns, but informally there is and this works appropriate. The preventative workflow is not formalized or uniform. There is no formal way of prioritizing PM and this makes it difficult to justify/force PM to be performed.

Results in: The breakdowns are recorded properly, but information gathered are not properly analyzed for optimum usage. The corrective workflow is uniform and are properly formalized this is because there is a large focus on breakdowns within the organization the attention on the corrective process due to the age of the plants/platforms. PM workflow is less structured and formal hence it gets less attention then it deserves.

Identified Gaps;

1. Formalize PM workflow to match CM workflow, this will increase quality of PM's and job plans enforce PM workflow.
2. Formalize breakdown escalation path
3. Give feedback on CM to the originator of CM

**PLANNING AND SCHEDULING**

Findings: Scheduling plant/platform overhauls are done on the long term basis. Short term scheduling or for PM is very fluid because of they are often disrupted by breakdowns. Although a fair amount of the PM which are scheduled or not are completed on opportunity basis. Therefore there short term planning is not properly implemented although they are put in place. However, there are serval initiative to improve the scheduling process which include gate sanction of jobs before being included the plan.

Results in: No proper mid-term and short-term scheduling leads to less efficient use of planned downtime. The changing/ambiguous scope also makes it more difficult to do good work preparation as planned and within budget. This leads to jobs and overhauls running over schedule. Missing detail in the job plans couple with no uniform way of setting up job plans leads to chaotic implementation of plant.

Identified

gaps;

1. Define and create scheduling and planning process blue print.
2. Set the standard for work preparation
3. Train offshore techs to use CMMS Maximo to do work prep (use job plans, use tasks, put materials on job plans)
4. Review and update job plans for high risk installations incl. work instructions
5. Make scheduling and planning across platforms/plants uniform
6. Take obsolescence and end-of-life into account into mid-term scheduling
7. Create end-of-life strategy

**PREVENTIVE MAINTENANCE**

Findings: The case study companies all have Preventive Maintenance (PM) in place which is manage via CMMS (Maximo or SAP). Most of the PM routine are is originated from legacy systems or from suppliers. Formal reviews of the PM takes place and this process is formalized through the change request process. The quality of the PM are relatively fine but with little or no optimization. The estimated hours are not accurate and cannot be relied upon. Case company A was the only company able to demonstrate that there is no formal (or informal) way of determining the risk of an installation or asset against business objectives.

Results in: PM is in place, but the quality of the jobs and estimates are not sufficient to adequately plan or perform the job, this leads to work extra in preparing the jobs. The job preparing process is hence face with extra burdened and this process already is being faced with challenges due to day-to- day firefighting. The lack of good job descriptions makes the quality of the job dependent on the person performing the job, this lead to difficultly in prioritization of CMs and PMs.

Identified
gaps;

1. High level risk assessment to identify risk of assets on “unit” level
2. Set the standard for PM
3. Train reliability engineers in RCM
4. Review and clean up Maximo/SAP of PM not meeting standard
5. Determine process to justify and review PM
6. Detailed risk assessment on asset level of high critical units
7. Risk assessment on asset level of medium and low critical units

**INVENTORY AND PURCHASING**

Findings: Purchasing process is procedurals but this not always follow up. Inventory management is not formalized and are performed different on the different platforms in any specific case study company. Maximo & SAP are used as inventory system, but the current use is more an item catalogue. Standard functionality for inventory management are not used by all the case study company (i.e. re- order points, stock corrections etc.), although it was noted that company A do have this functionality set up in its CMMS but where are no evidence that this had been used. There is no differentiation in the stock (i.e. critical spare are not identified)

Results in: The lack of control on the purchasing process leads to people getting involved in the process while should be focusing on other tasks. Absent of procedure to inventory process leads to stock-outs and ordering wrong materials. The inventory system is not well supported by inventory managers. The result can be that there is capital locked in stock and the costs of amortize stock is higher than needed. By not differentiating between different types of critical spare planned and unplanned downtime are longer than needed.

Identified

Gaps;

1. Identify inventory managers and train them in using standard Maximo / SAP functionality supporting purchasing and inventory (i.e. re-order points, stock corrections).

2. Formalize Purchasing and Inventory process and configure Maximo / SAP accordingly.

3. Identify critical spares of high critical installations.

4. Update item catalogue to meet business requirements.

**RELIABILITY AND BREAKDOWN**

Findings: Breakdowns are reported and information for analyses is included, but there is no structural analyzing of failures. The onshore engineers are aware of the data in Maximo & SAP, but are not trained to transform this data in valuable information. There is no formal way of analyzing failures. (E.g. no top 10 reports**,** all though there are RCA trained engineers)

Results in: Data from proper breakdown reporting is not used. This has a dual effect. This can lead to people questioning the purpose of breakdown reporting and eventual less commitment to the reporting of breakdowns. And second valuable information is there are no structural in place to manage continuation improvement of the assets. No structure for learning from failures, with will leads to making the same mistakes.

Identified
gaps;

1. Train engineers (maintenance and reliability) to use Maximo to extract data and form this in information.

2. Train reliability and maintenance engineers in RCA.

3. Focus on solving not fixing problems.

4. Create monthly top 10 breakdown reports (costs, performance, risks).

5. Do RCA on all critical failures and implement learning's.
6. Increase awareness of costs and benefits of improvements.
7. Justify improvements based on cost benefits analyses.

Findings: KPI's are calculated and communicated. The rules behind calculating KPI's and targets are unclear. The relationships between KPI's and objectives are not explicit. Different audits are performed with set procedures, but the follow up of the results of the audits is unclear in most cases.

Results in: Due to lack of insight in the calculation of KPI's and the evidence of the targets the KPI's are not trusted and thus not used to improve the organization to meet is objectives. There is an overall consensus that some KPI's can easily be manipulated. However, audits are performed to check and to meet requirements but are not used to improve it. Follow up of findings is poor and tempers continuous improvement.

Identified gaps;

1. Translate companies' objectives into KPI's
2. Communicate the objectives and algorithms of the KPI's
3. Involve responsible parties in setting realistic targets
4. Use KPI's to challenge and improve
5. Follow-up on actions from audits
6. Translate KPI's to how people can influence them

**FINANCIAL PLANNING**

Findings: There is no loss-accounting and downtime are not recorded in CMMS (Maximo & SAP). Uptime and availability is recorded for some equipment, but this can't be

translated to downtime for a platform. The budget is broken down to almost activity level and is based on historic data. The plan does not differentiate between PM and CM. Actuals are not measured in the same detail as the budget. Although some actuals are recorded in Maximo/SAP it is possible to get a good cost overview from CMMS. Justifications for improvement proposals lack evidence with cost and benefits.

Results in: Representative data about losses and availability is not available. This makes it hard to steer the organization on loss and availability. This is also visible in the lack of costs and benefits in the justification for improvement proposals.

Identified
gaps;

1. Set up loss-accounting and start measuring downtime
2. Differentiate between CM and PM costs in the budget and actuals.
3. Start registering accurate actual costs on assets
4. Roll up costs to match budget levels
5. Activity-based budgeting based on planned activities

**OPERATIONS - ASSETS REGISTERS**

Finding: Asset drawings are mostly up-to-date in all the case study company. There are continues review project to update the P&ID's. Maximo/SAP is used as asset register. However, researcher was not able to confirm that all assets on P&ID are in Maximo/SAP but there is no process in place to ensure this and overall consensus is that this is not the case. The asset register has a hierarchy on which information could be rolled up, but this is not used in company C and the completeness is not verified. There are also differences between the asset hierarchies of the different platforms in the same companies which makes benchmarking and comparing information between platforms less effective. There is a DMS /Documentum (data warehouse) in place, but finding right documents in the DMS is not ensured. Populating the DMS /Documentum (data

warehouse) is an on-going process and it depends on the discipline of the people who need to supply/upload the documents. Finding documents in the DMS is done based on a word search and not by linking documents to Maximo / SAP.

Results in: An incomplete asset register leads to missing PM and incorrect logging of breakdowns. The lack of a uniform asset hierarchy makes analyzing performance, risks and costs more ambiguous and less comparable between platforms.

Identified
gaps;

1. Up to date asset hierarchy documents.
2. Up to date DMS with all available documentation
3. Index documents with asset tags
4. Formalized knowledge sharing portal
5. Linking Maximo and DMS

**MAINTENANCE OBJECTIVES**

Findings: The mission or long term strategy of case study companies and the translation to influential level of this strategy are not communicated in a clear way. Although the focus on safety and uptime is known and clear translations of strategy to objective per platform are available on the intranet. On asset level there is clear distinction between Safety Critical Equipment (SCE) and non-SCE. The specific objectives (e.g. availability) of the SCE assets are described in the Performance Standards. Only for some rotating non-SCE assets objectives (uptime and availability) are set. Measuring and acting on the objectives is not done for most SCE and non-SCE assets.

Results in: By not sharing clear and formal objectives, the organization is not working towards common goals. This can lead to a sub-optimal result where departments are not working effectively together. Not translating the objectives to a lower level makes the

justifications for actions harder and makes a supported decision less likely. The lack of vision or formalized vision on asset management leaves the maintenance organization in the unclear where to improve to or what is expected of the organization.

Identified gaps;

1. Clearly communicated objectives to all level (objectives on different levels do exists).
2. Long term vision and strategy on Asset Management.
3. Clear relation between strategic, tactical and operational objectives.
4. Identify equipment specific requirements for high critical equipment and assign KPI measure to them.

## 6.3. POLAR DIAGRAM COMPARING THE CASE STUDY COMPANIES

In the polar diagram below are the scores for each benchmarked company presented. The scores are ranked on a scale from zero to four points where four is the highest. The score minus one are assigned on questions not applicable for that certain company and those will not be regarded when analyzing the result:

| S/N | Maintenance Function Scanning Sections | Company A | Company B | Company C |
|---|---|---|---|---|
| 1 | Maintenance Structure | 2.1 | 1.8 | 2 |
| 2 | Maintenance Training Program | 2.4 | 2.2 | 2.1 |
| 3 | Work Orders | 3 | 2.8 | 2.5 |
| 4 | Planning and Scheduling | 1.6 | 1.2 | 1.3 |
| 5 | Preventive Maintenance | 2 | 1.8 | 2.2 |
| 6 | Inventory and Purchasing | 2 | 1.9 | 1.5 |
| 7 | Computerized Maintenance Management System | 3 | 2.8 | 2.6 |
| 8 | Operations | 2.1 | 2.5 | 2.1 |
| 9 | Maintenance Reporting | 1.8 | 1.6 | 1.4 |
| 10 | Predictive Maintenance | 1.2 | 1.1 | 1.3 |
| 11 | Reliability and Breakdown | 1.9 | 1.7 | 1.6 |
| 12 | Maintenance – Key Performance Indicators | 2.1 | 2.4 | 2.1 |
| 13 | Financial Planning | 2.3 | 2.2 | 1.3 |

**TABLE 6.3: MSR COMPARISON BETWEEN THE BENCHMARKED COMPANIES**

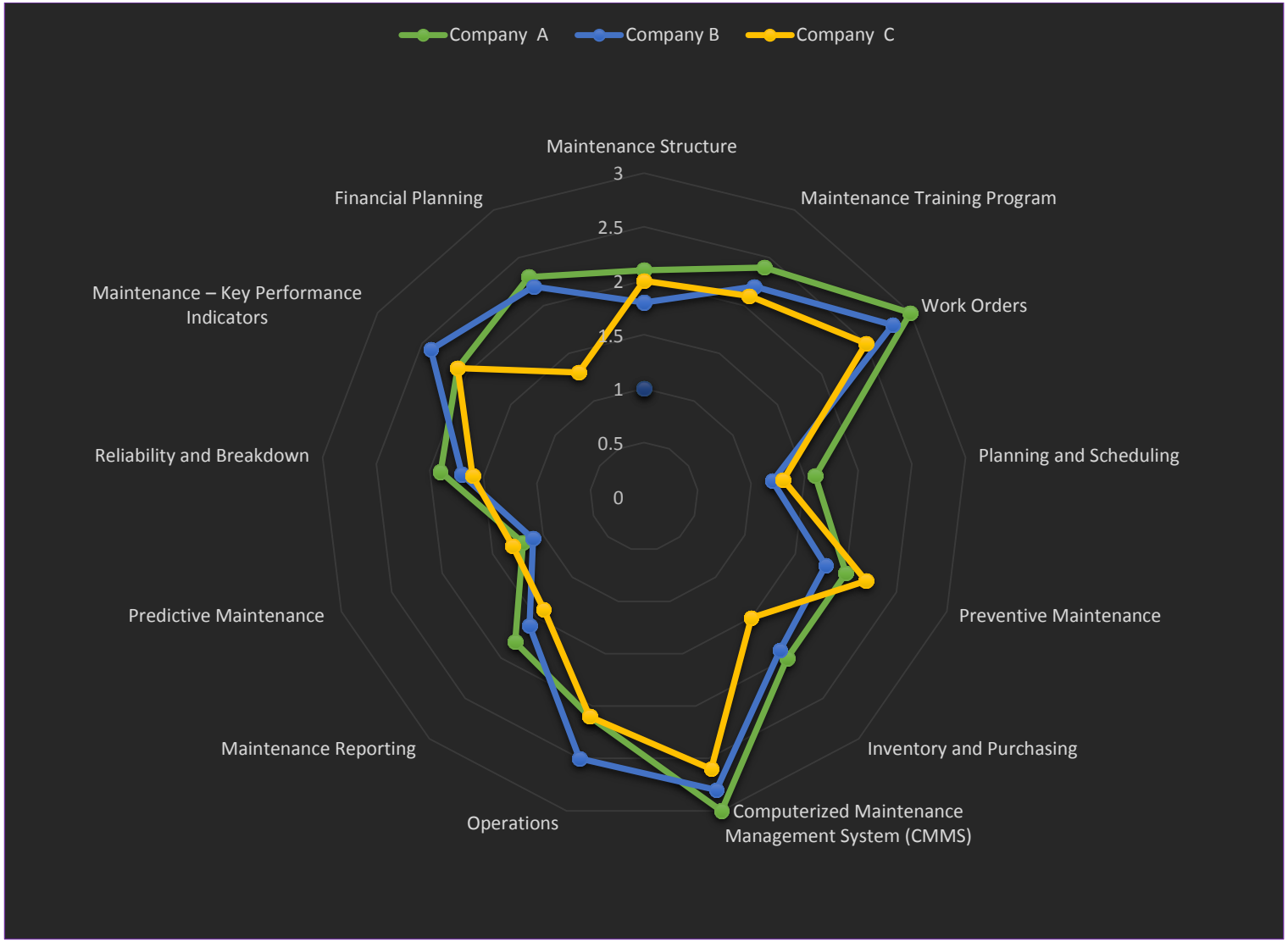



**FIGURE 6.2: POLAR DIAGRAM - MSR COMPARISON BETWEEN THE BENCHMARKED COMPANIES.**

Some of the key aspect identified lacking behind are listed below;

1. Planning and Scheduling
2. Maintenance reporting.
3. Inventory and purchasing
4. Predictive Maintenance
5. Reliability and breakdown
6. Maintenance structure.

**Inventory and purchasing**

Maintenance stores play a major role in supporting the maintenance dept. The main objective is to provide the material spares, services spare at the right time and the in the right quantities. This is because if the right and adequate material or service support is unavailable the repair will be delayed. This delay in turn increase both operation and maintenance cost. Maintenance technician spend 20 to 30 % of their time in a shift to search of the correct parts. To support maintenance technicians a reasonable amount of spare parts should be kept in stock, this enable timely repair of emergency breakdown.

In different facilities, the budget for spares part can be significant percentage of the total maintenance budget, these cist can easy be justified by the cost lost due to breakdown. This impossible for a maintenance department to stock all required as this would be very expensive and I some cases wasteful. Usually a quantitative decision method is use to determine what and when to buy. Some companies achieve the following when the quantitative method is design, optimize and implemented properly.

- 20% reduction in total cost
- 30% reduction in maintenance stock
- 40% reduction in manually prepared direct purchase requisitions.
- 30% reduction in the number of purchase orders for replenishment parts
- 20% reduction in the workload of maintenance planner.

In addition to these, majority of responsibility of a maintenance material personnel may be

met with good planning based on best practices. The correct time to decide what / number of parts and materials to be stock is before an asset is in service. A recommended spare list as well as the required preventative maintenance based the critically analysis e.g. Failure Modes and Effect Analysis (FMEA) conducted. The critically analysis can be used to optimize the spare list and provide a good estimate on what and how many spare should be stock.

All the case study companies have the relevant procedure in place to support an efficient inventory system, however most of these procedures are no more in line with the asset they support.

Key gap identified in this research are;

- Inventory managers need to take responsibility for using merging the CMMS, procurement system and live assets database which should include the criticality equipment's. They should be trained up in usage of standard Maximo / SAP functionality supporting purchasing and inventory (i.e. re-order points, stock corrections).
- Manager should work with operation and maintenance department to Identify critical spares of equipment in a plant.
- Update item catalogue to meet business requirements.
- Update inventory and spare part stock procedures to align with the both business and operational requirement.
- In addition to the above, key performance indicator (KPI) should be measured and monitored, this will help to track the performance on a regular basis and as such improvement can be evaluated. Some of the proposed KPI are;
    a. Percentage of inactive stock

       Number of inactive items/ Total item issued
    b. Stock Variance

       Difference between the actual number, amount, or volume of an inventory item and the balance shown in the stock records. These differences are summarized in the variance report that is prepared to record and resolve stock control issues.

c. Percentage of stock to plant value

   The total cost of stock divided by the total number of plant replacement cost

d. Stock growth rate in the number of items and supplier

   This is a measure to evaluate how many more items have been added to the stock list. The aim is to reduce the number of different item by standardization or outsourcing the supply of these items.

e. Percentage of Stock-out

   Number of stock outs divided by total items issued.

f. Stock turnover ratio

   The amount of time companies' investment in stock is coupled during an accounting period. It is the valve of the issue stock divided by average stock value in a company's financial year.

With increasing pressure on the oil and gas industry and couple with the dynamic business pressure facing the oil and gas maintenance department to review it operation and look for ways to operate cheaper, faster and more efficient than ever, this is clear that managing stock effectively is a key strategy that can't be over looked . It is also evident that unless the store /warehouse are integrated with purchasing, operation, maintenance and planning it will be impossible to achieve desire results.

**Planning and scheduling**

Planning and scheduling in maintenance settings is one of the most effective investments an organization can make to improve productivity and availability. The maintenance planning and scheduling department increases the Maintenance Department's ability to complete work orders. Work plans help to avoid expected delays so as to improve on past work. Advance scheduling help managers to allocate and control the work. Technician will be ready to go immediately to work upon receiving a planned work order because all work pack, materials, tools, and other arrangements are ready.

All Industries are now experiencing major change in maintenance approach. There are moving from an equipment repair service to a business process for increasing equipment reliability and ensuring plant uptime to insure profitability. Their maintenance managers are swapping their reactive cost center attitude for a proactive equipment asset management philosophy. Currently, leading companies now believe in common that maintenance is a business process and hence that formalize why planning and scheduling is key to its success.

Experience and literature shows that plants require some maintenance and planning which helps to make maintenance efficient. Maintenance planning includes classifying of spare parts and tools necessary for jobs. A common perception of planning is that once a person requests work order, a maintenance planner could easily determine and gather the necessary parts and tools before the job is assigned. The planner might even write instructions on how to do the job. With this preparatory work done, the technicians actually doing the job would not have to waste time first getting everything ready. This planning methodology would be thought to increase maintenance productivity. The maintenance planner would write a work order that identified parts needed along with their stock identification numbers. Then the planner would reserve them in the stock database to ensure their availability when the work order is to be completed. If the required parts were not available in stock, then planner would place a purchase order. The planner sometime might need to station some of the parts in a convenient location. With station parts the technician performing the work would not have to wait at the stock warehouse. The planner would also provide a bill of materials or an illustrated parts diagram. These documents would help the technician identify parts unanticipated at the time of planning or understand how the parts fit together. The planner would also work with vendors to ensure good sources of material supply. Finally, the planner would be involved in quality assurance and quality control of vendor shipments.

From the case study companies was observed that scheduling are done on the long term basis. Short term scheduling example PM is very fluid because of they are often disrupted by breakdowns. Although a fair amount of the PM which are scheduled or

not are completed on opportunity basis. Therefore there short term planning is not properly implemented although they are put in place. However, there are serval initiative to improve the scheduling process which include gate sanction of jobs before being included the plan. We also noticed that at there are no proper mid-term and short-term scheduling which leads to less efficient use of planned downtime. The changing/ambiguous scope also makes it more difficult to do good work preparation and to be within budget. This leads to jobs and overhauls running over schedule. Missing detail in the job plans couple with no uniform way of setting up job plans leads to chaotic implementation of plant plan.

Key gap identified in this research are;

- There are no define scheduling and planning process blue print available, case study companies do not have a specific department for planning who will be able to develop and manage this blue print which will also include the standard for work preparation. Planner are mainly under operation department.
- In addition to the above, key performance indicator (KPI) should be measured and monitored, this will help to track the performance on a regular basis and as such improvement can be evaluated. Some of the proposed KPI are;
    a. Percentage of planned work.

       This is a measure of all planned jobs, it is assumed that job cards, materials and tools are in place before the job is schedule. Industry benchmark is 90%
    b. Percentage of schedule compliance.

       This is a measure of job accomplishment on a weekly basis. Industry benchmark is 85%
    c. Percentage of rework

       This a measure of the work order requiring rework. Although the definition of rework is ambiguous, hence each organization will need to define what reworks means. Industry benchmark is 2%.
    d. Work order backlog

       This a measure of the amount of work ready to be completed. Industry benchmark is 4-6 week's backlog of work.

# 7.0 DISCUSSION

## 7.1 FORMULATION OF A MAINTENANCE STRATEGY

From the information gathered in this research, an oil and gas maintenance strategy formation model was presented. The model focuses on the shareholders both the internal - the maintenance and engineer, technicians, and the external customers - production department. The expectations are identified and afterwards translated into maintenance objectives which are used as the basis to formulate the strategy.

The key objective of this chapter 7 is to answer Research Question 3 – Which factors influence the achieving the anticipated state?

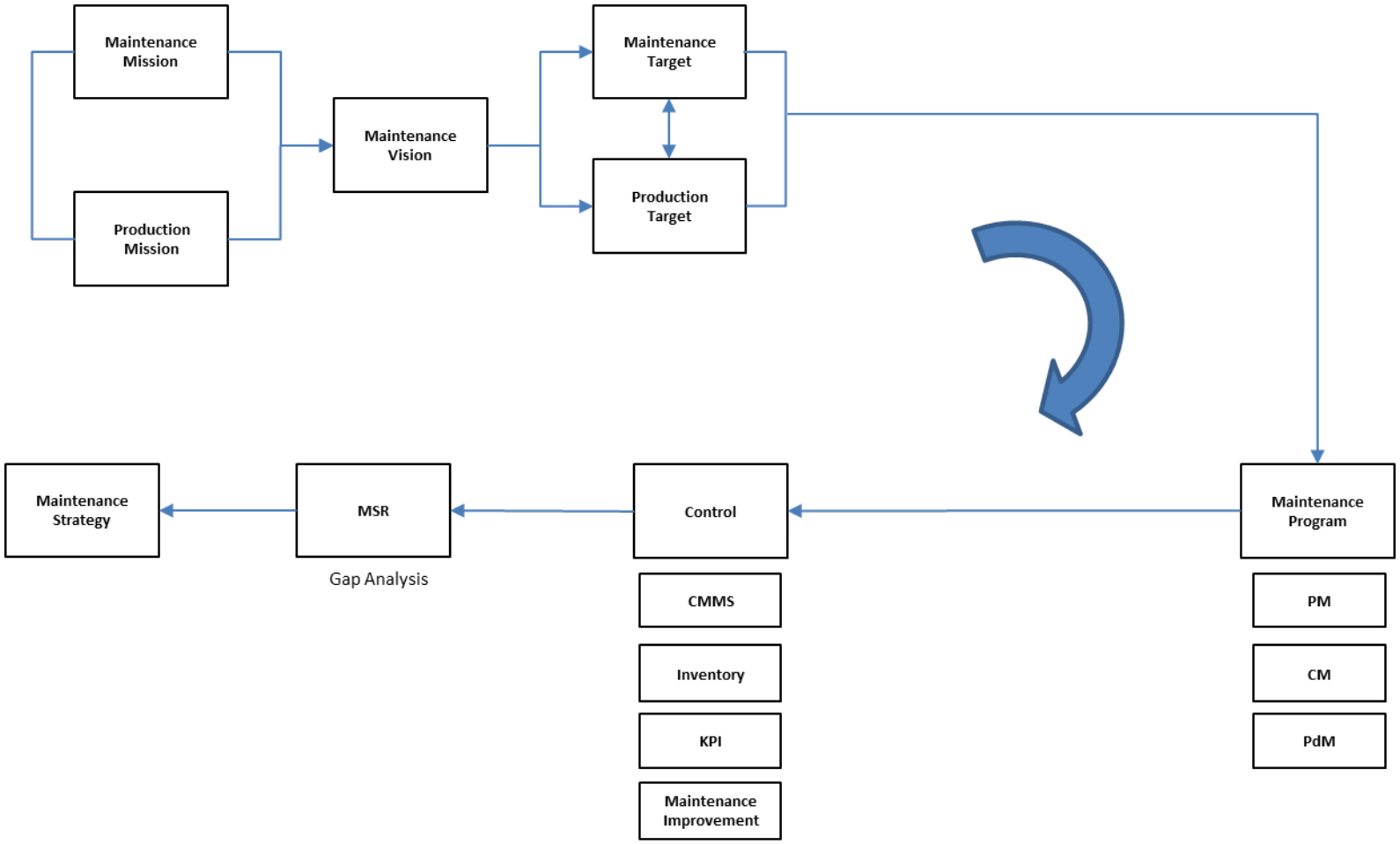



**FIGURE 7.1: MAINTENANCE STRATEGY FORMATION FRAMEWORK**

# 7.2 COMPREHENSIVE DISCUSSION OF THE MODEL

Bergman and Klefsjö (2010) highlighted the link between what organization wants, how to achieve it", where they want to be, and finally how they intend to get there i.e. policies, goals and the strategies. Therefore, organization need to know the listed below;

1. What its mission is?
2. What are expectations from shareholders?
3. What state are they in meeting the shareholders expectation?

Organization vision should present where the organization want to be in future. In the effort to reach its target, organization will need to define its long and short term target clearly. All these stages put together are used to create the strategy.

According to the standard (EN 13306, 1998), "maintenance strategy is a Management method used in order to achieve the maintenance objectives". It is very important as an organization to constantly strive to improve. Salonen (2009) highlighted the importance of continuously looking at ways to make businesses and maintenance an important factor efficient. This continual improvement is a change.

Slack and Lewis (2009) believes that change is a project and therefore should be act on accordingly. Continuous feedback from stakeholders and the numerous departments within the company is important. A process to achieve this is to use the PDCA cycle as previously been described. PDCA cycle is a tactic that is anticipated to solve the gap issues through continuous improvements (Bergman and Klefsjö, 2010). The sequence starts with the identification of goals and procedures to solve the issues in question. After the cause had been established and knowing the main issue to be solved. Outcomes are gauged continuously and results used for analysis. If the result is positive, the cycle starts over. If otherwise then, the identified gap can be acted upon accordingly. This therefore reflects

operating in, the Plan-Do-Check-Act. Finally, the authors share the view that a change of this magnitude is a progressive process, which should also be a satisfactory argument for the model's constant demands for feedback in closed loop.

## 7.3 DESCRIPTION OF MODEL COMPONENT

This section will discuss the different component that make up the shareholder focus model for the formation of maintenance strategy.

**Production Department Mission**

The production department of a typical oil and gas company existence constitutes the necessary processes in which is needed to produce oil and gas safely. Therefore, the production department is the main customer for the maintenance department. According Mobley (2004), it states that maintenance delivers uptime to its customer (Production). Production mission is the stated reason for producing oil & gas.

**Maintenance Department Mission**

Since maintenance department customer is the production department, therefore maintenance mission is to support adequately production mission. Maintenance mission is always derived from production department mission.

**Maintenance Department Vision**

Definition of a vision by (Bergman and Klefsjö, 2010) is the stage where an organization will like to achieve. (Bergman and Klefsjö, 2010) stated that a well-developed organization visions gives sense of purpose to any work performed to achieve an organization mission ,and hence inspires and encourages workers. Therefore, the author’s opinion is that the organization vision is of great importance when looking at organizations development.

**Production and Maintenance Target**

These are clear and measureable target an organization strives to achieve within a defined and agreed time frame. Bergman and Klefsjö, (2010) explained further that these are things that are observable and measurable.

The authors suggest that the target for production and maintenance department should be in sync. The will help both department to support each other's target effectively. Kelly (2006) states that, it is vital to know the operating modes of the plants and the relationship between the plant and its market. Therefore, authors' opinion is production and maintenance targets are vital part to consider. According to Kelly (2006), it is any established fact that successful companies have a strong link and association between production and maintenance department.

**Guiding Standard**

These are a guiding standard for company to provide direction in achieving its vision, consideration the ethics and practices of the company. These guiding standard is also a media to demonstrate the company's aim to employees and potential shareholders.

**Control**

Increased control of the maintenance organization may provide a reduction of costs.

- Data Management

  To control the maintenance organization requires proper data about events that occur, supported by (Wireman, 2009). Information is the establishment to pick up control and without powerful information gathering can't episodes be genuinely explored, root causes can't be explained, upgrades is difficult to perform and the ideal measure of spare parts is hard to establish. Practices such as The Plan-Do-Check-Act cycle, FMEA, FTA and RCA are suggested. It is suggested that one of two of these are selected to be utilized by the maintenance organization to take care of issues and enhance the organization.

  1. CMMS

In order to oversee maintenance tasks successfully a CMMS are required (Ylipää and Harlin, 2007) and (Wireman, 2009). Therefore, it is suggested to use a CMMS likewise introduces data visual and is anything but difficult to utilize. That is, to encourage the control of the maintenance organization and to facilitate the maintenance technician's reporting endeavors.

2. Inventory

   Keep the critical spare parts (built up after criticality grouping) accessible away to maintain a strategic distance from pointless holding up time and expenses due to for instance transportation and requesting when it is required. It is suggested that the maintenance department themselves control the stock of spare parts with respect to criticality

3. Measure KPIs

   Measure the built up KPIs consistently and present their qualities outwardly to the stakeholders. Talk about reasons why they are driving or slacking and assign resources to examine the purpose behind the variety further keeping in mind the end goal to make appropriate move to enhance maintenance performance.

4. Maintenance Improvement

   Maintenance ought to enhance ceaselessly, keeping in mind the end goal to make inspiration among employees assign suitable people to lead upgrades. It is significant that management backing and motivate to change endeavours furthermore makes conditions to collaboration when working with enhancements.

**MSR – Maintenance Section Review**

Refer to Section 5.1

**Maintenance Strategy**

Now a solid establishment of information, results, techniques and activities are accessible all together for the organization to formulate the maintenance strategy. Together with shareholders, build up guidelines for how to function and which critical thinking tools to utilize.

- Production strategic goals

  The maintenance strategy ought to be created in arrangement with the production strategic objectives and representatives from the management of the production department ought to partake when the strategy is detailed. This is supported by a contextual analysis introduced by Salonen (2009). The contextual investigation demonstrated stakeholder involvement may prompt a consistent perspective on the maintenance department anticipated provisions to the production department which may add to higher participation between these departments. The organization's efficiency will thus profit by this. Additionally, the capacity of an organization to accomplish its goals is influenced by the stakeholders.

# 7.4 IMPLEMENTATION OF MAINTENANCE STRATEGY

It is noted in numerous sources that an all-inclusive answer for usage of the model does not exists. Each organization is distinctive and will be worked with various conditions and issues, and will therefore confront diverse difficulties amid the execution stage (Rubenowitz, 2004). It is the authors' feeling, clear that a usage plan ought to be finished by exhaustive learning of the organization, the way of life inside the work environment and cross-useful by the organization's different departments. Slack and Lewis, likewise expresses that taking into consideration the risks of change and how to prevent, disconnect or work with an issue that may emerge from the change. Thus, the authors'

feeling, this is an element which ought to be checked inside the organization and highlighted at top management. Campbell and Reynes-Pickell (2006) additionally demonstrates that the execution plan ought to first be considered when the methodology is set up.

The implementation stage is in a few regards not a project, but instead a program or procedure. Slack and Lewis recommend that the distinction is that a project has a starting and an end, has characterized targets and utilizing specific resources. Significant change project can subsequently be rethought as a project, without characterized begin and end focuses. It is a progressing change. A critical factor is that one doesn't trust the change drops without anyone else rather sees the work change as consistent to enhance, and be focused.

Another element that the authors feel is urgent is input, both from shareholders. The execution ought to archive their stakeholders as these, which Slack and Lewis calls attention to, can impact on the change and hence never ought to be disregarded. This range may likewise be politically sensitive inside the organization, stakeholders and backing inside the hierarchy may along these lines turn out to be unequivocal factors. In addition to other things, likewise noticed, the capacity to usage in an underlying stage, may show as negative economically, for this situation, the authors view also is reinforced, the more critical support inside the hierarchy and by the stakeholders, the smoother the move will be.

## 7.5 MAINTENANCE SECTION REVIEW - MSR

MSR is a tool to be utilized for benchmarking and deciding potential improvement areas. The questions results in an outline of current status, as far as maintenance and asset management. MSR is divided to the distinctive area that maintenance department manages, which mirrors the perspectives that, as per Wireman (2010), the maintenance management involve. The question inside the MSR considers likewise the organization culture.

# 7.6 RELIABILITY AND VALIDITY OF METHODS

The subsequent section discusses dependability and validity of the research methods, and the results achieved.

**RELIABILITY**

The research has executed a present state investigation on the maintenance department in some North Sea oil and gas organizations. This was performed by surveys, interviews and using MSR. Regarding the dependability of these method, it must be noticed that these are not steady. Stability is acquired if the technique can be performed later on and get the same result, but as the maintenance organization is always changing (the same applies to the employees), it is likely that at a future review reactions additionally is created and got new results thereof. This ought not to be considered as negative, and the trust is that using the shareholder centered model the elaboration would demonstrate more productive opportunities. On account of internal reliability, this is dependably a variable to be checked. To be internal reliable, answers might not influence the reactions to each other. Subsequently, this is always an issue in interviews. For this situation, in any case, the interview completed are semi- structured, which implied that the opportunity existed to ask additional questions .Of this reason, the reactions are seen as internal reliable. Moreover, in between observed consistency, it is conceivable that the authors' understandings affected the answers. As our understanding may likewise be influenced by each other the risk is then bigger of the group answers are influenced. It is our hope that this has not been the situation, however the authors can't promise this completely.

**VALIDITY**

The literature described in the thesis is considered too be approved using face validity, implying that it has been analyzed by specialists within the area. For validation of the

methods and results, it is seen as that these has been validated through face validity. Also, the present state analysis of various case study organizations are each validated utilizing the maintenance section review (MSR) bringing about convergent validity. This is likewise the case with interviews, questionnaire and review of documentation to validate the present state analysis. Along these lines to close, the literature, methods and results, are considered by the authors to be both reliable and valid. On account of the benchmarking, it should sadly be said that these couldn't be validated in the desired amount, Due to the way of the straightforwardness of these organizations. The stability of these answers is nor not high, in any case, this is characteristic, because of the way that the associations develop, and subsequently not something that is thought to be an issue

# 8.0 PRINCIPAL COMPONENT ANALYSIS OF MSR

The data collected in the research have multiple variables, which are for 3 observations (case study companies) and 13 categories (Work order, Preventive Maintenance etc.) The groups of variables often move together. One reason for this is that more than one variable might be measuring the same driving principle governing the behaviour of the system. In many systems there are only a few such driving forces. But an abundance of instrumentation enables to measure dozens of system variables. When this happens, we can take advantage of this redundancy of information. You can simplify the problem by replacing a group of variables with a single new variable.

Principal component analysis is a quantitatively rigorous method for achieving this simplification. The method generates a new set of variables, called principal components. Each principal component is a linear combination of the original variables. All the principal components are orthogonal to each other, so there is no redundant information. The principal components as a whole form an orthogonal basis for the space of the data.

There are an infinite number of ways to construct an orthogonal basis for several columns of data. The first principal component is a single axis in space. When you project each observation on that axis, the resulting values form a new variable. And the variance of this variable is the maximum among all possible choices of the first axis. The second principal component is another axis in space, perpendicular to the first. Projecting the observations on this axis generates another new variable. The variance of this variable is the maximum among all possible choices of this second axis.

The full set of principal components is as large as the original set of variables. But it is commonplace for the sum of the variances of the first few principal components to exceed 80% of the total variance of the original data. By examining plots of these few new variables, we will be able to develop a deeper understanding of the driving forces that generated the original data.

| S/N | Maintenance Section Review | A | B | C |
|---|---|---|---|---|
| 1 | Maintenance Structure | 2.1 | 1.8 | 2 |
| 2 | Maintenance Training Program | 2.4 | 2.2 | 2.1 |
| 3 | Work Orders | 3 | 2.8 | 2.5 |
| 4 | Planning and Scheduling | 1.6 | 1.2 | 1.3 |
| 5 | Preventive Maintenance | 2 | 1.8 | 2.2 |
| 6 | Inventory and Purchasing | 2 | 1.9 | 1.5 |
| 7 | Computerized Maintenance Management System (CMMS) | 3 | 2.8 | 2.6 |

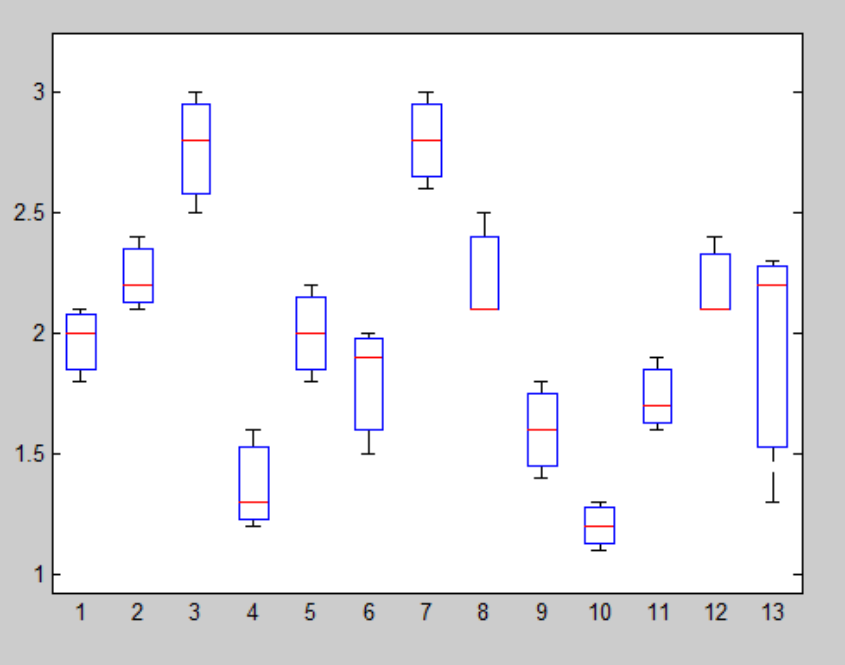
| | | | | |
|---|---|---|---|---|
| 8 | Operations | 2.1 | 2.5 | 2.1 |
| 9 | Maintenance Reporting | 1.8 | 1.6 | 1.4 |
| 10 | Predictive Maintenance | 1.2 | 1.1 | 1.3 |
| 11 | Reliability and Breakdown | 1.9 | 1.7 | 1.6 |
| 12 | Maintenance – Key Performance Indicators | 2.1 | 2.4 | 2.1 |
| 13 | Financial Planning | 2.3 | 2.2 | 1.3 |

We have written an M-file in Matlab to execute these steps. List below are the code, results and explanation.

The data we are using are already standardized, hence we can continue with our analysis with these raw data.

First we do a boxplot, this a standardized way of displaying the distribution of data based on the five number summaries: minimum, first quartile, median, third quartile, and maximum. These give an idea of the variation of the data.

Typically graph pairs of the original variables can be plotted, but there are 13-variable plots. Perhaps principal components analysis can reduce the number of variables needed to consider.




**Maintenance Section Review – Criteria (Variables)**

Next we compute the loading, these contains the coefficients of the linear combinations of the

original variables that generate the principal components.

**Interpretation of the principal components**

Interpretation of the principal components is based on finding which variables are most strongly correlated with each component, i.e., which of these numbers are large in magnitude, the farthest from zero in either positive or negative direction. Which numbers we consider to be large or small is of course is a subjective decision. You need to determine at what level the correlation value will be of importance. Here a correlation value above 0.3 is deemed important. These larger correlations are in boldface in the table above:

We will now interpret the principal component results with respect to the value that we have deemed significant.

| | | |
|---|---|---|
| Structure | 0.002246 | **0.360308** |
| Training | -0.17203 | 0.183659 |
| WO | -**0.32076** | 0.13519 |
| Planning | -0.12095 | **0.44002** |
| PM | 0.199812 | **0.30483** |
| Inventory | **-0.3463** | 0.00701 |
| CMMS | -0.2464 | 0.159425 |
| Operations | -0.10215 | **-0.51272** |
| Reporting | -0.2464 | 0.159425 |
| PDM | 0.099906 | 0.152415 |
| Reliability | -0.17203 | 0.183659 |
| KPIs | -0.07661 | **-0.38454** |
| Financial | -**0.71814** | -0.11416 |

**First Principal Component Analysis - PCA1**

The first principal component is strongly correlated with three of the original variables. The first principal component increases with decreasing work order, Inventory & purchasing, and financial reporting scores. This suggests that these three criteria vary together. If one increases, then the remaining ones tend to as well. This component can be viewed as a measure of the quality of work order, Inventory & purchasing and financial reporting. Furthermore, we see that the first principal component correlates most strongly with financial reporting. In fact, we could state that based on the correlation of 0.7 that this principal component is primarily a measure of the financial reporting.

It would follow that companies with good maintenance strategy would tend to have a strong financial reporting available.

**Second Principal Component Analysis - PCA2**

The second principal component increases with four of the values, decreasing maintenance KPI & Operation. The second principal component increases with increasing maintenance structure, planning & scheduling, preventive maintenance scores. The second principal component increases with decreasing operation and KPI. This suggests that these criteria vary together. If one increases, then the remaining ones tend to as well in the relevant direction. This component can be viewed as a measure of the quality of maintenance structure, planning & scheduling, preventive maintenance, operation and KPI. Furthermore, we see that the second principal component correlates most strongly with operation. In fact, we could state that based on the correlation of 0.5 that this principal component is primarily a measure of the operation. It would follow that companies with good maintenance strategy would tend to have a strong operation culture available.

# 9.0 CONCLUSION

The purpose of this thesis is to develop a model for the formulation of a maintenance strategy and in order to do so, we have three research questions been formulated. These three questions are aimed at grasping the key objectives of the thesis and also to function as guidance along the way of developing the model. The three research questions are the following:

**Research Question 1** – What is the current state of maintenance departments North Sea O&G industries and what is the anticipated state?

**Research Question 2** – Where do each case study North Sea O&G companies stand in comparison with each other, and what can they learn from each other.

**Research Question 3** – Which factors influence the achieving the anticipated state?

The maintenance department at the case study companies comprises mostly of a fire-fighting or reactive methodology, events and failures choose the direction. The Maintenance Section Review (MSR) created in this research is a tool for analysing the maintenance department for O&G North Sea companies and ought to ideally be performed with an interval of at least twice a year and to follow- up changes and update the present state as required. The outcome from the MSR demonstrates that the area in which there is most noteworthy potential for development are Planning & Scheduling, Maintenance Reporting, Inventory & Purchasing, Reliability & Breakdown and Maintenance Structure. Likewise, the need and productivity for a predictive maintenance program might be determined keeping in mind the end goal to facilitate building up the organization and the maintenance work.

More often, maintenance focused education opportunities for the support technicians with regards to new innovation or new operating procedure in asset will add to a larger amount of productivity and adequacy for the maintenance work. The management ought to support the technicians' thoughts and use the skill they have. This will likewise draw in and encourage them to enhance the organization which will encourage achieving the

desired state, that is a proactive domain. It is additionally key that training concerning the continuous changes inside the organization is given so that information about what is changing, why it is changing and what the goal of the change is. Else, the resistance to change will unquestionably be high. In this way, training is a crucial part in the Shareholder Focused Model (SFM). With a specific end goal to enhance the financial planning area the methodologies 'Life Cycle Cost' and 'Life Cycle Profit' are highlighted in the SFM.

There is a probability to increment and highlight the collaboration between the maintenance and production department. The maintenance department should be included at an early stage when new equipment is obtained keeping in mind the end goal to outline reliability and maintainability into equipment. The reliability engineering is incorporated into the SFM to stretch the significance of reliability and maintenance engineering.

Reliability engineering with relating methodologies is defined thoroughly in the explanation of that step. The following step in the SFM is maintenance program. This is incorporated due to the MSR result which demonstrated change potential inside preventive and predictive maintenance. This step incorporates assessment of failure patterns and a number of different types of maintenance programs, and the maintenance program should be enhanced persistently.

The proposed SFM is guidance for how to achieve the desired state – a proactive domain. Today is North Sea O&G organizations' maintenance organization on average further away from a proactive domain contrasted with most Industry benchmark (Cholasuke et al., 2004).

The SFM has been designed mainly from the issues the authors found to hinder the maintenance department from attaining the desired state and thus, it is guidance during the ongoing maintenance organization changes. Together with North Sea O&G companies expertise and experience within the own industry and the area of maintenance it is hoped

that the model will function as a bridge when developing and improving the organization to reach the vision.

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# APPENDIX 1 - INTERVIEWS QUESTIONS

**INTERVIEWS QUESTIONS FOR MAINTENANCE ENGINEERS AND TECHNICIANS**
Job Title:

Please give examples as required.

1. How many maintenance technicians and engineers work at the department (UK wide)?
2. What is your own opinions concerning the maintenance work at your department? (i.e. Workload, work pace, delays, efficiency, production disruption etc.)
3. Do you consider the tools/equipment supporting the work are high-quality and sufficient?
4. What types of training are provided for the maintenance department?
5. Do you consider yourself competence and equipped in knowledge to perform your work responsibility?
6. If an equipment can't be restore, how do you proceed?
7. Do you consider the technicians to have sufficient competence? – Engineers specific question
8. Is there a maintenance schedule to follow over the work to be performed? If yes, in what interval?
9. When the work is completed, who reports the consumed time, the supply, downtime and any other information?
10. Who do you report to?
11. The preventive maintenance includes what activities?
12. Are spare parts always in storage when needed?
13. Do operations personnel generate work order requests?
14. Are operations personnel involved in the maintenance work?
15. Are root causes clearly identified? And are they also analysed?
16. Do you work with continuous improvements? Do the organizations support continuous improvements efforts?
17. What KPI are maintenance activities measure against.
18. Organisation Layout - Maintenance Department Organogram ( a copy without names)
19. Maintenance objectives and responsibility

20. Maintenance Planning - How are Preventive, Corrective & Predictive planning done?
21. Are maintenance department involve at start of an investment or project sanction?
22. How improvement strategies are implemented and how do company measure and reward it?
23. Do you measure plant overall equipment efficiency and staff turnover?

# APPENDIX 2 - MSR

## Section 1 - Maintenance Structure

**1. Status of Maintenance Organization Chart**

A. Updated and completed - 4pts

B. Not completed or over one year old - 3pts

C. Not updated and not completed - 2pts

D. Don't exist - 0pt

**2. The maintenance departments' responsibilities and work are:**

A. Fully documented - 4pts

B. Clear, well communicated and have good coverage but are not fully documented - 3pts

C. Informally supervised and coordinated, there are gaps in job coverage - 2pts

D. Not clear, there are unclear lines of authority, jurisdiction - 0pt

**3. How clear are the maintenance structure's documents?**

A. Excellent - 4pts

B. Good - 3pts

C. Average - 2pts

D. Poor - 1pt

E. Very poor - 0pt

**4. How effective is the process for continuous improvements?**

A. Strong - 4pts

B. Moderate- 3pts

C. Weak - 2pts

D. None - 0pt

## Section 2 - Maintenance Training Program

**5. Training for employees with maintenance responsibility.**

A. Training have been provided to all with maintenance responsibility - 4pts

B. Documents regarding maintenance have been provided to support the work. - 3pts

C. Training is provided to new maintenance personnel by supervisors for at least the first month. - 2pts

D. No training is provided - 0pt

**6. Maintenance engineers and technicians training frequency concerning new and changes in equipment:**

A. Less than one year - 4pts

B. from 12 to 18 months - 3pts

C. Not to all employees, but to some in any of the above frequencies - 1pt

D. No education is offered - 0pt

**7. Maintenance competence and work quality of performed maintenance tasks are considered to be:**

A. Excellent - 4pts

B. Good - 3pts

C. Fair - 2pts

D. Poor (major improvement required) - 1pt

E. Unsuitable - 0pt

## Section 3 - Work Orders

**8. What percent of the total amount of work orders that is processed in the system are tied to an asset/ equipment number?**

A. 100% - 4pts

B. 75% - 3pts

C. 50% - 2pts

D. 25% - 1pt

E. Less than 25% - 0pt

**9. What percent of the total number of maintenance man-hours are reported to a work order?**

A. 100% - 4pts

B. 75% - 3pts

C. 50% - 2pts

D. 25% - 1pt

E. Less than 25% - 0pt

**10. What percent of the amount of work carried out is covered by work orders?**

A. 100% - 4pts

B. 75% - 3pts

C. 50% - 2pts

D. 25% - 1pt

E. Less than 25% - 0pt

**11. What percent of the total amount of work orders are available for historical data analysis?**

A. 100% - 4pts

B. 75% - 3pts

C. 50% - 2pts

D. 25% - 1pt

E. Less than 25% - 0pt

**12. Which of the following categories are covered in a work order? Please tick multiple answer if applicable – Add one point for each**

A. Required downtime

B. Required technician hours

C. Required materials

D. Requestor's name

## Section 4 - Planning and Scheduling

**13. What percent of the total amount of work orders have been delayed due to poor or incomplete plans: (previous year)**

A. Less than 10% - 4pts

B. From 10% to 20% - 3pts

C. From 21% to 40% - 2pts

D. From 41% to 50% - 1pt

E. More than 50% - 0pt

**14. Responsibility for planning the preventive work orders rests on?**

A. A dedicated maintenance planner - 4pts

B. A maintenance technician - 2pts

C. There is no responsible person, anyone can do it - 0pt

**15. When the maintenance job is completed, who reports the actual working time, used material, downtime, and other data?**

A. The technicians that performed the job - 4pts

B. The engineer or supervisor of the group - 3pts

C. Anyone else - 2pts

D. Data is not recorded - 0pt

## Section 5 - Preventive Maintenance

**16. To what extent does the preventive maintenance program cover critical equipment?**

A. At least 90% - 4pts

B. From 75% to 89% - 3pts

C. From 60% to 74% - 2pts

D. From 40% to 59% - 1pt

E. Less than 40% - 0pt

**17. What percent of the PM program is annually checked against corresponding item's history to ensure good coverage of the program?**

A. At least 90% - 4pts

B. From 75% to 89% - 3pts

C. From 60% to 74% - 2pts

D. From 40% to 59% - 1pt

E. Less than 40% - 0pt

**18. What is the frequency of the preventive maintenance program based on?**

A. The actual condition of equipment - 4pts

B. A combination of equipment run time or condition based, and fixed calendar interval - 3pts

C. Run time only - 2pts

D. Calendar intervals - 1pt

E. The program is dynamic and scheduled based on completion date of previous task - 0pt

**19. What percent of the total amount of work orders have been generated from preventive maintenance inspections?** (Previous year)

A. At least 80% - 4pts

B. From 60% to 79% - 3pts

C. From 40% to 59% - 2pts

D. From 20% to 39% - 1pt

E. Less than 20% - 0pt

## Section 6 - Inventory and Purchasing

**20. The availability of critical spare parts?**

A. More than 95% - 4pts

B. From 90% to 95% - 3pts

C. From 80% to 89% - 2pts

D. From 70% to 79% - 1pt

E. Less than 70% - 0pt

**21. Who controls the inventory of spare parts?**

A. Maintenance - 4pts

B. Anyone else - 0pt

**22. To what extent are the maximum and minimum levels for stored materials specified?**

A. More than 95% - 4pts

B. From 90% to 95% - 3pts

C. From 80% to 89% - 2pts

D. From 70% to 79% - 1pt

E. Less than 70% - 0pt

## Section 7 - Computerized Maintenance Management System (CMMS)

**23. What percent of all maintenance operations utilizes CMMS at present?**

A. At least 90% - 4pts

B. From 75% to 89% - 3pts

C. From 60% to 74% - 2pts

D. From 40% to 59% - 1pt

E. Less than 40% - 0pt

**24. To what extent is CMMS data structured and how often is this updated?**

A. At least 90% - 4pts

B. From 75% to 89% - 3pts

C. From 60% to 74% - 2pts

D. From 40% to 59% - 1pt

E. Less than 40% - 0pt

## Section 8 - Operations

**25. What percent of the total amount of operations personnel can generate work order requests? [%]**

A. At least 90% - 4pts

B. From 75% to 89% - 3pts

C. From 60% to 74% - 2pts

D. From 40% to 59% - 1pt

E. Less than 40% - 0pt

**26. Which of the following tasks are operators trained to perform? Please tick multiple answer if applicable. Add one point for each.**

A. Inspections

B. Lubrication

C. Minor maintenance task

D. Assist in maintenance repair work

## Section 9 - Maintenance Reporting

**27. Which of the following reports are produced for equipment: Please tick multiple answer if applicable. Add one point for each.**

A. Equipment downtime arranged from highest to lowest number of hours (weekly or monthly)

B. Equipment downtime arranged from highest to lowest in total lost production income (weekly or monthly)

C. Maintenance cost for equipment arranged highest to lowest cost (weekly or monthly)

D. MTBF and MTTR for the equipment

## Section 10 - Predictive Maintenance

**28. Does a predictive maintenance program exist? (If no, continue to question 32)**

A. Yes - 4pts

B. No – 0pt

**29. Does the predictive maintenance program include condition-based monitoring?**

A. Yes - 4pts

B. No – 0pt

**30. Are work orders generated from the predictive maintenance program?**

A. Yes - 4pts

B. No – 0pt

**31. Is the data gained from the predictive maintenance program used to improve asset performance and asset life expectancy? How?**

A. Yes - 4pts

B. No – 0pt

## Section 11 - Reliability and Breakdown

**32. To what extent is risk analyses used?**

A. At least 90% of the assets - 4pts

B. From 75% to 89% of the assets - 3pts

C. From 60% to 74% of the assets - 2pts

D. From 40% to 59% of the assets - 1pt

E. Less than 40% of the assets - 0pt

**33. Is RCM methodology used on critical equipment to adjust or refine the PM/PDM program?**

A. Yes - 4pts

B. No – 0pt

**34. How often are root cause of failure clearly identified and recorded?**

A. At least 90% of all failures - 4pts

B. From 75% to 89% of all failures - 3pts

C. From 60% to 74% of all failures - 2pts

D. From 40% to 59% of all failures - 1pt

E. Less than 40% of all failures - 0pt

**35. Are failures map to work orders and can they be accurately be tracked by work order history?**

A. At least 90% of all failures - 4pts

B. From 75% to 89% of all failures - 3pts

C. From 60% to 74% of all failures - 2pts

D. From 40% to 59% of all failures - 1pt

E. Less than 40% of all failures - 0pt

**36. Are failure analysis conducted by using analysis tool such as fishbone, tree, five why's or Pareto, to assure accuracy and standardization for each analysis?**

A. Yes - 4pts

B. No - 0pt

**37. Are failure frequencies calculated according to "The Six Failure Patterns" included in the RCM methodology?**

A. Yes - 4pts

B. No - 0pt

**38. Are any certain software (ex: Reliasoft, Relex etc.) used for calculating failure frequencies and other calculations?**

A. Yes - 4pts

B. No - 0pt

## Section 12 - Maintenance – Key Performance Indicators

**39. To what extent is equipment efficiency calculated to monitor the condition of critical equipment? [%]**

A. 90% or more - 4pts

B. 60 to 89% - 4pts

C. 30 to 59% - 2pt

D. Less than 30% - 0pt

**40. Is the extent of downtime in relation to total production time for the facility/equipment due to corrective maintenance known by the company?**
**(The proportion of production time that equipment has been down due to emergency corrective maintenance, including waiting time).**

A. Yes - 4pts

B. No - 0pt

**41. Is the percentage of the maintenance cost that consists of preventive maintenance known by the company? (Cost of preventive maintenance/Total maintenance cost) x 100**

**42. Is the proportion of total number of maintenance man-hours devoted to emergency corrective maintenance known by the company?**

## Section 13 - Financial Planning

**43. Is the concept Life cycle cost considered when initial investments are planned?**

A. Yes - 4pts

B. No - 0pt

**44. Is Life cycle cost considered when equipment conditions are determined?**

A. Yes – for all equipment - 4pts

B. Yes – only for critical equipment - 2pts

C. No - 0pt

**45. How do you want to classify your organization's financial knowledge regarding asset**

**determination based on equipment condition?**

A. The organization has extensive knowledge - 4pts

B. Limited knowledge - 2pts

C. Low or no knowledge- 0pt

# Appendix 3 – PCA

The M.file developed also output scores matrix, this contains the coordinates of the original data in the new coordinate system defined by the principal components. This output is the same size as the input data matrix.

Component Variances also known as latent is another output from the M-File created, variances, is a vector containing the variance explained by the corresponding principal component. Each column of scores has a sample variance equal to the corresponding element of variances.

Coeff =

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Structure | 0.002246 | 0.360308 | 0.048565 | 0.173281 | -0.17882 | 0.33171 | 0.189545 | 0.181777 | 0.190012 | -0.08287 | 0.209078 | 0.132598 | 0.722872 |
| Training | -0.17203 | 0.183659 | 0.557739 | -0.5695 | -0.29648 | -0.03521 | -0.03906 | 0.230525 | -0.04034 | -0.16613 | -0.30346 | 0.183116 | -0.05113 |
| WO | -0.32076 | 0.13519 | -0.38922 | 0.086075 | 0.026082 | -0.11998 | -0.35883 | 0.537325 | -0.3566 | 0.044249 | 0.091702 | 0.385161 | -0.03876 |
| Planning | -0.12095 | 0.44002 | 0.382866 | 0.707375 | -0.05103 | -0.11901 | -0.03599 | -0.0514 | -0.03695 | -0.03896 | -0.20499 | -0.03087 | -0.27969 |
| PM | 0.199812 | 0.30483 | 0.151331 | -0.15957 | 0.888288 | 0.021153 | -8.14E-05 | 0.10325 | -0.00039 | -0.06015 | -0.07179 | 0.079889 | 0.058927 |
| Inventory | -0.3463 | 0.00701 | -0.03686 | -0.03255 | 0.08804 | 0.874562 | -0.06687 | -0.09204 | -0.06699 | 0.042217 | -0.06337 | -0.068 | -0.27775 |
| CMMS | -0.2464 | 0.159425 | -0.2429 | -0.07425 | 0.02617 | -0.11135 | 0.876965 | 0.079859 | -0.12282 | 0.016153 | -0.06018 | 0.058141 | -0.19617 |
| Operations | -0.10215 | -0.51272 | 0.332446 | 0.211927 | 0.13945 | 0.041396 | 0.156307 | 0.650147 | 0.155907 | 0.064127 | 0.084186 | -0.25919 | -0.01667 |
| Reporting | -0.2464 | 0.159425 | -0.24041 | -0.07458 | 0.026223 | -0.11138 | -0.12254 | 0.078795 | 0.877677 | 0.016118 | -0.06052 | 0.057378 | -0.19663 |
| PDM | 0.099906 | 0.152415 | 0.110567 | -0.08451 | -0.05511 | 0.010142 | 0.006913 | 0.036724 | 0.006698 | 0.96943 | -0.04074 | 0.029265 | 0.023006 |
| Reliability | -0.17203 | 0.183659 | 0.254918 | -0.14689 | 0.012414 | -0.09465 | -0.01645 | -0.10073 | -0.01708 | -0.00271 | 0.877926 | -0.07045 | -0.2336 |
| KPIs | -0.07661 | -0.38454 | 0.22939 | 0.161642 | 0.104162 | 0.031295 | 0.113256 | -0.25387 | 0.112992 | 0.048379 | 0.065907 | 0.811709 | -0.00881 |
| Financial | -0.71814 | -0.11416 | 0.084175 | -0.02222 | 0.212539 | -0.24146 | -0.07975 | -0.30348 | -0.08024 | 0.099402 | -0.11607 | -0.22368 | 0.426497 |

Latent =

| |
|---|
| 0.583622 |
| 0.179711 |
| 0 |
| 0 |
| 0 |
| 0 |
| 0 |
| 0 |
| 0 |
| 0 |
| 0 |
| 0 |
| 0 |

We calculated the percent of the total variability explained by each principal component.

percent_explained = 100*variances/sum (variances)

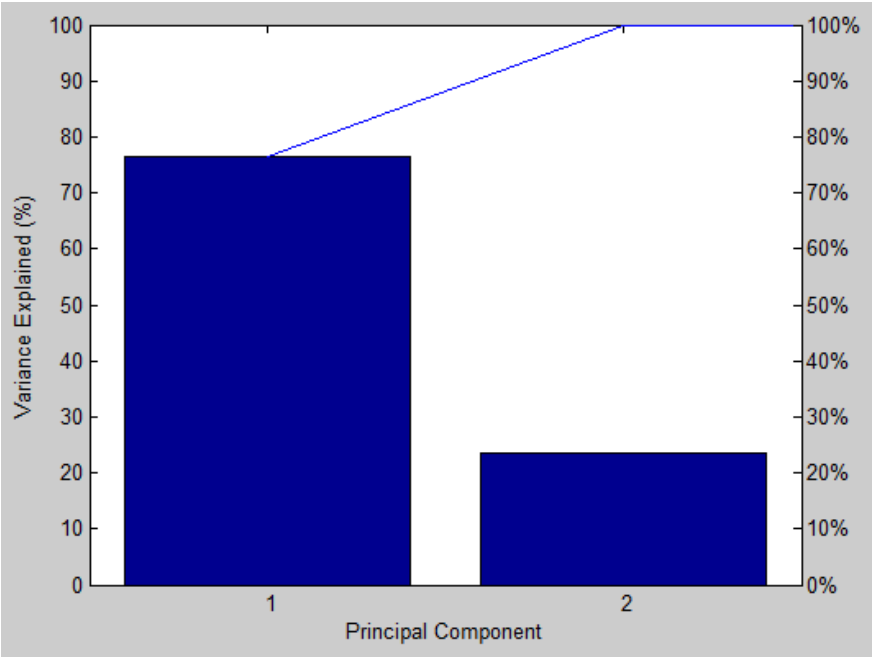
percent_explained =

| |
|---|
| 76.45708 |
| 23.54292 |
| 0 |
| 0 |
| 0 |
| 0 |
| 0 |
| 0 |
| 0 |
| 0 |
| 0 |
| 0 |
| 0 |

We made a screen plot of the percent variability explained by each principal component.

Pareto (percent_explained)

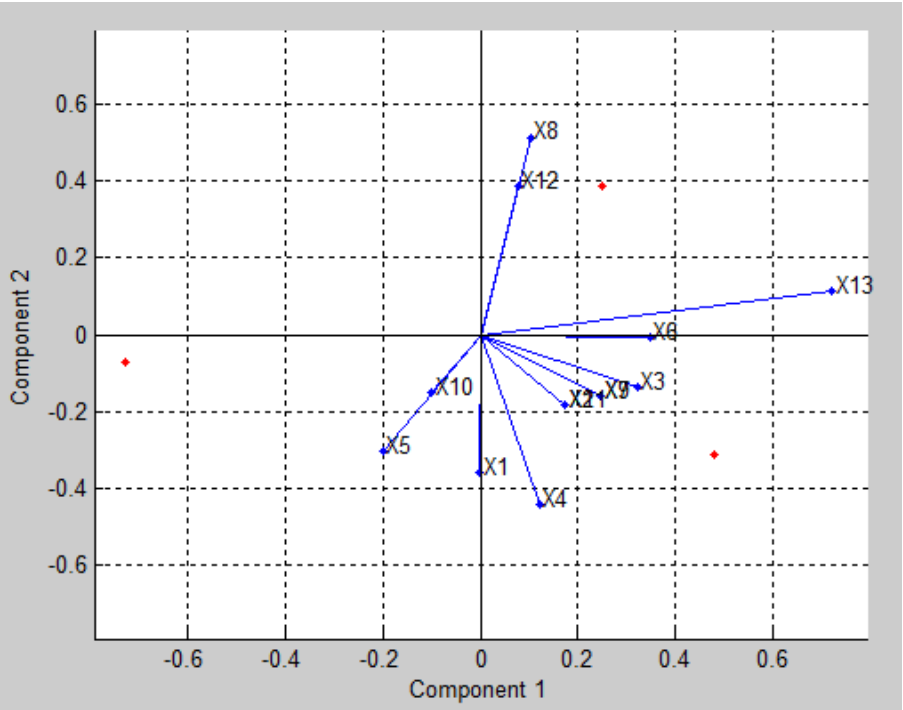
```
xlabel('Principal Component')
ylabel('Variance Explained (%)')
```




The preceding figure shows a clear break in the amount of variance accounted for by each component, which include between the first and second components, there are not third component. However, first component by itself explains less than 80% of the variance, so more second components are probably needed. You can see that the first two principal components explain entirely the total variability in the standardized ratings, so that might be a reasonable way to reduce the dimensions in order to visualize the data.

The last output from the M-Fileis Hotelling's T2it is a statistical measure of the multivariate distance of each observation from the center of the data set. This is an analytical way to find the most extreme points in the data.

We have visualized both the principal component coefficients for each variable and the principal component scores for each observation in a single plot.




Each of the 13 variables is represented in this plot by a vector, and the direction and length of the vector indicates how each variable contributes to the two principal components in the plot. For example, we have seen that the first principal component, represented by the horizontal axis, has positive coefficients for 11 variables and negative for 2 variables. We have also seen that the second principal component, represented by the vertical axis, has negative coefficients for the variables all expect operation, KPI and financial reporting, and negative coefficients for the remaining five variables. That corresponds to vectors directed into the bottom and top halves of the plot, respectively.

This indicates that this component distinguishes between case study companies that have high values for the first set of variables and low for the second, and case study companies that have the opposite.

Instead of using the 13 variables, now 2 components can be used to summarize the data.

```
%  Analysis to establish the principal components among the different
%  measurement for maintenance strategy
%
%  Load collected data from case study companies
J = [2.1 1.8 2;
   2.4 2.2 2.1;
   3 2.8 2.5;
   1.6 1.2 1.3;
   2 1.8 2.2;
   2 1.9 1.5;
   3 2.8 2.6;
   2.1 2.5 2.1;
   1.8 1.6 1.4;
   1.2 1.1 1.3;
   1.9 1.7 1.6;
   2.1 2.4 2.1;
   2.3 2.2 1.3];

M = [2.1 2.4 3 1.6 2 2 3 2.1 1.8 1.2 1.9 2.1 2.3;
   1.8 2.2 2.8 1.2 1.8 1.9 2.8 2.5 1.6 1.1 1.7 2.4 2.2;
   2 2.1 2.5 1.3 2.2 1.5 2.6 2.1 1.4 1.3 1.6 2.1 1.3];

MSR = ['MS' , 'WO', 'PS', 'PM', 'IP', 'CMMS', 'OP', 'MR', 'PDM', 'RB', 'KPI', 'FP'];
%  Make a boxplot to look at the distribution of MSR data.
figure()
boxplot(M)
%  Check the pairwise correlation between the variables.
C = corr(M,M);
E = eig(C);
W = 1./var(M);

stdr = std(M);
sr = M./repmat(stdr,3,1);
%  Compute principal components
%  PRINCOMP Principal Component Analysis (centered and scaled data).
%  COEFF, SCORE, LATENT, TSQUARE] = PRINCOMP(X) takes a data matrix X and
%  returns the principal components in COEFF, the so-called Z-scores in SCORES,
%  the eigenvalues of the covariance matrix of X in LATENT, and Hotelling's
%  T-squared statistic for each data point in TSQUARE.
[Coeff, Score, latent, tsquare] = princomp(M);

%  Check coefficients are orthonormal
I = Coeff' * Coeff;
R = cumsum(latent)./sum(latent);

figure ()
```

```
biplot(Coeff(:,1:2),'Score',Score(:,1:2),'VarLabels',...
{'X1' 'X2' 'X3' 'X4' 'X5' 'X6' 'X7' 'X8' 'X9' 'X10' 'X11' 'X12' 'X13'})

figure()
plot(Score(:,1),Score(:,2),'+')
xlabel('1st Principal Component')
ylabel('2nd Principal Component')
%gname;
percent_explained = 100*latent/sum(latent);
pareto(percent_explained)
xlabel('Principal Component')
ylabel('Variance Explained (%)')
```