Development of a maintenance management framework to facilitate the delivery of healthcare provisions in The Kingdom of Saudi Arabia

HESHAM ALZABEN

School of Science and Technology

A thesis submitted in partial fulfilment of the requirements of Nottingham Trent University for the degree of

Doctor of Philosophy

April 2015

Copyright Statement

Publications

Hesham Alzaben, Chris, McCollin, and Lai, Eugene.2013 Maintenance Planning in a Saudi Arabian Hospital. Advances in Risk and Reliability Technology Symposium (20^{th} AR^2TS) Loughborough. UK

Hesham Alzaben, Lai Eugene and Chris McCollin. 2014."Development of framework for maintenance management in healthcare industry in Saudi Arabia", 20^{th} ISSAT International Conference on Reliability and Quality in Design (RQD 2014)

Hesham Alzaben.Lai, Eugene.2015.Recommendation for improving maintenance procedures in a Hospital by implementing Total Productive Maintenance (TPM). Proceedings of the 2015 International Conference on Industrial Engineering and Operations Management. Dubai, UAE

Acknowledgments

I would first like to thank Dr. Eugene Lai for his valued supervision of this work. His advice and help were priceless throughout the project. Without his immense efforts and valuable suggestions, this work would not have been presented as complete story. Obviously, he spent a lot of time in reading and correcting even when he was on business or family trips. He read each chapter several times to ensure it meets the objectives of research in a coherent manner. I greatly admire his ability to locate minor errors like spelling mistakes not only in text but also in Figures. He fully committed to my research and felt a responsibility to produce this research with a complete picture.

Special thanks are due to Dr. Christopher McCollin for his continuous help and assistance throughout this study. As this research started with him as a first supervisor, he pointed out valuable recommendations and areas to focus on.

I would like to extend my thanks and gratitude to those who participated in survey for their time and contributions. Without the information they gave, this research could not have seen the light.

I would also like to thank the RMH and Medical Service Department of Armed Force for providing me with the opportunity to further explore the academic field through their sponsorship and support.

Special thanks to my wife for her deep support, unlimited love, patience, encouragement and taking care of our kids and I without any complaints.

Definitely I do not forget my little kids, Nawaf and Madhawi, who have been very grateful and have given me the strength to overcome these stressful years.

I will extend my appreciations to my family and friends in Saudi Arabia for providing emotional support through their calls and messages.

Abstract

The recent economic crisis has prompted many organizations to review their maintenance operations with the main objective of controlling costs while trying to maintain a similar level of services and quality. The healthcare industry in Saudi Arabia faced a similar set of problems as the main sponsor (i.e. the Government) received lower revenues from oil export. As intimated by Saudi government officials, the current growth rate in healthcare expenditure is unsustainable in the longer term and efforts are being made to manage resources more efficiently. One area under consideration is the maintenance functions of Saudi hospitals and clinics, as these operations accounted for the bulk of the maintenance-related expenditure. As the largest strategic hospital in the Kingdom, the Riyadh Military Hospital (RMH) has a long term plan to improve the quality and reliability of its services, through better utilization of resources. The present project forms part of the on-going strategic review of the hospital's current maintenance operations including outsourcing and subsequent management of contractors and suppliers. A key challenge is to understand how maintenance activities could be managed more successfully and implemented in a cost-effective way.

Two sets of questionnaires were designed and distributed to the staff including contractors in the Maintenance Department. The questionnaire surveys were supplemented by interviews to assess the managers' awareness/understanding of the importance of leadership, change management, transparency, documentation, communication and clarity of strategy. By means of statistical analysis, the data/information thus gathered was analyzed using a range of quality and reliability tools and techniques. A number of correlations have been identified which confirmed the observations of previous studies. For example, there appeared to be a significant correlation between "the clarity of strategy" and "consistency of maintenance performance", and between "a happy worker" and "the clarity of instructions" and "availability of appropriate tools". Five main parameters have been identified as critical to the success of the maintenance operations at RMH: clarity of policies and procedures; support of senior management; organizational structure; employee qualifications (i.e. technical knowledge and skills); and clarity of maintenance contracts (including communications with external contractors).

Informed by the work of others for the engineering and related industries, a maintenance management framework has been proposed for the healthcare industry in Saudi Arabia. Part of the framework has been implemented at the case study hospital to facilitate validation. It was found that the framework provides a useful means for integrating various maintenance-related activities and to allow guidelines to be provided on the monitoring and control of the processes. This in turn enabled a substantial revision to be made to the current maintenance procedures at the hospital. The effectiveness of the revised maintenance procedures has been investigated using limited field studies. It is pleasing to note that encouraging results have been obtained. For example, the total number of dockets (i.e. maintenance work orders) issued for general maintenance over a 4-month period fell by 23% when compared with the figure for the previous year.

The present study has made a significant contribution in the development of a maintenance management framework for the healthcare industry in the Kingdom of Saudi Arabia.

Table of Contenents

List of Figures

List of Tables

Abbreviations

TQM	Total Quliaty Managenet
TPM	Total productive management
TQMain	Total Quality Maintenance
RCM	Reliability Centred Maintenance
CMMS	Computer Maintenance Management System
CM	Corrective Maintenance
PM	Preventive Maintenance
PreM	Predictive maintenance
CBM	Condition Based Maintenance
BSC	Balance Score Card
AHP	Analytical Hierarchy
MTTF	Mean Time To Failure
MTTR	Mean Time To Repair
CSFs	Critical Success Factors
KPIs	Key Performance Indictors
PI	Performance Indicator
JIT	Just In Time
RMH	Riyadh Military Hospital
MSD	Medical Service Department
GCC	Gulf Council Cooperation
SPSS	Statistical Package for the Social Sciences

Chapter 1 Introduction

All organizations need some form of maintenance activities on a regular basis to ensure safe and effective operations of their facilities. This is particularly true for a hospital where the primary concern is to provide a safe healthcare environment for patients, staff and visitors. Moreover, due to the critical nature of some of the operations involved, the maintenance department of a hospital has to develop means of ensuring equipment/facilities are functioning properly, as any unplanned interruptions could adversely affect the well-being of patients and staff. This means equipment/facilities have to be risk assessed and any causes which may potentially contribute to equipment failure have to be identified and reduced or eliminated. Maintenance activities consume resources and maintenance operations are often seen as overheads which need to be tightly managed.
In common with other members of the Gulf Cooperation Council (GCC), Saudi Arabia has invested a substantial amount of its annual budget ($26.6bn in 2014 representing 19% of total expenditure) providing healthcare to its citizens and residents (US-SABC, 2015). Indeed, some 69% of the primary healthcare in Saudi Arabia is government funded. The Saudi government has indicated that the current growth rate in healthcare expenditure is unsustainable in the longer term and efforts are urgently needed to manage resources more efficiently. One area under consideration is the maintenance function of Saudi hospitals, clinics and specialist units, as these operations account for the majority of the maintenance-related expenditure.

Hospitals in Saudi Arabia are organised and managed in three ways: government hospitals under the full control the Ministry of Health (MOH); semi-government hospitals run by government departments with direct involvement of the private sector; and private hospitals. Most private hospitals tend to be specialist clinics with up to 100 beds. One of the main government departments that runs semi-government hospitals is the Medical Service Department (MSD), which is the medical branch of the Ministry of Defence. MSD is responsible for managing and operating 24 hospitals and 147 clinics around Saudi Arabia to provide medical treatments for Armed Forces employees and their families.
Maintenance operations in semi-government hospitals face many challenges including low standard of maintenance work which is provided by external contractors, lack of qualified maintenance staff, poor communication between hospital administration and maintenance contractors, poor budgetary control, inadequate maintenance process monitoring and

control, and limited information databases (Hassanain et al., 2013; Al-omari et al., 2015).

The Medical Service Department has a long term plan to improve the quality and delivery of hospital services, through better utilization of resources. The present project forms part of the on-going strategic review of the current maintenance operation in semi-government hospitals controlled by MSD including outsourcing and subsequent management of contractors and suppliers. A key challenge is to understand how maintenance activities could be managed more successfully and implemented in a cost-effective way. The following questions will need to be addressed – what are the key issues? How do they impact on maintenance activities and hence on the maintenance operations? What changes need to be made? How could these be accomplished including resource implications? What are the quantifiable business benefits?

1.1 Motivation of the research

Controlled by the Medical Service Department and with 1400 beds, Riyadh Military Hospital (RMH) is the largest strategic semi-government hospital in the Kingdom of Saudi Arabia. The author worked as a lead maintenance engineer at RMH for eleven years. Along with other lead engineers, he was responsible for ensuring the proper functioning of hospital facilities and had encountered numerous challenges covering technical, financial and managerial (e.g. non-availability of equipment, rising maintenance costs and no tangible performance indicators). Despite the criticality of its work, there is little appreciation from users of the importance of the maintenance function. The Maintenance Department serves all other departments in the hospital as shown in Figure 1.

For both professional and personal reasons, the author has developed a strong desire to investigate means of improving the maintenance procedures in Saudi hospitals. It was fortuitous that the hospital was about to embark on a detailed review of its maintenance operations. The proposal put forward by the author was accepted by the management as a basis for a PhD research project to be undertaken at a University with the expectation that there would be valuable research.

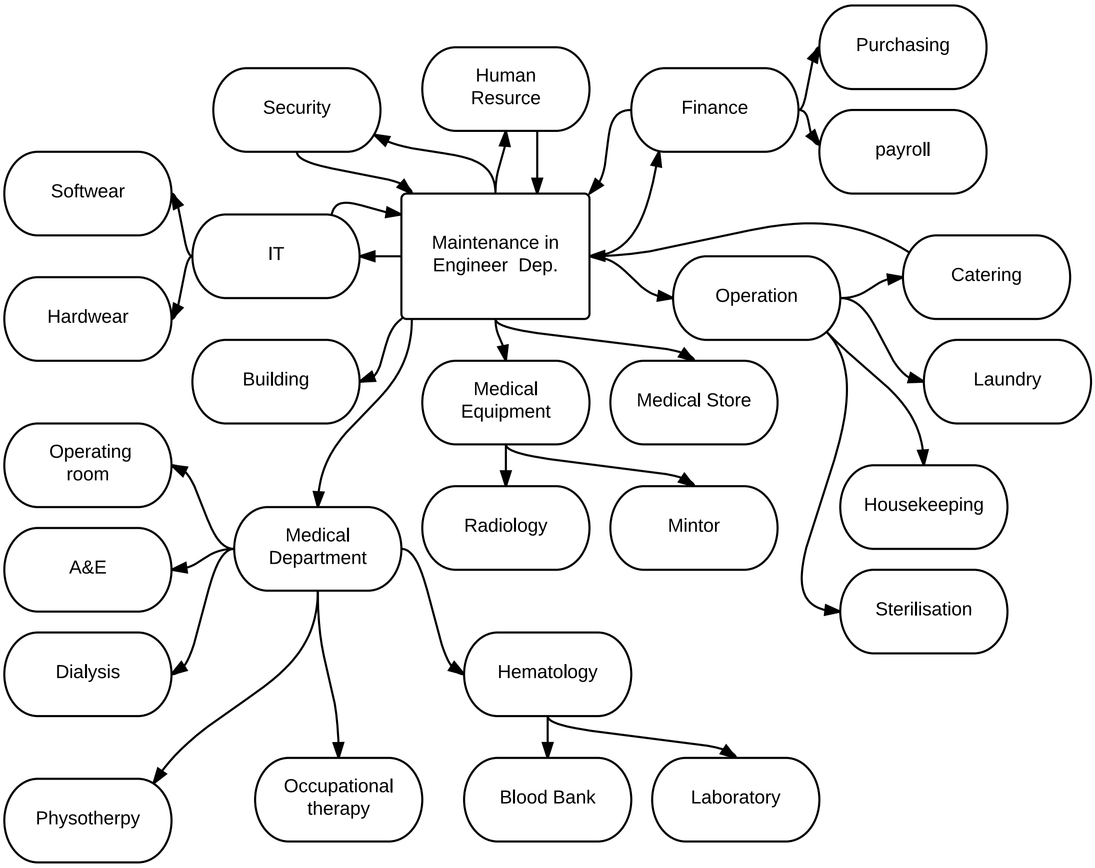


Figure 1 Relationship of the Maintenance Department with other hospital departments at RMH

1.2 Aims

The aims of the present study are twofold:

- To develop better understanding of the working of maintenance management in the healthcare industry in Saudi Arabia and its impact on the delivery of healthcare provisions by hospitals and specialist clinics in the Kingdom using Riyadh Military Hospital as a representative of Saudi Arabia hospitals.
- To contribute to the development of a maintenance management framework for the healthcare industry in the Kingdom.

1.3 Objectives

In order to meet the aims of the project, the following objectives have been identified:

- **Background research** – develop good understanding of the concepts, knowledge and practices of maintenance pertaining to the engineering and related industries; identify and understand the issues associated with the delivery of the healthcare provisions in the Kingdom of Saudi Arabia and the role played by maintenance management in the context of delivery healthcare in the Kingdom; study the organisational structure of the case study hospital, its quality policy, maintenance procedures, employee relations and working culture.

- **Literature review** – develop awareness of current knowledge and practices in maintenance methodologies, quality and reliability tools and techniques and their applications to analysing maintenance-related activities; examine relevant case studies of successful implementation of maintenance management in the engineering and related industries to identify best practices, assumptions and limitations. Examine how the identified approaches might be adopted for implementation in the healthcare industry in Saudi Arabia. The "lessons" thus learned helps to inform the design of the research process.
- **Data collection** – through extended site visits, conduct primary research including questionnaire surveys, interviews, discussions and observations. The main purpose is to gather information on maintenance-related issues (including management, finance, procedures and logistics) from a range of stakeholders (operators/contractors, technicians and managers) who are working in the case study hospital.
- **Data analysis** – informed by the knowledge gained from the background research and literature review, a range of quality and reliability tools and techniques are used to analyse the gathered data/information including Pearson correlation analysis, principal component analysis, theory of constraints, fault tree analysis, spaghetti diagram, critical success factors. The main purpose is to identify potential correlations between various parameters; identify, rank and prioritise key contributing factors which help to inform the design of a maintenance management framework for the healthcare industry in Saudi Arabia.
- **Development of a healthcare maintenance management framework** – building on the work done by previous research in engineering and related industries and the concept of total quality management, a new maintenance management framework is to be developed for the healthcare industry in Saudi Arabia. A number of potential solutions and their mapping to standard maintenance requirements will be examined.
- **Development and validation of new maintenance procedures** – by incorporating the salient features of the new framework, changes are to be proposed to the existing maintenance procedures at the case study hospital. The revised maintenance procedures will be implemented in a limited way and the validity of

the proposal is to be assessed through an extended site visit to the case study hospital.

- **Critical evaluation** – a reflective discussion of the work undertaken in the research study highlighting key issues identified and their relative impact in the context of the present study. It also discusses the extent to which improvement could be made to the maintenance procedures in a Saudi hospital through the incorporation of a healthcare maintenance management framework.
- **Preparation of thesis** – documents the activities undertaken at various stages of the research study, highlighting attainments and shortcomings with supporting evidence.

1.4 Scope and assumptions of the research

The areas covered at the planning stage of the present research are shown in Figure 2.

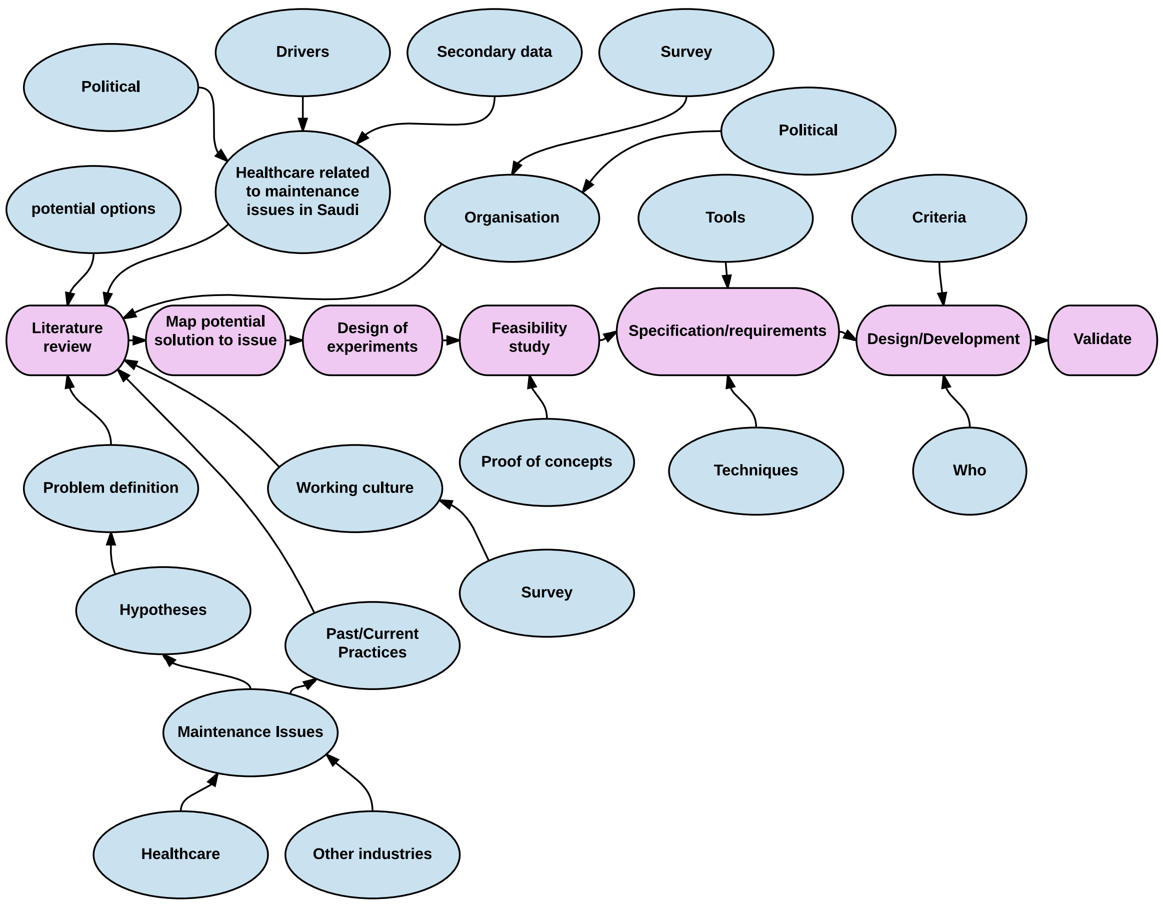


Figure 2 Topics covered at the initial stages of the thesis

The scope of the present study is detailed below:

- Literature review is focused mainly on maintenance management and maintenance-related issues in the engineering and related industries.
- Examination of the prevailing maintenance procedures, maintenance management and other related issues is limited to the case study hospital (Riyadh Military Hospital, Saudi Arabia). Other hospitals are not considered in this research.
- Issues related to the maintenance of complex medical equipment are not considered by this study because it is maintained by suppliers.

The main assumption of the present study is as follows:

- The maintenance management issues associated with the case study hospital are taken as representatives of those associated with other semi-government hospitals in the Kingdom given its size and strategic importance.

1.5 Research questions

- Are there significant differences in maintenance management between the engineering and related industries and the healthcare industry in Saudi Arabia?
- Could the practices, tools and techniques of maintenance management developed for the engineering and related industries be adopted for use in the healthcare industry in Saudi Arabia?
- What are the prevailing maintenance management issues in hospitals in Saudi Arabia?
- Could a maintenance management framework be developed for the healthcare industry in Saudi Arabia?
- To what extent could a maintenance management framework help to improve the maintenance procedures in Saudi hospitals?

1.6 Organization of the thesis

The thesis is organised into seven chapters and the information detailed in the individual chapters is summarised below.

Chapter 1 introduces the background to the investigation including the motivation for the research, potential knowledge gaps, project aims and objectives, research questions, project scope, assumptions and the organisation of the thesis.

Chapter 2 provides a critical review of previous research studies related to maintenance management including procedures and practices, methodologies, quality and reliability tools and techniques, maintenance management framework and case studies. The issues thus identified and "lessons" learned informed the design of the research process.

Chapter 3 details the current healthcare provisions in the Kingdom of Saudi Arabia and discusses how maintenance management could play an important role in the delivery of healthcare in hospitals and specialist clinics. Riyadh Military Hospital has been chosen as a case study because of its size and strategic importance within the Kingdom. An overview of the hospital's organisation, structure, vision, mission and strategy is also provided.

Chapter 4 details the research methodology adopted by the present study for the collection of data (questionnaires, interviews and observations) while the author was on site; and the application of quality and reliability tools for data analysis including Principal Component Analysis (PCA), Theory of Constraints (TOC) and Spaghetti Diagram.

Chapter 5 presents the results of the investigation including the identification of prevailing maintenance management issues at the case study hospital, correlations between various parameters, and the most "undesirable entities" which might have adversely affected the proper functioning of the current maintenance management system at the hospital.

Chapter 6 examines the current maintenance processes in term of time and cost when a complaint needs to be attended. This allows duplications and unproductive time to be identified and quantified. By incorporating the concept of a maintenance management framework, substantial changes to the current maintenance procedures have been proposed. The validity of the proposed new maintenance framework has been assessed in a limited way through field trials.

Chapter 7 provides a conclusion of the key findings and attainments of the research study with some recommendations for improving maintenance management in a Saudi hospital and suggestions for future work.

Chapter 2 Literature review/background research

2.1 Introduction

This chapter details the background research undertaken to develop better understanding of previous work done in the field of maintenance management and related topics, with particular emphasis on their applications to engineering and related industries. The 'lessons' thus learned would help to inform the design of the research methodology. A wide range of topics have been reviewed covering maintenance management concepts and approaches; maintenance strategies and policies including barriers to their adoption; applications of total quality management in maintenance management; performance metrics and the applications of quality and reliability tools and techniques for their analysis; facility management and building information modelling; and maintenance management frameworks.

2.2 Quality and reliability management in engineering

Quality and reliability management have been the subjects for investigation by numerous researchers in the past and their findings have been applied to a wide range of industries including product design, manufacturing, finance, retail and servicing. In engineering, quality management and reliability management are two distinct concepts often used in tandem to enable the desirable outcomes/goals to be achieved. They are normally realized through specification, process planning, monitoring and control (Chandrupatla, 2009).

The definition for quality has evolved over the past decades. Juran (1951), who set up the first statistical process control technique for factories, defined it as "fitness for use" in his book entitled 'The Quality Control Handbook'. Crosby (1979) defined quality as "conformance to requirements". He emphasized quality management through the application of the principles of "doing it correctly the first time" and "having zero defects". Based on his substantial experience advising Japanese companies to transform their industrial performance during the 50s, Deming (1982) defined good quality as "a predictable degree of uniformity and dependability in quality standard that is suited to the [needs of] customers". He believed that quality is the responsibility of the management and proposed a 14-point guide for implementing quality management in his book 'Out of the Crisis'. More recently, the American Society for Quality (ASQ) has expanded the definition of quality as a measure of customer safety: "Quality denotes excellence in goods and services, in particular the degree to which products conform to the requirements and safety of customers" (Bossert, 1991). Feigenbaum (1961) made a significant contribution to the development of processes for quality improvement. By implementing a three-step process namely quality leadership, quality technology and organizational commitment, he argued that an organization could operate at the most economical level while delivering customer satisfaction. It is widely accepted that Feigenbaum's quality concepts laid the foundation for the subsequent formulation of a ground breaking quality tool known as the Six Sigma, which was developed by the Motorola Company (Breyfogle III et al., 2000). In terms of quality, the aim of Six Sigma is to achieve an ideal figure of 3.4 defects per million. By changing one's mind-set, the Six-Sigma process requires a commitment from the users to adopt a data-driven approach statistically to define and resolve a problem. There are three categories of Six Sigma tools: collaborative tools, analytical tools and statistical tools (Salonen & Deleryd, 2011).

Reliability is a statistical concept that helps to reduce the incidence of breakdown and is often measured in terms of failure rates. It is defined as the probability of performing all functions with consistent statistics for a specified time in specified conditions of use (Marquez (2007). The concept has a significant correlation with the maintenance function in engineering, as regular maintenance of equipment and machines help to ensure they can be operated efficiently and safety. Lloyd (2001) suggested that reliability should be assessed based on two measures: failure rates and costs of failure.

Based on proven reliability techniques, Mueller & Bezella (1985) developed a program-based approach to assess/evaluate safety limits, modes of system failure, operating and emergency procedures for power plants particularly in the nuclear power industry. Through the creation of plant-specific performance databases, it was claimed that acceptable safety levels could be determined. The program-based approach consists of 3 functions, namely plant performance monitoring, performance evaluation and integrated corrective action.

A number of techniques are commonly used for assessing reliability of a process or operation including Fault Tree Analysis (FTA), Root Cause Failure Analysis (RCFA), Cause and Effect Diagram (CED) (or the Ishikawa fishbone diagram), Failure Mode and Effect Analysis (FMEA) and Mean Time Between Failures (MTBF). FTA and RCFA are known as deductive (or "top-down") approaches useful for identifying potential root causes from measurements, while CED and FMEA are inductive (or "bottom-up") approaches useful for the formulation of concepts or hypotheses based on the analysis of measured data (AICH, 1992). By analysing serious failures and accidents as well as high visibility events, RCFA can help to enhance process reliability by eliminating the causes of failure (Campbell and Jardine, 2001; Childs, 2012). However, the method can consume a great deal of resources in terms of time and money. FMEA is widely accepted as one of the most important data analysis tools for maintenance related functions due to its proven success in identifying potential failure modes, failure causes and failure effects. There are four steps involved: description of function, description of function failures, definition of the failure mode and the effects of the failure mode (McDermott et al, 1996). It is a structured process seeking to minimize the probability of a particular mode of failure recurring through corrective action. FMEA can also be used to reduce potential risks by improving the "detectability" of a failure mode (Raheja and Louis, 2012). The analysis requires close collaboration between the various stakeholders including analysts and designers. MTBF is a method useful for predicting failures in maintenance-related activities. However, a major shortcoming of the method is that the success of a prediction is highly variable as it depends on the statistical distribution of the gathered failure data. Consequently, many commercial organizations refrain from using this method.

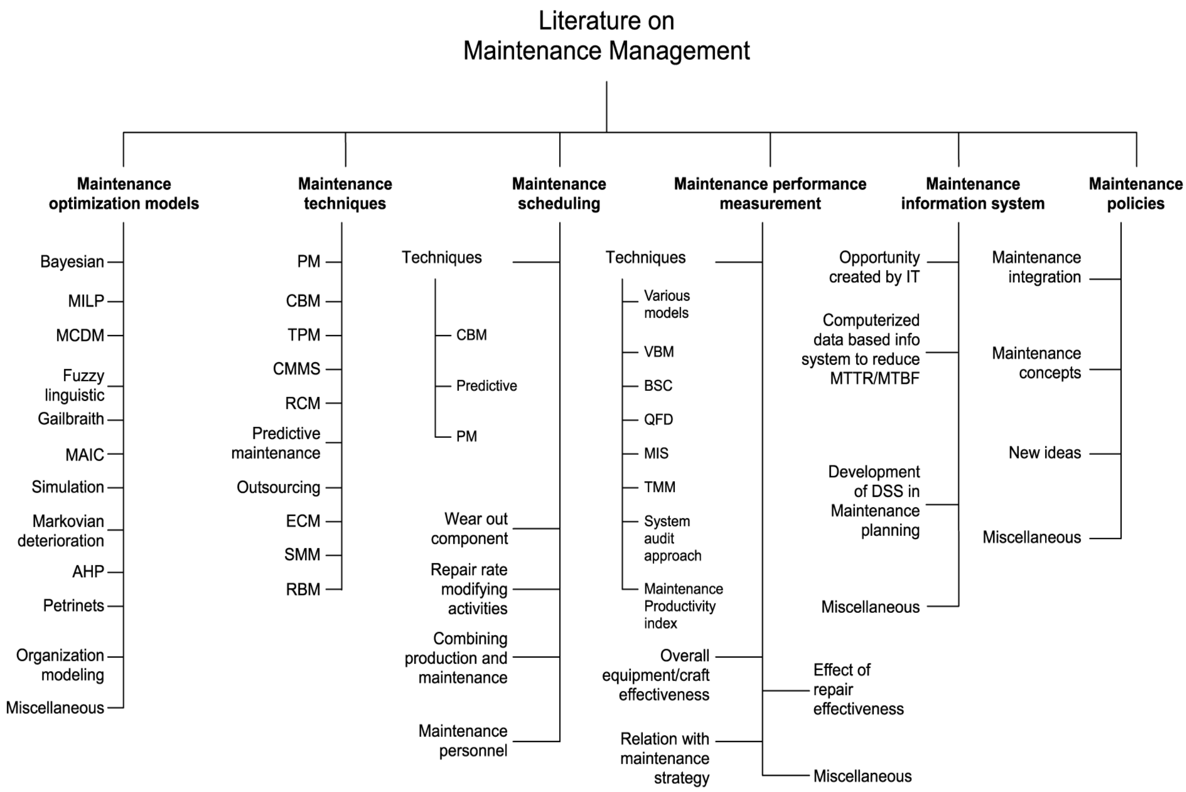
2.3 Maintenance management

To understand the basic perception of the maintenance function, one needs to define what constitutes maintenance. European Standard EN (2001) defined maintenance as "the combination of all the technical administration and managerial action during the life cycle of an item intended to retain it in or restore it to a state in which it can perform the required function". However, Waeyenbergh and Pintelon (2002) considered maintenance as a strategic tool for increasing competitiveness rather than simply an overhead expense that must be controlled.

Attempts have been made by Garg & Deshmukh (2006) to break down the field of maintenance management into six key areas and their associated functions, tools and techniques (Figure 3): maintenance optimization models; maintenance techniques; maintenance scheduling; maintenance performance measurement; maintenance information system and maintenance policies.

Unlike other management techniques which focus mainly on the deployment of resources to achieve defined business goals, maintenance management seeks to ensure the proper functioning of operations and associated equipment. More specifically, it involves planning, directing, organizing, monitoring and controlling all maintenance-related activities (Mukelas et al., 2012). It is a process that helps to ensure equipment and machines are working safely and reliability, thus ensuring their maximum utilization and reducing operating costs. Common maintenance activities cover inspection, monitoring, routine repair, overhaul and replacement.

There are a number of methods available in the pursuit of optimal levels of reliability, maintenance and availability. In the context of equipment maintenance, three methods are most popular (Sharma & Sharma, 2010): Failure Mode, Effect and Criticality Analysis (FMECA) for assessing critical failure modes; Root Cause Failure Analysis (RCFA) for identifying faults earlier in the process; and reliability-centred maintenance (RCM) for selecting the most suitable maintenance tasks.



Notes: MILP: Mixed Integer Linear Programming; MCDM: Multiple Criteria Decision Making; MAIC: Materially per Apparecchiature de Impiariti Chemiei; AHP: Analytic Hierarchy Process; PM: Preventive Maintenance; CBM: Condition Based Maintenance; TPM: Total Productive Maintenance; CMMS: Computerized Maintenance Management Systems; RCM: Reliability Centered Maintenance; ECM: Effectiveness Centered Maintenance; SMM: Strategic Maintenance Management; RBM: Risk Based Maintenance; VBM: Vibration Based Maintenance; BSC: Balanced Score Card; MTTR: Mean Time to Repair; MTBF: Mean Time Between Failure; QFD: Quality Function Deployment; MIS: Maintenance Information Systems; TMM: Total Maintenance Management; DSS: Decision Support Systems; ECM: Electronic Counter Measures

Figure 3 Maintenance management classification tree (reproduced from Garg and Deshmukh, 2006)

Maintenance approaches can be divided into three main categories: preventive maintenance, predictive maintenance and corrective maintenance. When an asset is serviced at predetermined time intervals, this is called preventive maintenance. Predictive maintenance is said to have occurred when it is serviced according to the performance of an asset. It is sometimes referred to as condition-based maintenance. Corrective maintenance is undertaken when equipment breaks down or cannot function as intended. Preventive and predictive maintenance are proactive in nature, while corrective maintenance is reactive. The concept of maintenance lines refers to the link between the level of maintenance and the organization responsible for undertaking the maintenance, whereas a maintenance policy refers to the interrelationship between maintenance lines (Marques, 2007).

Maintenance can be either immediate or deferred, depending on a number of factors including criticality of the identified faults, likely consequences, resource implications and availability of expertise and parts. These factors directly influence the choice of maintenance strategies and there are generally of five types (Vasseur and Llory, 1999): use-based maintenance; condition-based maintenance; failure-based maintenance; design-out maintenance and detection-based maintenance.

Maintenance strategies/policies vary from organization to organization, as there is no one-size-fits-all solution. The selection should be based upon expert judgment of risks relative to potential functional failures and the associated impact on the processes (Rosqvist et al., 2009). Clear commitments from stakeholders and management are essential for the successful development of a maintenance strategy, as maintenance activities are often considered as overheads to an organization (Al-Turki, 2011).

Given the relative importance of maintenance in ensuring efficient and effective running of a process, it is interesting to note that only about one-third of organizations seriously adopt good maintenance management practices and realize their potential business benefits. Many organizations cited costs as one of the main constraints in the undertaking of appropriate maintenance, but the following “barriers” to the adoption of maintenance management should also be considered (Marquez, 2007):

- Lack of maintenance management models
- Wide diversification in the maintenance problems
- Lack of plant/ process knowledge data

- Lack of time to complete the analysis required
- Lack of top management support
- The difficulties of implementing advanced manufacturing technology, which make it hard to diagnose the causes of failures
- New rules and regulations of safety and environmental factors

Maintenance costs are made up of two elements: direct cost and indirect cost. Direct costs consist of labour, spare parts and other costs that are clearly linked to maintenance activities. Indirect costs include the cost of recovery from lost production (e.g. equipment failures), inadequate management and administrative polices, penalties associated with contractual obligation resulting from any negative impact on the environment, lost of customers, warranty payments (Todinov, 2006). The concept of non-realized revenue as an indirect cost attributable to maintenance has been suggested by Ahlmann (2002). It refers to the potential loss of income due to reduced sales volume and missed delivery dates. He cited a study by the Swedish Centre for Maintenance Engineering and Management, which showed that the total maintenance related costs in Sweden in 2001 amounted to nearly 200 billion SEK, and the distribution was as follows: direct costs 55%, indirect costs 24% and non-realized revenue 21%.

A variety of performance indicators have been used to assess/quantify maintenance effectiveness including machine availability and utilization, deployment of resources, budgetary information, response times and recurring problems. Many organizations invested a sizeable portion of their budgets on capital expenditure including machinery and equipment, so it is of little surprise to note that maintenance-related expenditure often represents a significant portion of the operational budget. In a survey of US plant maintenance performance in 1993, it was found that the second highest cost of maintenance was attributed to maintenance spare part inventory (Cholasuke et al., 2004). Garg and Deshmukh (2006) confirmed that maintenance costs could account for a large part of any operational budget, second only to energy costs.

Topics pertaining to "effective maintenance management in the manufacturing industry" have been investigated by numerous researchers. Studies by Jonsson (1997) and Cholasuke et al., (2004) showed a strong correlation between effective maintenance management, maintenance approaches and continuous improvement. They argued that maintenance strategies needed to be linked to the manufacturing and corporate strategies of an organization covering human resource, support mechanism, tools, techniques and organizational framework. They also suggested that good maintenance practices and procedures need to be in place to achieve the desired outcomes and the sharing of good practices should be supported by good leadership. Other maintenance management "initiatives" that need to be considered include direction and support, means of communications, working culture, organizational structure, roles and responsibilities, system infrastructure and measurements (Mukelas et al., 2012).

The realization of effective maintenance management requires continuous improvement in the maintenance processes. Hassanain et al. (2001) proposed six areas where continuous improvement is considered essential: planning of maintenance of assets, scheduling of maintenance operations, execution of maintenance actions, assessment of suitability of assets (redesign of equipment if necessary), review of the effectiveness of operations.

Maintenance activities focus primarily on preserving equipment so that they are in good working condition, but can also include procurement and stock control. The following areas were considered essential for maintenance operations (Wireman, 1998): direct management involvement in operations; technical and interpersonal training; inventory and procurement control; availability of a computerized maintenance management system; a standardized work order system. Furthermore, it was argued that three maintenance related functions, namely planning (including the development of strategies and setting of performance targets), organization (including assigning priorities and responsibilities), supervision and control, must be properly integrated for a maintenance management system to be operated effectively (Marquez and Gupta, 2006).

2.4 Total quality management

Total Quality Management (TQM) is a system of uniform commitment to achieving quality in all areas of an organization. Its principal focus is on meeting the expectations and needs of stakeholders (mainly customers and employees) by encouraging active participation and engagement of everyone, and making decisions based on evidence and aims for continuous improvement (Deming, 1986; Juran, 1999). The implementation of TQM is not an easy undertaking, as it requires significant changes in the organizational culture, working culture and leadership when attempting to make improvements to a process (Lakhe and Mohanty, 1994).

Organizational culture is characterized by the general ability of the members of an organization to understand specific concepts, approaches and procedures governing various processes. Other factors that need be considered include workers' commitment, job satisfaction, policy, working condition, remuneration, equality, career progression and types of employment contract (Irani and Love, 2004; Mosadegh Rad, 2008).

Working culture is an important consideration in any strategic development which seeks to instil confidence among the employees about what they do and how they contribute to maintaining the success of an organization. In this context, the concepts of shared values and common goals are important to maintaining good team spirit, thus helping to ensure that the workers are working towards a common destination as coherent teams (Martin and Terblanche, 2003). However, it is widely recognised that working culture and shared values are some of the most challenging elements in any Change Management. This is because the performance of the employees of an organization is likely to be affected by a change of the working culture and staff resistance is inevitable. To overcome and reduce the resistance to change, Kotter (1996) suggested an eight-step approach to managing a change process in his book entitled "Leading Change". Listed below are the 8 steps which become unofficial guidelines for managers or leaders who are contemplating making changes in an organization.

- Create urgency – Developing a sense of urgency around the need for change can help the leader to spark the initial motivation in order to push the wheel of change.
- Form a powerful coalition – a change cannot be made without a coalition or team of influential people whose power comes from a variety of sources, including job title, status, expertise and political importance.
- Create a vision for change – a clear vision can help people to understand their responsibilities and their participation in reaching the goal.
- Communicate the vision – a clear vision in the organization is said to be a great motivation for creating a strategy.
- Remove obstacles – removing obstacles can empower the people needed to execute the vision of the organization and it can help the change to move forward. In this way an organizational structure, job description, performance system and compensation system can be modified to ensure they are in line with this vision.
- Create short-term wins – divide the target into short-term targets and at each stage let the change team see the successful result so as to motivate the entire staff.
- Build on change – many change projects fail because victory was declared too early. Therefore, each success provides an opportunity to build on what went well

and identify what could be improved.

- Anchor the change in the corporate culture – in order to do so, continuous efforts must be made to ensure that the change is seen in every aspect of the organization. Moreover, top management continuously has to support the changes to avoid ending at the point where they started.

Leadership, with support from top management, is a significant factor in order to implement TQM successfully (Powell, 1995). Leadership means the ability to influence others within an organization to achieve common goals and to provide clear direction for the way forward. Research has shown that quality improvement can be influenced by leadership styles and strong leadership is needed in order to bring about changes in an organization's activities, which may in turn lead to improvement (O'Eocha, 2000; Berson and Linton, 2005; Idris and Ali, 2008).

According to Goleman (2000), there are six distinct leadership styles namely, coercive, authoritative, affiliative, democratic, pacesetting and coaching. Leaders may exercise any of these styles depending on the circumstances. The importance of leadership rests with its ability to encourage the development of a supportive work environment, allowing people and groups to cooperate and work together effectively, and to influence an individual's behaviour, motivation, performance, and work attitude to achieve common goals.

There are 21 tools associated with TQM organized into three main categories (Dervitsiotis, 1998): 7 tools of quality, 7 new management tools and 7 product-planning tools. The constituent parts of the individual categories are shown in Figure 4.

Figure 4 TQM tools organized into three categories (Dervitsiotis, 1998)

Mosadegh Rad (2005) suggested that the TQM concept should be underpinned by five principles: produce quality work at the first time, focus on the customer, have a strategic approach to improvement, improve continuously and encourage shared respect and team work. To promote awareness of the importance of quality in business organizations, the US government established the Malcolm Baldrige National Quality Awards under the Baldrige Excellence Framework to "*recognize U.S. companies for their achievements in quality and business performance and to raise awareness about the importance of quality and performance excellence in gaining a competitive edg*e" (NIST, 2015). The latest Baldrige framework focuses on

- *" managing and leading all the components of your organization as a unified whole;*
- *managing change; and*
- *dealing with data analytics, data integrity, and cybersecurity"*

Hamidi and Zamanpawar (2008) examined the factors which could influence a successful implementation of TQM within an organization and highlighted the following as negative factors: poor commitment from management, unsympathetic working culture and frequent unplanned changes, lack of employee involvement, cultural changes, ineffective organizational structure, dated information systems, low technical skills and lack of team work.

The Toyota production system is considered as a successful example in the application of what are commonly referred to as the 5 “S” principles to the TQM journey. The 5 “S” stand for five Japanese words, namely Seiri (Sort), Seiton (Strengthen), Seiso (Shine), Seiketsu (Standardize) and Shitsuke (Sustain) (Shingo, 1989; Osada, 1991). A key component of TQM, the main aim of the 5 “S” principles is to create a clean, orderly and efficient work place. The method can be used in conjunction with lean deployment/manufacturing to drive changes within an organisation. The potential benefits of implementing a 5 “S” program are: improved productivity (e.g. reduced rework and lower costs of poor quality); higher efficiency of processes (e.g. utilisation of resources, minimised waste); better services (e.g. customer satisfaction) and competitive advantage (Antony et al., 2002).

The Toyota production system is considered as a successful example in the application of what are commonly referred to as the 5 “S” principles to the TQM journey. The 5 “S” stand for five Japanese words, namely Seiri (Sort), Seiton (Strengthen), Seiso (Shine), Seiketsu (Standardize) and Shitsuke (Sustain) (Shingo, 1989; Osada, 1991). A key component of TQM, the main aim of the 5 “S” principles is to create a clean, orderly and efficient work place. The method can be used in conjunction with lean deployment/manufacturing to drive changes within an organisation. The potential benefits of implementing a 5 “S” program are: improved productivity (e.g. reduced rework and lower costs of poor quality); higher efficiency of processes (e.g. utilisation of resources, minimised waste); better services (e.g. customer satisfaction) and competitive advantage (Antony et al., 2002).

The concept of Critical Success Factors (CSFs) and their application to TQM implementation has been studied by many researchers. Because of the complexity involved when attempting to implement TOM, there is a need to identify potential barriers which must be overcome. Determination of CSFs would help an organization to develop its strategy by focusing its resources on increasing strengths and overcoming weaknesses. Examples of CSFs include business strategy, top management commitment, adoption of new ideas, putting the customer first, improve the quality of working environment, teamwork and people empowerment, effective data driven problem solving, eliminate waste and non-value added activities (Freund, 1988; Sharp et al., 1997). Motwani (2001) presented seven critical success factors of TQM: top management commitment; quality measurement; quality benchmarking; process management; product management; customer involvement and customer satisfaction. Incorporating the work of Saraph et al. (1989), Antony et al., (2002) proposed a eleven-critical-success-factor model containing 72 elements. The critical success factors are: management commitment; role of the quality department; training and education; employee involvement; continuous improvement, supplier partnership, product/service design; quality policies; quality data and reporting; communication to improve quality and customer satisfaction orientation.

Within the framework of TQM, continuous process improvement is an important element. In this context, Six Sigma is widely used as a monitoring and control tool in a range of industries to reduce defects to specific levels. However, there are barriers to the implementation of Six Sigma and three have been identified as most critical: lack of knowledge of professionals, poor financial resources and inadequate top management support (Aboelmaged, 2011).

2.5 Maintenance management approaches

Previous studies suggested that there are similarities between TQM and Total Productive Maintenance (TPM). The latter focuses on six key areas: productivity, quality, cost, delivery, safety and morale (Nakajima, 1988). Muthu et al. (2001) suggested that the concepts of TPM are essentially the application of TQM principles to maintenance engineering, as the two methods share many of the common business goals (e.g. near zero defects, lean deployment and continuous process improvement).

A quantitative metric, known as the Overall Equipment Effectiveness (OEE), is widely used to measure the level of success of a TPM implementation in terms of equipment availability, performance efficiency and the degree of quality. These measures relate to machine breakdowns, unplanned stoppages and associated costs. TPM standards are said to have been met when the following thresholds have been achieved (Levitt, 1996): 90% equipment availability, 95% performance efficiency and 99% quality. However, a later work by Parida & Kumar (2006) questioned the suitability of using OEE as a method for measuring the performance of maintenance activities. The reasons given were that the method focuses mainly on assessing factors representing the internal measures of effectiveness including productivity, cost per unit, skills and competence, reliability and efficient use of resources, while ignoring the indicators of external measures of effectiveness including service quality, timeline of delivery, safety and the growth of the market share.

Based on their experience of TPM implementation in the UK, Raouf and Ben-Daya (1995) and Davis (1997) highlighted the need to have a realistic approach to TPM and to develop a practical plan that involves the use of the project management principles. The long interval before the results of TPM became visible should be accepted by senior management and continuous support should be made available. It was also suggested that a TPM program should be linked to human resource management.

There are many studies investigating the factors influencing the successful implementation of TPM and their likely impact. The identified main factors are: alignment with the company's mission statement; employee involvement; cross-functional training; commitment of senior management; maintenance strategy and planning of implementation (Swanson, 1997; Bamber et al., 1999; Rodrigues and Hatakeyama, 2006).

With regards to how TPM should be implemented, Willmott (1994) suggested two enablers:

- A structured approach that uses a number of tools and techniques to achieve highly effective utilisation of plant and production equipment including the determination of their effectiveness.
- A philosophy based on the empowerment and encouragement of shopfloor-based personnel.

Other factors could also help to enhance the implementation of TPM including equipment management, effective communications, leadership, worker participation in decision making, acceptance of ideas and regular feedback (Ben-Daya, 2000; Ahuja & Khamba, 2008). Leflar (2001) devised a five-step plan to guide TPM implementation as follows:

- Restoring equipment to a new condition
- Identifying complete maintenance plans
- Implementing maintenance plans with precision
- Preventing recurrent machine failure
- Improving machine productivity

Ahuja and Kumar (2007) investigated a case study where the concept of TPM had been implemented in an Indian manufacturing company. By using the concept of Overall Efficiency of Equipment (OEE) as the core quantitative metric for measuring performance, they showed the systematic application of TPM in the organization could help to improve the productivity, quality and safety in the production of precision tubes, thus enhancing the cost effectiveness of the manufacturing processes. Through delegation of responsibilities, the study also found that TPM helped to raise the overall morale of the workforce.

Reliability Centred Maintenance (RCM**)** was developed by the aircraft industry for the servicing and maintenance of aircrafts, with the principal aim of achieving the highest possible flight safety. With the support of the regulatory bodies (e.g. Federal Aviation Authority in the US and Civil Aviation Authority in the UK), a set of standardized maintenance policies and procedures have been developed including the accreditation of maintenance personnel. Through continuous improvements, enormous benefits to the aircraft industry in general and airlines in particular have been achieved in terms of reduced maintenance costs and excellent safety record. The success of applying RCM in the aircraft industry helps to encourage other industries (e.g. oil exploration, petrochemical) which involve the maintenance of critical or complex equipment, to adopt similar approaches to deliver preventive maintenance. A case study by Afefy (2010), who applied the RCM methodology to a steam process plant, showed that the mean time between the probability of sudden equipment failure and their actual failure had fallen significantly. This resulted in appreciable cost savings associated with reduced labour involvement, less downtime and fewer spare parts, when compared to the costs associated with a different maintenance programme used previously.

By creating a common database to store real-time data from various functions, Al-Najjar and Alsyouf (2000) developed the concept of Total Quality Maintenance (TQMain). The method analyses and assesses any deviations in the state of a production process including product quality, thus enabling users to continuously maintain and improve the technical and economic effectiveness of an asset. TQMain differs from other maintenance concepts in three ways: availability of real-time measurements, proactive maintenance and continuous cyclic improvement.

2.6 Facility management and building information modelling

Facilities Management (FM) is a multi-disciplinary field integrating people, place, process and technology in support of the core business of an organization by ensuring proper functioning of the built environment (Cotts et al., 2009; Atkin and Brooks, 2009). It is holistic in nature covering a wide range of disciplines including real estate, financial management, maintenance and cleaning.

The design of buildings and built environments are increasingly sophisticated and their maintenance necessitates the collection of real-time information covering building elements, fabric data, operational costs, contract types, room utilization, logistics, maintenance, among others. This in turn allows a virtual representation of the physical and functional characteristics of a building to be made. As building maintenance is considered as an important activity in the context of facility management, potential maintenance-related issues should be taken in consideration at early stages of the building design process (Barrett and Baldry, 2003).

Gallagher (1998) examined the applications of healthcare facility management in the National Health Service in the UK, focusing on areas where the implementation has been considered successful. He concluded that there existed a positive correlation linking the growth and development of the facility management profession with strategic planning, customer care, quality of the facility provided and environmental management. A study by Codinhoto et al. (2008) showed that the characteristics of a healthcare environment (covering ergonomics, fabric and ambience, art and aesthetics) could have an impact on the wellbeing of patients and employees. They concluded that one characteristic of the environment might affect several healthcare outcomes. For example, the level of lighting could affect depression, melanoma and retinopathy, while the stress level could be affected by ambient temperature. Furthermore, they suggested that maintenance of buildings and equipment are essential to providing a stable environmental condition. Kwon et al. (2011) investigated the relationship between building maintenance management and customer satisfaction. It was concluded that building maintenance management played an important role in the design and implementation of services, thus ensuring maximum availability of the living environment (and its surroundings) of a building to meet the needs of its occupants. Mukelas et al., (2012) argued that much effort is needed to identify and rectify habitual procedures in building maintenance management that are inappropriate and which could have an adverse impact on the facilities and services provided.

The information collected as part of the building monitoring process needs to be stored and processed systematically so that the state of the building is made known. In this context, an approach known as Building Information Modelling (BIM) has been investigated by many researchers (e.g. Shohet et al., 2002; Jnug and Joo, 2011; Arayici et al., 2012; Almagor and Symond, 2015). By collecting and analyzing the properties of building components, building information modelling seeks to enable the establishment of an effective management of building information from early concept to operation. A case study undertaken by Avsatthi (2015) showed that a building information model could gain popularity among engineers and architects in a hospital environment, because they felt empowered through better knowledge of the physical and functional characteristics of the buildings to be maintained. Autodesk Revit and Graphicsoft ArchiCAD are two software packages commonly used in building information modelling (BIFM, 2012).

In the context of facility management, the perceived benefits of using a building information model may be summarized as follows:

- Promote greater transparency.
- Promote collaboration between suppliers which could lead to reduce waste through all levels of the supply chain.
- Provide a structured database containing all the relevant building information. This is particularly important at a “hand-over” phase of building development.
- Provide easier access to the assets of an organization during the execution of planned maintenance (Becerik-Gerber et al., 2012).
- Provide easier access to built environment drawings and documentations by contractors and facility managers (BIFM, 2012).
- Data and information collected during the building lifecycle could be used to develop a Facility Management system, which could be used for space management, emergency management, energy control and monitoring, and personnel training and development (Teicholz, 2013; BIM Task Group, 2013).

Indeed, the BIM Task Group (2013) summarized the benefits of using building information modelling as follows:

“BIM will provide a fully populated asset data set into CAFM systems and therefore reducing time wasted in obtaining and populating asset information enabling us to achieve optimum performance quicker, reduce running costs and refine target outcomes”

A building information model contains maintenance-related information including the schedule for servicing and replacing equipment/parts in order to meet health and safety requirements, this allows refurbishment or alterations of a building to be carried out without needing prior surveys (Bedrick, 2008; Delany, 2015). By linking work-order data to a building information model, maintenance activities can be made more transparent. This helps to identify the spatial trends for each type of repair activity and the spatial relationships between different types of activities (Akcamete et al., 2010).

Indeed, Kelly et al. (2013) suggested that the use of BIM could help to improve the accuracy of facility management data and to increase the speed of execution of work orders. In the case of a maintenance problem such as the occurrence of a fault in a plumbing system, BIM can provide visual information on the location of the fixture and how it relates to other fixtures within a building. Thus, similar fixtures used in other locations in the building can be identified and then assessed for potential damages. This in turn allows the facility management team to attend to the problems more quickly (Arayici et al., 2012). The importance of collecting and managing information systematically about a building during its entire lifecycle is confirmed by the UK Government's Construction Strategy, which stipulates that all publicly-funded construction projects are expected to incorporate collaborative Level 2 BIM by 2016 (Kelly et al., 2013; Eadie et al., 2015).

In spite of the apparent advantages being offered by the deployment of a BIM as a valuable tool in facility management, there exists a perception that facility managers have been slow to engage with the development of BIM (BIFM, 2012). Most recent efforts investigating BIM applications in the context of facility management tended to focus mainly on new buildings (Becerik-Gerber et al., 2012; Kelly et al., 2013). A study by Motawa and Almarshad (2013) suggested that current BIM applications lack the capability to capture various forms of knowledge of construction operations such as building maintenance. They proposed an approach to facilitate the transformation from 'Building Information Modelling' to 'Building Knowledge Modelling'. In the case of building maintenance, a taxonomy for building maintenance is to be created and made available to maintenance teams. Ideally, the taxonomy should contain information on the full history of building elements, previous maintenance operations and the associated 'lessons' learned.

According to Porwal and Hewage (2013), the main challenges of using Building Information Modelling (BIM) in Facility Management (FM) are:

- The lack of tangible benefits despite the suggested potential of BIM in FM.
- The lack of inter-operability between BIM and FM technologies.

- The lack of clear requirements for the implementation of BIM in the context of FM.
- The lack of clear framework governing roles, responsibilities, contract and liability.
- The procedural and cultural mindset in the building industry where FM managers are involved only at a very late phase in the project.
- Adoption of BIM depends mainly on the preferences of the clients or owners of the construction projects.

2.7 Maintenance performance (Assessment of the effectiveness of maintenance management)

Performance measurement is an important management tool that allows an organization to develop a systemic process of evaluating how well an organization is being managed and the values it delivers to customers and other stakeholders. It works on the basic principle that if it cannot be measured then it cannot be improved (Duffy, 1990). In this context, the use of Key Performance Indicators (KPIs) and benchmarking is considered fundamental to the development of any business strategy. It is worth noting that some of the contentious issues facing performance measurement are 'what to measure', 'when to measure' and 'how to measure'. So the choice of performance measurements is likely to reflect on the priorities outlined in the business strategy of an organisation and will differ from one organization to another. Kaplan and Norton (1996) pointed out that it normally takes several years to achieve the full benefit of a performance measurement system and identified 4 barriers to its implementation:

- Vision and strategy may not be actionable.
- Business strategy is not linked to departmental, team and individual goals.
- Business strategy is not based on the resources available and their allocations.
- Feedback is often tactical and not strategic.

Previous studies have shown that maintenance activities could make a significant contribution to improving the performance of an organization and hence its profitability (e.g. Maggard and Rhyre, 1992). This statement is generally true, but the concept of maintenance performance needs qualifying as different functions within an organisation may assess maintenance performance from different perspectives. For example, Finance Department may view maintenance as a cost centre so it may be interested in cost accounting information; Technical Department may focus on the number of breakdowns, speed of response and equipment availability as indicators of performance; Public Relations Department may be interested in the level of customer satisfaction and publicity (favourable or unfavourable). Moreover, as the consequences of an inefficient maintenance system might not be immediately apparent, it would be difficult to devise appropriate metrics for measuring maintenance performance (Pintelon and Van Puyvelde, 1997).

Building on the six generic KPIs (namely customer satisfaction, financial, product/service quality, employee satisfaction, operational and public responsibility) suggested by Brown et al. (1994) for assessing the overall performance of an organization, Coetzee (1998) proposed 20 KPIs under four headings for assessing maintenance-related activities (Table 1).

Machine/facility maintenance	**Task efficiency**	**Organizational efficiency**	**Profit/cost efficiency**
Downtime	Number of tasks received	Total production time	Total maintenance cost
Number of breakdowns	Time allowed on tasks	Clocked time	Cost of lost production
Value of stock at the end of period	Number of tasks completed	Production	Plant investment value
Time spent on breakdowns	Number of tasks overdue	Time spent on tasks	Total direct maintenance costs
Time spent on scheduled tasks	Time planned for overdue scheduled tasks	Time planned for scheduled tasks	Cost of breakdowns

Table 1 KPIs for assessing maintenance-related activities (Coetzee, 1998)

Shohet and Lavy (2006) introduced 11 performance metrics or KPIs for healthcare facilities maintenance management, in addition to the four KPIs proposed for hospital buildings based on his earlier work (Shohet and Lavy, 2003). The KPIs for healthcare facilities are: the built area; occupancy assets; facility age; number of employees per 1000 m^2 of built area; scope of facility management outsourcing; managerial span of control; maintenance organizational structure; building performance indicator; annual maintenance expenditure; annual maintenance expenditure per patient bed and maintenance efficiency indicators. The four original KPIs for hospital buildings are: asset development, organization and management, performance management, and maintenance efficiency parameters. Taken together, these indicators could be used by a facility manager to monitor the state of a building, the performance of the systems and components contained therein.

Assessment of maintenance performance requires the determination of a range of maintenance-specific parameters including: Time Between Failures (TBF); Up Time (UT); Down time (DT); Time to Repair (TTR); Logistic Delay Time (LDT); and Time To Failure

(TTF). The corresponding mean values of the individual parameters can be determined using the following expressions (Marquez, 2007).

Time Between Failures (TBF) = Down Time (DT) + Up Time (UT) (1)

Down Time (DT) = Time To Repair (TTR) + Logistic Delay Time (LDT) (2)

Mean Time Between Failures (MTBF) = $\frac{\sum_{i=1}^{i=n} TBF_i}{n}$ (3)

Mean Up Time (MUT) $= \frac{\sum_{i=1}^{i=n} UT_i}{n}$ (4)

Mean Down Time(MDT) $= \frac{\sum_{i=1}^{i=n} DT_i}{n}$ (5)

Mean Time To Repair (MTTR) $= \frac{\sum_{i=1}^{i=n} TTR_i}{n}$ (6)

Mean Logistic Delay Time (MLDT) $= \frac{\sum_{i=1}^{i=n} LDT_i}{n}$ (7)

Mean Time To Failure (MTTF) $= \frac{\sum_{i=1}^{i=n} TTF_i}{n}$ (8)

Availability (A) $= \frac{MUT}{MUT-MDT} \times 100$ (9)

Mean Time Between Failure (MTBF) is the period of time that a piece of equipment is in a good working condition to fulfil its designed function, which relates to (equipment) Availability. Mean Time To Failure (MTTF) is the period of time that a piece of equipment will probably fulfil its designed function under certain operating conditions and it relates to (equipment) Reliability. Mean Time To Repair (MTTR) is the period of time that a piece of equipment will probably continue to fulfil its designed function after repair, which relates to (equipment) Maintainability. It is important to note that these measurements of time do not include any delay attributable to the collection of the required spare parts or variations in the work schedule. Consequently, additional time allowances have to be made when assessing the duration of a breakdown.

Myeda et al., (2009) developed a framework for assessing maintenance-related activities covering three principal areas: Functional Management Deliverance (covering tangibles, reliability, responsiveness, empathy, assurance); Technical Maintenance Services (covering cleaning & landscaping, general maintenance, lightings, air-conditioning, lifts/escalators, sanitary & washing facilities, access, signage & parking, safety & security); and Building Images (covering external and internal finishes/decorations).

Developed by Kaplan and Norton (1992), the Balanced Score Card (BSC) provides a means to obtain a fuller picture of the state of a business and is often used for periodic performance reviews. The method helps a company to clarify its business strategy, align and update strategic initiatives, and communicate the strategy throughout the company. It has the greatest impact on business performance when attempting to drive changes within an organisation or a process. Marques et al., (2009) investigated the usefulness of applying BSC to maintenance management and concluded that suitable key performance indicators could be developed for maintenance-related activities/tasks. They claimed that the method could be used to reduce the variability of performance measures and help an organization to meet its strategic maintenance objectives. Furthermore, BSC could also be used in conjunction with a quantitative technique known as the Probability Risk Number (PRN) to prioritise tasks/activities in a maintenance process. After detailed risk assessment of assets under consideration, each asset is assigned a numerical value according to the perceived risk and its potential impact on the process. The assets are then ranked in descending order and those near the top are to be dealt with first.

The concept of outsourcing work in manufacturing started in the 70s and the initial main driver was to reduce labour and operating costs, thus helping a company to gain competitive advantage (McIvor et al., 1997). The concept has evolved over the past three decades and there are now many reasons for its adoption by a range of industries. In response to rapid demands for healthcare facilities and services in the MENA (Middle East and North Africa) region, outsourcing is increasingly used as a practical solution of delivering healthcare in member countries of the Gulf Cooperation Council (GCC) for a number of reasons including costs, technical expertise (both medical and non-medical), healthcare management knowledge and skills, private infrastructure development (through direct foreign investment). Assaf et al., (2011) discussed the factors (38 in total) that could influence the decisions to be made on whether to outsource maintenance services in Saudi Arabia universities under six headings: strategic; economic; management; technological; function characteristics and quality. It concluded that Saudi universities are likely to make their decisions based on quality, management and strategic factors when making outsourcing decisions.

Outsourcing involves the use of contractors to a varying extent, so attempts have been made to monitor and manage the work done by contractors using a concept known as the Cost of Poor Quality (CoPQ). It is a measure of the total estimated cost to a company as a result of rectifying imperfect products and/or processes including potential losses in sales (Salonen & Deleryd, 2011). This concept has recently been adopted for application to maintenance management and a similar concept known as the Cost of Poor Maintenance (CoPM) has emerged. CoPM focuses on the costs associated with prevention, appraisal and failure (Salonen et al., 2011). It allows any weaknesses in maintenance performance to be identified, thus enabling the formulation of Corrective Maintenance or Preventive Maintenance.

2.8 Maintenance management framework

Maintenance management is one of the important functions that help to determine the success of an organization's operations. It normally consists of three levels of business activity: strategic, tactical and operational (Marquez and Gupta, 2006). At the strategic level, activities are focused on identifying the business priorities and linking them with the maintenance priorities. At the tactical level, activities are focused on determining the best results of maintenance skills, tools and equipment. At the operational level, activities are focused on ensuring that maintenance objectives are completed in the time allocated by the suitably-skilled technicians and with appropriate tools.

A maintenance framework is essentially a conceptual structure that allows various processes containing tasks/activities to be organised, coordinated, monitored and managed in a systematic way to enable the work of maintenance to be completed satisfactorily. Implementing a maintenance management framework is not an easy undertaking and it requires the involvement and support of senior management as well as all the relevant functions.

A number of maintenance management frameworks have been put forward by researchers in the 90s. Pintelon and Gelders (1992) suggested a maintenance management framework consisting of three simple blocks: management system design, maintenance management decision-making and a toolkit to model the occurrence of failures in the system statistically. They highlighted the importance of training as a means to improve the knowledge of maintenance workers so that they can operate in a safe environment. Vanneste and Van Wassenhove (1995) suggested that a maintenance framework should include two management processes: analysis of process effectiveness and analysis of process efficiency. The former seeks to identify any major issues and potential solutions, while the latter focuses on the identification of suitable procedures. They proposed an 8-stage loop for evaluating the maintenance management processes: determination of current performance; analysis of quality problems; analysis of downtime problems; analysis of potential solutions; analysis of maintenance procedures; plan and execute action; data collection including observation of events; and data processing.

Wireman (1998) proposed a maintenance framework in the form of a pyramid structure. It consists of 11 blocks organised into 5 levels and is underpinned by a preventive maintenance program at the base level (Figure 5). The second level contains a Computerised Maintenance Management System (CMMS), a work order system, provision of spare parts and the training of maintenance personnel form. The third level consists of predictive maintenance, involvement of operations and RCM. The fourth level focuses on the implementation of the total productive maintenance and the application of statistical tools for financial optimization. The top level of the framework addresses continuous process improvement.

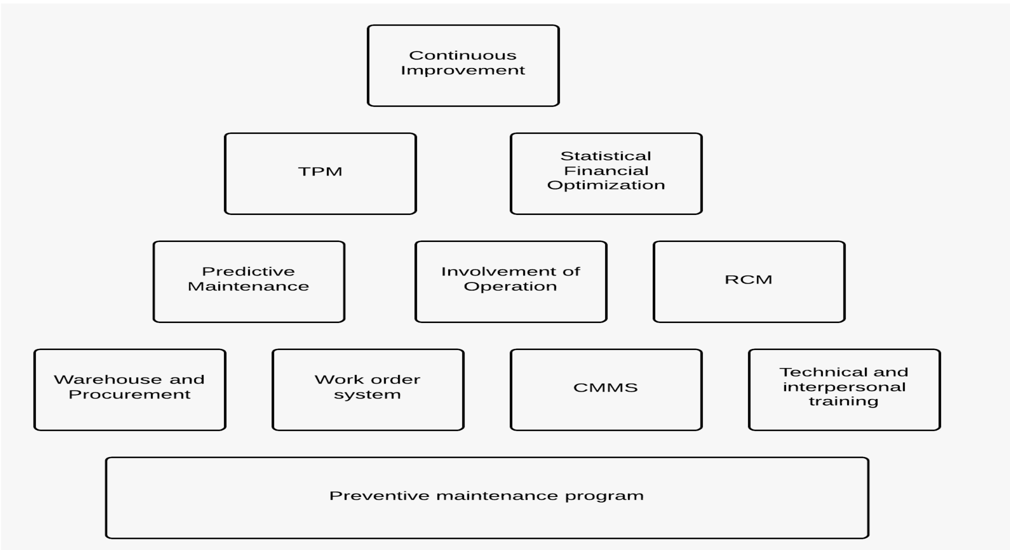


Figure 5 A maintenance management framework (reproduced from Wireman (1998))

A different framework for maintenance management was put forward by Campbell (1998), which has four levels (Figure 6). The base level is concerned with the development of maintenance strategies for the assets and associated human resource implications of any changes to the working culture (e.g. roles, responsibilities and leadership issues). The second level focuses on 4 aspects. The first is the monitoring and control of the individual assets during their lifetime to make sure that they perform to their designed functions in full. The second is the development of a measurement system so that performance metrics can be gathered. The third deals with the planning and scheduling of maintenance activities. The fourth focuses on one or more of the following eight tactics: run to failure; redundancy; scheduled replacement; scheduled overhaul; ad-hoc maintenance; preventive maintenance (either age-based or use-based); condition-based maintenance; and redesign if necessary. The third level covers the application of two highly successful maintenance methodologies, namely TPM and RCM, with the intention of achieving continuous improvement. The top level seeks to sustain the improvement already achieved through maintenance re-engineering.

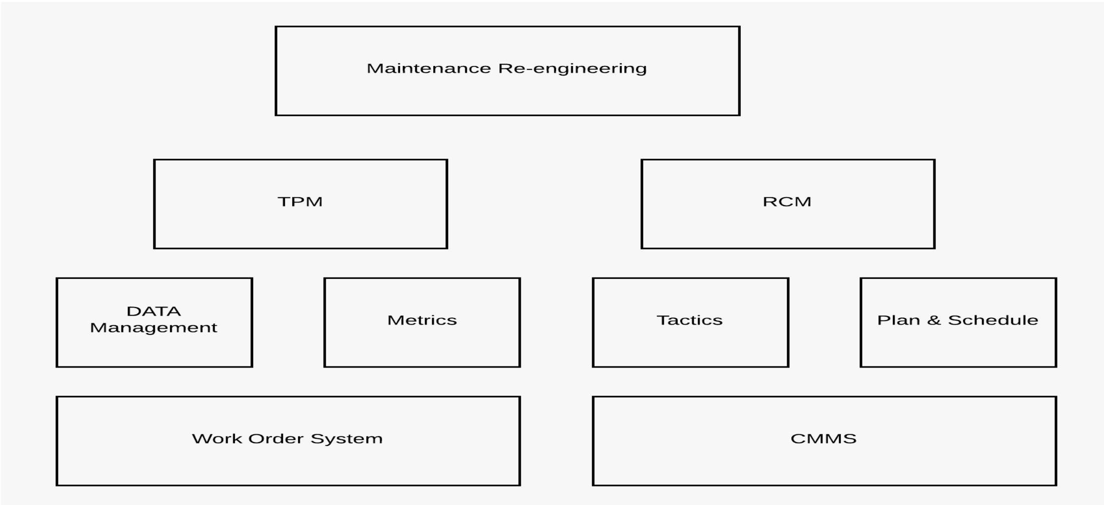


Figure 6 A maintenance management framework (reproduced from Campbell (1998))

According to Tsang (2002), Visser (1998) considered a maintenance system as a transformation process encapsulated in an enterprise system (Figure 7). The system "transforms" seven inputs (labour, material, spares, tools, information, money and external services) to achieve a desired level of maintainability.

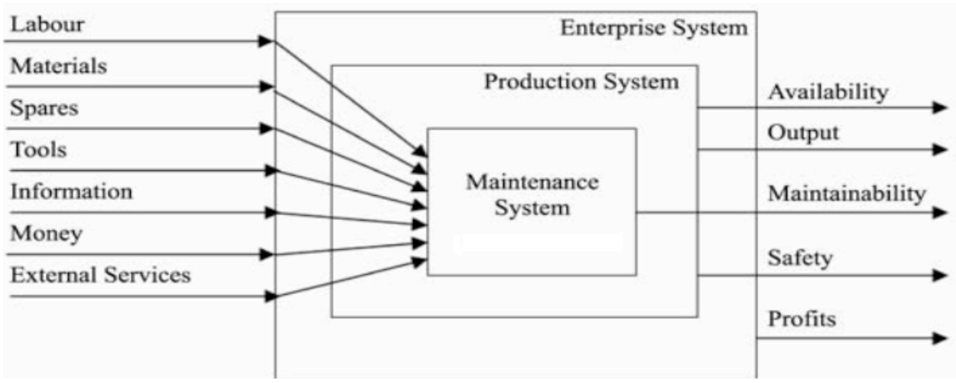


Figure 7 Maintenance system as a transformation process (reproduced from Visser (1998))

Hassanain et al (2001) suggested a framework for integrating maintenance management activities, which consists of five sequential steps: identify asset; identify performance requirements; evaluate current performance of assets; plan maintenance; and control maintenance operations. Waeyenbergh and Pintelon (2002) proposed a similar framework consisting of six steps: identify objectives; securing resources; prioritise high impact equipment; identify most critical components; selection of maintenance policy; and decide on an appropriate maintenance strategy (either block-based or time based).

Following a review of published maintenance frameworks, Takata et al. (2004) redefined the role of maintenance from the perspective of development life cycle. They argued that a framework should provide a connection between the product development phase and the operation phase bridged by maintenance strategy planning. The life cycle maintenance framework contains 3 feedback loops (Figure 8): the first loop uses Deming's PDCA cycle (Plan-Do-Control-Action) to plan the maintenance tasks, select a task (such as inspection, monitoring, diagnosis or treatment), execute the chosen task and evaluate the results. The second loop involves selecting a maintenance strategy following examination of process deterioration and the assessment of the effects of failure. The maintenance approach may be revised after evaluating the effectiveness of maintenance technology during the product's life cycle. The third loop seeks to improve the design of equipment based on the "lessons" learned previously.

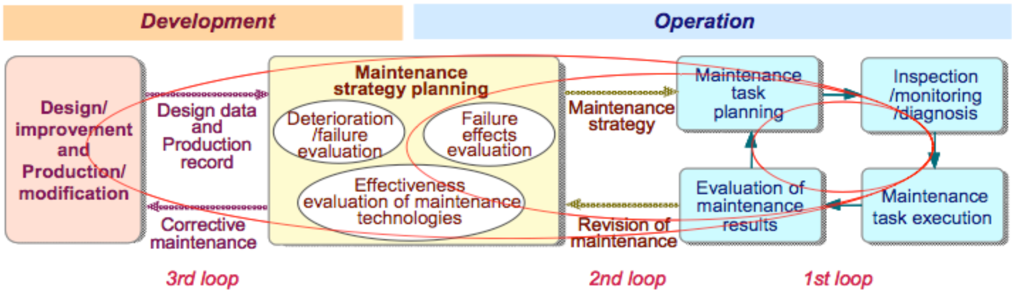


Figure 8 A framework for life cycle maintenance (reproduced from Takata et al., 2004)

Márquez et al, (2009) proposed a conceptual framework for maintenance management as shown in Figure 9. It contains eight blocks organised in sequence to cover four functions: effectiveness; efficiency; assessment; and improvement. ***Effectiveness*** allows maintenance objectives and associated KPIs to be defined, assets prioritised, appropriate maintenance strategy specified and high impact weak points to be acted upon. ***Efficiency*** covers the design and optimization of preventive maintenance plans including resources and schedules. ***Assessment*** focuses on maintenance execution, monitoring and control, as well as asset life cycle analysis and replacement optimization. ***Improvement*** addresses the issues pertaining to continuous improvement through the incorporation of new techniques where appropriate. The most important aspect of the proposed conceptual framework is that it emphasizes on the importance of integrating maintenance engineering tools and techniques with management concepts.

Naughton and Tiernan (2012) outlined a nine-step framework for developing and implementing an individualized maintenance strategy (Figure 10). The nine sequential steps are: focus on the positives and define one's position; identify constraints and limitations (assessing complexities); system classification; machine classification; policy selection; align performance indicators; structure maintenance data; implement and monitor; and feedback.

To the best of the author's knowledge, all of the frameworks detailed in this section are of conceptual nature and there is no information of either their implementation or validation.

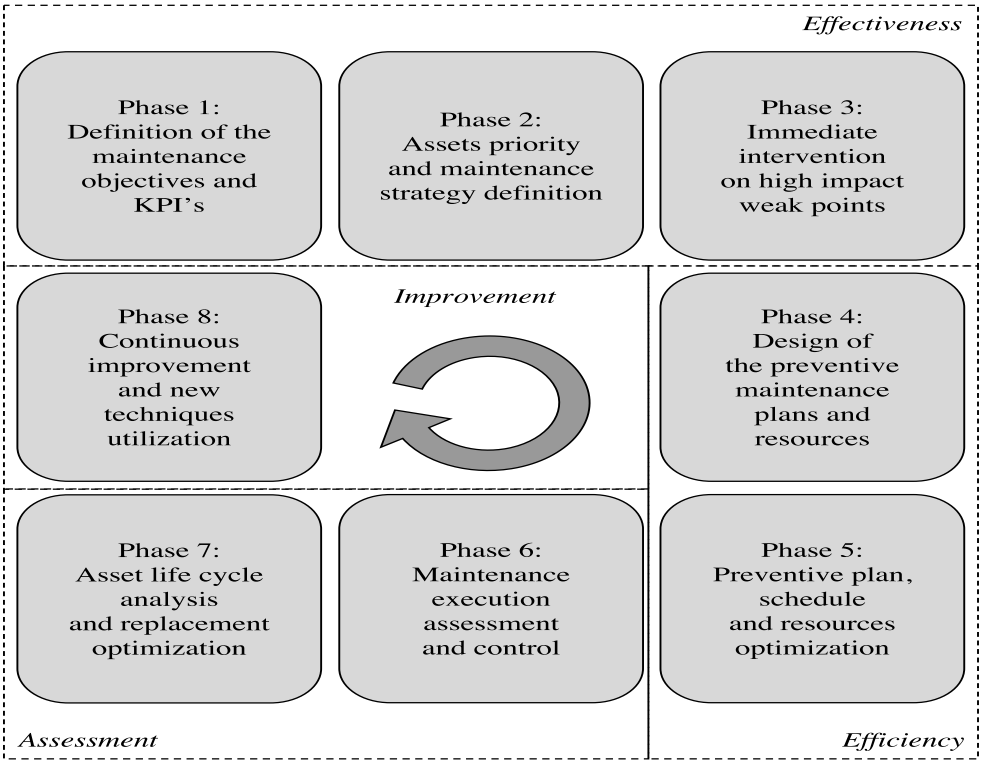


Figure 9 A generic maintenance framework proposed by Márquez et.al's (2009)

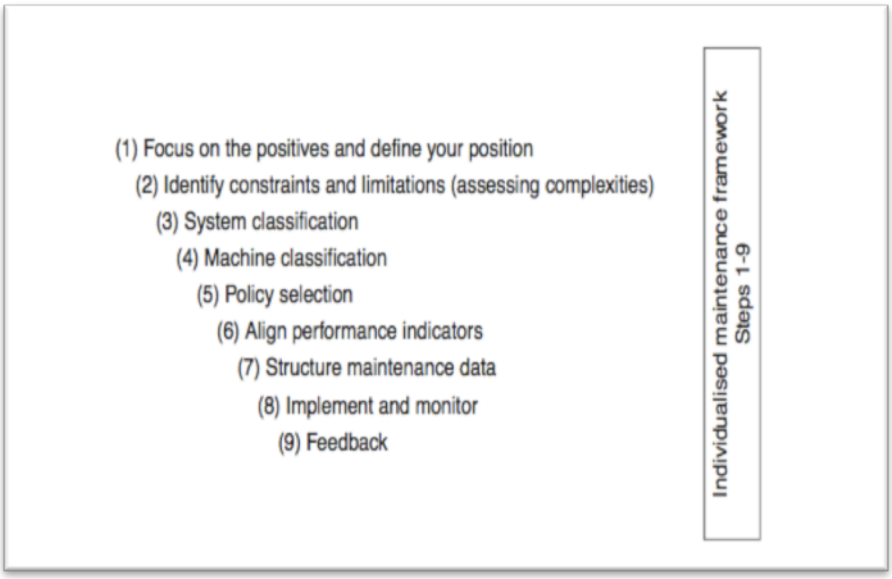


Figure 10 A 9-step individualized maintenance framework (reproduced from Naughton and Tiernan, 2012)

2.9 Maintenance management in the healthcare industry in developed countries

A healthcare system is increasingly seen as an essential service for any society, as it makes possible the prevention and treatment of sickness as well as preserving mental and physical well-being. Providing a healthcare system is a very expensive undertaking for any governments worldwide, as healthcare-related expenditure usually represent a substantial amount of a government's annual budget. According to the World Health Organization (WHO, 2008), healthcare expenses worldwide exceeded 5 trillion US dollars and consumed around 10% of the GDP of the industrialized countries in 2008. In 2012, the total expenditure on healthcare in the UK was £144.5bn representing 9.8% of GDP, while the figures for other developed countries were: USA 15% of GDP (US$3 trillion), France 11.6%, Canada 11.2%, Germany 11.3% and Japan 9.6% (ONS, 2012). Not all healthcare-related expenditure is used to provide treatments to patients. Hadfield (2006) reckoned that for each dollar spent on healthcare, more than three-quarters is spent on non-patient care activities (e.g. infrastructure, equipment, facilities among others). Nesje (2002) studied the distribution of facility management expenditure at St Olavs Hospital in Norway and found that facility maintenance, energy consumption and cleaning accounted for approximately one-third of the hospital's annual total operating costs.

In the context of maintenance engineering, the healthcare industry has unique operating characteristics, which makes it challenging to adopt standard performance management techniques. Quality in healthcare services is usually assessed by three parameters: structure, processes and outcomes (Donabedian, 1988). A quality management system (QMS) could be introduced in a hospital by applying it either in selected departments or to the whole organization. The existence of external drivers such as government policies and insurance companies could be treated as positive indicators of change. However, Green et al. (2000) observed that specific metrics could not accurately measure processes in a hospital, due mainly to (1) the huge amount of data to be stored on an on-going basis and (2) the effort/time needed to process the collected data before any actions could be taken. It was suggested that greater care should be exercised when selecting performance indicators to measure the return on investment in maintenance activities. This might also be used to provide the motivation for the maintenance function.

Operational failure in a hospital (such as equipment breakdown, lack of spare parts, inadequate supply of materials, faulty equipment and poor procedures) could lead to frustrated employees, delayed patient care, additional overheads and an increased probability of putting patients at risk. Goldstein et al. (2002) observed that the success of certain practices (e.g. environmental factors, organizational strategies, operational decisions, technology investments) in other industries has encouraged the healthcare industry to adopt them. It was suggested that new performance indicators are needed to measure service quality, equipment availability and operational efficiency. To assist with the management of healthcare facilities, Shohet and Lavy (2004) recommended that facility managers should be made responsible for five key areas covering: maintenance management; performance management; risk management; supply services management; and development; with ICT (Information and Communication Technology) as an integrator (Figure 11).

The lean concept is one of the latest quality approaches that have recently been applied to the healthcare industry. Based on similar philosophical approaches to lean manufacturing, the concept seeks to identify and eliminate waste in healthcare-related business practices and distinguish value-added from non-value added activities. The intention is to help a healthcare organization to provide higher quality services by using fewer resources and eliminating unnecessary processes (England, 2010).

Figure 11 Healthcare facilities management core domains (reproduced from Shohet and Lavy, 2004)

2.10 Concluding remarks

In common with other established management techniques, maintenance management has been shown to be a useful concept that can help to improve equipment reliability and availability, working environment, product quality and hence competitive advantage in the engineering and related industries. Some of the reliability tools and techniques for identifying causes of breakdowns in equipment and building as well as recurrent failures could be adopted for application in the healthcare industry. These include Failure Mode and Effective Analysis (FMEA), Fault Tree Analysis (FTA), Reliability Centre Maintenance (RCM), Root Cause Failure Analysis (RCFA). Other factors that can help to provide high level of maintenance services include relevant knowledge and skills, appropriate tools, work preparation, choice of maintenance strategy/approach (preventive, corrective and run-to-failure), choice of maintenance policies (use-based, condition-based, failure-based, design-out, and detection-based), types of maintenance task (inspection, monitoring, routine repair, overhaul, and replacement).

Previous studies suggest that the selection of a maintenance strategy and/or policy is often based upon the expert judgment of risks and potential function failures, and their mapping to the "risk appetite" of an organization and its business strategy.

As maintenance activities are usually labour intensive, maintenance performance is to a large extent dependent on how well the maintenance activities are conducted taking into consideration of the various constraints. One area where potential risks could be minimized is the reduction of human errors. The application of a maintenance management framework may also help when organising, coordinating, monitoring and controlling maintenance-related activities.

A number of maintenance managenent frameworks have been proposed in publications and, to the best of the author's knowledge, none has been validated in a practical environment. However, the framework concept suggested by Márquez et.al (2009) appears to provide a good basis for the development of a maintenance management framework for the healthcare industry in Saudi Arabia, as it seems to have the closest match to the requirements of the present study. The framework model is cyclical and dynamic, allowing interactive engagement of stakeholders through a computerised management system. Furthermore, the framework permits process optimisation to be carried out by means of specific tools using the data/information collected from various maintenance activities. Unlike the engineering industry, workers in the Saudi healthcare industry have vastly different working practices, so resistance to change is likely to be a key issue. Furthermore, cooperation from medical staff is needed for a healthcare environment to function properly.

The next chapter outlines the maintenance management issues confronting the healthcare providers such as hospitals and clinics in Saudi Arabia and discusses their impact on the delivery of primary healthcare in the Kingdom.

Chapter 3 Current situation of healthcare managennet in the Kingdom of Saudi Arabia

3.1 Chapter overview

This chapter presents a brief overview of the current state of maintenance management in the healthcare sector and the associated issues confronting the primary healthcare providers in the Kingdom of Saudi Arabia. Saudi Arabia is one of six members of the Gulf Cooperation Council (GCC) and all member countries share similar culture, practices and challenges. Past experience suggested that any successful development/implementation of a healthcare strategy in one GCC country is likely to be adopted by other member countries.

3.2 Healthcare challenges in Gulf Cooperation Council

Thanks to similarities in culture, social life and the same language and religion, the Gulf Cooperation Council (GCC) was established in May 1981 to achieve integration and increase security between the following six countries: Bahrain, Kuwait, Oman, Qatar, Saudi Arabia (SA) and the United Arab Emirates. The GCC has a total area of about 241,071,000 km^2, producing 35.7% of the world's total output oil and has a GDP of $1.6 Trillion (GCC, 2014). These figures have attracted international companies to invest in oil and gas exports, infrastructure projects, financial services and healthcare services within the GCC. As a key member of the GCC, Saudi Arabia has the largest healthcare market with a population of 28.9 million (World Bank, 2012).

In the past 30 years, the GCC has changed substantially in many social and culture aspects and the population has grown from 28 million in 1998 to nearly 40 million in 2012 (McKinsey et al., 2012) and is likely to reach 46 million in 2015. This in turn has led to an increased demand for healthcare services. The GCC also has the highest incidence of lifestyle diseases according to the World Health Organization (WHO, 2014). This has put more pressure on the GCC governments to increase their investment in healthcare. The high growth of the economy and increased role of the private sector in providing healthcare services have contributed to a significant improvement in the healthcare industry in the GCC. Indeed, the GCC healthcare market is projected to reach US$ 69.4 billion by 2018 from about US$ 39.4 billion in 2013 (Alpen, 2011). Despite the huge investment, the number of "beds" per 10,000 population in the GCC is still relatively low when compared to the developed European and North America Countries (Figure 12).

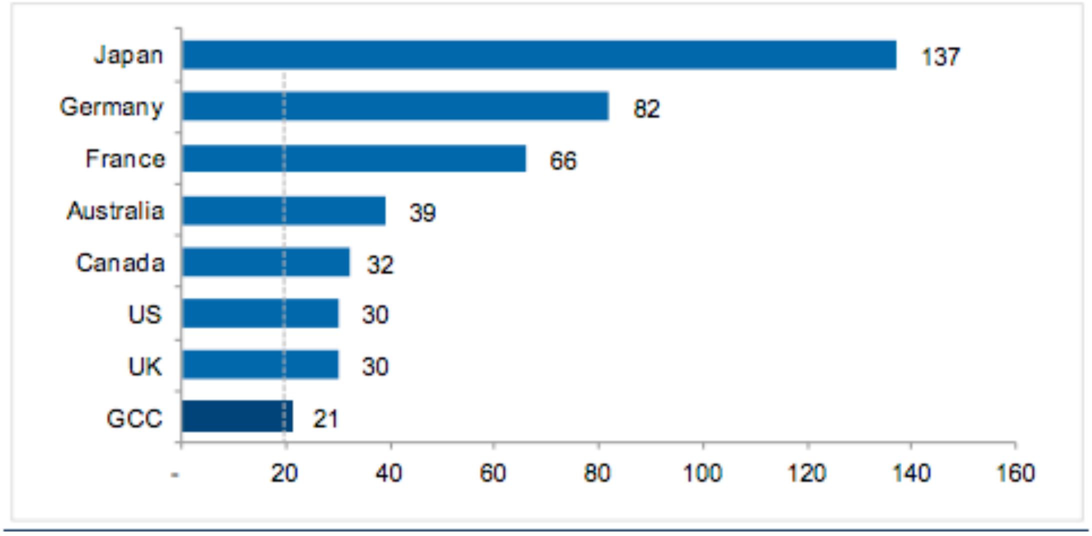


Figure 12 Hospital beds per 10,000 population (reproduced from WHO (2014))

In order to improve the healthcare system in the GCC, there are many significant challenges to be addressed, both internal and external. Some of the key challenges include infrastructure, budgetary constraints, lack of standard policies and procedures, health insurance, shortage of qualified personnel, relatively low quality of service, population growth, rapid rise of health costs and high proportion of elderly people in the population who have long-term health issues.

The rapid growth of the GCC economies over the past three decades has resulted in large inflow of foreign labours covering all sectors (McKinsey et al., 2012). The Economist (2009) pointed out that several factors have contributed to the increase in the number of foreign workers in the GCC countries including meeting project requirements, economic development activities and infrastructure construction.

The huge number of migrant workers has exerted both positive and negative impact on the society. It has changed not only the demographics of a country and raised its general economic output, but also created social and security-related issues.

A report published by the IMF (2013) indicated the GCC invited in about 7 million foreign workers to participate in its booming infrastructure projects between 2000 and 2010. From the employment standpoint, foreign workers limited the employment opportunities of national labours. The large outflow of money from GCC member countries is also an increasing concern. In the case of Saudi Arabia, the outflow amounted to approximately 30.3 billion Riyals ($9.8 billion) in the second quarter of 2010 (Arabian Business, 2011).

Security concerns included the dangerous presence of some foreign workers engaging in organized illegal activities such as selling drugs, money laundering and the counterfeiting of currency (Tanmia-Idaria, 2013). The GCC governments are working hard to prepare their nationals through a number of initiatives to meet the demands and challenges of the labour market, thus reducing their dependence on foreign workers. Furthermore, a decision has been made by the GCC council to limit the number of foreign workers to no more than 20% of a country's population (Aleqt, 2012).

3.3 Healthcare industry in Saudi Arabia

According to a National Commercial Bank report published in 2009, the beds-to-population ratio in Saudi Arabia hospitals over the past ten years declined to 2.2 beds per 1,000. In order to meet the population growth and increasing life expectancy, Saudi government announced a new five-year healthcare plan in 2011, which included the building of 121 new hospitals and the renovation of 66 existing ones. This scheme is part of the efforts by the Saudi Ministry of Health to meet the short-to-medium demands for hospital care (MOH, 2012). Figure 13 shows the estimated number of hospitals and beds over a 5 years period between 2008-2012 (Colliers, 2012). The new hospital projects would inevitably increase the demand for maintenance services which would be needed to sustain the buildings.

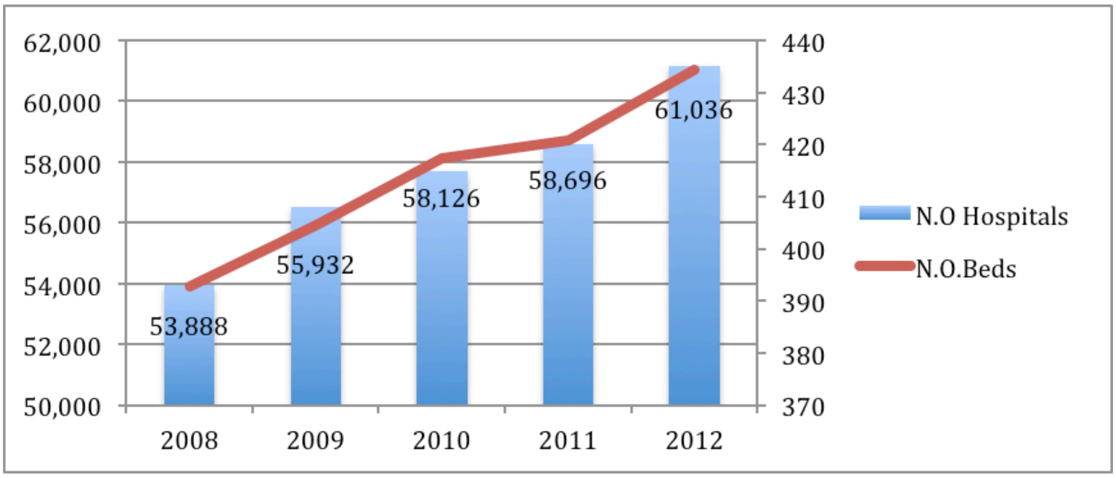


Figure 13 Number of hospital and beds in Saudi Arabia (Colliers, 2012)

The healthcare industry in Saudi Arabia is mostly run by government departments and semi-public organizations (accounting for roughly 69%, Figure 14) namely, Ministry of Health (MOH); the Medical Services Department (MSD) of the Ministry of Defence and Aviation (MODA); the National Guard of Health Affairs (NGHA) of the Saudi Arabian

National Guard (SANG) and the Security Forces Hospital Program (SFHP) of the Ministry of Interior (MOI).

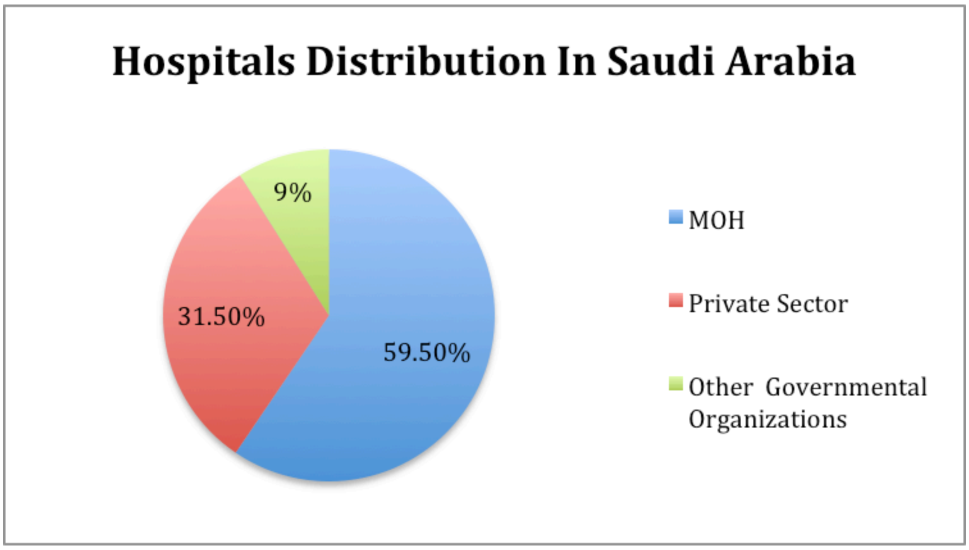


Figure 14 Hospital distributions in Saudi Arabia 2009 (MOH, 2014)

According to Almalki et al., (2011), 59.5% of Saudi healthcare services were provided by the MOH, while 19.3% by Referral Hospitals (Figure 15). The Referral Hospitals consist of King Faisal Specialist Hospital and Research Centre, Eye Hospital, Military Hospitals, Ministry of Higher Education Hospital, ARAMCO Hospital, Royal Commission for Jubail and Yanbu Health Services, School Health Units of the Ministry of Education, Red Crescent Society and private hospitals. The MOH plans to establish 195 new healthcare projects, including thirty-three new hospitals (MOH, 2014).

Under the government's ten-year strategic plan "2010-2020", the Ministry of Health is in charge of many developmental projects, some under implementation or construction. These projects include the development and construction of medical cities, specialist and general hospitals, and medical towers. They cover the entire Kingdom and contribute to improving the level of health services. For example, 776 primary healthcare centres were established and equipped in the last three years (2010-2013) and 637 new centres are currently under construction, bringing the total number of medical units to 1413. By the end of the strategic plan, the total number of centres is expected to increase to 2750 and would cater for 55 million patients annually.

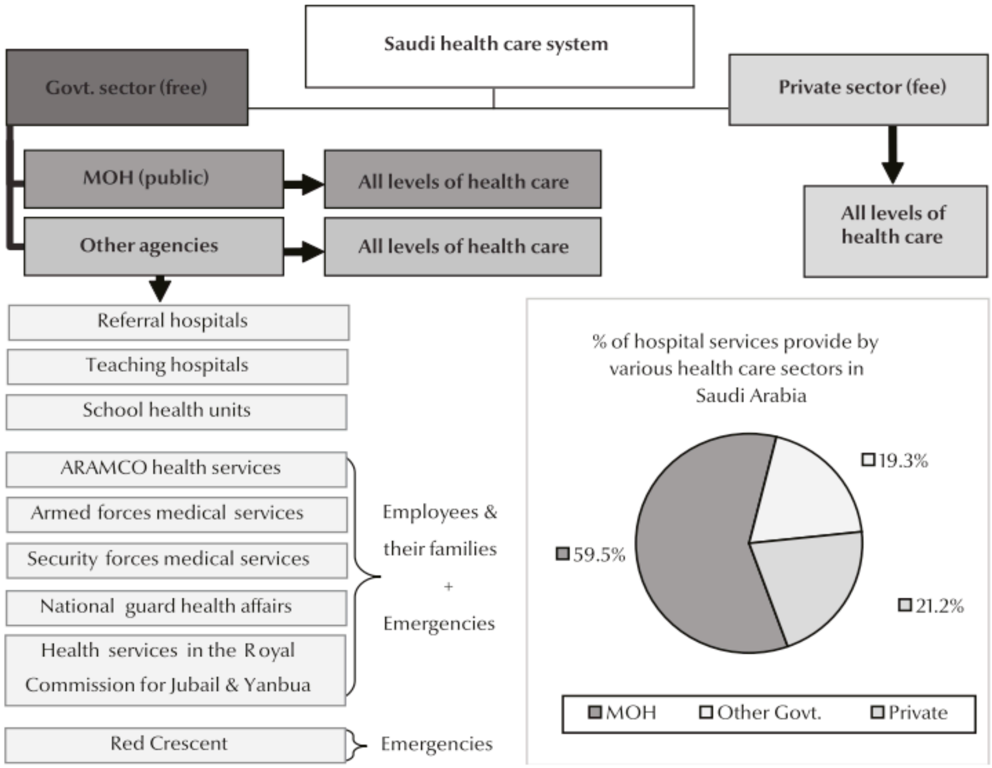


Figure 15 Current structure of the healthcare sectors in Saudi Arabia. (Reproduced from Almalki et al.,2011)

The implementation of Total Quality Management (TQM) in Saudi public sector organisations has been investigated by a number of researchers in the past two decades (e.g. Milakovich, 1992; Kravchuk and Leighton, 1993; Al-Qahtani and al-Metheb, 1999). A number of barriers have been identified as follows:

- Ineffective human resource management
- Lack of quality structure
- Inadequate technical support
- Frequent changes in leadership
- Poor communication and inadequate information
- Wide range of customers with different needs
- Ambiguity of training programmes
- Poor individual performance appraisal
- Disempowered employees and uncommitted top management

The impact of TQM on the performance of four MOH hospitals has been investigated by Alaraki (2014) focusing on 8 key elements: Leadership, Employee Management, Information Analysis, Training, Customer Focus, Continuous Improvement, Process

Management and Supplier Management. The study concluded that there existed a close correlation between TQM and general hospital performance, but the perception on the part of physicians and nurses was low.

In the case of delivering healthcare in Saudi Arabia hospitals, the following are the identified barriers (Khoja and Kabbash, 1997; Al-Ahmadi, 2009; Wardhani et al., 2009; Balghonaim, 2010):

1. Lack of commitments by managers and employees
2. Lack of quality-oriented culture
3. Lack of independent decision making
4. Lack of information
5. High staff turnover
6. Lack of career progression
7. Stressful working conditions
8. Lack of coordination
9. Lack of team spirit
10. Poor technology
11. Unclear accountability
12. Unclear job description
13. Variation in staff skills
14. Poor organizational culture
15. Poor organisational/structural design
16. Lack of leadership
17. Lack of involvement of clinical staff

Al-Ahmadi and Roland (2005) investigated the influence of organizational culture on improving primary healthcare in Saudi Arabia, but the study was mainly focused on the medical practitioners. However, it concluded that the morale and motivation of maintenance staff could be raised by improving their working hours, workload, salaries, resources and facilities.

To the best of the author's knowledge, there is not a single study which adequately covers the integration of maintenance management for the healthcare sectors in Saudi Arabia. A number of factors have been suggested that could impede the delivery of quality healthcare and hence could adversely affect the lives of patients and staff. These include the lack of management knowledge and skills, regular breakdown of hospital equipment and unsafe use of hospital facilities. It is therefore a concern to note that recent research showed that 90% of managers in charge of government of hospitals in Saudi Arabia have no formal management qualifications (Aleqt, 2012).

The way healthcare is being delivered in the Kingdom has changed significantly since 1999, with a welfare-oriented system replaced by a national healthcare insurance system. The intention is to make employers responsible for providing medical/healthcare cover for their workers, in addition to emergency healthcare which is still provided by the government (CCHI, 2014). Cooperative health insurance was first introduced in 1999 for residents, which has subsequently been extended to ensure all workers are covered by healthcare insurance. Employment–related healthcare insurance is being introduced in two phases. Phase one, which covered all private sector employees, started in July 2006. Phase two is due to start in 2015 and will cover public sector employees.

3.4 Healthcare maintenance management in Saudi Arabia

Maintenance management in healthcare means providing the necessary maintenance activities to ensure that all services are functioning in a safe condition/environment. Many engineering function of Saudi's hospitals are outsourced to specialist contractors and maintenance companies. Each hospital has a maintenance department but its primary responsibility is to coordinate maintenance activities and to ensure that external contactors comply with the agreed maintenance contracts when delivering services throughout the hospital. However, a study by Al-hazem (2007) concluded that most work undertaken by contractors often did not meet the required minimum standards which were the main causes of many undesirable incidents. A number of plausible reasons have been suggested, namely ineffectual maintenance contractors, unqualified maintenance staff, failure to monitor work on site, poor communication between hospital administration and maintenance contactors, extra work requested by medical departments without proper authorisation.

The issues of training and accreditation of maintenance staff have been investigated by Al Sultan (2006), who proposed the following recommendations:

1. Establish a national maintenance program at foundation level
2. Introduce new maintenance courses in engineering and business schools
3. Government support for research studies on maintenance-related issues
4. Increase awareness of maintenance costs to encourage reuse and recycle
5. Allow foreign investment in maintenance consultancies
6. Promote local manufacture of spare parts
7. Publish maintenance management handbooks in Arabic
8. Hold conference twice a year to share good maintenance practices
9. Reward companies that implement good practices

To study the factors affecting the cost of maintenance of hospital facilities in Saudi Arabia, Hassanain et al. (2013) interviewed ten experienced facility managers in 20 public and 20 private hospitals in the Eastern Province. The following factors have been identified:

1. Transfer of incomplete project to the Maintenance Department for resolution
2. Lack of coordination between the construction and maintenance groups
3. Lack of quality control measures during the installation of systems
4. Failure to use a life cycle costing analysis
5. Lack of control of the budget allocated to maintenance

It is important to note the maintenance of healthcare buildings differs from that of general purpose buildings because healthcare buildings normally contain expensive, sophisticated and complex medical equipment/facilities. Furthermore, the living environment can have a significant impact on the wellbeing of patients. In terms of costs, a defective bed in a hospital can typically cost up to £350 per day as a result of loss of use.

A study by Alaloola and Albedaiwi (2008) showed that in one Riyadh tertiary centre, patient satisfaction showed a significant association with room comfort, room temperature and the availability of a room call button system.

In order to increase the reliability and availability of healthcare facilities, the Ministry of Health published a policy for the maintenance and operation of non-medical equipment. The aims of this policy are threefold: standardize maintenance work and its scope; determine maintenance requirements and their functions; identify the responsibilities of maintenance workers (MOH, 2014). The policy also seeks to promote closer cooperation between different departments within a hospital and between hospital departments and external contractors. It is a good step for MOH to monitor and regulate maintenance contractors, thus reducing mistakes and improving maintenance efficiency.

3.5 Riyadh Military Hospital - the case study hospital

The Riyadh Military Hospital (RMH) in the capital city of Saudi Arabia has been selected as a case study. The following sections provide an overview of RMH including the current maintenance processes.

Medical services provided for the armed forces started with the establishment of a clinic, the Medical Army Taif, in 1947, which subsequently expanded to ten clinics. In 1950 the clinics formed the Prince Mansour Military Hospital. The General Administration of the Medical Services of the Armed Forces became an autonomous function in 1972, and was subsequently renamed the General Directorate of the Medical Services of the Armed Forces (MSD). In 1973 the Armed Forces Hospital in Al-Kharj and the Armed Forces Hospital in Riyadh were opened. By 2011, the armed forces were served by 24 hospitals covering most regions with more than 5172 beds (MSD, 2011).

Riyadh Military Hospital (RMH) has a large campus covering an area of 200,000m^2 and is situated in the centre of the city. It was established under the sponsorship of King Khalid bin Abdul Aziz in 1978 with an initial capacity of approximately 365 beds. RMH has undergone numerous expansions over the years. It now has about 10,000 staff and a capacity of 1,400 beds. (PSMMC, 2014).

It is generally recognized that the medical services of the armed forces has continuously improved at every stage of its growth under the Ministry of Defence and Aviation and the Inspector General. An example is the establishment of fully integrated and coherent systems enabling hospitals to work together to deliver preventive medical care and harmonize therapeutic activities.

A government policy known as “Saudization” was initiated in 2011, which encouraged the replacement of foreign workforce with Saudi nationals in a range of disciplines covering administration, medical and technical. An ambitious plan, the policy also applies to MSD with the aim of achieving self-sufficiency without compromising the quality of the healthcare services.

Recognizing the value of training in improving staff knowledge and skills, MSD also established many colleges and institutes, such as the Prince Sultan Military College of Science and Health in Dhahran and the Prince Abdurrahman Advanced Dental Institute and Military School of Nursing. There is also cooperation between the Medical Services of the Armed Forces and advanced centres around the world through the establishment of a communication network, which is supported by engineers using the latest information technology devices. This allows RMH to link with various research centres over the world and to share medical information where appropriate.

Healthcare promotion/education is also a responsibility of RMH. Numerous campaigns have been organized to increase health awareness and health education of general public about the major diseases in the Kingdom and ways of alleviating them. Government statistics showed that MSD has distributed more than 8 million leaflets over a five year period (2007-2011) and published more than 97 papers in medical journals, such as the medical Arabia magazine (MSD, 2011).

MSD, with the cooperation of RMH, provides several mobile hospitals including specialized clinics to offer a high level of medical welfare to citizens. The medical services also participated in many relief campaigns outside the country, such as the establishment of a field hospital in Iraq during the recent crisis and 15 fully equipped ambulance teams in Mina during the Hajj.

3.5.1 Mission and Vision

RMH – Vision

"Riyadh Military Hospital as the premier hospital seeks to provide the highest standards of healthcare services for its patients, to be the benchmark for other hospitals in the Kingdom and to achieve excellence in all medical specialists in the Middle East "(PSMMC, 2014)

RMH – Mission

"The Hospital Management is committed to providing the best healthcare services for its patients by: meeting their expectations; full commitment to the principles of Total Quality Management; providing optimum support to all employees through effective training; improving the efficiency of management operations; and ensuring a work culture of continuous improvement.

Offering a comprehensive service in an environment where innovation, maintaining the hospital building and equipment, renovation and construction, new building and providing state of the art technology is integral to its care. It is proud to serve patients and to meet the challenge of complex medical needs, which is viewed as defining competency and where quality and safety of care are a constant" (PSMMC, 2014).

3.5.2 Technical Affairs Department

Part of RMH's remits is to offer health education and advanced training thus providing preventive and corrective medical care primarily for members of the Armed Forces, and also for the citizens and residents whenever possible.

Given the significant impact that maintenance can have on the delivery of healthcare, the Department of Technical Affairs of RMH, which supervises the Facilities Department, is charged with the following responsibilities:

1. Supervise the supporting services of the hospital including issuing building permits and coordination with relevant departments for the delivery of services
2. Maintain buildings, equipment, roads, sidewalks and lighting columns within the hospital campus
3. Review applications for building development to ensure compliance with the hospital strategic plan
4. Review applications from contractors and monitor subsequent transactions
5. Review the architectural design and construction of buildings to ensure compliance with relevant engineering standards
6. Contribute to the development of design requirements and specifications; drafting of building regulations
7. Issue permits for drilling, maintaining and demolition; issue certificates of completion of construction
8. Study the needs for expansion in specific departments
9. Study the needs for the procurement of new equipment in specific departments
10. Operate and maintain air-conditioning systems, heating systems, water treatment systems, dialysis units, medical gas systems, elevators, water and sewage pipes, electrical power, security cameras systems and standby generators
11. Perform routine and scheduled maintenance work
12. Develop departmental training programmes
13. Review policies and procedures

The organizational structure of the Technical Affairs Department is summarized in Figure 16. The Facilities Department, which comes under the Technical Affairs Department, is responsible for providing maintenance-related activities.

3.5.3 The Facilities Department

The Facilities Department of RMH is responsible for all maintenance-related activities. Its number one priority is to keep all equipment functioning properly, thus providing a reliable service to users at all time. The Facilities Department consists of the Head of Department and a secretary, the Finance Officer and three Hospital Engineers with their assistants and secretaries (Figure 16). The Department divides its functions into three areas each has a dedicated but largely autonomous maintenance team: the main building (building 100), the maternity building (building 109) and the VIP building (building 111). Each team is led by an engineer, assisted by an engineer assistant and a clerk working together to provide maintenance cover. It works with other departments in maintenance related activities including ordering new equipment. It is also responsible for any alteration work around the hospital.

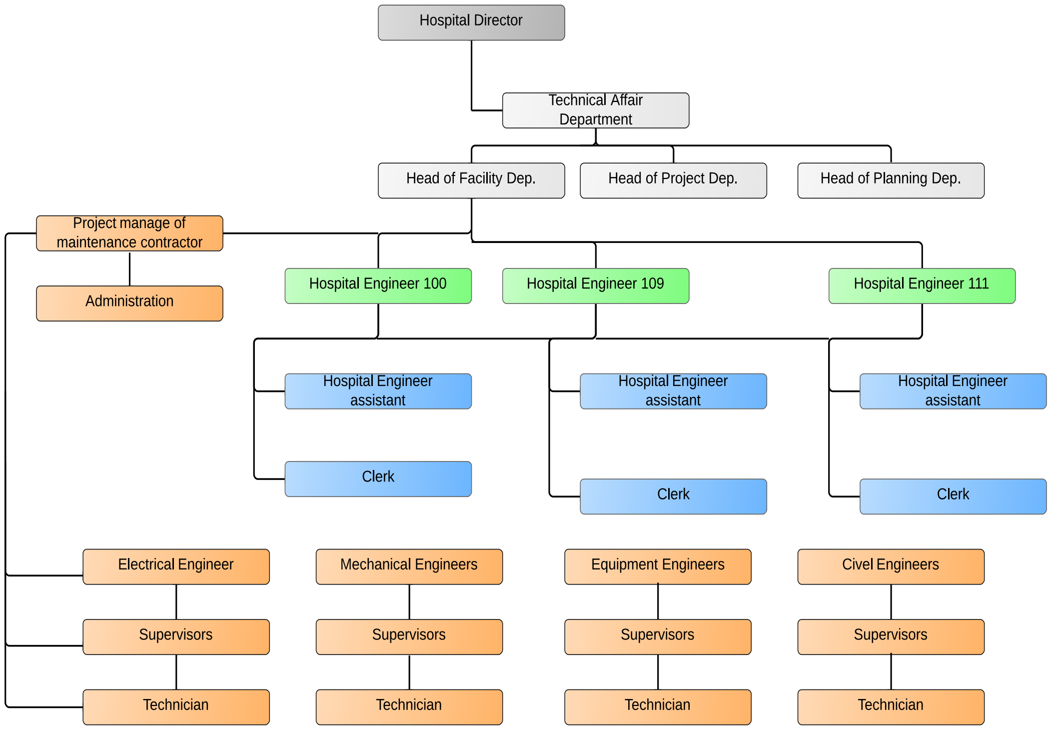


Figure 16 Structure of the Technical Affairs Department

3.6 Concluding remarks

Saudi Arabia, a member of the Gulf Cooperation Council (GCC) with the largest population, has seen its healthcare-related expenditure increase by 91 % from 13.94 $bn in 2009 to 26.6 $bn in 2014. Published documents suggest that the rising healthcare costs are attributable to a range of factors most noticeably rapid population growth, aging population and lifestyle illnesses such as Corona and obesity. As indicated by Saudi government officials, the current growth rate in healthcare expenditure is unsustainable in the longer term and efforts are being made to manage resources more efficiently. One area under consideration is the maintenance function of Saudi hospitals, clinics and specialist units, as these operations account for the bulk of the maintenance-related expenditure.

In common with other government hospitals, the Riyadh Military Hospital (RMH) has a long term plan to improve the quality and reliability of its services, through better utilization of resources. As a research programme, the present project contributes to the on-going strategic review of the hospital's current maintenance operations including outsourcing and subsequent management of maintenance contractors and suppliers. A key challenge is to understand how maintenance activities could be managed more successfully and implemented in a cost-effective way. Therefore, reduction of operation costs is seen as one of the first options an organization is expected to consider when attempting to reduce its maintenance costs.

In addition to maintaining complex medical equipment and equipment associated with different design standards (US, Europe and China), the maintenance department of a Saudi hospital often has to deal with new information technology and managing staff some of whom might lack specialist maintenance knowledge and skills. Consequently, maintenance managers have to constantly adopt and adapt new maintenance techniques to keep pace with changes. The problem is most severe whenever a piece of new state-of-the-art equipment needs to be purchased and installed. Outsourcing maintenance activities is increasingly used as a solution to bridge the knowledge and skill gaps, but this in turn gives rise to other problems. These include language barriers, different working culture and practices, and different level of appreciation of the health & safety issues.

Having identified the maintenance management issues in the Saudi healthcare sector and informed by the 'lessons' learned from previous research, the next chapter will outline the research methodology developed for the present study.

Chapter 4 Research methodology

4.1 Chapter Overview

This chapter outlines the research methodology developed for the present project in order to address the research aims and objectives and to provide answers to the research questions. The following key areas will be detailed: methods of data/information collection including questionnaire surveys, interviews and observations; methods of data analysis including correlation analysis and the determination of critical success factors by means of factor analysis; and various measures of maintenance performance.

4.2 Introduction

Research methodology is a very important area when conducting research because it can guide researchers appropriate steps in order to meet the research objectives. To provide answers to the research questions, gathering of both primary data and secondary data is deemed necessary. Part I of the present study focused on a detailed literature review of maintenance management so as to develop an understanding of relevant published information on related topics. To this end, a systematic approach has been adopted when reviewing the literature; this helps to reduce bias and is seen as a cornerstone of an evidence-based approach (Bryman and Bell, 2011). Part II focused on gathering information about the current maintenance management in the healthcare sector in Saudi Arabia and the drivers for change. The primary research involved gathering information about maintenance management in the Riyadh Military Hospital as a case study covering questionnaire surveys, group meetings, interviews and observations. The research is focused on a bounded study of a case study hospital for an in-depth analysis. The secondary research involved the use of a range of sources including the worldwide web in addition to official publications of the Saudi Arabian Ministry of Health and the Riyadh Military Hospital (RMH), books, journals and conference articles.

Stream Analysis is one of the popular methods for diagnosing and managing organizational changes (Porras 1987). By analysing organizational issues, stream analysis allows the ‘drivers’ for change to be determined, which in turn helps to prioritize and develop integrated responses to them. The method, which involves three stages (problem diagnoses, planning interventions and tracking the change process), may be expressed in 7 steps:

- Forming a change management team
- Collecting data
- Categorizing the problem
- Identifying interconnections
- Analysing the problem chart
- Forming a plan of action
- Tracking the intervention process

The stream analysis has been applied to the present study and the proposed research steps are summarized in Figure 17.

4.3 Research philosophy

Research philosophy depends on the way that a researcher goes about developing knowledge. The theory of knowledge is a branch of philosophy that studies the nature of knowledge and perspective. The development of knowledge is divided into three views: Positivism, Interpretivism and Realism (Bryman and Bell, 2011). "*Positivism is the philosophical approach that deals with natural sciences and can work with an observable social reality. It is a philosophy that relies on figures and quantifiable "things". Interpretivism is the name of a contrasting epistemology. This is a philosophy that relies on commentary and seeks to understand subjective reality. This philosophy encourages the researcher to understand subjective reality so as to make more sense of communities and empathize with their concerns. Realism can be identified through the practical and theoretical work of the social and natural sciences. Realism is located between the philosophy of Positivism and that of Interpretivism. In other words, realist research is a systematic investigation to find answers to a problem. Research in the traditional areas of science has generally followed the traditional objective scientific method" (Bhaskar, 1989; Cohen and Manion, 1994; Bryman and Bell, 2011).*

4.4 Deductive and inductive research

The relationship between research and theory needs to be understood in term of deductive and inductive research strategies. The process of deductive strategy begins when a researcher creates a theory and proposes the supporting hypotheses. Sufficient data is then collected and analysed to either accept or reject the hypotheses. This approach is known as the deductive approach. Inductive strategy, on the other hand, guides research by creating a number of themes or scenarios, which emerge from specific observations. Data collected is then analysed to enable suitable hypotheses to be formulated. This in turn leads to the development of a theory.

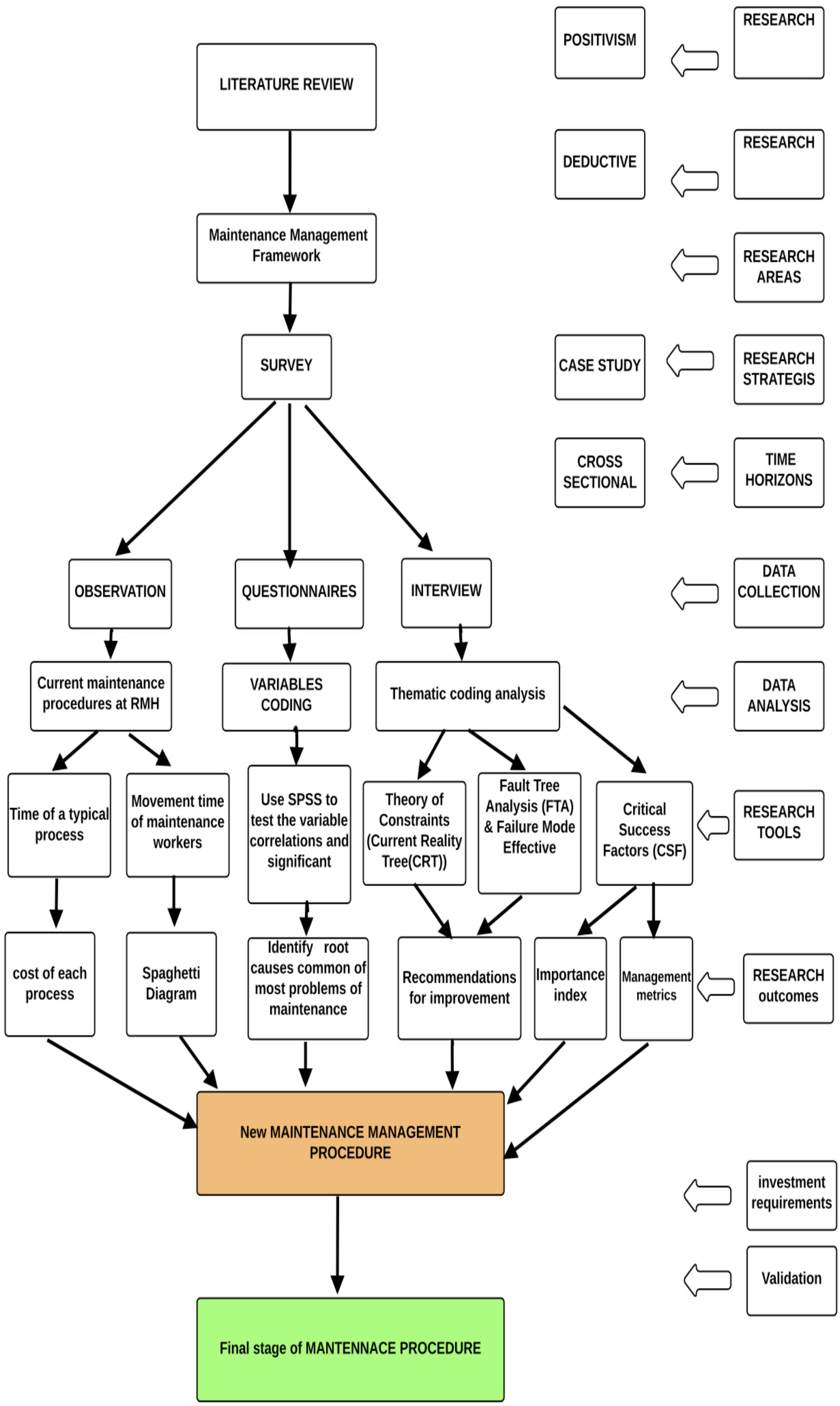


Figure 17 Steps in the research methodology

A deductive approach has been adopted in the present study in which pre-existing theoretical ideas will be tested. The quantitative research involves the use of questionnaire surveys, structured interviews and observation of specific activities. It is said to be closely linked to a positivist outlook where it seeks to develop a better understanding of a problem in addition to identifying relationships between variables.

4.5 Quantitative and qualitative research

Two methods have been used for data collection in the present study, namely quantitative and qualitative. When planning to use quantitative research, data is gathered by measuring and quantifying the answers provided by the participants. This method allows the collection of a large quantity of data due to the simplicity of delivery and collection of questionnaires, which can be done on-line. Furthermore, it can be analysed statistically.

With regards to qualitative research, information is collected by means of interviewing the participants and through observation of their actions. The present study made use of one-to-one interviews, case studies and focus group meetings.

4.6 Research approach

This study has to consider a large number of variables and any functional relationships between them need to be identified and studied. Both quantitative and qualitative approaches have been used in data collection involving questionnaire surveys, interviews and observation of specific events as part of the primary research. 'Lessons' learned from publications pertaining to the engineering and related industries in the field of maintenance management, as well as the information governing the current state of the healthcare industry in Saudi Arabia have been gathered as part of the secondary research.

The Riyadh Military Hospital (RMH) has been chosen as a case study due to its central location in the capital city of Riyadh and it is the largest strategic hospital in Saudi Arabia (Hziegler, 2013). Any maintenance-related issues thus identified are likely to be representative of the worst-case scenarios of all hospitals in the Kingdom of Saudi Arabia. A case study allows a bounded problem to be investigated in greater detail using multiple sources of evidence (Robson 2002).

The employees of the Technical Affairs Department have been surveyed involving four categories of staff, namely managers, engineers, technicians and helpers. The main elements in the survey strategy covered questionnaires, observations, interviews and focus group meetings.

4.7 Data collection

With prior agreement of the participants, the surveys of selected employees in RMH were focused on their attitudes/work ethics, efficiencies/productivities and level of maintenance-management knowledge. Three different types of approaches were used (Figure 18).

- Two sets of questionnaires containing different questions were administered to two groups of selected technical staff to facilitate comparative studies. The first set targeted the "frontline workers", namely hospital engineers, supervisors, technicians and helpers. The second set targeted management personnel namely hospital lead engineers and managers.
- In-depth interviews with the lead engineers and managers of the Technical Affair Department have been conducted in order to get a better understanding of management-related issues that were likely to emerge in the study. Focus group meetings were also convened with eight selected employees representing the hospital maintenance workers.
- Observations were carried out on selected maintenance workers while they conducted their routine activities/duties.

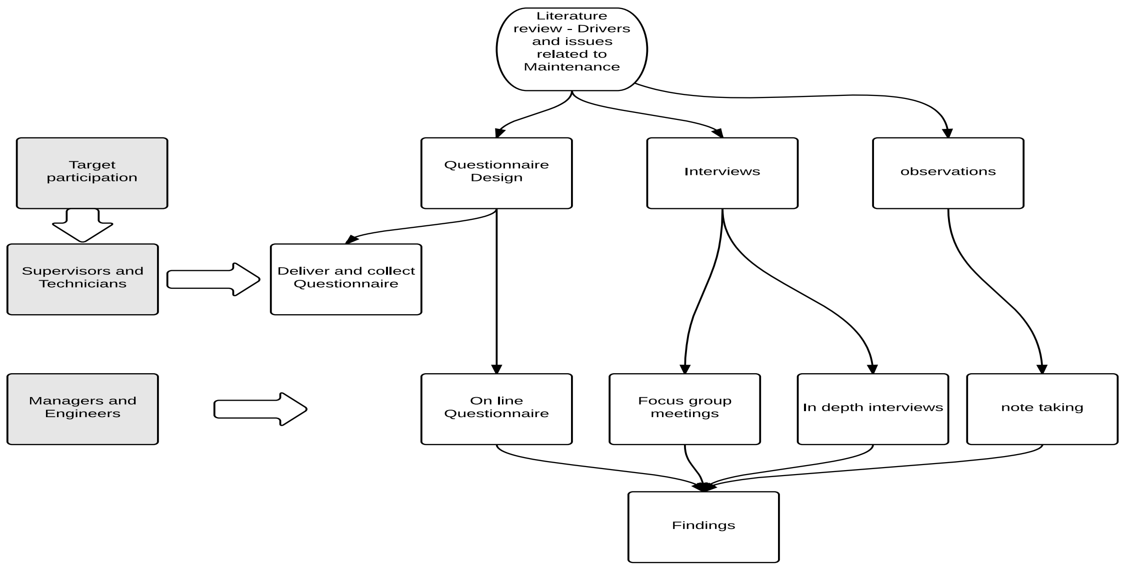


Figure 18 Data Collection methodologies

4.7.1 Sampling

Cohen and Manion (1994) suggested that the method of sampling could either be probability or non-probability sampling. Probability sampling covers simple random, systematic, stratified random and cluster, while non-probability sampling covers quota, convenience and snowball. Yamane (1967) suggested that the type and number of people to be sampled in a survey depends on five factors: the type of study to be undertaken, the overall population size, sampling errors, level of confidence, and degree of variability. According to Bryman and Bell (2011), the following benchmark values are acceptable for general studies: a range of sample errors of $\pm$5%, a confidence level of 95% and the degree of variability of 0.5. For a survey to be acceptable/valid, a sample size of 30 is generally considered by many as the minimum number that permits some form of statistical analysis of the data to be conducted.

Random sampling is the most common form of probability sampling and it provides a better way to reduce sampling error than non-probability sampling. In the present study, 35 technical staff who worked in the Maintenance Department were involved in the survey.

In addition, semi-structured and in-depth interviews were also used to seek clarification or elaboration on issues identified by the questionnaire surveys. This helped to yield qualitative information pertaining to the maintenance activities.

4.7.2 Questionnaire design

Two sets of questionnaires containing a total of 111 questions grouped under five parts have been designed using simple closed questions. The first set (known as questionnaire 1) covers parts 1 and 2, while the second set (known as questionnaire 2) covers parts 3, 4 and 5. The areas to be covered in each of the five parts are summarized below.

Part I focused on roles, knowledge and skills of participants**.** The respondents were asked to indicate their positions within the organization and associated affiliations (departments). They were also asked to indicate their level of knowledge and skills in the use of equipment and their understanding of the maintenance procedure provided to the operators.

Part II focused on the policy and procedure of the case study organization – the Riyadh Military Hospital in the Kingdom of Saudi Arabia. The respondents were asked to indicate their normal practices when dealing with any faults in the equipment delivered, and the types of maintenance program they normally followed.

Part III focused on the operation and responsibilities of maintenance personnel and operators. The respondents were asked to indicate their reaction when responding to any maintenance requests (e.g. repair of faults) and the interface between departments.

Part IV focused on the degree of understanding by maintenance personnel and contractors of the hospital's organisational culture, working culture and leadership issues.

Part V focused on the general understanding of the hospital's maintenance strategy by maintenance personnel and contractors.

To maintain the exploratory nature of this research, each question contains no more than five possible answers. This helps to minimize any potential misunderstanding of the questions (Saunders et al*,* 2003). A sample questionnaire is given in Appendix I.

Both sets of the questionnaire were personally delivered to and collected from the participants during site visits by the author. The managers and lead engineers received an on-line questionnaire to complete. There were opportunities for the author to meet with some of the participants to discuss informally about the questionnaire. As far as the flow of the survey is concerned, filtered questions were also included in the questionnaire to allow the participants to skip any questions that they thought inapplicable. For practical reasons, a 5-point Likert scale (never true, rarely true, sometimes true, always true and not applicable) was used which made it easier to analyse the result by a computer program. The questions are formulated based on 8 themes emerged from the literature review, namely:

- Importance of a clear strategy
- Existence of policy and procedure
- Job satisfaction
- Knowledge and training
- Team work
- Maintenance situation
- Leadership
- Performance management

The affiliation of the questions to the individual themes is shown in Table Table 2.

Theme emerged from literature review	Theme covered by questions in Questionnaire 1	Theme covered by questions in Questionnaire 2
Importance of a clear strategy	Q8	Q51,Q52,Q53,Q54,Q55,Q56,Q57,Q58,Q59,Q60
Existence of policy and procedure	Q16,Q20,Q27,Q33,Q34,Q35,	Q11,Q13.Q20,Q22,Q69,Q72
Job satisfaction	Q8	Q39,Q40,Q41,Q42,Q43,Q44,Q45,Q47,Q48,Q49,Q50
Knowledge and training	Q9,Q13,Q14,Q15,Q17,Q18,Q25,Q28,Q29,Q30,Q31	Q36,Q37,Q38,Q71
Team work	Q10,Q11,Q12,Q21,Q22,Q23,Q24,Q32	Q20,Q26,Q27,Q33,Q34,Q35
Maintenance situation	Q36,Q37,Q38,Q39,	Q13,Q17,Q18,Q19
Leadership	---------	Q1,Q2,Q3,Q4,Q5,Q6,Q7,Q8,Q9,Q10,Q11,Q12,Q14,Q15,Q16,Q21,Q22,Q23,Q24,Q25,Q46
Performance management	---------	Q28,Q29,Q30,Q31,Q32

Table 2 Affiliation of questions to the themes

4.7.3 A pilot study

Unclear questions can often lead to inaccurate data gathering. For this reason, an initial survey in the form of a pilot study has been conducted involving just three participants. The main purpose was to get some initial ideas about the current situation with respect to the hospital's leadership and management, organizational culture, maintenance management and processes. A subsequent meeting with the participants was held to identify any concerns/issues that they might have about the survey, particularly the clarity of questions which could have an impact on the validity of the survey. It became clear that they did not fully understand the meanings of some of the initial questions and sometime chose answers that were not intended. Constructive comments from the participants have subsequently been incorporated into the final design of the questionnaire.

4.7.4 Semi-structure and in-depth interviews

Interviews are said to be a purposeful discussion between two or more people in order to gather valid and useful data which may help to gauge the relationships between variables (Saunders et al, 2003). There are three types of interview, namely structured interviews, semi-structured interviews and unstructured interviews. Focus group interviews have been shown to be a particularly useful technique to probe deeper the attitudes and perceptions of the participants on their experience of specific issues.

With kind permissions of the RMH senior management and prior consent of the participants, interviews were conducted with selected employees on site over a period of 4 months between June to September 2013. The purpose was to develop a better understanding of the current status of maintenance management in the hospital. In the present study, semi-structured interviews were held with lead engineers and managers about their views of the current work environment focusing on policies, procedures and operations. Unstructured interviews were held with eight technicians who worked in the Maintenance Department focusing on operations, roles, knowledge and skills. This approach allows clarification to be sought on some of the answers given in the main questionnaire survey.

Efforts have been made to minimise disagreement on issues and the promise of anonymity and confidentiality helped to improve the engagement of participants in group meeting discussions as recommended by Stewart and Shamdasani (1990). Written notes were taken to record the interviews and they have subsequently been circulated to the participants to check for accuracy.

4.7.5 Observations

Collecting primary data through observations is important in the study of the behaviours of individuals. There are two types of observation (Saunders et al., 2003): participant observation, which is a qualitative method that helps to discover the meanings that people attached to their actions; and structured observation, which is a quantitative method dealing with the frequency of occurrence of actions. Although participant observation is not often used in the study of management, it can provide valuable information when employed in conjunction with other research methods.

With prior agreement of the participants and formal approval of their affiliated Department, the author observed selected maintenance workers while they undertook their tasks/duties as part of the research program. The following data was collected: process time of maintenance docket flow; transfer time of maintenance workers between workshop, complaint locations, spare-part warehouse, lead hospital office, project manager office, and head of facility department office.

4.7.6 Reliability and validity of data

In order to reduce the possibility of inaccurate answers, the question of data reliability and validity has been considered so that the information thus obtained would be repeatable and fit for the purpose.

Reliability of data

Reliability is in fact achieved through the ability to repeat the study with the same results, observations and transparency of sense in the raw data (Easterby-Smith et al., 2002). To ensure reliability in quantitative research, Robson (2011) recommended the use of standardized research instruments, formal tests and scales. To improve the design of the questionnaire and the response rate, the questions used in the present research were kept simple and short. The intention was to avoid asking "double-barrel" questions, leading questions, negative questions and questions on sensitive topics. Coding was used to identify particular responses by numerical symbols, which could be used later in the analysis. To test the internal reliability of the quantitative research, Cronbach's alpha test was conducted and a value of 0.80 was set as the benchmark (Bryman and Bell 2011). Besides the quantitative questionnaire, qualitative research in the form of interviews with selected employees was also used to develop a better understanding of the current situation governing maintenance management in the case study hospital. This also allows cross-references to be made between the two set of responses.

Validity of data

The validity of data/information gathered through both quantitative and qualitative research needs to be assessed. This would help to add confidence to the research work by ensuring that the domain under consideration has been adequately covered and fit-for-the-purpose. In other words, the research actually measures what it says it measures (Joppe, 2000). For this reason, a pilot questionnaire survey has been conducted with three selected workers of the Maintenance Department before the main research to assess whether the survey questions are both valid and justifiable in relation to the objectives of the study.

Steps have been taken to minimise any unintended personal bias and that the information collected from interviews reflects accurately the views of the participants. Participants were encouraged to offer detailed account of their work experience focusing on any maintenance management-related issues which, in their views, might have impacted (positively or negatively) on the maintenance operations, including teamwork and their ability to discharge their roles professionally. A copy of the interview summary was made available to the participants to check for accuracy.

4.7.7 Ethical considerations

The present study abided by the regulations outlined in the University's ethics handbook. All of the participants were employees of the case study hospital working in the Maintenance Department. They were considered to have access to sensitive information that could affect the reputation of the hospital and hence on the patients' trust. Thus, information confidentiality would be respected and safeguarded where appropriate.

Steps have also been taken to protect the interest of individual participants who provided information on their work environment and their views on general maintenance management. A summary of the interviews was made available to participants to check for accuracy. To reduce any unintended bias, the author avoided making comments during the interviews or expressed any views on the topics being discussed.

In cases where observations of maintenance personnel were deemed necessary, the participants were informed in advance of the objectives of the research study and their agreement sought. They were given a copy of the post-observation notes to check for accuracy.

The questionnaires were made anonymous, referring only to aliases and not gender-specific to ensure the confidentiality of the information provided. The data collected from the hospital was used solely for the purpose of the PhD study and would be destroyed after its completion. Furthermore, all participants have been briefed before the collection of data/information (covering questionnaire surveys, interviews and observations) about the research project, their potential contribution to the study and data protection measures.

4.8 Tools and techniques

The data obtained through quantitative and qualitative methods were analysed using a range of techniques. The questionnaire responses were analysed by identifying the parameters which might be considered as potential obstacles to the proper functioning of maintenance activities. The SPSS statistical software package was used to identify correlations and significance between the parameters. As the study considered a relatively large number of parameters, a method known as the Principal Component Analysis (PCA) has been applied within the SPSS to reduce the number of parameters to a manageable level. For the qualitative analysis, a technique known as thematic coding has been used to identify potential issues which might have affected the maintenance operations. The thematic coding analysis was carried out in conjunction with other information analysis techniques including Critical Success Factors (CSF), Fault Tree Analysis (FTA), Failure Mode and Effect Analysis (FMEA) and Theory of Constraints (TOC). With prior agreement of the participants, direct observation of events was also undertaken as part of the qualitative research. The main reasons are as follows:

1. To assess workers' attitude when discharging their responsibilities
2. To ascertain the degree of compliance with current maintenance procedures by contractors
3. To obtain estimates of the travel times between various locations undertaken by maintenance workers within the hospital compound
4. To obtain estimates of the total time taken for a worker to complete a maintenance request or complaint

Items 3 and 4 allow the overheads/costs associated with a maintenance process to be estimated for the current operations.

4.8.1 Critical Success Factors (CSFs) and performance measurement

Critical Success Factors are commonly used as a tool for assessing organization performance (Zawawi et al., 2011). Attempts have been made to identify and define CSFs for the individual functional areas within the Maintenance Department and their mapping to the hospital's performance indicators as outlined in the organizational strategy. This method allows the causes of failure (and success) and their potential impact on the current maintenance management procedures to be studied.

Formulae are available to provide measures of maintenance performance in the manufacturing industry (Marqze, 2007) and they have been adopted for application to the healthcare industry in the present project as listed below. For example, Maintenance Cost of Unit Production (MCUP) in manufacturing becomes Maintenance Cost Per Docket (MCPD) in healthcare.

$$\text{Maintenance Cost Per Docket } (MCPD) \quad \frac{Total\ maintenence\ cost}{Total\ no.\ of\ dockets\ issued}$$

Maintenance Cost as a percentage of Engineering Cost (MCEC)

$$MCEC = \frac{Total\ Maintenence\ Direct\ Cost}{Total\ Engineering\ cost}$$

Cost of Lost Beds Failure of the engineering service provided to a patient bed.

$$\text{Cost of Lost Bed Failure } (CLBF) = C_{DT} \times \sum_{i=1}^{i=n-1} DTi$$

Where DT is the down time.

The overall maintenance efficiency is given by the Maintenance Quality Index (MQI):

$$MQI = \frac{\text{Preventive Maintenance Cost } (PMC)}{\text{Corrective Maintenance Cost } (CMC) + \text{Cost of Lost Bed Failure } (CLBF)}$$

Efficiency in maintenance scheduling (EMS):

$$EMS = \frac{Number\ of\ PM\ activities\ carried\ out\ within\ a\ certain\ timeframe}{Number\ of\ PM\ activites\ planned\ within\ a\ certin\ timeframe} x100$$

Efficiency in Maintenance Execution:

$$EME = \frac{Time\ scheduled\ for\ the\ PM\ to\ be\ carried\ out}{Real\ time\ needed\ for\ the\ PM} x100$$

Efficiency in Maintenance Logistic (EML):

$$EML = \frac{Maintenance\ logistic\ downt\ ime\ (MLDT) x C_{DT}}{Working\ capital\ required\ for\ maintenece\ inventory}$$

Efficiency of Maintenance Manpower (EMM):

$$EMM = \frac{Number\ of\ dockets}{Number\ of\ manpower}$$

4.8.2 Fault Tree Analysis (FTA)

An effective symbolic logical method of failure analysis of a complex system, Fault Tree Analysis (FTA) has been used in the present study to identify the minimal ways in which the top events are linked to the basic events. Top events are undesirable events that can directly affect the well-being of patients, while basic events are those that can contribute to system failure (for example no ventilation).

4.8.3 Failure Mode and Effective Analysis (FMEA)

Failure Mode and Effective Analysis (FMEA) is an essential function in design that enables all modes of failure in a system to be identified. The method seeks to analyse the different ways or models that a system can fail and assess how each failure mode would impact on the system. It is also used to classify each failure mode according to its severity. The method has been applied to the present study to identify potential critical failures that could have an impact on the well-being of patients. The procedure starts from a specific event such as a failure in the air conditioning system and generates a maintenance strategy for associated critical equipment, such as the chiller system.

4.8.4 Theory Of Constraints (TOC)

The Theory Of Constraints (TOC) is a top-down-driven system of improvement focusing on identifying any system constraints so that appropriate resources could be directed to the maximization of system benefits (Husby, 2007). One of the key thinking processes introduced by Dr. Goldratt in the theory of constraints is the Current Reality Tree (CRT), which is created by organizing undesirable effects (UDEs) into effect-cause-effect relationships (Scheinkopf, 1999). According to Goldratt (1992) a thinking process is a series of steps used to locate the constraints (why to change?), determine the solutions (what to change?), and how to implement the solutions (how to make the change?). The CRT is read from the bottom up starting with the core problem and progressing upward through the tree using if-then statements in a logical order. It has specific characteristics and terminology (Entity, Arrow, Cause, And–connector (ellipse), Effect, Assumption and Entry Point). There are six steps involved when constructing a CRT (Scheinkopf, 1999):

1. Determine the scope of the analysis
2. List between 15-17 pertinent entities
3. Identify effect-cause-effect relationships that exist among the pertinent entities
4. Review and revise for clarity and completeness

5. Apply the 'so what' test
6. Identify the core causes

In the present study, the method of CRT has been applied to identify the core problems which might have prevented the proper functioning of the maintenance management system at the case study hospital RMH, thus permitting any relationships between causes and effects to be identified and quantified. This allows a better understanding of any relationships that might exist between three key factors (namely system patterns; basic conflicts; drivers for undesirable effect) and the formation of new entities.

4.8.5 Spaghetti Diagram

If a technician needs to leave a workshop in order to attend to a complaint, then he normally travelled from a centralized location where the workshop is located. The travelling time between locations is considered as unproductive time which adds to the overheads/costs of the maintenance operations.

A spaghetti diagram is an established mapping tool for Lean Process Improvement widely used in the manufacturing industry. Based on the observation of the distances travelled by workers, the diagram can be used to expose inefficiencies between key locations and highlight some of the resources wasted in the process (Bicheno and Holweg, 2008). The method has been applied to the present study by observing the movements of the maintenance crews within the hospital compound and the associated travelling times. Liker and Meier (2005) suggested that spaghetti diagrams are best used in conjunction with other tools/techniques in order to provide a bigger picture of the work environment. Attempts have also been made to integrate a Spaghetti Diagram with a Current Reality Tree in order to identify areas for improvement.

4.9 Data Analysis

The data analysis was conducted in three main steps: thematic coding analysis, coding of variables and estimation of the operating costs associated with the current maintenance procedures.

4.9.1 Thematic coding analysis

A technique that is often used to analyse qualitative data in management research, Thematic Coding can help to make replicable and valid inferences from text to the context of their use. The technique consists of two constituent parts (Krippendorff, 2004): coding and themes.

The thematic coding approach was used to analyse the qualitative data that labelled the code of interest information and then codes with the same label were grouped together to form a theme. By analysing the interview and summarizing it to a valid point, content analysis is one of the techniques used to extract meaning and classify the context (Neuendorf, 2002). However, Krippendorff (2004) defined it as a research technique for making replicable and valid inferences from texts to the context of their use. To extract useful information from a text, Robson (2011) claimed that the key features of content analysis can be extracted not only from written material, but from a range of data, such as works of art, images, maps, sounds, signs, symbols and numerical records. He suggested that coding should involve identifying and recording related passages from qualitative data and the generalization of these messages to allow themes to be developed. Thus by grouping the similarities of a code, different themes related to a research question can be captured. A drawback of the technique is that it is difficult to enforce with any degree of consistency. As long as the people performing the coding are not expressing their opinions, the technique may help to identify significant areas for further analysis. For the present study, the thematic coding technique has been used to analyse the outcomes of focus group meetings. The motives were to identify the types of obstacle facing maintenance management at RMH. The coding of variables involves 3 steps:

1. The questionnaires are analysed by considering the variables that showed a marked effect on the progress of maintenance
2. Principal Component Analysis (PCA) is used to reduce the number of variables to a management level, thus making them easier to visualize
3. The SPSS statistical software is then used to assess the strengths of any identified correlations between variables and to perform the PCA

4.10 New maintenance management framework proposal and validation

Based on the ‘lessons’ learned from literature review, the desire to improve healthcare maintenance management in Saudi Arabia and informed by the data analysis, a new maintenance management framework consisting of eight functional blocks has been proposed. To evaluate the appropriateness of the proposed new framework, typical maintenance procedures for the case study hospital RMH were studied. Times and costs associated with individual activities of the current maintenance procedures have been estimated. Changes to the current maintenance procedures were suggested based on the implementation of the new maintenance management framework. To validate the revised maintenance procedures, times and costs associated with the individual activities of the revised procedures have been estimated, so that comparisons can be made with the current time and cost of maintenance procedures.

4.11 Concluding remarks

The chapter outlines the research methodology that was adopted for the PhD work. Informed by background research on data collection techniques, a multitude of approaches have been used in the present study to collect relevant information involving both primary and secondary research.

Two sets of questionnaire were designed to gather information pertaining to the current practices of maintenance management in the case study hospital RHM and they were intended for the staff in the Maintenance Department. The first set sought to find out the competencies of front-line workers covering technical knowledge, skills, experience, teamwork, communication and level of organisational support. The second set intended to assess the level of management knowledge of managers and lead engineers.

Given the relatively small number of lead engineers and managers employed by the Maintenance Department, the questionnaire survey was supplemented by interviews to assess their awareness/understanding of the importance of leadership, change management, transparency, documentation, communication and clarity of strategy. Furthermore, their views were also sought on potential barriers to the rationalization of the maintenance management processes.

Range of tools and techniques have been considered to facilitate the analysis of the collected information/data in order to identify maintenance metrics, importance indices, root causes of most common problems of maintenance, potential areas for improvement, and any potential issues which could have an impact on the maintenance operations. The issues thus identified would be used to inform the development of a new maintenance management framework for the healthcare industry in Saudi Arabia, and the appropriateness of which for implementation in the Kingdom would be validated by means of the case study hospital RMH.

The next chapter will present the results of the primary research conducted at the case study hospital covering questionnaire surveys, interviews and observations.

Chapter 5 Presentation of results

5.1 Chapter Overview

To assess the state of the current maintenance management operations at the case study hospital (RMH), data were collected by means of surveys, interviews and observations. Two questionnaires were distributed; the first questionnaire targeted maintenance workers in the Maintenance Department. The questionnaire aimed to develop understanding of the current state of maintenance skills, knowledge, equipment, and teamwork as well as to identify potential relationships between them. The data were specifically collected in order to describe and analyse the background information and experiences of the respondents. The second questionnaire targeted lead engineers and managers who worked in the Maintenance Department to study the relationships between maintenance management issues and maintenance activities. In addition, focus group meetings with 8 hospital engineers were conducted, to identify any barriers to the improvement of maintenance activities and to assess their views of leadership styles and organizational culture. With their prior agreement, maintenance workers were observed when undertaking their jobs to assess how maintenance tasks were executed.

5.2 Questionnaire surveys

Two sets of questionnaires were distributed to two selected groups of hospital employees based on their roles and responsibilities. The first questionnaire was intended to gather the views of technical managers, hospital engineers, supervisors, technicians and helpers focusing on policies, procedures, teamwork, knowledge, skills and working conditions. It consists of 39 questions as shown in Appendix I. The second one was targeted only at the hospital's engineers. It was intended to identify the factors which could influence the operations and hence the performance of the Maintenance Department, including the understanding of strategies, leadership styles, keys performance indicators, motivation and customer satisfaction. The second questionnaire consists of 72 questions as shown in Appendix II.

5.2.1 Questionnaire 1: Understanding of the current state of maintenance operations in RMH

The first questionnaire has been designed to develop a better understanding of the current state of maintenance operations at the case study hospital RMH. A total of 35 questionnaires were distributed to technical managers, hospital engineers, supervisors, technicians and helpers (who have no technical qualifications) by personal delivery and 31 of them were completed representing a response rate of 81%.

The categories of the respondents are summarized in Table 3. The respondents were asked to state their positions within the Technical Affairs Department, which has line management responsibilities for the Maintenance Department. It is rather disappointing to note that the helpers did not make any contribution to the survey probably due to their low level of literacy.

Respondent' Category	Manager	Engineer	Supervisor	Technician	Helper
	1	7	11	12	0
Total number of the respondents	31				

Table 3 The respondents' category

5.2.1.1 Respondents' training programs

Although training programs play an important role in improving the knowledge and skills of the employees at RMH, it was found that 12 respondents had not attended a training program in the use of critical equipment or any other complex equipment since joining the hospital (Figure 19). Four respondents attended a training program covering all equipment and 3 respondents attended a training program covering most of the equipment. Furthermore, approximately one-third of respondents did not have adequate information about the equipment that they were supposed to maintain.

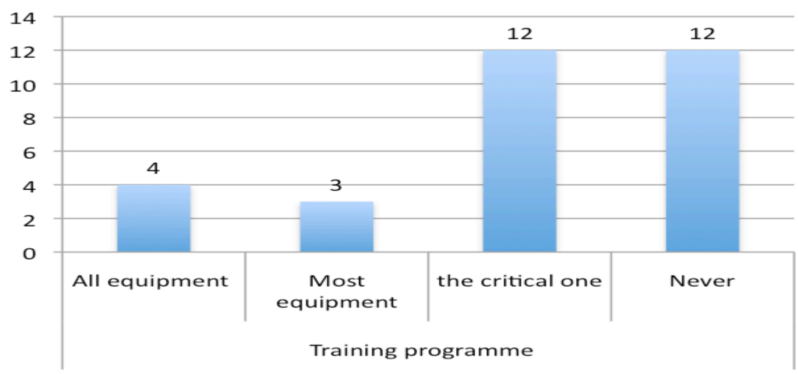


Figure 19 Respondents who attended a training program

5.2.1.2 Usage of maintenance programs

Three types of maintenance program were used in RMH: Corrective Maintenance, Periodic Maintenance and Preventive Maintenance. Only 55% of the respondents indicated that they followed standard procedures when maintaining the equipment, while 45% did not follow any standard procedures or were not aware of their existence (Figure 20). The respondents were asked to identify all of the maintenance strategies they employed in their work. It was found that 25 out of 31 maintenance workers used preventive maintenance, while 23 out of 31 used corrective maintenance. Periodic maintenance, on the other hand, received the lowest usage of 8 out of 31. The variance in the use of the maintenance programmes indicates a lack of uniformity in the application of maintenance strategies within the hospital.

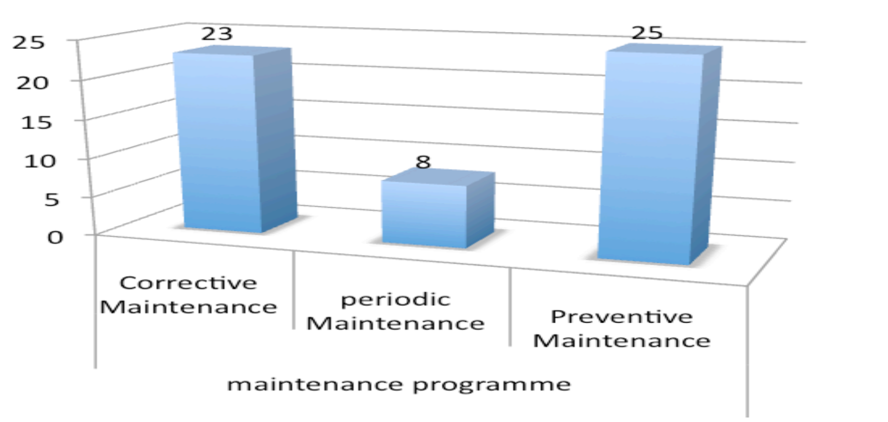


Figure 20 Usages of maintenance programs (note: respondents were asked to choose all that applied)

5.2.1.3 Clarity about roles and responsibilities

Clarity about the roles and responsibilities of individual employees within an organization is a significant factor for giving an employee the confidence needed to discharge his/her duties professionally. Most of the respondents (25) stated that their roles and responsibilities were made clear to them and one has limited knowledge, but 5 stated that they did not know their roles and responsibilities adequately (Figure 21).

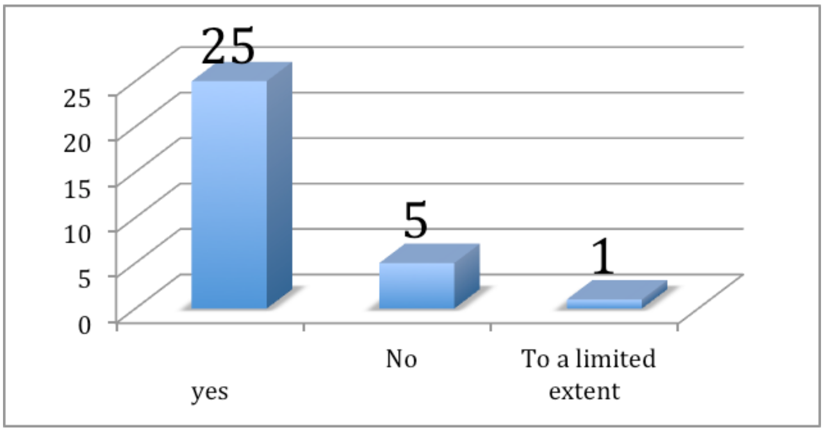


Figure 21 Clarity about of roles and responsibilities

5.2.1.4 Cooperation between functions/departments

The types of cooperation between operations, technical and maintenance have been assessed. Formal cooperation is most common accounting for 58% of the replies, while 19% suggested a mixture of formal and informal cooperation between departments (Figure 22).

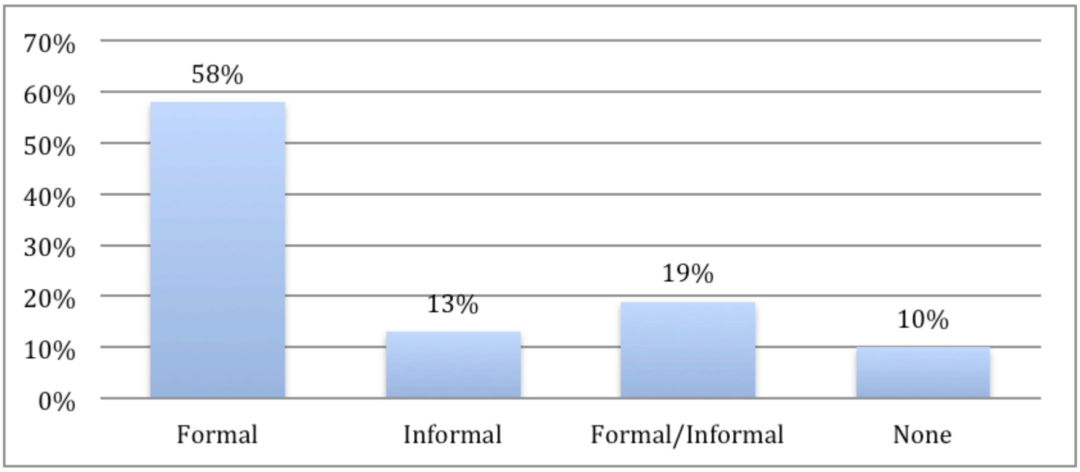


Figure 22 Cooperation between functions/departments

5.2.1.5 Occurrence of faults

Quick responses by the maintenance staff or operators to emergencies such as equipment break down and machine faults are of utmost importance. The respondents were asked a number of questions related to this area and the results are presented in the follow sections. Based on the experiences of those surveyed, the results indicated that 45% of equipment faults recurred frequently (Figure 23). However, the responses were normally quick when it came to repairing the faulty equipment. Indeed, 61% of respondents always attended to the complaints immediately, while 39% of attended to it within a short time period, although the definition of a short time period has not been elaborated (Figure 24). It is not always easy to recognize a fault. Only 39% of respondents could identify a fault correctly the first time, while 61% of respondents could occasionally identify a fault when it occurred.

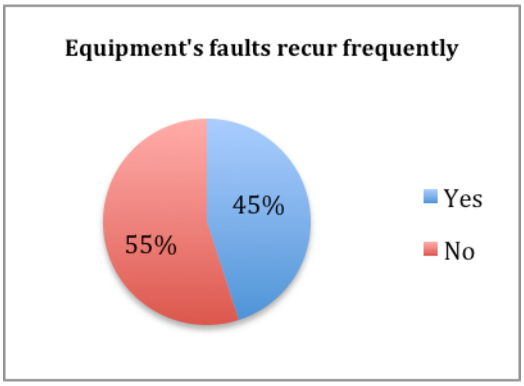


Figure 23 Faulty equipment recurs frequently

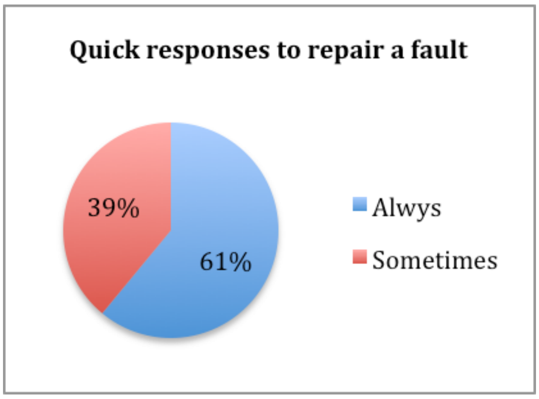


Figure 24 Responses to repair a fault

For economic reasons, it is important to increase the lifespan of a piece of equipment. Running a machine with a known fault is a poor practice, as it could lead to more damage to other parts. The survey suggested that 81% of respondents believed that a high proportion of equipment was operating with faults and 19% believed that equipment was shut down after a fault had developed (Figure 25 and Figure 26).

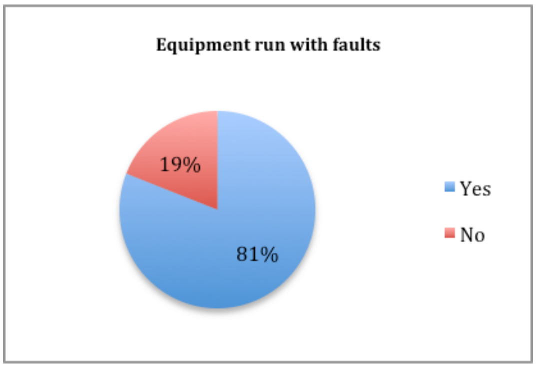


Figure 25 Equipment runs with faulty condition

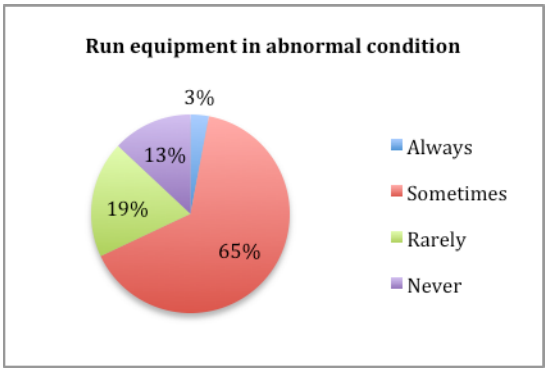


Figure 26 Run equipment in abnormal condition

5.2.1.6 Availability of facilities

The questionnaire asked the respondents about the availability of spare parts, illustrations, maintenance catalogues, logbooks, computerized systems and specialist tools to ensure that full services are provided for all equipment. A high percentage of respondents (65%) stated that spare parts were sometimes available when needed and only 6% said that spare parts were always available (Figure 27). Nearly 30% of respondents experienced difficulties in finding specific spare parts in the warehouse. Consequently, the data suggested that a significant proportion of equipment were running under abnormal conditions. A similar high level of respondents (65%) stated that they sometimes had the relevant illustrations and catalogues for the equipment for which they were responsible (Figure28) and 13% said that there was some kind of historical data available for all the equipment. However, 19% could not access the maintenance logbooks for all equipment.

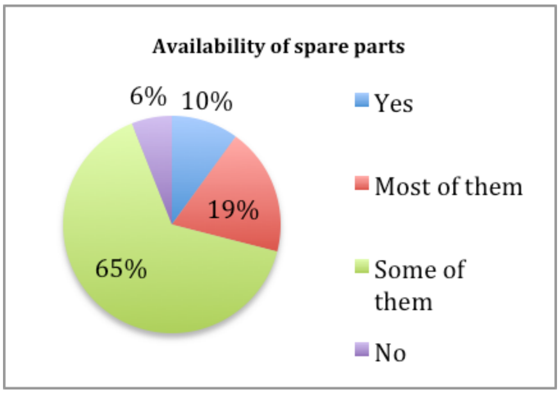


Figure 27 Availability of spare parts

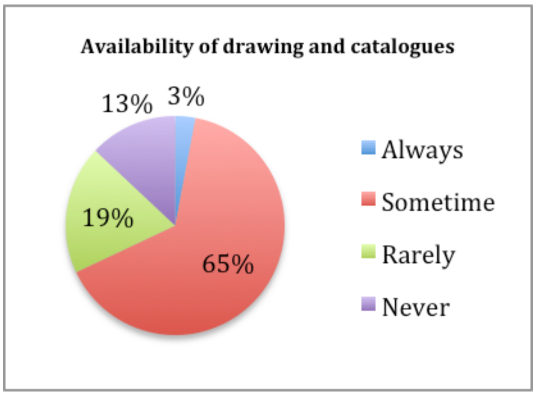


Figure 28 Availability of drawing and catalogues

The use of computerized systems and maintenance software is useful to help monitor the maintenance processes in any organizations. The respondents were asked if they had used any computerized systems to manage their work. It is rather surprising to learn that more than half of the respondents (61%) were not aware of the existence of any computerized systems for maintenance related work (Figure 29). As will be seen later, the results of interviews revealed that they either did not use the available computerized systems or chose to perform their duties in a more traditional manner.

They were asked about the availability of specialist tools to assist with their maintenance work. Surprisingly, 42% replied that they lacked one or more specialist tools, only 23% had access to specialist tools to complete their jobs (Figure 30). This may explain why

81% of respondents believed that equipment was operating with known faults (Figure 25).

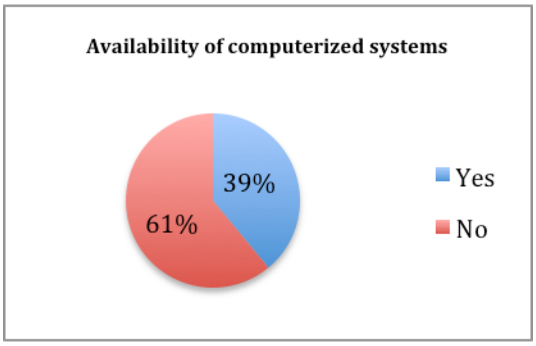


Figure 29 Availability of computerized systems

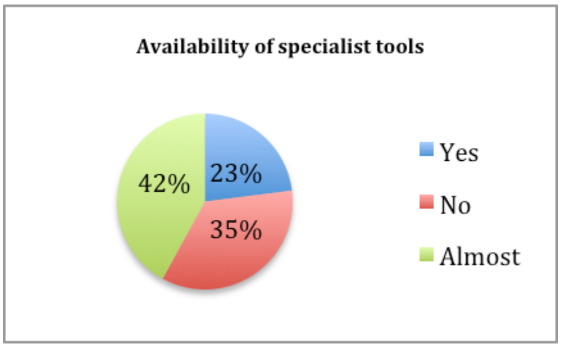


Figure 30 Availability of a specialist tools

5.2.1.7 Discussion by technicians and supportive supervisors

The respondents were asked to state the extent to which technicians discussed available options before deciding on a solution to repair an equipment fault and the support provided by supervisors. The results are tabulated in Table 4 and Table 5. All of the respondents indicated that there was some form of discussion on how a problem should be resolved but the level of participation was variable. Just over half of the respondents (51.6%) received support from their supervisors and 13 respondents (41.9%) received support when they asked for it (e.g. in a critical situation). However, 6.5% did not receive any support at all.

Negotiation with group of technician to solve a problem

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	always	19	61.3	61.3	61.3
	Sometimes	12	38.7	38.7	100.0
	Total	31	100.0	100.0	

Table 4 Discussion by technicians

Support provides to you

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	yes	16	51.6	51.6	51.6
	no	2	6.5	6.5	58.1
	when I ask	13	41.9	41.9	100.0
	Total	31	100.0	100.0	

Table 5 Supportive supervisors

5.2.1.8 Analysis of questionnaire 1 results

Based on the results of the first set of questionnaire, attempts have been made to identify potential relationships between the performance of maintenance workers and the current state of the maintenance processes at the case study hospital - Riyadh Military Hospital. This has been done with the help of a software package SPSS. Out of 37 variables measuring the knowledge, skills, co-operation and resources devoted to maintenance work, 35 variables were studied statistically.

To determine whether a correlation exists between two variables, a Pearson correlation R-value between them needs to be calculated, which is expected to lie between -1 and +1. A R-value close to -1 or +1 indicates a strong correlation either negatively or positively. A R-value close to 0 indicates a weak correlation. Pearson correlation is used because the data is considered categorical. A confidence level also needs to be specified when testing a potential correlation. This is set at 95%, corresponding to 0.05 significance level (S=0.05) for 1-tailed test.

Table 6 shows the results of a correlation analysis between 'happiness at work' and various parameters where N is the sample size. It can be seen from the first row that the Pearson correlation value is 0.449 with a significance value of 0.006. This means that a reasonably good correlation exists between "supports provided to you [an employee]" and "happiness at work". It is found that maintenance workers felt happier when they were given a promotion, carried out predictive maintenance and had access to drawings, catalogues and maintenance logbooks of hospital equipment. However, they generally disliked preventive maintenance and interruption of important work in order to undertake routine maintenance tasks.

Table 7 shows the results of correlation tests between 5 key factors, namely training, standardization of maintenance, clear responsibilities, information about equipment and relevant maintenance knowledge. It can be seen that there are good correlations between the "standardization of maintenance work" and (i) training (R=0.485, S=0.003), clear about responsibilities (R=0.543, S=0.001), (ii) having information about equipment (R=0.434, S=0.007), and (iii) knowledge about the equipment (R=0.550, S=0.001). With

Parameter	Correlation	Happiness at work
Support provided to you	Pearson Correlation	0.449**
	Sig. (1-tailed)	0.006
	N	31
Promotion given to operators to carry out regular maintenance	Pearson Correlation	0.328*
	Sig. (1-tailed)	0.036
	N	31
Use of periodical maintenance as Maintenance Programme	Pearson Correlation	0.389*
	Sig. (1-tailed)	0.015
	N	31
Use of preventive maintenance as Maintenance Programme	Pearson Correlation	-0.311*
	Sig. (1-tailed)	.044
	N	31
Time wasted on simple maintenance tasks and the postponing of important tasks	Pearson Correlation	-0.338*
	Sig. (1-tailed)	0.031
	N	31
Having drawings and catalogues of all equipment	Pearson Correlation	0.505**
	Sig. (1-tailed)	0.002
	N	31
Log books for all equipment	Pearson Correlation	0.381*
	Sig. (1-tailed)	0.017
	N	31

**. Correlation is significant at the 0.01 level . *. Correlation is significant at the 0.05 level .

Table 6 Relationship between happiness at work and various parameters

Parameter	Correlation	Training programme for operator to understand how to maintain equipment	Standardisation of maintenance jobs	Clear responsibilities	Information about equipment	Knowledge of ways to maintain and operate equipment
Training programme for operator to understand how to maintain equipment	Pearson Correlation	1	0.485**	0.345*	0.103	0.249
	Sig. (1-tailed)		0.003	0.029	0.291	0.089
Standardisation of maintenance jobs	Pearson Correlation	0.485**	1	0.543**	0.434**	0.550**
	Sig. (1-tailed)	0.003		0.001	0.007	0.001
Clear responsibilities	Pearson Correlation	0.345*	0.543**	1	0.466**	0.453**
	Sig. (1-tailed)	0.029	0.001		0.004	0.005
Information about equipment	Pearson Correlation	0.103	0.434**	0.466**	1	0.195
	Sig. (1-tailed)	0.291	0.007	0.004		0.146
Knowledge of ways to maintain and operate equipment	Pearson Correlation	0.249	0.550**	0.453**	0.195	1
	Sig. (1-tailed)	0.089	0.001	0.005	0.146	

**. Correlation is significant at the 0.01 level. *. Correlation is significant at the 0.05 level.

Table 7 Relationship between training provided to maintenance workers and their attitude regards to policy and procedure, it was found that “clear responsibilities” have a significant correlation with (a) training (R=0.345, S=0.029), (b) standardization (R=0.543, S=0.001), (c) availability of information about the equipment (R=0.466, S=0.004), and (d) knowledge to maintain and operate equipment (R=0.453, S=0.005).

When assessing the state of the current maintenance operations, attempts have been made to identify the factors that could affect the capabilities of the technicians to discharge their roles professionally. It is found that the following parameters, namely quick response to repair an equipment fault, recognize any fault early before a breakdown, and repair faults directly have positive correlation with training, standardized work, clear responsibilities, and the power to discover the main cause for equipment failure (Table 8). It can be seen that “equipment faults recurring frequently” correlates negatively with (i) training program (R=-0.365, S=0.022); (ii) standardization of maintenance jobs (R=-0.457, S=0.005) and (iii) knowledge to maintain and operation equipment (R=-0.302, S=0.049). The results also show that “the availability of spare parts” in the warehouse could improve with training programs (R=0.362, S=0.023), standardization maintenance of jobs (R=0.609, S= 0.000), clear responsibilities (R=0.554, S=0.001) and information about equipment (R=0.366, S=0.032).

With regards to the analysis of maintenance programs and work practices, Table 9 shows that there is a negative correlation between corrective and preventive maintenance (R=-0.311). It is also found that a shortage of spare parts and the lack of information about the equipment could lead to a high level of corrective maintenance, which in turn delayed the response time to repair an equipment fault. It is surprising to note that workers generally dislike preventive maintenance and it appears to have contributed to the lowering of their morale. This is perhaps attributable to a lack of understanding of the needs to carry out maintenance to make sure that equipment can run properly. It is therefore not unexpected to note that preventive maintenance shows a negative correlation with “running equipment in an abnormal condition”.

Parameter	Correlation	Support provided to you	Training programme for operator to understand how to maintain equipment	Standardisation of maintenance jobs	Clear responsibilities	Information about the equipment	Knowledge to maintain and operate equipment
Equipment Faults recurring frequently	Pearson Correlation	-0.186	-0.365*	-0.457**	-0.259	-0.178	-0.302*
	Sig. (1-tailed)	0.158	0.022	0.005	0.080	0.170	0.049
Quick response to repair an equipment fault	Pearson Correlation	0.149	0.357*	0.801**	0.445**	0.297	0.396*
	Sig. (1-tailed)	0.212	0.024	0.000	0.006	0.052	0.014
Recognise any fault early before breakdown	Pearson Correlation	0.526**	0.169	0.060	0.125	0.003	0.397*
	Sig. (1-tailed)	0.001	0.182	0.375	0.251	0.494	0.013
Wasting time on simple maintenance tasks and postponing important tasks	Pearson Correlation	-0.097	0.033	-0.485**	-0.477**	-0.017	-0.483**
	Sig. (1-tailed)	0.301	0.429	0.003	0.003	0.464	0.003
Repairing faults directly	Pearson Correlation	0.138	0.161	0.017	-0.335*	-0.125	-0.049
	Sig. (1-tailed)	0.229	0.193	0.463	0.033	0.252	0.396
Discovering what the main cause is	Pearson Correlation	-0.138	-0.161	-0.017	0.335*	0.125	0.049
	Sig. (1-tailed)	0.229	0.193	0.463	0.033	0.252	0.396
Availability of spare parts in warehouse	Pearson Correlation	0.007	0.362*	0.609**	0.554**	0.366*	0.133
	Sig. (1-tailed)	0.485	0.023	0.000	0.001	0.021	0.238
Having access to drawings and catalogues of all equipment	Pearson Correlation	0.296	0.273	0.301*	0.293	0.069	0.211
	Sig. (1-tailed)	0.053	0.068	0.050	0.055	0.356	0.127
Ease of finding drawings in an emergency	Pearson Correlation	0.011	0.423**	0.533**	0.581**	0.297	0.588**
	Sig. (1-tailed)	0.476	0.009	0.001	0.000	0.052	0.000
Use of a computer system	Pearson Correlation	0.066	0.246	0.494**	0.204	0.203	0.347*
	Sig. (1-tailed)	0.363	0.091	0.002	0.135	0.136	0.028
Up to date system	Pearson Correlation	0.215	0.475**	0.443**	0.219	0.298	0.336*
	Sig. (1-tailed)	0.123	0.003	0.006	0.119	0.052	0.032
Condition of tools	Pearson Correlation	0.093	0.423**	-0.036	0.046	-0.200	-0.097
	Sig. (1-tailed)	0.309	0.009	0.423	0.404	0.140	0.301
Keeping the tools in a suitable location	Pearson Correlation	0.042	0.333*	0.489**	0.266	0.597**	0.408*
	Sig. (1-tailed)	0.412	0.033	0.003	0.074	0.000	0.011

**. Correlation is significant at the 0.01 level . *. Correlation is significant at the 0.05 level .

Table 8 Correlations of a wide range of maintenance related parameters

Parameter	Correlation	Using corrective maintenance as the Maintenance Programme	Using preventive maintenance as the Maintenance Programme
Happiness level	Pearson Correlation	0.239	-0.311*
	Sig. (1-tailed)	0.098	0.044
Support provided to you	Pearson Correlation	0.212	-0.324*
	Sig. (1-tailed)	0.126	0.038
Standardisation of maintenance jobs	Pearson Correlation	-0.400*	0.395*
	Sig. (1-tailed)	0.013	0.014
Having information about the equipment	Pearson Correlation	-0.331*	0.286
	Sig. (1-tailed)	0.035	0.059
Using corrective maintenance as the Maintenance Programme	Pearson Correlation	1	-0.377*
	Sig. (1-tailed)		0.018
Using preventive maintenance as the Maintenance Programme	Pearson Correlation	-0.377*	1
	Sig. (1-tailed)	0.018	
Quick response to repair a fault in equipment	Pearson Correlation	-0.362*	0.288
	Sig. (1-tailed)	0.023	0.058
Running equipment in an abnormal condition	Pearson Correlation	0.009	-0.343*
	Sig. (1-tailed)	0.481	0.030
Availability of spare parts in warehouse	Pearson Correlation	-0.331*	0.286
	Sig. (1-tailed)	0.035	0.059
Ease of finding a drawing the equipment in an emergency	Pearson Correlation	-0.508**	0.137
	Sig. (1-tailed)	0.002	0.232

**. Correlation is significant at the 0.01 level . *. Correlation is significant at the 0.05 level .

Table 9 Correlations between maintenance programs and a range of parameters

5.2.2 Questionnaire 2: Investigating factors affecting maintenance management

The second set of questionnaire contained 74 questions which were designed to investigate issues pertaining to maintenance management. Three managers, six engineers and one assistant engineer were involved in the survey. They were asked about their overall job satisfaction, ability to discharge their roles professionally, intention to leave the organization if they were to receive a better offer from another healthcare organization, and whether they would recommend the hospital as an employer to others for its working environment. The survey was conducted in two parts. In part I, the participants were asked to elaborate on their understanding of the current maintenance policies, procedures and maintenance regimes. In part II, the questionnaire used a Likert type scale with five response options: Never True, Rarely True, Sometimes True, Always True and Not Applicable. There were 68 questions in Part II covering organizational culture, leadership behaviour and organizational behaviour. Out of 10 questionnaires distributed, 8 were returned with a response rate of 80%. The sample size was limited by the number of employees holding management/supervisory positions in the Maintenance Department.

Job satisfaction

When asked about their happiness with work, 12.5% replied that they were happy, 37.5% were satisfied but 50% of them were not. Just over half (57.1%) would sometimes provide good services to the patients because they feared the consequences of being the target of a complaint. 25% of the respondents indicated that they could not be successful at work even if they followed the legal and professional standards. About a quarter of the respondents felt they were uncomfortable with the working environmental because their supervisors appeared to be looking out for mistakes. 62.5% said that their supervisors might blame them for any mistakes at work in order to protect themselves. The same percentage of the respondents also said that their supervisors were the sources of conflict between staff. Only 37.5% of the respondent would recommend RMH as an employer.

Knowledge about the equipment

With only 50% of the respondents claiming to have sufficient knowledge to maintain the equipment and 78% not previously attended any training programs, it is easy to see why only 62.5% of the respondents felt they had the capacity, ability and knowledge to perform the work some of the time. With inadequate training, the same percentages of respondents chose 'sometimes' as an answer when describing (i) their limited ability to recognize faults early before a breakdown; (ii) how their supervisors often avoided coaching them because he wanted them to fail; (iii) how training opportunities were often withheld to prevent them to have any career advancement in the service; (iv) the lack of information on some of the equipment impacted on the maintenance work; (v) their belief that some of the maintenance staff are not fully qualified and hence do not have the right skills to perform their duties. Interestingly, the same percentage of respondents also said they knew how to complete a task once a decision to do work has been made.

Equipment conditions

87.5% (7 out of 8) of the respondents said that equipment failed regularly and 50% of them said they often knowingly let equipment running under abnormal conditions. Some spare parts were not always available when needed as claimed by 87.5% of the respondents; this may be one of the reasons why faulty equipment was kept running.

Accessing data

62.5% of the respondents said access to maintenance information was not easy as they did not use a computerized system for maintenance tasks in an emergency situation. However, the same percentage could locate drawings of the equipment.

Teamwork

All of the respondents said they had to engage in some forms of negotiation in order to make a final decision either with the department or the team. 75% of the respondents 'sometimes' had to take quick action without any discussion with the team when dealing with equipment in a critical state. 75% did not consider any suggestions from subordinates but 62.5% would 'sometimes' discuss with the team as to how a technical problem might be solved. There were no regular meetings to discuss work-related problems. Most of the respondents (87.5%) agreed that staff in the Maintenance Department cooperated well and that most work was completed by a team. They qualified their answer by stating that the cooperation often depended on task priority, the availability of time and the amount of overtime provided.

Leadership

Good communication and informal instructions are preferred by workers. 50% used emails, memos, or voice mail to send information. 75% of the respondents indicated that they were free to determine what needed to be done and how to do it, but 50% felt that this freedom carried some kind of risks. 37.5% said it was always true that no action would be taken against an employee when a mistake was made and 50 % said that it was sometimes true.

Vision, Mission and Strategy

The institution's vision, mission and strategy were not clear to 37.5% of the respondents and 25% were not sure about their features. Most believed that much of their work was of an emergency nature and short-term in scope. 62.5% of the respondents did not believe that the current maintenance processes would meet the organization's business objectives and any reduction in equipment failure would not add value to the business.

Support at work

When asked about the support provided at work, 62.5% of the respondents said not enough support was given to enable workers to complete their work in a satisfactory manner. 87.5% said not enough support was given when they needed a favour and 75.5% of respondents said their supervisors showed very little concern for them. However, most workers preferred to be supervised closely (75%); one of the reasons given was a believe that the work done would be appreciated more by the line managers. A similar percentage agreed that appreciation helped to increase motivation and 87.5% of respondents needed frequent and supportive communication. Table 10 summaries the responses regarding the support provided at work.

Support at work	Never True	Rarely True	Sometimes True	Always True	Not Applicable
Not enough support received to complete the work	12.5%	50%	25%	12.5	0%
Not enough support when they need a favour	12.5%	37.5%	37.5%	12.5%	0%
Supervisor shows very little concern	0%	25%	37.5%	37.5%	0%
Prefer to be supervised closely	37.5%	25%	0%	37.5%	0%
Need appreciation/ rewards	12.5%	12.5%	0%	75%	0%
No encouragement of innovation	0%	12.5%	37.5%	50%	0%
Need frequent and supportive communication	0%	12.5%	37.5%	50%	0%

Table 10 Support provided at work

Management issues

Unclear supervision was indeed an issue, as 7 out of 8 respondents agreed about a general lack of coherence and transparency in management guidance. 25% of the respondents needed clearer instructions to resolve ambiguities and 50% said they ‘sometimes’ needed further elaboration on instructions. The lack of clarity about responsibilities could be the reason why 62.5% respondents felt the need to protect themselves from criticism. 50% claimed to have no clear responsibilities as they were not allowed to carry out maintenance of equipment by themselves, while 70% felt no standardization about maintenance jobs. 62.5% had some interaction with management when completing their work. The same percentage also stated that there was no clear link between hospital departments. It is a concern to note that 87.5% of the respondents said health and safety procedures have not been properly followed.

Causes of delays in services

Five factors have been mentioned as the main causes contributing to delays in services: the shortage of staff, uncertainty of instructions, unclear policies and procedures, lack of motivation and shortage of resources (spare parts, tools etc.). Indeed, shortage of staff was cited by 62.5% of the respondents as the main reason as to why overtime was frequently available. Table 11 presents the ranking of these factors.

Value	Percentage	No. of. Respondents naming this factor
Shortage of staff	85.7	6
Shortage of resources (spare parts, tools, etc.)	85.7	6
Unclear policy and procedure	57.1	4
Lack of motivation	28.6	2
Uncertainty about instructions	28.6	2

Table 11 Causes of delay in services

Reliability test

It is a good practice in statistical analysis to assess the reliability of the collected survey data by evaluating whether the scale of multiple Likert questions is reliable (Santos, 1999). This is done by determining the Cronbach's Alpha value (Pallant, 2007), which offers an indication of the internal consistency of the construct of the entire questionnaire. According to Devellis (1991), the calculated alpha value should be at least 0.6 for the data to be acceptable. Based on a selection of 65 maintenance management factors, a reliability test has been conducted and the calculated alpha value is found to be 0.863, which is well above the threshold value (Table 12).

Cronbach's Alpha	Cronbach's Alpha based on Standardized Items	No of factors
0.863	0.868	65

Table 12 The reliability test

Factor analysis

In the present study, 65 maintenance management factors/variables were initially identified. Principal Component Analysis (PCA) has been used to classify these variables in order to reduce them to a manageable number for detailed analysis. Only those factors/variables with an Eigenvalue of greater than 1 would be considered (Kim and Mueller, 1978) and the results are shown in Table 13. It can be seen that the first seven components accounted for 100% of the total variance. The results of an associated Scree test (Cattell, 1966) are shown in Figure 31. The test is a graphic method that helps to identify the principal components. As a result, 65 factors have been reduced to 7 principal components for further analysis.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	23.659	36.399	36.399	23.659	36.399	36.399	20.973	32.266	32.266
2	10.320	15.877	52.275	10.320	15.877	52.275	10.719	16.491	48.757
3	9.397	14.457	66.732	9.397	14.457	66.732	8.101	12.462	61.220
4	7.679	11.814	78.547	7.679	11.814	78.547	7.240	11.138	72.358
5	5.697	8.765	87.312	5.697	8.765	87.312	7.038	10.828	83.185
6	4.217	6.488	93.800	4.217	6.488	93.800	6.252	9.619	92.804
7	4.030	6.200	100.000	4.030	6.200	100.000	4.677	7.196	100.000

Table 13 Total variance explained

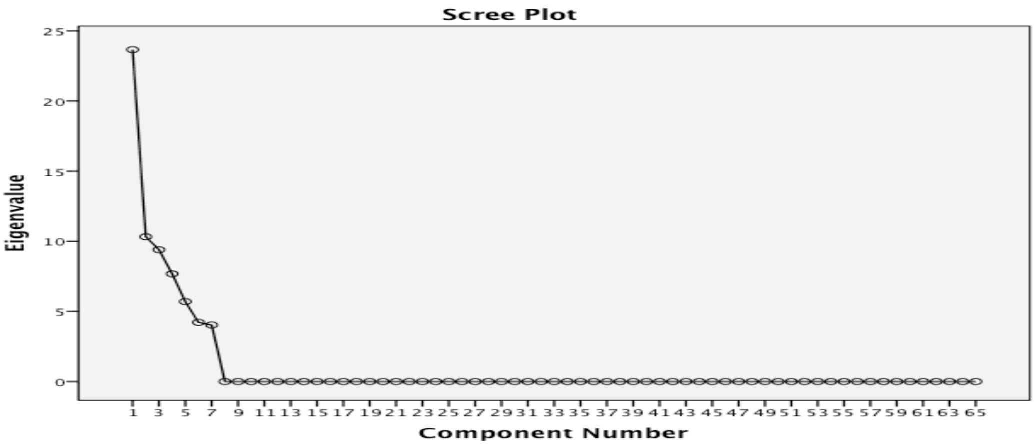


Figure 31 A Scree plot

In order to find out what each of the seven principal components represents, further analysis has been undertaken and the results are tabulated in Table 14. Only those variables with a correlation value of 0.4 (the threshold value) or greater are shown (Tabachnick and Fidell, 2001; Hair et al., 2006).

Take for example component 1, the first variable "Decision making authority within the department or team" has a correlation value of less than 0.4 so it is given a blank. The second variable "Including one or more employees in determining what to do, but final decision taken by the head" has a value of 0.494 so it is retained. Thus, component 1 contains a set of 19 variables. A name is then chosen for component 1 which has been labelled **Commitment of organization** (Table 15). Seven variables are associated with the second component, which has been labelled **Change management,** covering training in maintenance skills (Table 16). Eleven variables are associated with the third component, which has been labelled **Senior management support**, covering enhanced motivation, respect for maintenance, morale and the out sourcing of maintenance contracts (Table 17). Six variables are associated with the fourth component, which has been labelled **Organizational structure** (Table 18). Eleven variables are associated with the fifth component, which has been labelled **Maintenance strategy planning and communication** (Table 19). Six variables are associated with the sixth component, which has been labelled **Clarity of policies and procedures** (Table 20). Five items were found to be associated with the seventh component, which has been labelled **Employee qualifications** (Table 21).

Items/ Variables	Component						
	1	2	3	4	5	6	7
1-Decision making authority within the department or team						0.63	
2-Including one or more employees in determining what to do, but final decision taken by the head	0.494						
3-Voting for a major decision with my team			0.459				
4-Not considering suggestion made by my team		0.609					
5-Asking for employees' ideas and giving input on upcoming plans and projects					0.529		
6-Getting the approval of each individual or the majority in order to take a major decision					0.647		
7-Telling my employees what has to be done and how to do it						0.772	
8-Getting information by email, memos or voice mail					0.41		
9-Training staff when mistakes occur and making notes		0.869					
10-Allowing my employees to choose how to do their work				0.418			
11-Believing that workers know more than managers about their jobs and can carry out the decisions to do their job			0.621				
12-Delegating tasks to implement a new procedure or process	0.79						
13-Believing that employees can lead themselves just as well as their boss can			0.809				
14-Letting employees do their work as they think best			0.711				
15-Refusing to explain actions			0.75				
16-Encouraging the use of uniform procedures		0.858					
17-Getting enough support to complete the task	0.92						
18-Knowing the organization's strategy	0.85						
19-Understand the vision and mission of the organization				0.715			
20-Need to be supervised closely to complete the work		0.814					
21-Need to be supervised closely to perform satisfyingly		0.746					
22-Like to be part of the decision making process						0.809	
23-The boss letting subordinates solve the problems in complex situations						0.834	
24-Believing that leadership requires staying out of the way of subordinates as they do their work				0.769			
25-Improving the motivation by rewards and punishments		0.852					
26-Needing frequent supportive communication from one's boss					0.419		
27-Having complete freedom to solve a problem	0.85						
28-Having clear responsibilities and clear procedures						0.93	
29-Preferring to receive precise orders to little input from leader				0.54			
30-People protecting themselves above all else	0.68						
31-No encouragement of innovation					0.663		
32-No improvement of personal morale			0.45				
33-People being prepared to do anything to provide the best service to the patient	0.88						
34-Successful people who follow legal or professional standards						0.571	
35-Using my mistakes to attack me			0.425				
36-My supervisor blaming me so as to protect himself			0.814				
37-My supervisor letting me be blamed for his mistakes			0.63				
38-No training, so as to ensure failure							0.703
39-Supervisor encouraging discord in the team			0.611				
40-No training so as to prevent career advancement	0.722						
41-Help provided by organization if a special favour is needed	0.963						
42-Feeing proud of my work and organization amongst other people	0.653						
43-Recognizing good work	0.939						

44-Holding frequent meetings to discuss work problems with team				0.813			
45-Very little concern shown for staff			0.827				
46-Clear links between departments				0.506			
47-A clear path for advancement in the organizational structure				0.477			
48-Less emergency work and more scheduled work					0.479		
49-Clear maintenance timetables					0.744		
50-More long term than short term planning					0.818		
51-Overtime or covering other colleagues’ shifts because of staff shortages					0.43		
52-Availability of data	0.888						
53-Availability of emergency plans	0.532						
54-Budget limitations affecting job performance		0.504					
55-Different maintenance regimes are used at the same time					0.975		
56-Maintenance staff are suitably qualified							0.975
57-Maintenance staff have the skills to accomplish their task							0.406
58-There is cooperation between the members of the maintenance team	0.888						
59-There is quick support from other colleagues	0.686						
60-Current process meeting the organization's objectives	0.963						
61-Current processes leading to added value	0.782						
62-Current process reducing failure	0.882						
63-Current process reducing waste	0.871						
64-Having the capability and knowledge to do the work							0.724
65-Following safety procedures							0.655
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.[a]							
a. Rotation converged in 20 iterations.							

Table 14 Rotated component matrix

Variables	Score
2-Including one or more employees in determining what to do, but final decision taken by the head	0.494
12-Delegating tasks to implement a new procedure or process	0.79
17-Getting enough support to complete the task	0.92
18-Knowing the organization’s strategy	0.85
27-Having complete freedom to solve a problem	0.85
30-People protecting themselves above all else	0.68
33-People being prepared to do anything to provide the best service to the patient	0.88
40-No training so as to prevent career advancement	0.722
41-Help provided by organization if a special favour is needed	0.963
42-Feeing proud of my work and organization amongst other people	0.653
43-Recognizing good work	0.939
52-Availability of data	0.888
53-Availability of emergency plans	0.532
58-There is cooperation between the members of the maintenance team	0.888
59-There is quick support from other colleagues	0.686

60-Current process meeting the organization's objectives	0.963
61-Current processes leading to added value	0.782
62-Current process reducing failure	0.882
63-Current process reducing waste	0.871

Table 15 Commitment of organization-summary of principal factors analysis of PC1

Variables	Score
4-Not considering suggestion made by my team	0.609
9-Training staff when mistakes occur and making notes	0.869
16-Encouraging the use of uniform procedures	0.858
20-Need to be supervised closely to complete the work	0.814
21-Need to be supervised closely to perform satisfyingly	0.746
25-Improving the motivation by rewards and punishments	0.852
54-Budget limitations affecting job performance	0.504

Table 16 Change management-summary of principal factors analysis of PC2

Variables	Score
3-Voting for a major decision with my team	0.459
11-Believing that workers know more than managers about their jobs and can take and carry out the decisions about doing their job	0.621
13-Believing that employees can lead themselves just as well as their boss can	0.809
14-Letting employees do their work as they think best	0.711
15-Refusing to explain actions	0.75
32-No improvement of personal morale	0.45
35-Using my mistakes to attack me	0.425
36-My supervisor blaming me so as to protect himself	0.814
37-My supervisor letting me be blamed for his mistakes	0.63
39-Supervisor encouraging discord in the team	0.611
45-Very little concern shown for staff	0.827

Table 17 Senior management support-summary of principal factors analysis of PC3

Items/ Variables	Score
19-Understand the vision and mission of the organization	0.715
24-Believing that leadership requires staying out of the way of subordinates as they do their work	0.769
29-Preferring to receive precise orders to little input from leader	0.54
44-Holding frequent meetings to discuss work problems with team	0.813
46-Clear links between departments	0.506
47-A clear path for advancement in the organizational structure	0.477

Table 18 Organizational structure-summary of principal factors analysis of PC4

Items/ Variables	Score
5-Asking for employees' ideas and giving input on upcoming plans and projects	0.529
6-Getting the approval of each individual or the majority in order to take a major decision	0.647
8-Getting information by email, memos or voice mail	0.41
10-Allowing my employees to choose how to do their work	0.418
26-Needing frequent supportive communication from one's boss	0.419
31-No encouragement of innovation	0.663
48-Less emergency work and more scheduled work	0.479
49-Clear maintenance timetables	0.744
50-More long term than short term planning	0.818
51-Overtime or covering other colleagues' shifts because of staff shortages	0.43
55-Different maintenance regimes are used at the same time	0.975

Table 19 Maintenance strategy planning and communication-summary of principal factors analysis of PC5

Items/ Variables	Score
1-Decision making authority within the department or team	0.63
7-Telling my employees what has to be done and how to do it	0.772
22-Like to be part of the decision making process	0.809
23-The boss letting subordinates solve the problems in complex situations	0.834
28-Having clear responsibilities and clear procedures	0.93
34-Successful people who follow legal or professional standards	0.571

Table 20 Clarity of policies and procedures-summary of principal factors analysis of PC6

Items/ Variables	Score
38-No training, so as to ensure failure	0.703
56-Maintenance staff are suitably qualified	0.975
57-Maintenance staff have the skills to accomplish their task	0.406
64-Having the capability and knowledge to do the work	0.742
65-Following safety procedures	0.665

Table 21 Employee qualifications-summary of principal factors analysis of PC7

Critical Success Factors (CSFs) and Key Performance Indicators (KPIs)

CSFs and KPIs are often used interchangeably, but they are in fact representing different concepts. CSFs are the causes contributing to an organization's success, while KPIs measure the effects/outcomes of the organization's actions.

5.3.1 Critical success factors

To the best of the author's knowledge, the concept of Critical Success Factors (CSFs) has not been widely applied to maintenance management in the healthcare industry. Indeed, Mohammed et al. (2014) suggested that most of the current studies in the healthcare sector tend to focus mainly on quality management and related topics.

The seven principal components identified from the factor analysis have broken down into 17 critical success factors (Table 22), so that their relative importance to maintenance employees and their work can be investigated further.

Components	Critical Success Factor
1- Commitment of organization	1-Attention to the mental well-being and staff morale 2-The existence of frequent training programmes 3-The need to respect the efforts of maintenance workers
2-Change management	4-Good modern information systems 5-Good performance management indicators 6-Need to pay attention to change management
3-Organizational structure	7-A well organized structure
4-Senior management support	8-Top management support 9-Achieving customer satisfaction 10-A good motivation system
5-Clarity of policies and procedures	11-Clarity of policies and procedures 12-Clear maintenance contracts
6-Maintenance strategy	13-A maintenance strategy compatible with the organization's goals. 14-Promoting teamwork and sharing information and experiences 15-Limit out-sourcing of maintenance work
7-Employess qualifications	16-Employees working according to their qualifications and job descriptions 17-Recruiting employees with high technical skills

Table 22 Breakdown of 7 principal components into 17 CSFs

By determining their Relative Impotence Index (RII), the 17 CSFs have been ranked based on the views expressed by 8 selected employees at RMH who participated in the interviews and the results are tabulated in Table 23. The RII is calculated by means of the following formula (Kometa et al., 1994).

$$RII=\sum W/(A*N)$$

Where RII is the relative importance index; W is the weighting given to each factor by respondents (ranging from 0 to 4); A is the highest weight (i.e. 4 in this case); and N is the total number of respondents. The RII has a range of 0 to 1 with 1 being the most important.

Rank	**Factor**	**RII**
1	Clarity of policies and procedures	0.975
2	Senior management support	0.95
3	A well organized structure	0.925
	Having employees with high technical skills	0.925
5	The clarity of the maintenance contract	0.9
6	The existence of frequent training programmes	0.875
7	Promoting teamwork and sharing of information and experiences	0.875
8	Maintenance strategies compatible with the organization's goals.	0.85
9	Employees working according to their qualifications and job descriptions	0.825
10	Good performance management indicators	0.825
11	A good motivation system	0.825
12	The need to respect the efforts of maintenance workers	0.775
13	Achieving customer satisfaction	0.775
14	Attention to the mental well-being of staff and their morale	0.75
15	Need to pay attention to change management	0.725
16	Good modern information systems	0.725
17	Limit out-sourcing of maintenance work	0.575

Table 23 Ranking of critical success factors

It can be seen that clear policies and procedures, senior management support and organizational structure are the top 3 factors critical to the success in the running of a hospital. The fourth factors are technical knowledge and skills of employees.

5.3.2 Key performance indicators (KPIs)

One of the fundamental building blocks of TQM is said to be performance management, which is widely implemented in many organizations particularly multinational companies. Headline grabbing performance measures tend to focus on cost accounting information including earnings, profit and improvement on shareholder value. There is little emphasis on working environment, employee and customer satisfaction.

Based on the results presented earlier, 34 performance indicators (PIs) have initially been identified at the case study hospital RMH (Table 24).

No	Process	Performance indicators (PIs)
1	Dockets	Number of complaints received
2	Dockets	Number of corrective maintenance work
3	Dockets	Number of Preventive maintenance work
4	Financial	Total Maintenance costs per month = labour cost + overtime cost
5	Identify critical equipment	State of the equipment (new/medium/old)
6	Process	Feedback received (yes/no)
7	Motivation	Maintenance staff's behaviour (good/ normal/ bad)
8	Resources	Outsourcing used
9	Dockets	Average number of days open of maintenance requests
10	Dockets	Average overdue time of maintenance requests
11	Contract, financial and process	Maintenance efficiency: Maintenance man-hours including maintenance wages, staff and contractor hours (for preventive and corrective maintenance)
12	Process	Recurring maintenance problems
13	Dockets	Mean time to repair (MTTR)
14	Dockets	Mean time to failure (MTTF)
15	Recourses	% Equipment availability (bed availability KPI)
16	Process	Response time
17	Financial	Overtime hours
18	Dockets	% Preventive maintenance tasks completed by due date
19	Process	Corrective actions right first time
20	Contactor (purchasing)	Time of delivery of spare parts
21	Financial	Total corrective maintenance costs
22	Financial	Total preventive maintenance costs
23	Dockets	% Neglected maintenance requests
24	Dockets	% Incorrectly assigned maintenance requests
25	Dockets	% Escalated maintenance requests
26	Dockets	Average duration of closure due to maintenance requests
27	P.M. process	Ratio of corrective maintenance to preventive maintenance time
28	Dockets	Maintenance requests with 'Delayed' status due to unavailability of services as % of maintenance requests with 'Delayed' status
29	Dockets	% of maintenance requests remaining in 'Requested' status
30	Dockets	Average overdue time of maintenance requests % Maintenance requests with 'Delayed' status due to unavailability of resources
31	Dockets	% Maintenance requests with 'Delayed' status due to unavailability of manpower
32	Dockets	% Maintenance requests with 'Delayed' status due to unavailability of equipment
33	Dockets	% Maintenance requests with 'Delayed' status due to unavailability of services
34	Dockets	Ratio of corrective maintenance to preventive maintenance

Table 24 Performance indicators for RMH

These in turn allow key performance indicators (KPIs) to be identified by grouping similar processes in a single category. For example, the number of complaints received (item 1), corrective maintenance (item 2) and preventive maintenance (item 3) among others can be grouped under the heading "dockets performance". In this way, 34 PIs have been reduced to 6 KPIs (Dockets, Financial, Critical equipment, Process, Resources and Contractors efficiency) for further investigation.

5.4 Focus group meeting: discussion of potential barriers to maintenance activities

A meeting was held with four lead engineers and one supervisor in June 2013, to review the current practices of the Technical Department at RMH and to seek elaboration on some of the issues highlighted in the survey of maintenance workers. At the start of the meeting, the participants mostly agreed that the present maintenance operations were less than satisfactory, felt unease with the working environment and there was little incentive to encourage innovation. Participant 1 said that the processes were unclear and instructions were often informal, but they had to be followed whether the instructions were correct or not. There was little morale support if instructions were to result in further complication or unfavourable comments from other departments. Moreover, the programme director often gave staff informal instructions without prior knowledge of the head of the Technical Department. The challenges to completing their work professionally are two-fold, according to the views expressed by participant 2: the lack of planning (including scheduling) for new projects and the lack of technical knowledge and skills of some of the existing staff. It was also suggested that the pressure on maintenance staff could be reduced through better planning and coordination of new projects. For example, the work for a new complex project could be scheduled over 2 to 3 years with a clearly defined set of activities. Participant 3 suggested devising a proper action plan to replace older and ineffective equipment and its inclusion in the hospital's short-to-medium term procurement strategies. However, participant 4 indicated that separate lists of new equipment requests have already been prepared and submitted by the individual lead engineers for consideration by the hospital management. There appeared to be an apparent lack of communication and coordination between the lead engineers when prioritising their needs. All participants concurred that the software package CMMS (Computer maintenance management system) used by contractors to create 'dockets' is in urgent need of updating.

5.4.1 Theory of Constraint (TOC)

The data gathered by the survey has been critically reviewed in light of the information emerged from interviews, group meetings and observations. The main purpose is to identify potential constraints/barriers to maintenance operations at the case study hospital RHM.

The Current Reality Tree (CRT)

The costs of running maintenance operations at RMH between 2010 and 2013 are summarised in Table 25 averaging about SR 20 million per year. One of the challenges is to find means of delivering a similar level of services while maintaining an acceptable level of quality and reliability despite growing demands. This is where the application of CRT may help.

Period	Manpower cost SR	Reimbursable cost SR	Petty Cash SR	Total
June 2010 to July 2011	10,319,839.73	8,997,843.93	155,378.92	19,473,062.58
June 2011 to July 2012	10,284,081.07	10,497,051.38	179,725.61	20,960,858.06
June 2012 to July 2013	10,229,930.29	11,246,173.36	328,625.20	21,804,728.85

Table 25 Maintenance operation cost for RMH

Based on the analysis of the data/information collected, the first step is to identify a set of maintenance-related issues which could have an impact on the maintenance performance at the case study hospital RHM. These are listed below.

1. Lack of spare parts
2. High prices of spare parts
3. Technicians do not have the ability to get the job done professionally
4. Delay in completing the work
5. Repeated breakdowns
6. Lack of support from supervisors
7. Old equipment and devices
8. Lack of modern technology
9. Accumulation of faults
10. Awarding projects to contractors who may not have the appropriate experience to complete the work as required
11. Lack of cooperation between technicians and supervisors
12. Frequent overtime
13. Lack of motivation to finish the work
14. Lack of encouragement for innovation
15. Lack of consideration for on-the-job training
16. Lack of a clear plan of maintenance related activities
17. No specialized and technical courses
18. Poor personal relationship
19. Lack of commitment
20. Easy to break procedures

21. Poor quality of spare parts
22. Not following the manufacturer's recommendations in the periodic maintenance and use of spare parts
23. Length of time taken to process a complaint
24. Level of authorization
25. Poor documentation
26. Lack of transparency
27. Level of access
28. Dissatisfied employees
29. Do not have maintenance logbooks for equipment
30. Not able to easily identify a fault before occurs
31. Lack of uniformity in maintenance strategy
32. Absence of historical data
33. Non-availability of specialist tools
34. Poor mapping of maintenance strategy with hospital vision

As a second step in the creation of a Current Reality Tree (CRT), hospitals engineers were asked to reflect on their past experience on maintenance operations. They were then asked to select 17 items from the list above, which they considered to have the most undesirable effects (UDEs) on their work. The results are as the follows:

UDE 1 Lack of spare parts

UDE 2 High prices of spare parts

UDE 3 Technicians do not have the ability to get the job done professionally

UDE 4 Delays in completing the work

UDE 5 Repeated breakdowns

UDE 6 Lack of a clear plan of maintenance related activities

UDE 7 Old equipment and devices

UDE 8 Lack of commitment

UDE 9 Accumulation of faults

UDE 10 Delay in work which affects the performance of other departments

UDE 11 Awarding projects to contractors who may not have the appropriate experience to complete the work as required

UDE 12 Lack of cooperation between technicians and supervisors

UDE 13 Frequent overtime

UDE 14 Lack of motivation to finish the work

UDE 15 Lack of encouragement of innovation

UDE 16 Lack of consideration for on-the-job training

UDE 17 Poor quality of spare parts

The third step involves the schematic representation of the cause-effect-cause relationships that exist among the listed UDEs, which are often referred to as the 'pertinent entities' in publications. The schematic diagram is known as the Current Reality Tree (CRT). There are two types of connections (or relationships) between known UDEs in a CRT: a linear connection (one entity links to another entity) or an and–connection (a number of entities linking to a single entity, represented by an ellipse). Figure 32 shows the current reality tree for the present study.

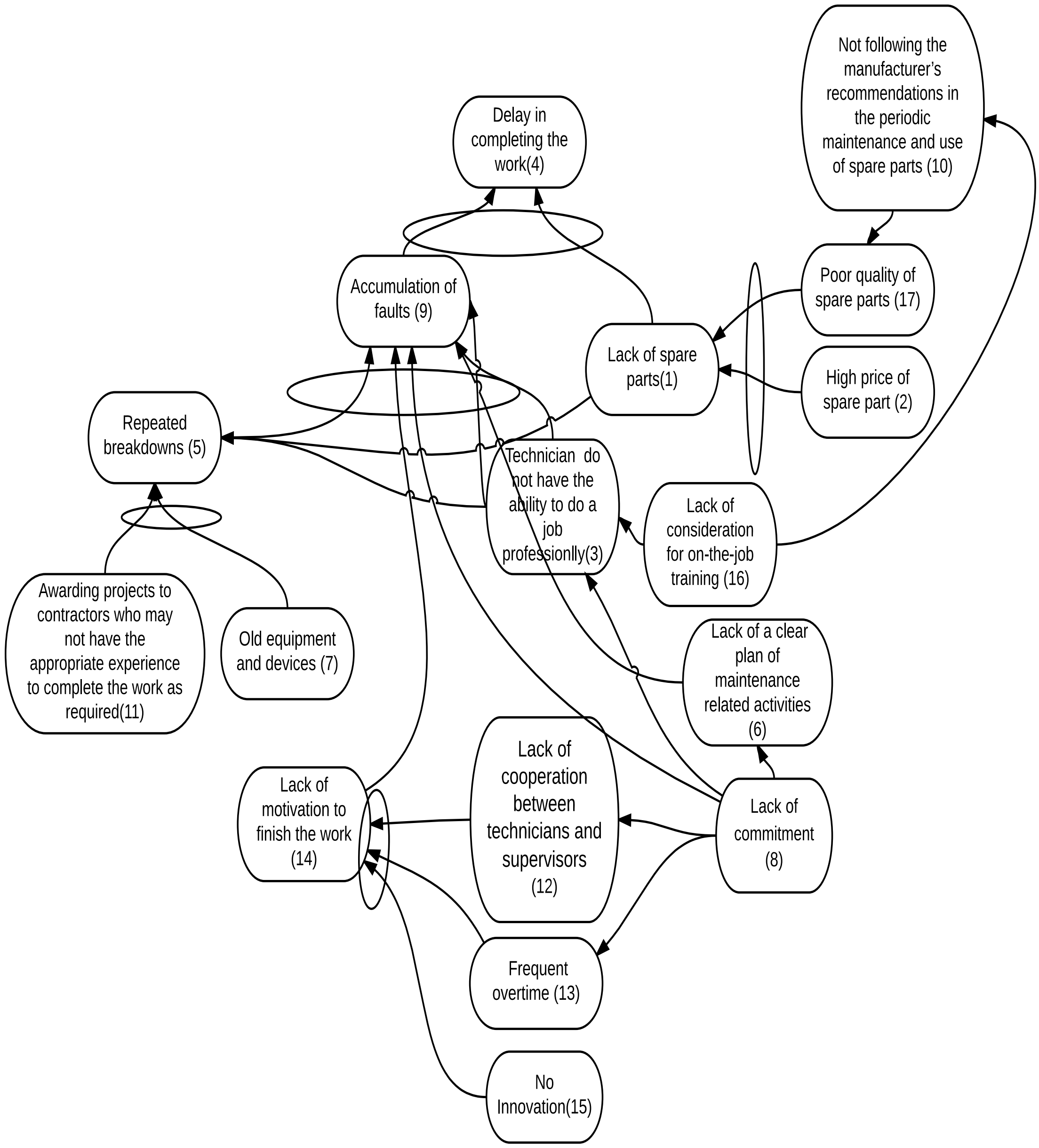


Figure 32 A current reality tree for the present study

The interpretation of a problem in a CRT is as follows. Take "Accumulation of faults" (UDE 9) as an example which is highlighted by the yellow arrow (Figure 33), this entity is influenced by 5 other entities (as indicated by 5 incoming or feeding arrows) and an and-connection is said to exist. The five feeding entities are "Technician do not have the ability to do a job professionally" (UDE 3), "Repeated breakdowns" (UDE 5), "Lack of a clear plan of maintenance related activities" (UDE 6), "Lack of commitment" (UDE 8) and "Lack of motivation to finish the work" (UDE 14). The interpretation of the specified and-connection is as follows. **If** "technician do not have the ability to do a job professionally, repeated breakdowns, lack of a clear plan of maintenance related activities, lack of commitment, and lack of motivation to finish the work", **then** "faults will be accumulated".

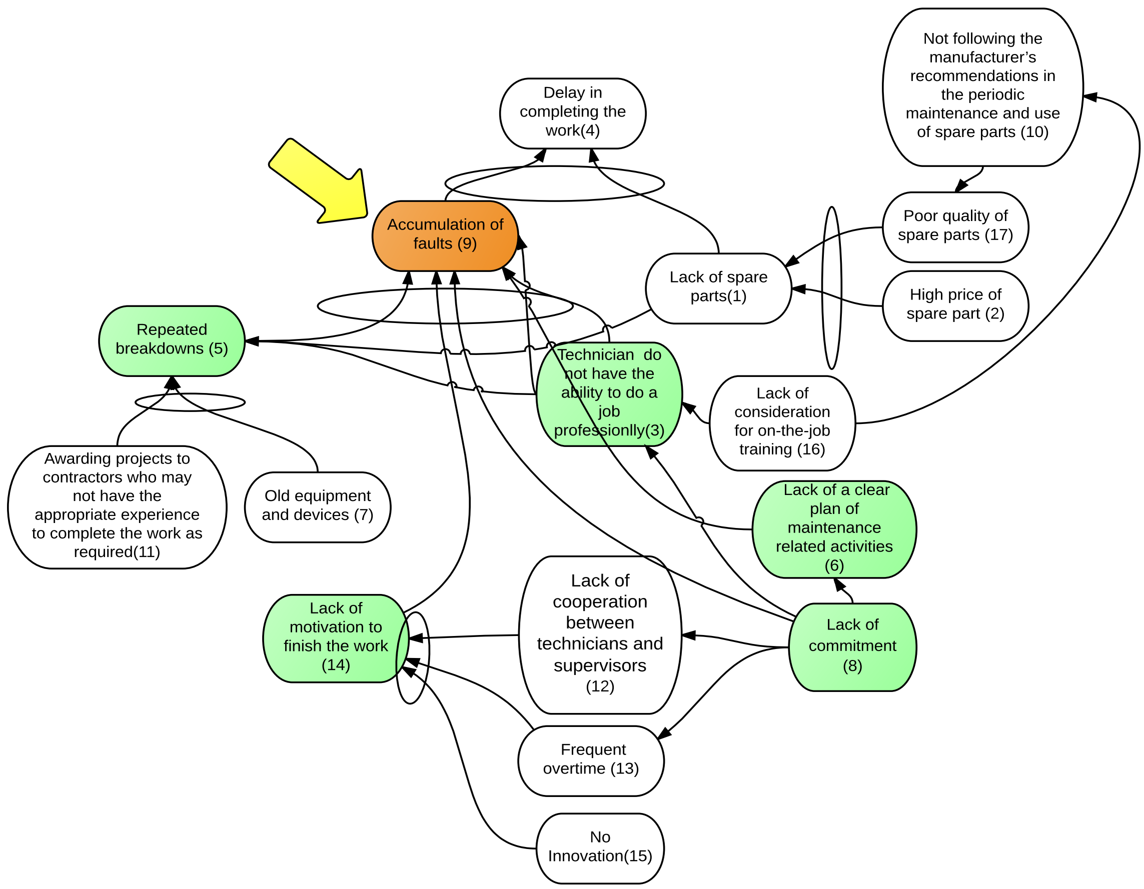


Figure 33 Illustration of an and-connection in a CRT

With the establishment of a CRT, the root causes of a problem can be identified by using a method known as the 'so what?' test (Scheinkopf, 1999). The test helps to distinguish between pertinent and non-pertinent UDEs (or entities). In the present study, the result of the survey and subsequent interviews suggested that the following six root causes could adversely affect the maintenance management programme at RMH:

UDE1 Lack of spare parts

UDE3 Technicians do not have the ability to get the job done professionally

UDE8 Lack of commitment

UDE 9 Accumulation of faults

UDE 11 Awarding projects to contractors who may not have the appropriate experience to complete the work as required

UDE14 Lack of motivation to finish work

These UDEs appeared to have prevented the Maintenance Department from performing well and they would be used to inform the changes to be made to the current maintenance procedures to be detailed in Chapter 6.

5.4.2 A spaghetti diagram

Unplanned movement of workers within an organization is considered as unproductive time that can increase the overheads. A spaghetti diagram is a graphical method that permits the study of the movement of workers within the physical layout of a facility (Allen, 2010). By computing the total travel distance (TTD) that a maintenance worker has to cover between locations within the hospital compound, the present study sought to identify any unproductive maintenance time and associated travel costs. The hospital compound is divided into three zones, namely Zone 100, Zone 109 and Zone 111 and each zone has its own workshop. Figure 34 shows a spaghetti diagram tracking the movement of technicians between the workshops of the three zones and the spare part warehouse. The distance is approximately 360m one way and the travel time by foot takes 30 minutes on average. It is not uncommon that a technician visited the warehouse only to find that the required spare parts were out of stock. The current hospital policy requires all spare parts to be stored centrally to minimize misplacement of parts and theft by employees. Therefore, the introduction of an appropriate inventory management system is likely to alleviate the problem associated with stock control.

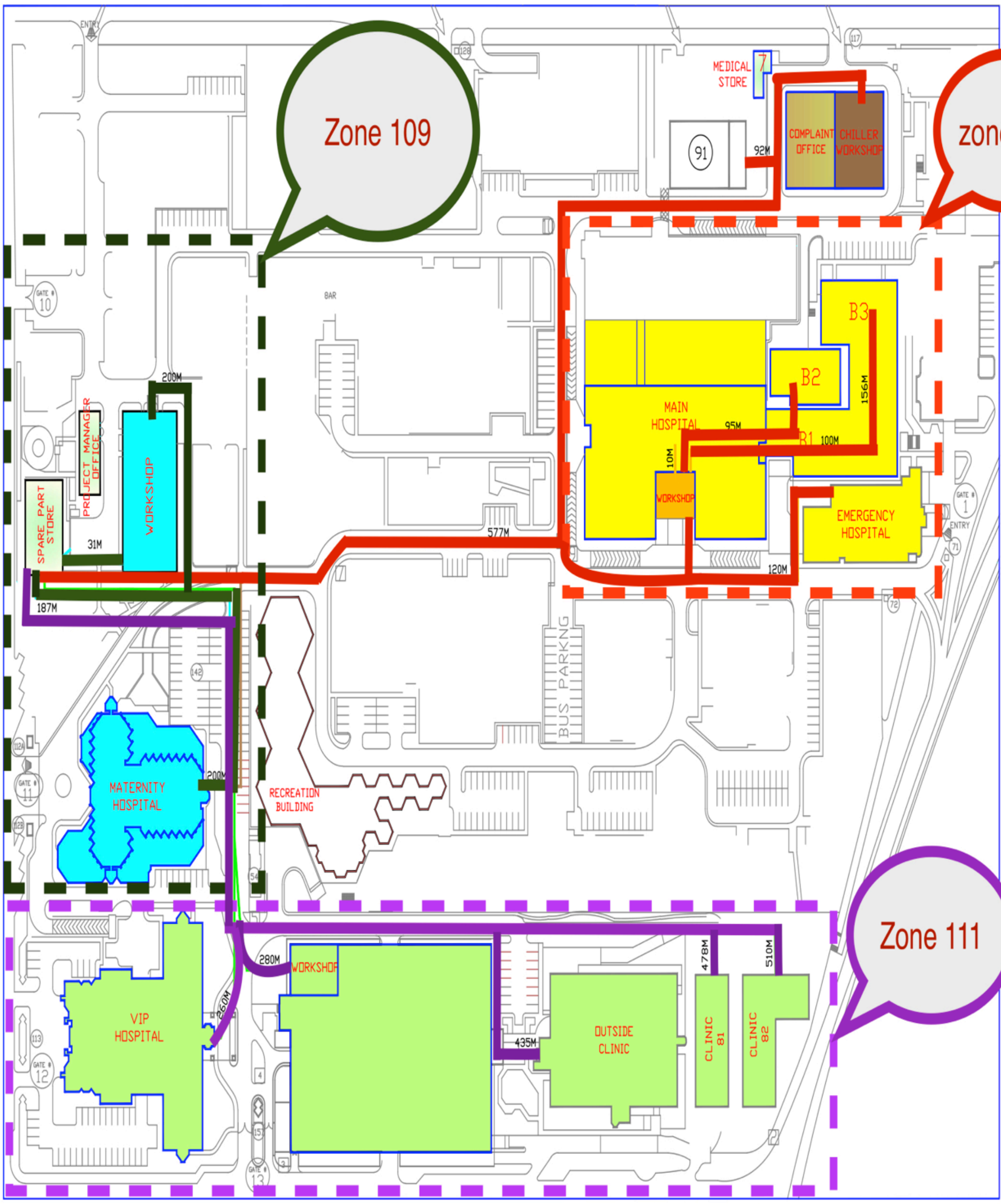


Figure 34 Three zones of the RMH hospital compound and a typical spaghetti diagram

Location A	Location B	Distance (m)	Travel time (minutes)
Current maintenance workshop to	Zone B109	200	19
	Zone B111	230	22
	Zone B100	360	30

Table 26   Distances between the current Maintenance workshop and other locations, and associated travel times

Table 26 shows some of the distances between key locations within the hospital compound and the associated travel times. Assuming a complaint originated in Building 109, a typical procedure to be followed by a maintenance technician based in the main workshop is as follows. Upon receipt of instructions, the technician investigates the complaint in Building 109. He returns to the base to brief his supervisor and to obtain authorisation. He then collects the required items from the store and goes back to Building 109 to fix the fault. The total estimated travel time is about 19 minutes (Figure 34).

It became apparent during meetings with engineers and technicians that unproductive travel time could be reduced if the main workshop were to be relocated closer to the centre of the hospital compound. Taking into account the issues identified by the analysis of the Current Reality Tree for maintenance management at RMH, it was suggested that a workable solution would be to locate the new maintenance workshop in Building 32 (Figure 35).

Table 27 shows the estimated travel distances and times between the proposed new maintenance workshop in Building 32 and the three key locations, namely B109, B111 and B100. The corresponding estimated reductions in travel times are 38% to Zone 109, 42% to Zone 111 and 11% to Zone 100. The potential time saving is expected to allow better utilisation of maintenance resources.

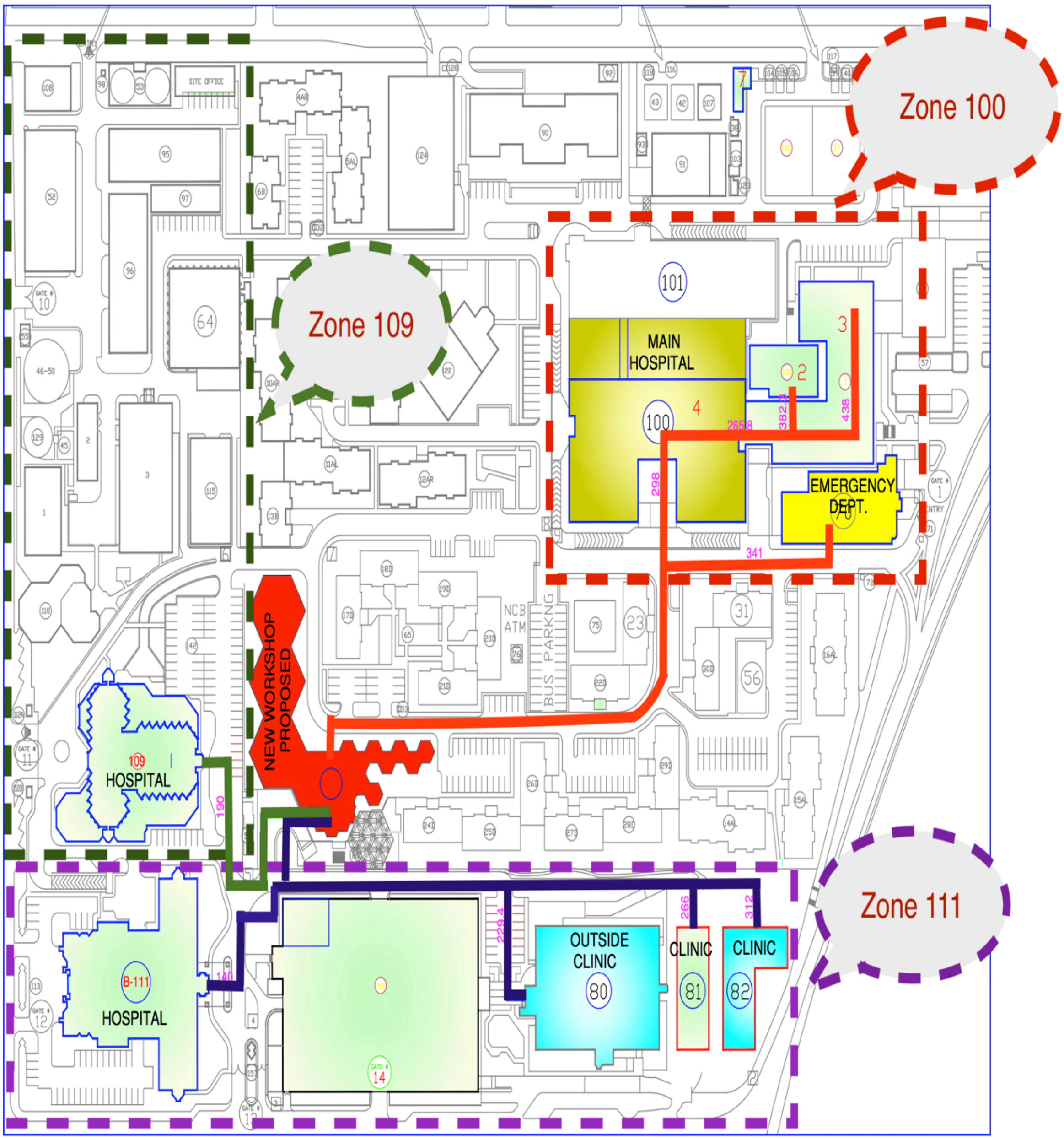


Figure 35 The proposed location of a new maintenance workshop in Building 32

Location A	Location B	Distance (m)	Travel time (minutes)
Proposed new workshop in Building 32	Zone B109	130	12
	Zone B111	143	13
	Zone B100	298	30

Table 27 Distances between the proposed new maintenance workshop in Building 32 and other locations, and associated travel times

5.5 Concluding remarks

The responses to the questionnaire surveys are generally good except for one target group of participants–'the helpers'. It is disappointing to note that none of the helpers responded to any of the questions asked. On further investigation, it became apparent that low literacy level was an issue. They were also 'afraid' of making their views known for job security reasons. While their information is valuable to provide a bigger picture of the events, its likely impact on the validity of the results is minimal as the helpers represented only a small percentage of the sample. With the benefits of hindsight, informal interviews might be better suited to collecting information from workers where literacy and/or cultural background might be an issue.

To facilitate data collection, two visits were made to the case study hospital (Riyadh Military Hospital (RMH)) each lasting for 4 months. With the cooperation of the hospital management, contractors and workers, the level of engagement of participants in the data collection process is considered adequate to enable prevailing maintenance management issues to be identified and their impact on current operations to be assessed. The fact that the author worked at RMH for 11 years as a maintenance engineer also helped to offer reassurance to the stakeholders by addressing some of the concerns raised including confidentiality and data protection.

Review of the current maintenance operations at RMH appears to suggest that the Maintenance Department might not have been given adequate support by the hospital management. One of the main reasons cited by employees was that the maintenance function was seen as a cost centre and other 'high profile' areas including reducing patients' waiting time, and the purchasing of medical equipment and medicines had been given higher priority by the management. Based on the most recent data provided by the hospital, it is estimated that maintenance, energy and cleaning accounted for about 30% of the hospital's operating costs in year 2013. Engineering services provided by the hospital including continuity of electricity supply, air conditioning and general environmental conditions. These services can have a direct impact on the quality of services provided to patients and the well-being of hospital staff and visitors.

The information collected from staff appears to suggest that some maintenance activities are chosen based on personal preferences with no proper risk assessment and documentation. In a few cases, there is evidence to indicate that either the workers did not understand the procedures to be followed or chose to ignore them. There is evidence of good maintenance practices although these have not been adequately assimilated by the management or shared among technicians. The main factors contributing to the realization of a successful maintenance management system have been identified as follows: support of senior management; effective organizational culture; leadership; clear roles and responsibilities; and commitment of workers. There are also other contributing factors including policies and procedures, training, teamwork and preventive maintenance. In the context of delivery of medical services in a hospital environment, reliability and availability of equipment are two additional but equally important factors when prioritizing maintenance activities.

Data has been analyzed using a range of techniques: the SPSS to identify potential correlations between variables and to reduce the number of factors to a manageable size for further analysis; thematic coding to identify themes for the determination of critical success factors in the maintenance management system; theory of constraints to identify potential barriers that prevent maintenance management of achieving higher levels of services; spaghetti diagrams to identify areas of unproductive times which could be minimized.

Indeed, the theory of constraints (TOC) could be used to help management recognize the importance of having a clear strategy for the Maintenance Department that is compatible with the organization's business strategy.

The correlation analysis is useful to identity potential relationships (either positive or negative) between selected variables. The present results confirm the general observations made by previous studies with respect to maintenance management in engineering and related industries, but not in areas directly related to the healthcare sector. For example, the ability of a maintenance worker to discharge his role professionally depends on the type of training received, clarity of maintenance strategy, cooperation between the stakeholders (operator, technician and supervisor), availability of spare parts, tools and historic information. The data also suggests that the following factors would make a worker happier: management support; promotion; undertake corrective rather than preventive maintenance; and access to drawings, catalogues and logbooks.

Given the organization is a hospital with its sensitivity to unfavourable publicity, it is surprising to learn that some equipment was allowed to run even with known faults.

Shortage of spare parts and lack of relevant maintenance expertise were cited as the main reasons as to why little or no actions have been taken.

For practical and economic reasons, a substantial amount of maintenance work at RMH is outsourced to contractors who often do not have enough suitably qualified workers. The shortfall has resulted in a relatively high level of overtime work by in-house technician staff with additional expenditure incurred by the hospital. Informal discussions revealed that some migrant workers were apparently not happy with their work or the working environment, but were reluctant to voice their concerns to the relevant management/authority fearful of becoming a target of complaints.

By means of Principal Component Analysis, 7 key maintenance management issues have been identified, which in turn allowed the formation of 17 critical success factors for detailed analysis of prevailing maintenance management issues at the Maintenance Department of RMH. It is found that "clear policies and procedures", "senior management support", "organizational structure", and "technical knowledge and skills" are the top 4 factors critical to the successful running of maintenance operations at RMH.

The study also examined the factors that could have a negative impact on maintenance management at RMH. By using the Theory of Constraints (TOC) and Critical Reality Tree (CRT), six negative factors have been identified: lack of spare parts; technicians do not have the ability to get the job done professionally; lack of commitment; accumulation of faults; awarding projects to contractors who may not have the appropriate experience to complete the work as required; and lack of motivation to finish work. These negative factors appeared to have prevented the Maintenance Department from offering higher levels of services.

Informed by the 'lessons' learned from the literature review and the outcomes of the analyzed data/information, the next chapter will detail the development of a new maintenance management framework for the healthcare industry. The appropriateness of the framework for implementation in Saudi Arabia will be assessed through changes made to the maintenance procedures at the case study hospital RMH. These changes are considered necessary to minimize the impact of some of the identified negative factors. Furthermore, attempts have also been made to reduce/eliminate some of the non value-added activities.

Chapter 6 Development of a healthcare maintenance management framework and its implementation at the case study hospital RMH.

6.1 Chapter Overview

The results presented in the previous chapter highlighted a number of management issues which inadvertently affected the proper functioning of the current maintenance processes. These identified issues appeared to have adversely impacted on the delivery of healthcare at the case study hospital RHM and a substantial revision to the current maintenance procedures is deemed necessary. Informed by the knowledge gained from the secondary research, this chapter details the development of a new maintenance management framework for the healthcare industry in Saudi Arabia. The changes to be made to the current maintenance procedures are guided by the new healthcare framework and are intended to meet three key requirements: low investment cost, high impact on maintenance operations and easy to implement. The validity of the revised maintenance procedures has been investigated using limited field studies.

6.2 Current maintenance procedures

The Facilities Department supervises maintenance work undertaken by contractors/companies, which provide expertise in the operation and maintenance of the hospital's facilities. A contractor normally consists of a project manager with an administration team and four lead engineers covering mechanical, electrical, civil and equipment. A maintenance team is led by an engineer who is supported by a team of supervisors, technicians and helpers. Approximately 520 contractor staff are currently working in the case study hospital RMH.

There are three ways that the Maintenance Department can respond to customer requests:

1. Complete a 'complaint' form, get it signed by the Head of Department concerned and send it to the Maintenance Department. A copy of this form is given to the 'customer'.
2. Contact the secretary to the Hospital Engineer responsible for the area where the complaint is associated.
3. In case of an emergency, contact the relevant Hospital Engineer directly, either by phone or a mobile device, called a 'bleep'.

The current maintenance procedures are summarised in a flowchart (Figure 36).

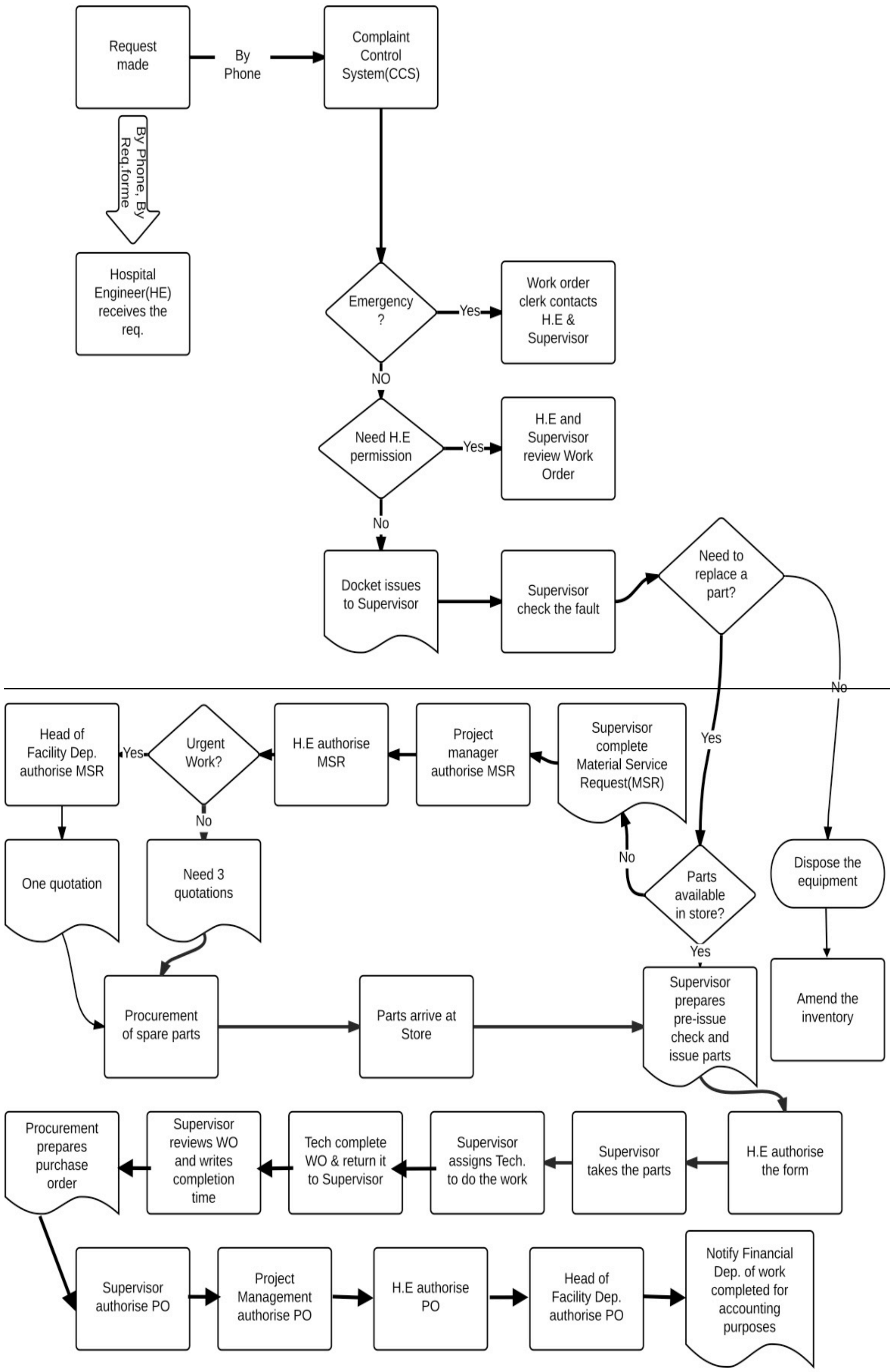


Figure 36 Flowchart of the current maintenance procedures at RMH

6.2.1 Determination of current maintenance information flow

When the Maintenance Department receives a ‘complaint’ (or a request), a docket is issued to the supervisor who is responsible for the area concerned. A member of the maintenance team is then dispatched and the complaint investigated. The faulty equipment is either repaired on site or the team supervisor is notified of the nature of the unresolved complaint. Further actions will be initiated until the complaint has been resolved satisfactory. In the case where a repair needs spare parts, there are two possible outcomes. If the parts are available at the store, the supervisor completes a pre-issue check form, get it endorsed by the project manager and the hospital engineer. If the parts are not available at the store, the supervisor has to complete a Material Request Service (MSR) form. After authorisation by the project manager and the hospital engineer, the completed MSR is submitted to the Maintenance Purchasing Department. The processing of a MSR normally requires quotations from 3 different suppliers, except in the case of an emergency when only one quotation is required. When the spare parts arrive, the Maintenance Purchasing Department will complete an appropriate Purchase Order (PO) for processing by the Hospital Financial Department. In cases where a fault cannot be rectified in a cost effective manner, a rejection form is issued and a replacement order is filed to the relevant Head of Department for authorization. The procedure for sourcing the replacement equipment is similar to sourcing spare parts.

6.2.2 Times and costs associated with current maintenance information flow

Attempts have been made to obtain estimates of the overheads associated with the current maintenance management processes, from the initiation of a complaint until it has been resolved satisfactorily. There are typically eight key stages involved covering docket issue, complaint office, related department, check work, time to start, repair time, close docket and request to Financial Department. A typical information flow is indicated by the flow of ‘red’ arrows in Figure 37. Table 28 shows the corresponding processing times and costs associated with the individual activities assuming spare parts are needed. The author collected the data during site visits to the case study hospital between June and September 2014.

It can be seen in this example that the maintenance request involving the requisition of spare parts could take approximately 288 minutes to complete from start to finish, with an estimated cost of £81.75.

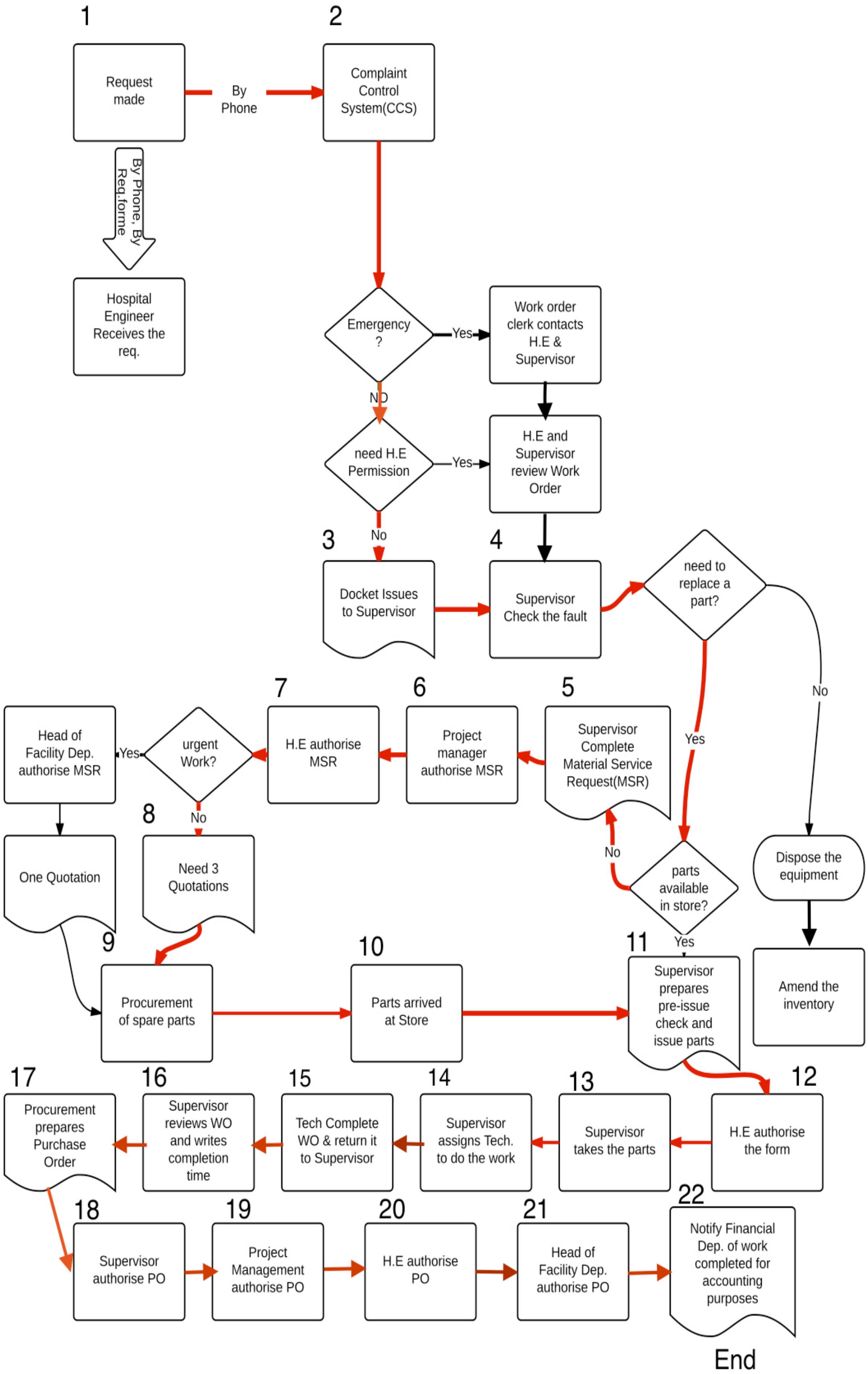


Figure 37 A typical maintenance information flow

Step	Activity	Average processing time (min.)	Man-Hours	Average cost @ £17/ hour
T1	Compliant was made	7.5	0.12	2.08
T2	Complaint control system receive a request	3.0	0.05	0.95
T3	Hospital engineer receives the request	n/a	n/a	n/a
T4	Work order Clerk contact H.E & Supervisor	n/a	n/a	n/a
T5	Hospital Engineer supervisor review work order	n/a	n/a	n/a
T6	Docket issue to Supervisor	2.0	0.03	0.60
T7	Supervisor check the fault	7.5	0.12	2.08
T8	Dispose the equipment	n/a	n/a	n/a
T9	Amend the inventory	n/a	n/a	n/a
T10	Supervisor full Material Service Request form (MSR)	6.5	0.10	1.84
T11	Project manager sings MSR	5	0.08	1.42
T12	H.E authorize MSR	20	0.33	5.67
T13	Head of facility Dep. Sings MSR	n/a	n/a	n/a
T14	Need One quotation	n/a	n/a	n/a
T15	Need Three quotations	25	0.4	7.08
T16	Procurement orders parts	17	0.28	4.82
T17	Parts arrives at store	23	0.38	6.52
T18	Supervisor full pre-issue Form check to take the part from store.	8	0.13	2.27
T19	H.E authorize the Form	20	0.33	5.67
T20	Supervisor takes the part	25	0.41	7.08
T21	Supervisor assigns a tech. to do the job	19	0.32	5.38
T22	Technician complete WO and return it to Supervisor	17	0.28	4.82
T23	Supervisor review WO and close the docket	9.5	0.16	2.67
T24	Procurement prepares Purchase Order (PO)	22	0.37	6.23
T25	Supervisor authorize PO	6.5	0.11	1.84
T26	Project manager sings PO	5	0.08	1.42
T27	H.E authorize PO	20	0.33	5.67
T28	Head of facility Dep. authorize PO	20	0.33	5.67
Total		288	**4.80**	**81.75**

Table 28 Estimated times and costs associated with the individual activities following the ‘red’ arrows from start to finish in Figure 37

6.3 Identified maintenance–related issues

The investigation has revealed a large number of issues (see also section 5.4.1), which are reproduced below.

1. Lack of spare parts
2. High prices of spare parts
3. Technicians do not have the ability to get the job done professionally
4. Delay in completing the work
5. Repeated breakdowns
6. Lack of support from supervisors
7. Old equipment and devices
8. Lack of modern technology
9. Accumulation of faults
10. Awarding projects to contractors who may not have the appropriate experience to complete the work as required
11. Lack of cooperation between technicians and supervisors
12. Frequent overtime
13. Lack of motivation to finish the work
14. Lack of encouragement for innovation
15. Lack of consideration for on-the-job training
16. Lack of a clear plan of maintenance related activities
17. No specialized and technical courses
18. Poor personal relationship
19. Lack of commitment
20. Easy to break procedures
21. Poor quality of spare parts
22. Not following the manufacturer's recommendations in the periodic maintenance and use of spare parts
23. Length of time taken to process a complaint
24. Level of authorization
25. Poor Documentation
26. Lack of Transparency
27. Level of access
28. Dissatisfied employees
29. Do not have maintenance logbooks for equipment
30. Not able to easily identify a fault before it occurs
31. Lack of uniformity in maintenance strategy
32. Absence of historical data
33. Non-availability of specialist tools
34. Poor mapping of maintenance strategy with hospital vision

Any changes to be made to the current maintenance processes will inevitably involve additional resources and there are far too many issues to be addressed in the case study. A method known as 'minimization' has been applied to reduce these issues to a manageable number for further analysis taking into account technical complexity and business justification covering 'what to improve', 'how to improve', 'how much will it cost', 'how long will it take', and 'quantifiable business benefits'. For practical reasons, the minimised issues have been categorized under 3 headings: ease of implementation (Table 29), impact on maintenance operations (Table 30), and costs involved (Table 31). In addition, the issues in each category have also been ranked according to their relative impact pertaining to that heading.

Relative impact	**Issue**
Straight forward	Repeated breakdowns
	Lack of support from supervisors
	Poor personal relationship
	Easy to break the procedures
	Not following the manufacturer's recommendations in periodic maintenance and use of spare parts
	Lack of commitment
	Level of authorization
	Do not have maintenance logbooks for equipment
Fairly challenging	Technicians do not have the ability to get the job done professionally
	Length of time taken to process a complaint
	Poor documentation
	Lack of transparency
	Level of access
	Dissatisfied employees
	Not able to easily identify a fault before it occurs
	Lack of uniformity in maintenance strategy
	Poor mapping of maintenance strategy with hospital vision
Very challenging	Awarding projects to contractors who may not have the appropriate experience to complete the work as required
	Lack of cooperation between technicians and supervisors
	Frequent overtime
	Lack of motivation to finish the work
	Lack of encouragement for innovation
	Lack of consideration for on-the-job training
	Lack of a clear plan of maintenance related activities

Table 29 Ease of implementation

Relative impact	Issue
High	Delay in completing the work
	Accumulation of faults
	Poor mapping of maintenance strategy with hospital vision
	Poor documentation
	Lack of transparency
Medium	Easy to break procedures
	Poor quality of spare parts
	Not following the manufacturer's recommendations in periodic maintenance and use of spare parts
	Do not have maintenance logbooks for equipment
	Absence of historical data
	Lack of consideration for on-the-job training
	Not able to easily identify a fault before it occurs
	Awarding projects to contractors who may not have the appropriate experience to complete the work as required
Low	Length of time taken to process a complaint
	Lack of uniformity in maintenance strategy
	Lack of motivation to finish the work
	Lack of encouragement for innovation

Table 30 Impact on maintenance operations

Relative impact	Issues
Low	Lack of cooperation between the technicians and supervisors
	Poor documentation
	Lack of motivation to finish the work
	Lack of encouragement for innovation
	Lack of consideration for on-the-job training
	Length of time taken to process a complaint
Medium	Accumulation of faults
	No specialized and technical courses
	Poor quality of spare parts
	Dissatisfied employees
	Non-availability of specialist tools
	Lack of consideration for on-the-job training
	Lack of spare parts
High	Awarding projects to contractors who may not have the appropriate experience to complete the work as required
	High prices of spare parts
	Old equipment and devices
	Lack of modern technology

Table 31 Costs involved

To facilitate field trial studies (see also section 6.6), the issues listed in Table 32 have been considered first as they offered the best combinations of relatively low cost, high impact on maintenance operations and easy to implement.

<table>
<tr><th>Easy to implement</th><th>High impact on maintenance operations</th><th>Low cost involved</th></tr>
<tr><td>Repeated breakdowns</td><td rowspan="2">Delay in completing the work</td><td rowspan="3">Lack of cooperation between technicians and supervisors</td></tr>
<tr><td>Lack of support from the direct supervisor</td></tr>
<tr><td>Bad Personal relationship</td><td rowspan="2">Accumulation of faults</td></tr>
<tr><td>Easy to break the procedures</td><td>Poor of documentation</td></tr>
<tr><td>Not following the manufacturer's recommendations in the periodic maintenance and use of spare parts</td><td>Poor mapping of maintenance strategy with hospital vision</td><td>Lack of motivation to finish the work</td></tr>
<tr><td>Lack of commitment</td><td>Poor documentation</td><td>Lack of encouragement for innovation</td></tr>
<tr><td>Level of authorization</td><td rowspan="2">Lack of transparency</td><td>Lack of consideration for on-the-job training</td></tr>
<tr><td>Do not have maintenance logbooks for equipment</td><td>Length of time taken to process a complaint</td></tr>
</table>

Table 32 Issues selected for “field” trial studies

6.4 A proposed maintenance management framework for the healthcare industry in Saudi Arabia

The ideas of developing a maintenance management framework is derived from the knowledge gained from previous studies pertaining to the development and application of maintenance management systems in the engineering and related industries both in developed and developing countries (Márquez et.al, 2009; Shohet and Lavy, 2004; Naughton and Tiernan, 2012).

Figure 38 shows a proposed maintenance management framework for the healthcare industry in Saudi Arabia consisting of 8 phases: Data collection; Critical Success Factors (CSFs) and Key Performance Indicators (KPIs); Strategies/Policies; Risk/Cost activity planning; Identification of methodology; Identification of maintenance issues; Monitoring and control; and Continuous improvement.

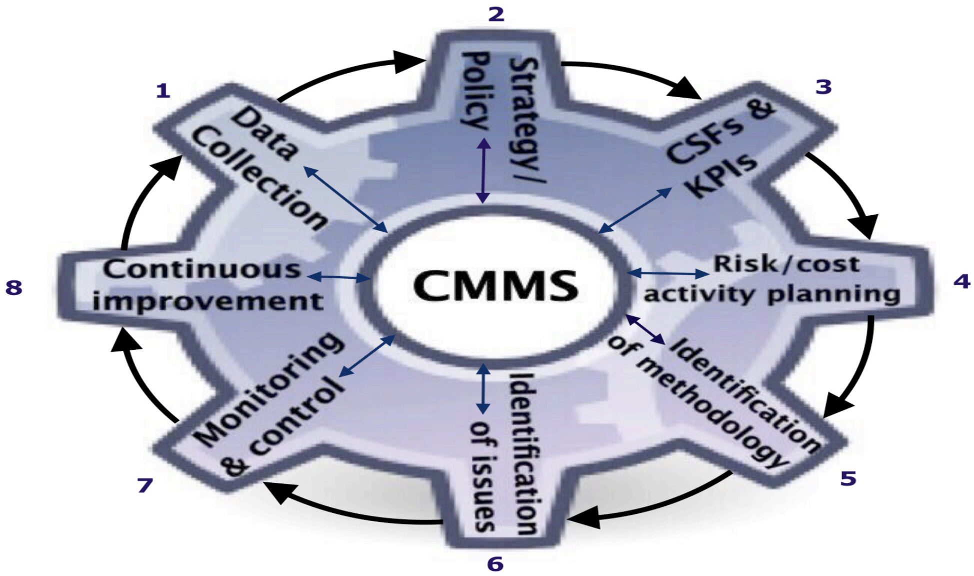


Figure 38 A proposed healthcare maintenance management framework

Phase 1: Data collection

The first step is to assess the current state of maintenance management at a healthcare organisation and this requires data collection/intelligence gathering. The question remains as to what type of data should be collected, when and how. In the present study, data was collected pertaining to maintenance-related activities including the total number of work orders issued per day, total number of work orders completed per day, total cancelled work orders per day, total on-hold work orders, total material cost for a defined time period, staff availability, and total actual working time. The data/information thus obtained will enable the identification of potential undesired consequences before they happen.

Phase 2: Strategy and policy

The maintenance strategy and policy needs to align with the organisation's business objectives and priorities, so that reliable and quality services could be provided. For the present study, the patients, staff and visitors are the stakeholders and their well-being is the number one priority. In this context, hospital facilities/environment including patients' wards, operation rooms, general purpose rooms, nurse-call systems, ventilation systems, supply of medical gases, clean water supply, toilets, kitchens among others have to operate efficiently. Maintenance policy should be a clear statement of the objectives and methods to be employed in keeping buildings fit for use and preserving their asset value. It should have a clearly defined organizational structure and suitable resources to ensure effective control of critical activities.

Phase 3: CSFs and KPIs

Critical Success Factors (CSFs) are the causes contributing to the organization's success, while Key Performance Indicators (KPIs) measure the effects/outcomes of the organization's actions. For the present study, 17 critical success factors and 34 performance indicators have been identified (see also Section 5.2) for the case study hospital. The 5 most important CSFs are: clarity of policy and procedure, senior management support, a well-organized structure, having employees with high technical skills and clarity of the maintenance contract. The 6 KPIs are dockets, finance, critical equipment, processes, resources and contractors. The 'Outputs' associated with these indictors should be used to assess and quantify maintenance performance.

Phase 4: Risk and cost activity planning

The main purpose of healthcare maintenance is to ensure safe environment for all stakeholders (patients, staff and visitors), safe and reliable facilities/equipment for operations. Potential risks and their relative impact need to be assessed and quantified, so that mitigating measures are put in place. Measurement of assets availability, mean time to repair and mean time to failure are some of the measures that can be used to assess potential risks in maintenance operations. This helps to ensure proper functioning of equipment at an acceptable cost. Maintenance cost is considered as one of the key performance indicators and appropriate cost-effect analysis for specific operations needs to be undertaken to aid the planning process.

Phase 5: Identification of methodology

Using the good practices developed for the engineering and related industries, appropriate maintenance methodologies should be adopted to guide maintenance activities in a healthcare environment. Standard maintenance methods include Reliability Centred Maintenance, Total Productive Maintenance, and Root Cause Failure Analysis.

Phase 6: Identification of issues

The prevailing maintenance-related issues need to be identified so that appropriate actions can be devised for their resolution. Questionnaire surveys, interviews, group discussions and observations are some of the popular methods for gathering data/information for detailed analysis. The investigation should focus on issues which could have an adverse impact on the maintenance processes and the well-being and safety of stakeholders (patients, staff and visitors). In addition, maintenance efficiency and equipment reliability should also be considered. This in turn allows the most undesirable effects (UDEs) associated with the maintenance operations to be identified.

Phase 7: Monitoring and control

Specific maintenance activities need to be monitored in a systematic manner to ensure they fulfil their intended functions and appropriate actions be taken, if necessary, to rectify any shortcomings. It is important that operators are properly briefed with the maintenance policy and procedures before the commencement of the monitoring process. A simple checklist of services can be produced for the more straightforward tasks. For more complex activities, Statistical Process Control (SPC) is a suitable tool for use in the monitoring and control process.

Phase 8: Continuous improvement

The framework is designed as an iterative loop so that experience gained or 'lessons' learned from previous activities/tasks can be regularly incorporated into future events to improve the processes. Kaizen is a suitable method to identify potential opportunities for improvement by considering and incorporating appropriate staff feedback/suggestions. This helps to build team spirit and encourage teamwork. Good communications and recognition of attainments also help to increase staff motivation.

6.5 Proposed changes to the current maintenance procedures

The new maintenance management framework detailed in the last section has been applied to the case study hospital RMH. As a result, a number of changes have been proposed to amend the current maintenance procedures covering five key areas (Blocks A to E) as shown in Figure 39.

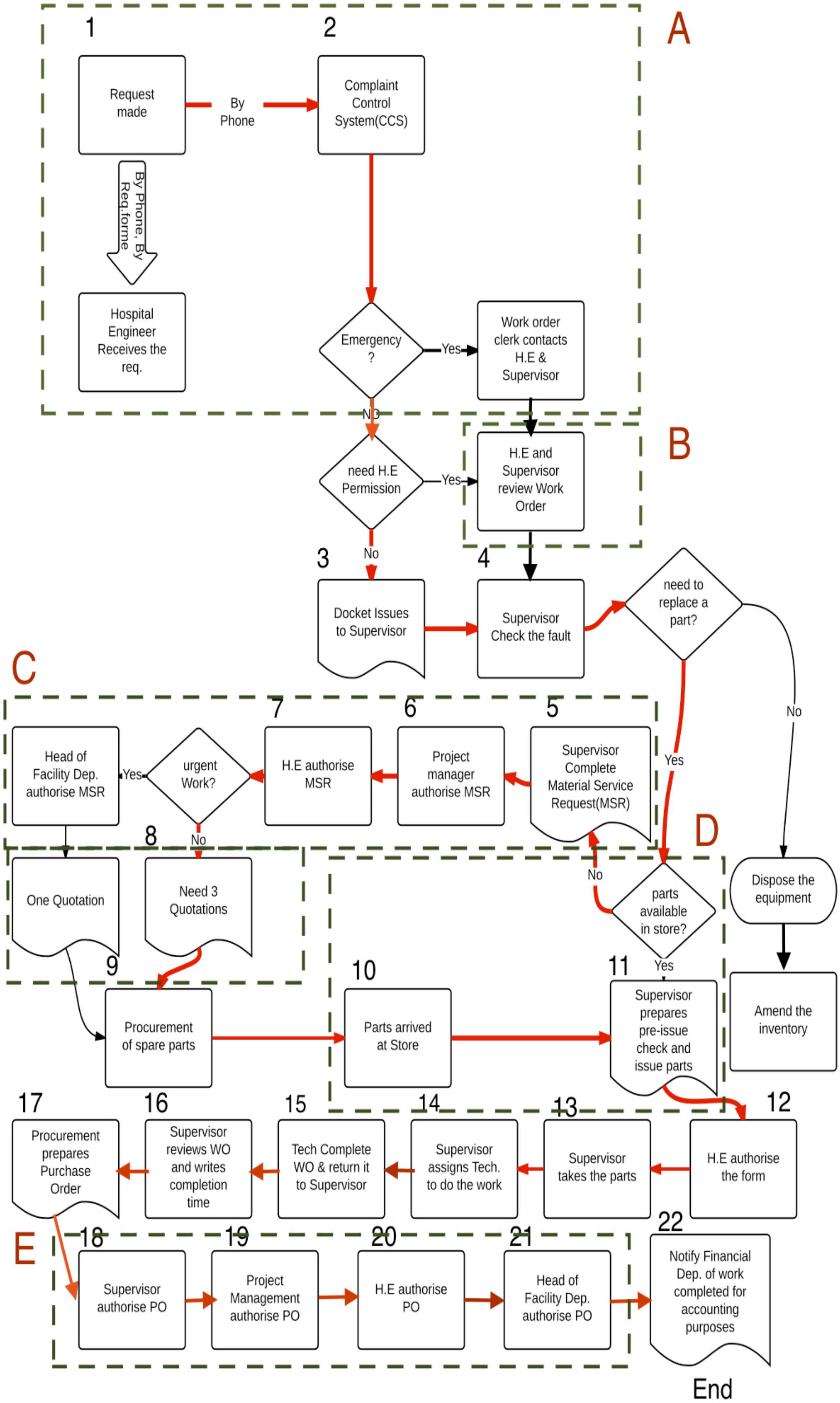


Figure 39 Five areas (Blocks A to E) where proposed changes are to be made

6.5.1 Initiation of a complaint (Block A)

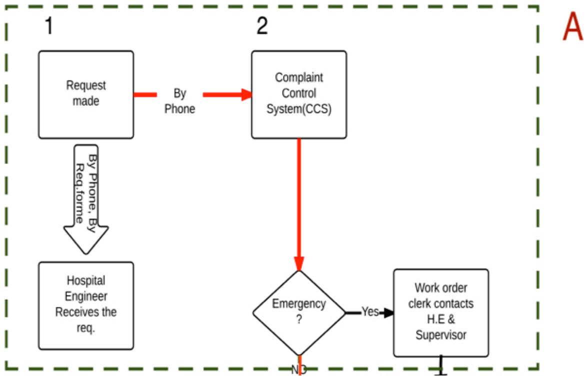


Figure 40 Existing block A

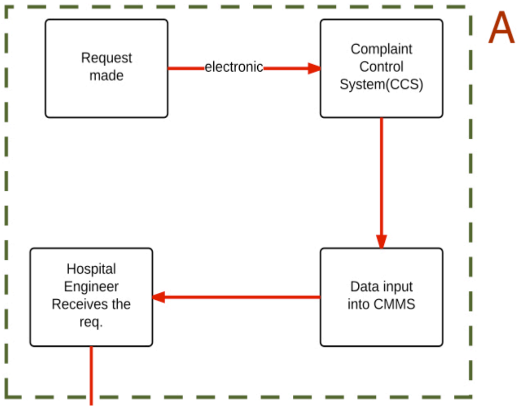


Figure 41 Revised block A

The first part of the revised procedure focuses on the relationship between the requester of a 'complaint' (or request) and the Maintenance Department. The issues to be addressed are the length of time to process a complaint, the transparency of decision-making and documentation. By introducing new maintenance related computer software, which is to be fully integrated within the hospital mainframe, a requester will be able to log a complaint or submit a report directly with the Complaint Office and to check its subsequent status.

6.5.2 Reviewing possible remedial action (Block B)

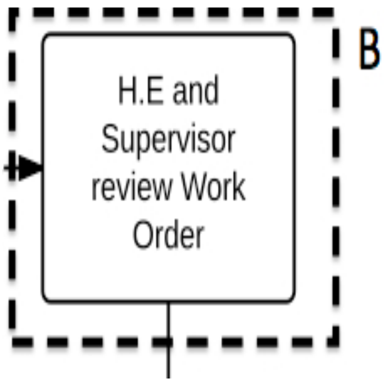


Figure 42 Existing block B

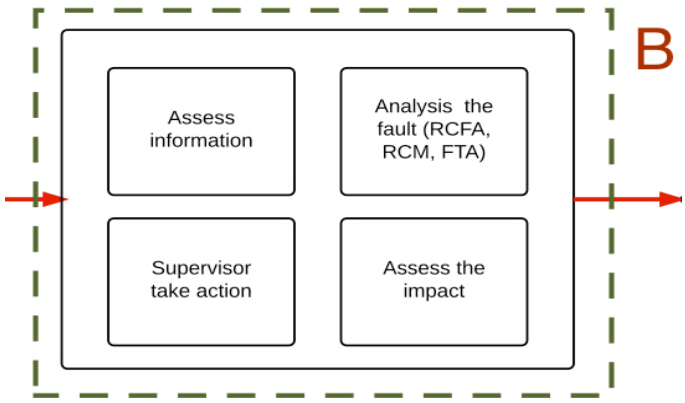


Figure 43 Revised block B

Upon receipt of a 'complaint' by the Maintenance Department, a hospital lead engineer and a senior member of his team (usually the supervisor) will review the received work order dockets. A range of possible actions will be considered including the inspection of the faulty equipment. The reviewing process sometimes takes a long time to complete due partly to the lack of specific expertise of some of the complex medical equipment, and partly to the inadequate documentation and process standardization. Any delay in decision making can lead to a backlog of maintenance work. The use of reliability tools including Root Cause Failure Analysis (RCFA), Reliability Centred Maintenance (RCM) and Fault Tree Analysis (FTA) should help to speed up the detection of faults.

6.5.3 Initiation of a requisition order (Block C)

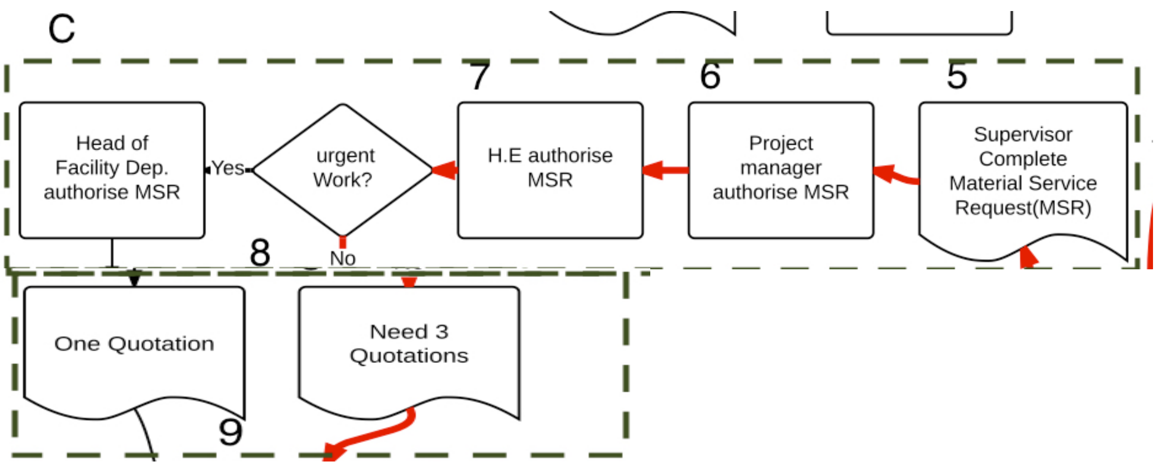


Figure 44 Existing Block C

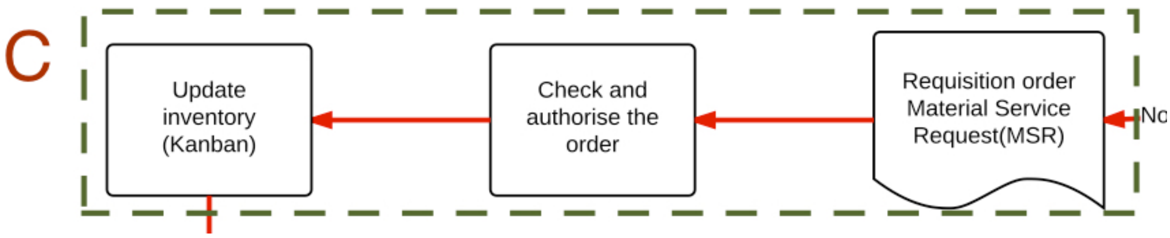


Figure 45 Revised block C

Once appropriate actions have been decided, fault repair tasks are to be allocated to a maintenance team. A wide range of standard spare parts are normally stocked by the hospital. However, if specialist parts are required, the current process involves the completion of a Material Service Request (MSR) form, seeking approval from the contractor's project manager and hospital engineer, and obtaining quotations as appropriate. This manual process can take approximately 288 minutes if three quotations are required.

By introducing a new Computer Maintenance Management System (CMMS), the requisition of spare parts including authorization and despatch to suppliers can be done electronically. This will also help to improve documentation and transparency.

6.5.4 Stock control and inventory level update (Block D)

The survey suggested inadequate stock control, ineffective inventory management, inadequate documentation, and poor communication between the Maintenance Department and the Store. Consequently, maintenance workers often did not know what spare parts were available in the Store, as catalogues had not been updated at frequent intervals.

Furthermore, it was a frequent occurrence that new supplies of spare parts had not been properly logged by the Store and the requesters of spare parts had not been notified accordingly.

The introduction of an inventory management system such as Kanban, which is an inventory scheduling tool that allows systematic monitoring and control of stocks, will help to inform the storekeeper to restock items before they run out and to regulate the flow of stocks.

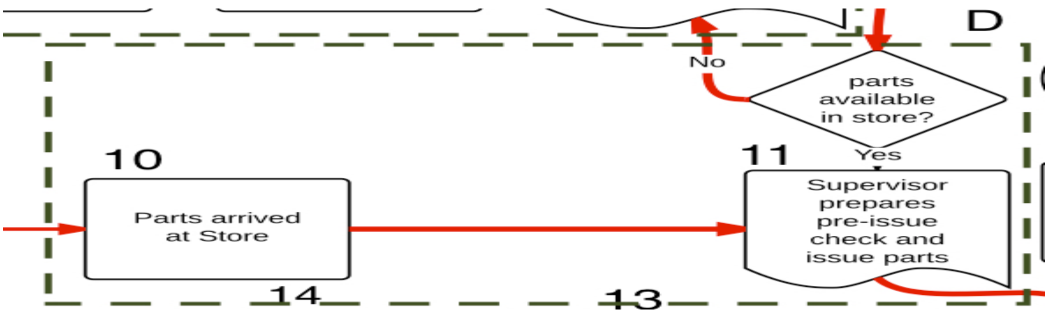


Figure 46 Existing block D

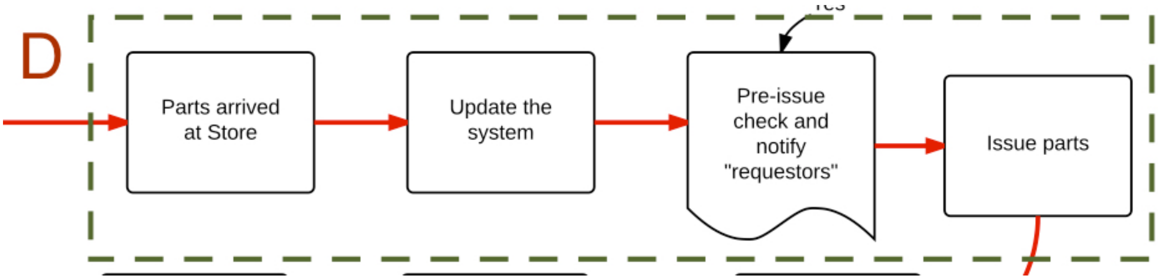


Figure 47 Revised block D

6.5.5 Purchasing orders and reimbursement (Block E)

Completion of purchase orders, authorization and reimbursement of expenses to contractors are currently done manually and the process is very cumbersome. The introduction of a new Computer Maintenance Management System will help to speed up the process, improve transparency and documentation.

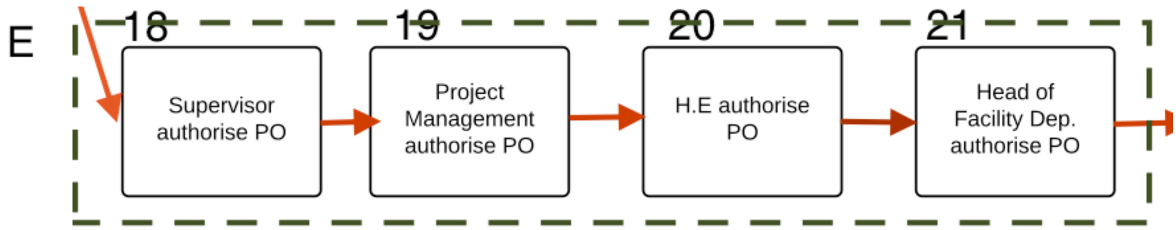


Figure 48 Existing Block E

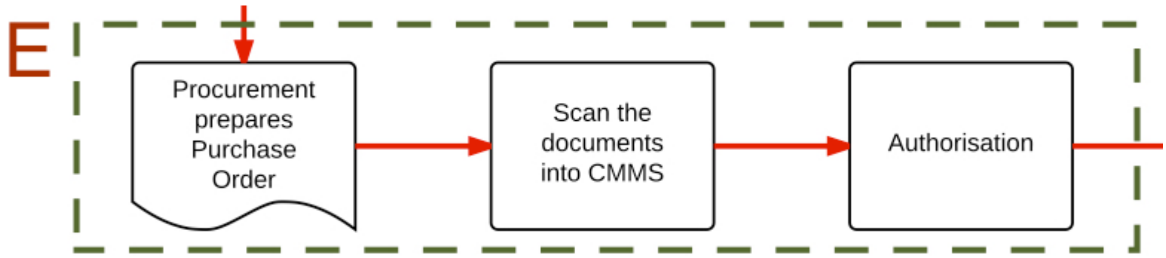


Figure 49 Revised block E

The flowchart of the revised maintenance procedures for the case study hospital RMH incorporating the changes detailed in previous sections is shown in Figure 50.

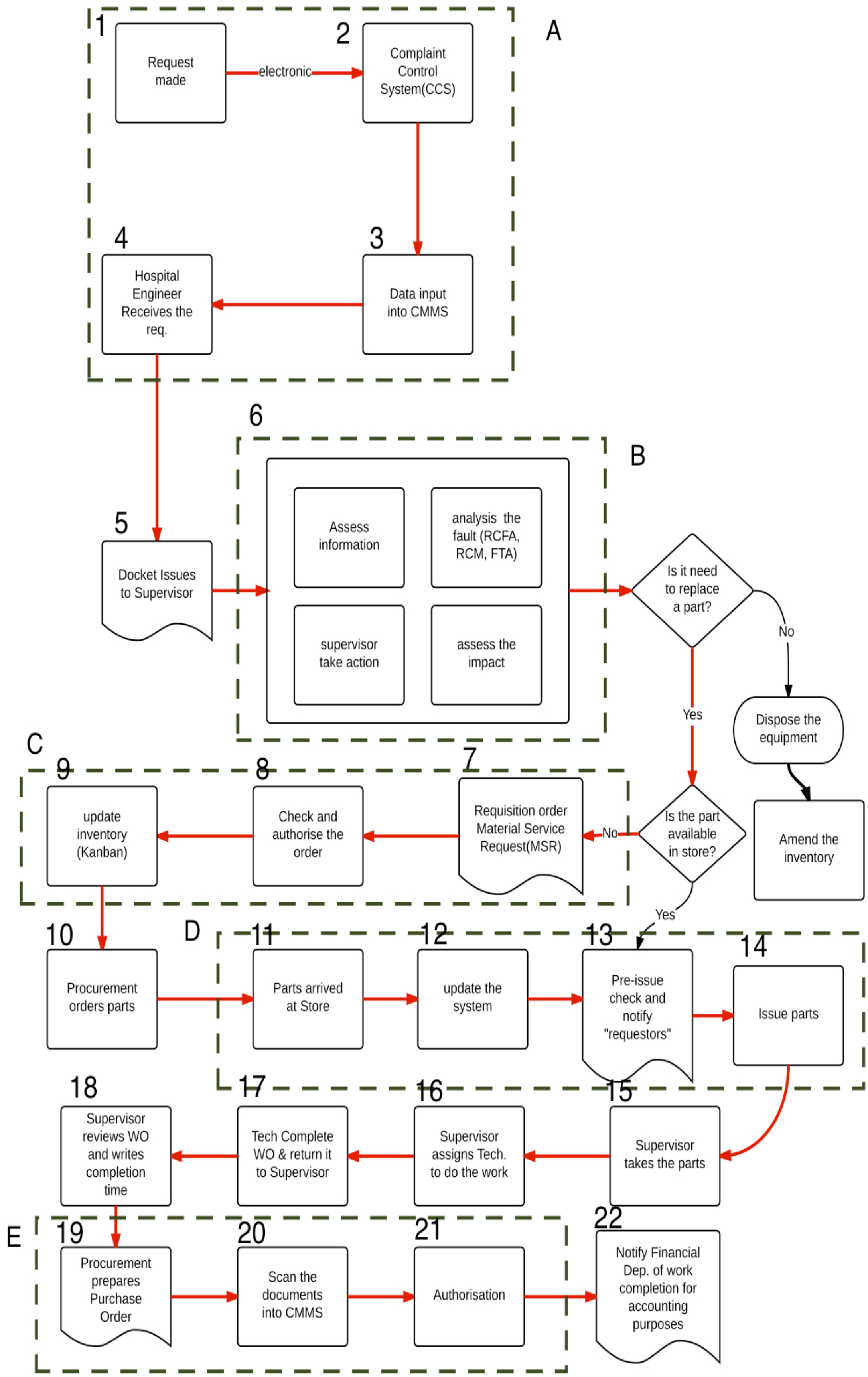


Figure 50 A flowchart of the revised maintenance procedures at RMH

The overheads in terms of processing times and costs associated with the individual activities from start to finish have been estimated for the revised maintenance procedures and are shown in Table 33.

Step	Activity	Average processing time (min.)	Man-hour	Average cost @ £17/ hour
T1	Request made	7.5	0.12	3
T2	Complaint control System	3.5	0.05	3
T3	Data input into CMMS	5	0.08	2
T4	Hospital Engineer receives WO	7.5	0.12	2
T5	Docket issues to Supervisor	2.0	0.04	2
T6	Assess information-Analysis the fault (RCFA, RCM, FTA, etc.)-Assess the impact-Supervisor do action	3.5	0.06	2
T7	Assess information	2.5	0.04	2
T8	Analysis the fault (RCFA, RCM, FTA, etc.)	2.5	0.04	3
T9	Assess the impact	2.5	0.04	1
T10	Supervisor do action	2.5	0.04	1
T11	Dispose the equipment	n/a	n/a	n/a
T12	Amend the inventory	n/a	n/a	n/a
T13	Requisition order Material Service Request (MSR)	6.5	0.11	2
T14	Check and authorise the order	3.5	0.06	3
T15	Update inventory (Kanban)	2.5	0.04	3
T16	Procurement orders parts	17	0.28	3
T17	Parts arrived to store	23	0.38	5
T18	Update the system	2.5	0.04	1
T19	Pre-issue check and notify requestors	8	0.13	2
T20	Issue parts	15	0.25	2
T21	Supervisor takes the parts	9.5	0.16	1
T22	Supervisor assigns Technician to do the work	19	0.32	3
T23	Technician complete WO and return it to Supervisor	17	0.28	2
T24	Supervisor reviews WO and writes completion time	15	0.25	8
T25	Procurement prepares Purchase Order (PO)	22	0.37	1
T26	Scan the documents into CMMS	7.5	0.13	2
T27	Authorisation	15	0.25	2
Total		**221**	**3.7**	**£65**

Table 33 Costs associated with the flow of information after changes

With the revised maintenance procedures, there are fewer steps involved. The total estimated time and cost have reduced from approximately 288 minutes to 221 minutes and from £81.75 to £65, representing respectively a potential saving of 23% of time and 20% of cost (Figure 51 and Figure 52).

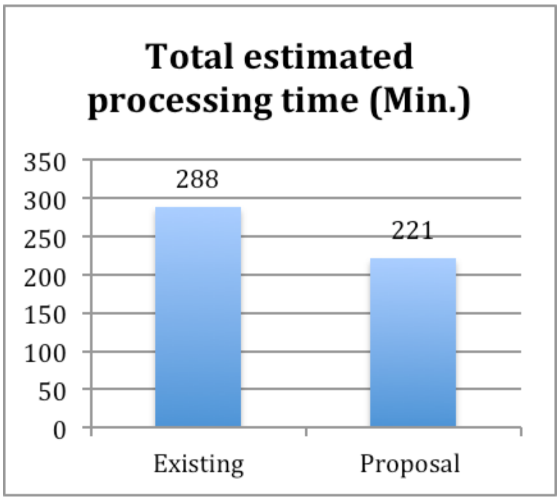


Figure 51 Saving in total processing time

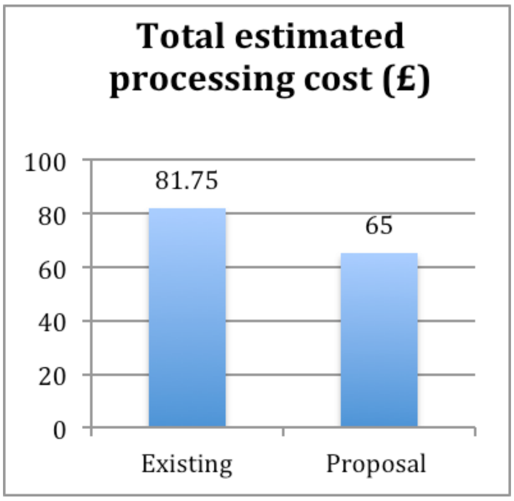


Figure 52 Saving in total processing cost

Through the introduction of a new Computer Maintenance Management System (CMMS) equipped with appropriate data analysis tools, the revised maintenance procedures also help to reduce unproductive times, thus allowing maintenance personnel to focus on dealing with value-added activities.

6.6 Field trial studies

The validity of the revised maintenance procedures has been investigated using limited field studies pertaining to Block A (Initiation of a complaint) and Block B (Reviewing possible remedial actions) of Figure To facilitate data/information collection, a site visit by the author to the case study hospital was made between June and September 2014.

Block A - Initiation of a complaint

Under the new procedures, all complaints are to be logged by the CMMS system. Any new complaints reporting the same faults will not be accepted, if the reported faults have an 'open' (i.e. unresolved) status. Furthermore, a 'filtering' mechanism is also introduced, so that any non-maintenance related complaints will be not registered by the Maintenance Department and will not be considered by a hospital engineer. Examples of non-maintenance complaints logged by the system include 'clean a floor', 'a curtain needs cleaning' or 'remove a side table from a room'. These are the responsibilities of the

Housekeeping and Porter Department. The revised Block A helps to direct complaints to the appropriate departments for actions.

Block B – Reviewing possible remedial actions

After initial investigation of a reported complaint/fault by a technician, the new maintenance procedures require a report to be completed electronically in the CMMS within 48 hours. The submitted report is sent directly to a hospital engineer for consideration. The engineer's decisions are e-communicated (electronically) to a maintenance team for action within a reasonable time frame. Any delay in carrying out the allocated repairs/remedial work will be highlighted by a 'red flag' on the maintenance system's dashboard. This alerts the hospital engineer or his line manager that further actions are required. By focusing on improving reporting, communications and monitoring, the revised Block B seeks to minimise delay in maintenance decision-making and its subsequent implementation.

The revised maintenance procedures for Block A and Block B were implemented as trial studies for a period of 4 months between June and September 2014 at the case study hospital RMH. To assess and quantify the potential benefits that can be achieved using the revised maintenance procedures, the number of dockets issued covering both corrective and preventive maintenance were monitored and the results are shown in Figure 53 and Figure 54. It can be seen that the total number of maintenance dockets issued covering mechanical, electrical, equipment and civil fell from 2048 in June to 1571 in September of the same year, representing a reduction of about 23%. The figures for the same period in 2013 were 4763 in June and 4737 in September.

The number of preventive maintenance dockets issued also reduced from 576 in the first week of the trial to 387 in the last week of the trial representing a reduction of 32.8% (Figure 54).

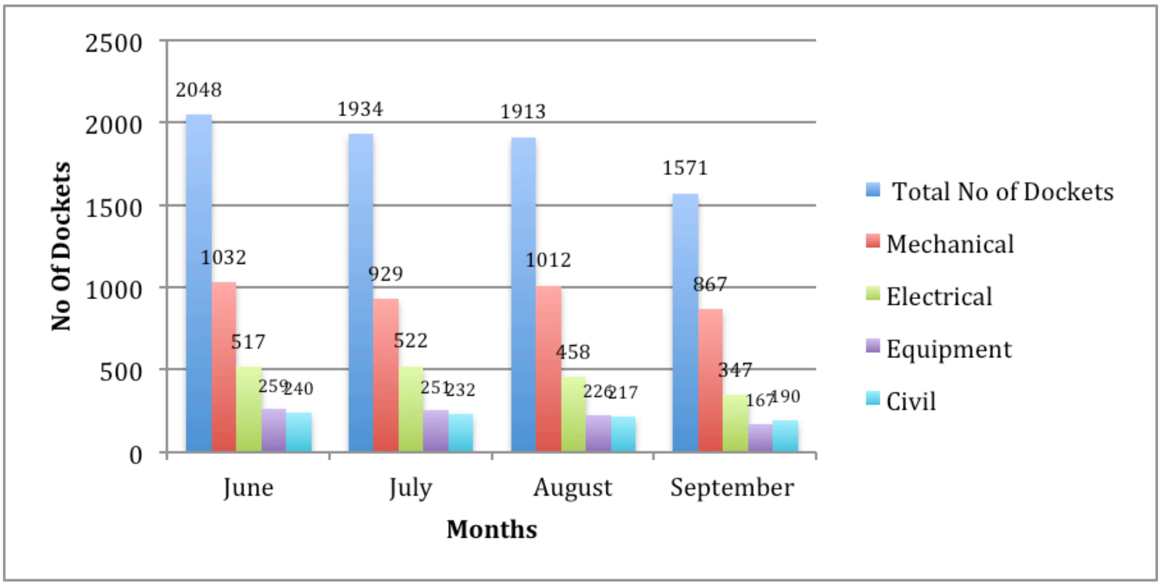


Figure 53 Corrective maintenance dockets issued during a 4-month period

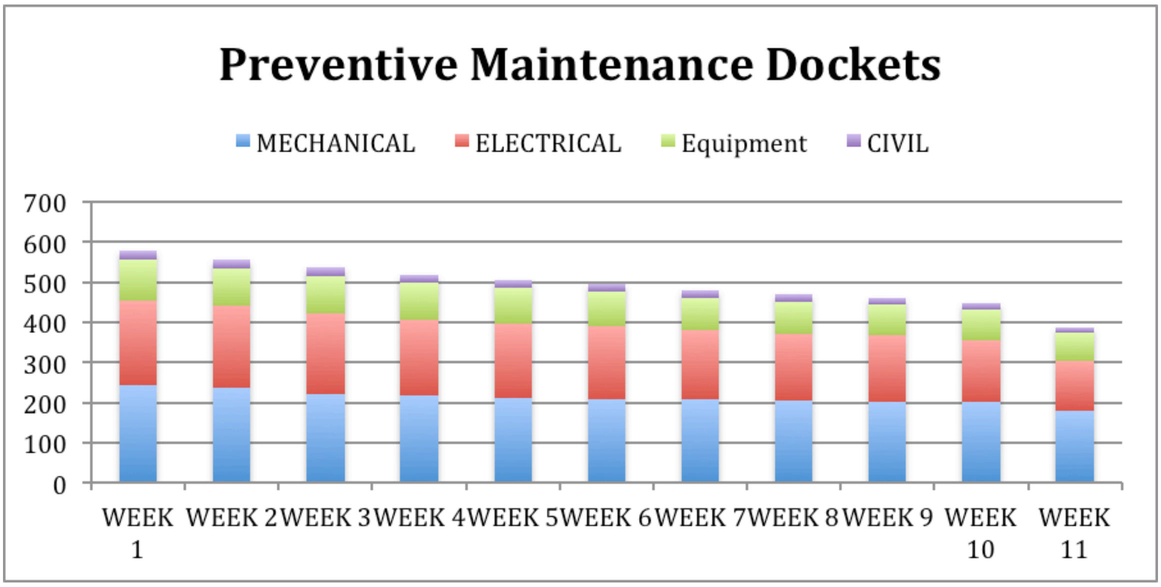


Figure 54 Preventive maintenance dockets issued during a 11-week period

6.7 Concluding remarks

The results have highlighted a number of issues which might have inadvertently undermined the effectiveness and efficiency of the current maintenance procedures at the case study hospital RMH. There appeared to be unnecessary duplications in the reporting or 'complaining' of faults and the ways the complaints were handled. It is not unusual for an identical fault to be reported a few times via different but 'legitimate' channels and there is little or no cross-referencing between these channels. Consequently, valuable staff resources are often wasted because of duplicate issue of dockets (maintenance work orders). For historic and cultural reasons, a top-down approach is the normal practice when responding to the compliant of a fault. As a result, the maintenance approaches/methods are often strongly influenced by the personal preferences, knowledge and experience of the supervisor concerned.

Given that there are approximately 520 people (mostly contractors) working on maintenance-related activities at RMH and the majority have different cultural and educational background, the lack of standardized practices, inadequate documentation and poor communications have been identified as three major concerns. Lack of transparency of stock control of spare parts and poor logistic planning are contributing to a relatively high level of overheads because of unproductive times. By examining the maintenance information flow, it is estimated that a typical minor maintenance request (e.g. a simple plumbing problem) involving the requisition of spare parts takes on average 288 minutes to complete from start to finish costing the organization about £82. Until now, the costs of associated with unproductive times (e.g. travelling time within the hospital compound) have not been estimated/quantified, but the amount is not insignificant when considering the number of requests or complaints processed by the Maintenance Department each working day.

There are many 'invisible' barriers/obstacles which appeared to have prevented the Maintenance Department from delivering higher levels of services. With a better understanding of the current maintenance operations at the case study hospital RMH through data collection and analysis, a substantial revision to the current maintenance procedures is deemed necessary. Through rationalization of the processes, the intention is to deliver better level of services without incurring significant increases in operating costs. The questions remain as to 'why to change', 'what to change' and 'how to change'.

Informed by the work of Shohet and Lavy (2004), Márquez et al. (2009), Naughton and Tiernan (2012) on the development of management frameworks/structures for the engineering and related industries, a new maintenance management framework has been developed for the healthcare industry in Saudi Arabia. In the form of a closed loop, the new healthcare maintenance framework focuses on 8 key areas: data collection; critical success factors and key performance indicators; strategies/policies; risk/cost activity planning; identification of methodology; identification of maintenance issues; monitoring and control; and continuous improvement.

Incorporating the knowledge and understanding thus gained from primary and secondary research, the new framework has been used to facilitate the identification of key changes to be made to the current maintenance procedures at RMH. The selection of activities for consideration is guided by three principles: low investment cost, potentially high impact on maintenance operations and relatively easy to implement. The revision focuses on 5 blocks of activities each focusing on a specific function: initiation of a complaint; reviewing possible remedial actions; initiation of a requisition order; stock control and inventory level update; and purchasing orders and reimbursement. Preventive maintenance has been chosen to provide the 'backbone' of the revised maintenance procedures given the critically of many of the hospital's functions. Other methodologies such as corrective maintenance will also be used, where appropriate, and are expected to be deployed at a local level. Preventive maintenance is not new to the hospital, but its current applications are limited mainly to the servicing of newer and more complex medical equipment.

The structure of the revised maintenance procedures incorporating the proposed changes has been given in the form of a flowchart (Figure 50). The overheads in terms of execution times and costs associated with the individual activities from start to finish have been estimated. By simplifying the maintenance procedures, the total estimated execution time has been reduced from the current level of approximately 288 minutes to about 221 minutes, representing a potential saving of 23% in man-hours. The corresponding cost saving is about 20% from the current £82 to £65. A number of assumptions have been used when calculating the figures so they should be treated as indicative values. For example, time estimations for all selected activities were based on observations by the author during a site visit over a four-month period between June and September 2014 and an average value of the individual activities has been used.

With agreement of the hospital management, the validity of the revised maintenance procedures has been investigated using limited field studies. New work practices pertaining to Block A (Initiation of a complaint) and Block B (Reviewing possible remedial actions) have been introduced and new data was collected to assess the progress. It is encouraging to note that the total number of dockets (maintenance work orders) issued for general maintenance over a 4-month period fell by 23% when compared with the figure for the previous year.

It is hoped that the revised maintenance procedures will help to (1) simplify the protocols to be followed by technicians; (2) improve documentation and accessibility to information;

(3) allow tracking of events by management; and (4) permit better utilization of resources. It is understood that RMH is in the process of purchasing a new computerized management system to further improve the integration of the various hospital functions including engineering and maintenance. So, the proposed new maintenance procedures will be complementary to the new system development.

The results presented in Chapter 5 also suggest that further investment in staff development/training will be required to facilitate the implementation of the revised maintenance procedures. In addition to updating technical knowledge and skills, the training remits should also cover business and management-related issues including managing change, working culture, communications, motivation and commitment, leadership, awareness of targets and priorities, and alignment of maintenance processes with organization strategies. Furthermore, a key challenge to be faced by the management is to find ways of changing the mind-set of workers, given their diverse cultural background.

The next chapter will summarise the key findings of the present research in the form of conclusions. Attempts will be made to quantify the degree of attainments by providing answers to the research questions listed in the introductory chapter, to be followed by some suggestions for future work.

Chapter 7 Conclusion and suggestions for future work

7.1 Chapter Overview

This chapter presents the main findings of the present research including the contribution of this study to the advancement of knowledge and practices in the area of maintenance management for the healthcare industry in the Kingdom of Saudi Arabia. Building on the work completed so far, some suggestions for future work will be made.

7.2 Conclusion

The present study forms part of an on-going strategic review of the maintenance operations at the Riyadh Military Hospital (RMH) in Kingdom of Saudi Arabia as a case study. Because of its size and strategic importance, RMH is considered by the Saudi Government as a benchmark hospital for the development of healthcare policies governing the delivery of primary healthcare in the Kingdom. One of the remits of the present research was to review the current maintenance management practices, identify maintenance-related issues and quantify their likely impact on the maintenance operations in a hospital environment. The second remit was to propose a maintenance management framework for the healthcare industry in Saudi Arabia. The third remit was to show how the management framework thus developed could be adopted for maintenance operations in a hospital and to assess the relative impact of its implementation on the hospital's maintenance procedures. The outcomes of the investigation suggested that these have been achieved satisfactorily.

With the support of the hospital management and active participation of the maintenance staff (including contractors) at all levels, the chosen data collection techniques were considered appropriate to gather relevant data/information governing various aspects of the maintenance operations at the case study hospital RMH. A range of issues have been identified and their potential impact on the maintenance operations has been assessed. The 'number one' problem faced by the Maintenance Department is the lack of consistency in maintenance performance, reflecting probably the diverse cultural background of its workforce (technicians, operators and helpers) made up mainly of migrant workers. Further investigation revealed that it is often a consequence of workers' misunderstanding in the interpretation and implementation of maintenance strategies covering policies, approaches, procedures and techniques. There are indeed some good practices in the Maintenance Department but they have not been adequately assimilated and shared among staff.

The quality and reliability tools and techniques developed for the engineering and related industries are found to be equally applicable for the study of healthcare maintenance issues, although some form of contextualization in the interpretation of events is needed. For example, the Theory of Constraints has been integrated with the Spaghetti Diagram when assessing the ways in which maintenance activities were conducted. The concepts of Critical Success Factors and Key Performance Indicators have been applied for the assessment and quantification of maintenance performance.

The Technical Affairs Department (which oversees the Maintenance Department) is one of the largest departments in the hospital and consumes about one-third of its operating costs (non-salary based). However, the evidence suggested that it did not receive much support from senior management as the Department is seen as a cost centre with intangible value added activities. A substantial amount of resources has apparently been invested in new projects but the annual budget allocation to the Maintenance Department is just enough to enable the undertaking of day-to-day 'fire-fighting' maintenance activities.

There is no clear strategy guiding the work of the Maintenance Department and no clear policy on updating staff knowledge and skills to cater for the introduction of new facilities/equipment. Consequently, there is a heavy reliance on external contractors to supply the necessary expertise. The limited budget allocated for maintenance activities has meant that a difference working culture have to be developed to maintain a similar level of services despite the growing demands. As users of the facilities, the involvement of medical staff particularly physicians in developing maintenance strategies is highly desirable as they have unparallel authority and can influence the organizational culture and decision-making process of the hospital.

The data collection methods used for gathering information are considered appropriate to enable the views from a range of stakeholders to be sourced. The non-contribution of a group of employees namely 'the helpers' was unexpected, but this had little impact on the overall outcomes of the investigation given their relatively minor roles in the Maintenance Department. With the benefit of hindsight, group discussions could have been a more appropriate method for those where literacy/culture background might be an issue. The interviews conducted with different groups of participants are found to be useful to fill the gaps of knowledge particularly on issues which could not be easily quantified including communications, leadership styles and work practices. The fact that the author was a member of staff of the Maintenance Department helped to offer reassurance to participants of the academic nature of the research work and that the data would be destroyed after the completion of the study.

By means of statistically analysis, a number of correlations have been identified which confirmed the observations of previous studies. For example, there appeared to be a significant correlation between "the clarity of strategy" and "consistency of maintenance performance", and between "a happy worker" and "the clarity of instructions" and "availability of appropriate tools". Five main parameters have been identified as critical to the success of the maintenance operations at RMH: clarity of policies and procedures; support of senior management; organizational structure; employee qualifications (i.e. technical knowledge and skills); and clarity of maintenance contracts (including communications with external contractors). Other factors which could have an impact on hospital operations include maintenance strategy planning and communication, transparency of decision-making, documentation, clarity of job descriptions, delegation of responsibilities for engineers and technicians, availability of spare parts and monitoring of services provided by contractors.

Informed by the research work of others for the engineering and related industries, a maintenance management framework has been developed for the healthcare industry in Saudi Arabia. The benefits of a framework are that it helps to integrate different activities and to provide guidelines on the monitoring and control of the implementation process. The framework has been adopted for implementation at the case study hospital. As a result, substantial revision has been made to the current maintenance procedures. Limited validation has been carried out on the revised maintenance procedures involving two of the five blocks of activities (i.e. Block A (Initiation of a complaint) and Block B (Reviewing possible remedial action), see also Section 6.4). The validation involved an extended visit to the hospital by the author during the summer of 2014 and the implementation involved making significant changes to the organization of activities, protocols and working culture. It is pleased to note that encouraging results have been obtained confirming that the research is on the right track. The healthcare maintenance management framework is considered sufficiently generic for it to be applied to other hospitals and clinics in Saudi Arabia.

7.3 Difficulties and limitations

A number of practical problems were encountered when collecting data/information during the visits by the author to the case study hospital.

First, some of the data needed for the analysis belongs to Departments other than the Maintenance Department, hence the author had no access to the relevant data because of confidentiality. For example, the information on purchasing of equipment is held by the Purchasing Department, while the information on staff training is held by the Human Resource Department. The 'gaps' were filled by sourcing information from managers and lead engineers based on their best knowledge of past events.

Second, a great deal of the historic data documenting maintenance activities is held in databases within a dated Work Information System (WIMS) which was installed in 1983. Although the system has been updated a number of times over the years, the data storage records were incomplete. Furthermore, retrieval of any information required the input of a request number which is stored in a paper-based logbook. Consequently, consultations with operators allowed estimates to be made in some instances.

Third, validation of the new maintenance procedures required changes to be made to the current practices including the use of IT facilities. This often involved lengthy negotiations with the IT Department and the training of maintenance personnel. Staff participation and commitment was an issue as there were no extra resources to support the field trials. It took a great deal of persuasion and coercion by the management to enable the work to be completed.

7.4 Contribution to knowledge (why the research is important)

The present research …

- provided an in-depth study of the maintenance management issues in a large and strategic hospital (Riyadh Military Hospital) in Saudi Arabia;
- proposed a new maintenance management framework for the healthcare industry in Saudi Arabia;
- showed how the framework thus developed could be used to facilitate the rationalization of maintenance procedures in a hospital as a case study;
- demonstrated the likely business benefits associated with the implementation of the new maintenance management framework.

7.5 Recommendations

- To improve the effectiveness in the monitoring and control of maintenance operations, the current Computerized Maintenance Management System (CMMS) needs to be replaced with a more up-to-date software package. This will also allow dockets to be created and transmitted electronically, thus improving the processing time and documentation.

- The Maintenance Department should be involved in making procurement decisions on hospital equipment and facilities to ensure the right products are purchased at the right time and to minimize the possibility of duplications.
- Key performance indicators covering finance, customer satisfaction, staff motivation, productivity of contractors, reliability of processes, health and safety should be included in any performance measurement strategy.
- Annual staff development programmes should be organised to update the knowledge and skills of maintenance personnel at all levels (including contractors). This will inevitably increase the operating costs in the short term, but could help to improve staff productivity and reliability of equipment in the longer term.
- In consultation with contractors, policies and procedures need to be established to enable the systematic monitoring and control of contractor staff for mutual benefit. This should include the setting up of relevant databases containing the qualifications, experience and accreditation of all maintenance staff (including operators employed by external contractors). The databases should only be accessible by designated people.

7.6 Answers to the research questions

The following sections seek to provide answers to the research questions listed in the Introductory chapter (Chapter 1).

Are there significant differences in maintenance management between the engineering and related industries and the healthcare industry in Saudi Arabia?

There are many similarities in maintenance operations and associated activities for a wide range of industries in Saudi Arabia. What distinguish the healthcare industry from other industries is the criticality of the working environment and the expectations of the stakeholders. For example, any delay in the maintenance of equipment in a hospital may affect the well-being of patients, staff and visitors. In extreme cases, it may cause serious harm to an individual or even death. Furthermore, it is not uncommon to encounter interference of maintenance planning by senior medical staff in Saudi hospitals.

Could the practices, tools and techniques of maintenance management developed for the engineering and related industries be adopted for use in the healthcare industry in Saudi Arabia?

A range of well-established maintenance approaches such as corrective maintenance, condition-based maintenance and preventive maintenance have already been applied in the healthcare industry in Saudi Arabia, but with a varying degree of success. The main issues are three-fold: lack of support from senior management, poor leadership and lack of accountability and transparency. Techniques such as Failure Mode and Effect Analysis (FMEA), Theory of Constraints (TOC) and Fault Tree Analysis (FTA) could be used in conjunction with a fully-integrated Computer Maintenance Management System (CMMS) to improve the monitoring and control of maintenance activities. Standard quality assurance tools could also be applied to improve the transparency in work processes including coordination, accountability and documentation. However, additional resources are needed for the training of maintenance staff and this will help to overcome any resistance to change.

What are the prevailing maintenance management issues in hospitals in Saudi Arabia?

The prevailing maintenance management issues in Saudi hospitals identified by the present research may be summarised as follows:

- Lack of spare parts
- Technicians do not have the ability to get the job done professionally
- Lack of commitment
- Accumulation of faults
- Awarding projects to contractors who may not have the appropriate experience to complete the work as required
- Lack of motivation to finish work

Could a maintenance management framework be developed for the healthcare industry in Saudi Arabia?

Yes. Informed by the work of others on the development of maintenance management frameworks/structures, the present research proposed a new maintenance management framework for the healthcare industry in Saudi Arabia. In the form of a closed loop, the new healthcare framework focuses on 8 cyclical phases linked to a computer maintenance management system: data collection; critical success factors and key performance indicators; strategies/policies; risk/cost activity planning; identification of methodology; identification of maintenance issues; monitoring and control; and continuous improvement. Furthermore, the framework is considered sufficiently generic for it to be adapted for implementation in other member countries of the Gulf Cooperation Council due to similar culture.

To what extent could a maintenance management framework help to improve the maintenance procedures in Saudi hospitals?

The healthcare framework thus developed has been applied to Riyadh Military Hospital as a case study. As a result, substantial changes have been made to rationalise the current maintenance procedures through re-organisation of 5 blocks of activities each focusing on a specific function: Initiation of a complaint; Reviewing possible remedial actions; Initiation of a requisition order; Stock control and inventory level update; and Purchasing orders and reimbursement. It is hoped that the new maintenance framework will help to (1) simplify the protocols to be followed by technicians; (2) improve documentation and accessibility to information; (3) allow tracking of events by management; and (4) permit better utilization of maintenance resources.

By simplifying the maintenance procedures, the total estimated execution time for a typical maintenance request has been reduced from the current level of approximately 288 minutes to about 221 minutes, representing a potential saving of 23% in man-hours. The corresponding cost saving is about 20% (from the current £82 to £65). A number of assumptions have been used when calculating the figures so they should be treated as indicative values.

The validity of the revised maintenance procedures has also been investigated using limited field studies involving Block A (Initiation of a complaint) and Block B (Reviewing possible remedial actions). It is encouraging to note that the total number of dockets (maintenance work orders) issued for general maintenance over a 4-month period fell by 23% when compared with the figure for the previous year.

7.7 Future work

The present study has made a significant contribution in the development of a new maintenance management framework for the healthcare industry in Saudi Arabia. The implementation of the framework in a hospital has brought about substantial revision to its maintenance procedures. For practical reasons, it was not possible to validate the whole of the revised maintenance procedures at the case study hospital RMH, as only Block A (Initiation of a complaint) and Block B (Reviewing possible remedial action) have been considered. The results are generally encouraging but they highlighted a number of issues pertaining to change management (practices, communications and training), measurements (what, when and how) and third party evaluation (involvement of the Maintenance Department). It is important to undertake further work to validate the remaining three blocks (see also Section 6.4) namely, Block C (Initiation of a requisition order), Block D (Stock control and inventory level update) and Block E (Purchasing orders and reimbursement). The results thus obtained allow an assessment to be made concerning the alignment of the new maintenance procedures to the business strategy of the Maintenance Department. The potential business benefits associated with the proposed changes need to be further quantified in order to provide justification for the introduction of the maintenance management framework.

It is also important to study the resource implications of implementing the new maintenance procedures covering changes to work practices, staff development/training, new IT facilities, staff time/commitments for process monitoring and control, reporting and documentation.

Hospitals and specialist clinics are autonomous public organizations funded by the central government. In the context of managing the maintenance functions, each organization has its own strategy and policy. Although the developed maintenance management framework is considered sufficiently generic for it to be applied to Saudi healthcare organisations particularly hospitals and clinics, some adjustments may be necessary to allow for differing organisational culture and practices. It would be useful to undertake some comparative studies to assess its relative impact on maintenance management against a range of key performance indicators.

References:

Alaraki, Mohammad Shamsuddin. 2014. “The Impact of Critical Total Quality Management Practices on Hospital Performance in the Ministry of Health Hospitals in Saudi Arabia.” *Quality Management in Healthcare* 23.PP 59-63.

Aleqt. 2012. 90% of Hospital Managers do not have certifications. http://www.aleqt.com/2012/09/25/article_695956.html. Access [on line] Available [accessed 12/3/2014].

Aleqt. 2012. available at [online] *http://www.aleqt.com/a/591420_182372* *[assessed 22/1/2015]*

Afefy, I. H. (2010). Reliability-Centered Maintenance Methodology and Application: A Case Study. *Engineering*, *02*(11), 863–873. doi:10.4236/eng.2010.211109

Ahuja, I.P.S. and Khamba, J.S. (2007), “An evaluation of TPM implementation initiatives in an Indian manufacturing enterprise”, Journal of Quality in Maintenance Engineering, Vol. 13 No. 4, pp. 338-52.

Akcamete, Asli, Burcu Akinci, and James H. Garrett. 2010.Potential utilization of building information models for planning maintenance activities. Proceedings of the international conference on computing in civil and building engineering.W Tizani. Nottingham .UK.

Al-Turki, U. 2011. A framework for strategic planning in maintenance. *Journal of Quality in Maintenance Engineering*, *17*(2), 150–162. doi:10.1108/13552511111134583

Al-Omari, Awad, Hesham S. Abdelwahed, and Mariam A. Alansari.2015. "Critical care service in Saudi Arabia." *Saudi medical journal* 36.6.pp.759-761.

Antony, J., Leung, K., Knowles, G., & Gosh, S. 2002. Critical success factors of TQM implementation in Hong Kong industries. *International Journal of Quality & Reliability Management*, *19*(5), 551–566. doi:10.1108/02656710210427520

Al-Qahtani, S.S. & Al-Methheb, M.M. 1999. Implementation of Total Quality Management in some Saudi Public Sector Organizations. JKA: Econ & Adm, 13(2), 23-38.

Al Masah Capital Management Limited. 2012. GCC Women: Challenging the Status Quo

Al-Hazmi, Mohammed. 2007. Hospital Maintenance, King Fahad Hospital for Example. [online] http://www.alriyadh.com/269651available [accessed 1/5/2014].

Almalki, Mohammed, G. Fitzgerald, and M. Clark. 2011. “Health care system in Saudi Arabia: an overview.” Eastern Mediterranean health journal 17.10.

Alpen Capotal. 2011. GCC Healthcare Industry. [online] available

Al-Sultan, Khaled.1996 Maintenance in Saudi Arabia: needs and recommendations for improvement. Journal of Quality in Maintenance Engineering, Vol. 2 No. 4, 1996, pp. 5-16. © MCB University Press, 1355-2511.

Arabian Business. 2011.http://www.arabianbusiness.com/saudi-build-121-hospitals-as-part-of-new-health-care-plan-403310.html(http://www.tanmia-idaria.ipa.edu.sa/Article.aspx?Id=590 [accessed 20 Jan 2014].

Alriyadh 2011 available at[online]
http://www.alriyadh.com/647710[accessed 12/2/2012]

Ahlmann, H.R. 2002. "From traditional practice to the new understanding: the significance of life cycle profit concept in the management of industrial enterprises", Proceedings of the International Foundation for Research in Maintenance Management and Modelling Va ¨ xjo ¨ Conference (IFRIM-2002), Va ¨ xjo ¨ , Sweden.

Adolfo Crespo Marquez A, Gupta JND. 2003. Modern maintenance management for enhancing organizational efficiency. In: Gupta JND, Sharma S, editors. Intelligent enterprises of the 21st century. Hershey. USA: Idea Group Publishing; PP. 321–32.

Adolfo Crespo Marquez, A., & Gupta, J. N. D. 2006. Contemporary maintenance management: process, framework and supporting pillars. *Omega*, *34*(3), 313–326. doi:10.1016/j.omega.2004.11.003

Adolfo Crespo Márquez, P. Moreu de León, J.F. Gómez Fernández, C. Parra Márquez, M. López Campos. 2009. "The maintenance management framework: A practical view to maintenance management", Journal of Quality in Maintenance Engineering, Vol. 15 Issue: 2, pp.167 - 178

Adolfo Crespo Márquez. 2007. The maintenance management framework : models and methods for complex systems maintenance /. London : Springer

Al-Najjar, B., & Alsyouf, I. 2000. Improving effectiveness of manufacturing systems using total quality maintenance. *Integrated Manufacturing Systems*,*11*(4), 267-276.

Al-Najjar, B. 1996. A n a pp r o a c h f o r c o n t i n u o u s r e du c t i o n i n. *Journal of Quality in Maintenance Engineering*, *2*(3), 4–20.

Allen, Theodore 2010. Introduction to engineering statistics and lean sigma. London, Springe.

Ali Mohammad Mosadegh Rad. 2005."A survey of total quality management in Iran: Barriers to successful implementation in health care organizations", Leadership in Health Services, Vol. 18 Iss: 3 pp. 12 - 34

Ali Mohammad Mosadegh Rad, A. M. 2008. A survey of total quality management in Iran: Barriers to successful implementation in health care organizations. *Leadership in Health Services*, *18*(3), 12–34. doi:10.1108/13660750510611189

Atkin, B. and A. Brooks. 2009. Total facilities management (3rd Ed.). Chichester, UK: Wiley-Blackwell.

Aviad Almagor and Barry Symond. 2015. Building Information Modelling: A New Approach to Design, Quantification, Costing, and Schedule Management with Case Studies.

Balghonaim, Fawziah S. 2010 Establishing TQM Barriers in Saudi Government Hospitals. "Brunel Business School." Doctoral Symposium – 4th & 5th March 2010

Bamber, C.J., Sharp, J.M. and Hides, M. 1999. "Factors affecting successful implementation of total productive maintenance: a UK manufacturing case study perspective", Journal of Quality in Maintenance Engineering, Vol. 5 No. 3, pp. 162-81.

Ben-Daya, M. 2000."You may need RCM to enhance TPM implementation", Journal of Quality in Maintenance Engineering, Vol. 6 No. 2, pp. 82-5.

Berson, Y., & Linton, J. 2005. An examination of the relationships between leadership style, quality, and employee satisfaction in R & D versus administrative environments. *R and D Management*, 35(1), 51- 60.

Brown, M.G., Hitchcock, D. and Willard, M. 1994. Why TQM Fails and What to Do About It, Irwin Professional, Burr Ridge, IL.

Bohoris, G.A., Vamvalis, C., Tracey, W. and Ignatiadou, K. 1995. "TPM implementation in Land-Rover with the assistance of a CMMS", Journal of Quality in Maintenance Engineering, Vol. 1 No. 4, pp. 3-16.

Bourne, M., Neely, A., Mills, J., & Platts, K. 2003. Implementing performance measurement systems : a literature review John Mills and Ken Platts. *International Journal of Business and Management*, *5*(1).

Bossert, J.L. 1991. Quality Function Deployment: A Practitioner's Approach, ASQ Quality Press, Milwaukee, WI.

Bryman, Alan, and Emma Bell. 2011. *Business Research Methods 3rd ed'n.* Oxford University Press.

Breyfogle III, Forrest. W., Cupello, James. M., & Meadows, Becki. 2000. *Managing Six Sigma: a practical guide to understanding, assessing, and implementing the strategy that yields bottom-line success*. John Wiley & Sons.

Bicheno, John. Holweg, Matthias. 2008. The Lean Toolbox: The Essential Guide to Lean Transformation. Picsie Books

Barrett,P. Baldry,D. 2003. Facilities Management: Towards Best Practice, 2nd, Blackwell Science, Oxford.

BIM and FM: Bridging the gap for success.2012. www.bifm.org.uk

BIM Task Group. 2013. *The Government Soft Landings Policy*. http://www.bimtaskgroup.org/gsl-policy-2 (last accessed Sep. 20, 2015).

Becerik-gerber B., Jazizadeh F., Li N., –Calis G.2012. "Application areas and data requirements for BIM-enabled facilities management", *Journal of Construction Engineering and Management* 138: 431-442.

Becerik-Gerber,B. Rice,S. 2010 The perceived value of building information modeling in the U.S. building industry, ITcon 15,185–201.

Bhushan Avsatthi. 2015.http://www.healthcarefacilitiestoday.com/posts/BIM-is-changing-the-healthcare-industry-really-Architecture--9817#sthash.zvqs99C2.dpuf

Campbell, J.D. and Jardine, A.K.S. 2001. Maintenance Excellence, Marcel Dekker, New York, NY.

Campbell, J.D., 1998. Uptime, strategies for excellence in maintenance management. Portland, OR: Productivity Press.

Cattell, R. B. 1966. The scree test for the number of factors. *Multivariate Behavioral Research, 1,* 245-276.

Central Intelligence Agency. 2014. The World Fact book. [Online] Available at https://www.cia.gov/library/publications/the-world-factbook/geos/sa.html[accessed 19 May 2014].

Colliers. 2012. Kingdom of Saudi Arabia Healthcare Overview. [Online] Available http://www.colliers.com/ [Accessed 7/3/2013]

Childs, Joseph A. 2012. "Reliability Design Tools." *Design for Reliability*: 15-35.

Crosby, Philip, 1979. *Quality is Free*. New York: McGraw-Hill

Condra, Lloyd. 2001. *Reliability Improvement with Design of Experiment*. CRC Press.
Coetzee, J.L. (1998), Maintenance, Maintenance Publishers, Hatfield.

Cholasuke, C., Bhardwa, R., & Antony, J. 2004. The status of maintenance management in UK manufacturing organisations: results from a pilot survey. *Journal of Quality in Maintenance Engineering*, *10*(1), 5–15. doi:10.1108/13552510410526820

Codinhoto, R., Tzortzopoulos, P., Kagioglou, M., & Cooper, R. 2008. The impacts of the built environment on health outcomes. doi:10.1108/02632770910933152

Cohen, Louis and Lawrence Manion. 1994 Research methods in Education. London-New York Routledge.

Cotts, D., Roper, K. O., & Payant, R. P. 2009. The facility management handbook. New York, NY: AMACOM.

Chandrupatla, Tirupathi R. 2009. *Quality and reliability in engineering*. Cambridge University Press,

Daniel Coleman 2000. Leadership That Results. Harvard Business Review Product No. 4487

Davis, R. 1997. "Making TPM a part of factory life", TPM Experience (Project EU 1190, DTI, Findlay, sponsored by the DTI.

Deming, W.E. 1982. Quality, Productivity and Competitive Position, MIT Centre for Advanced Engineering Study, Cambridge, MA

Deming, W.E. 1986. Out of Crisis, MIT Centre for Advanced Engineering Study, Cambridge, MA.

Dervitsiotis, K. N. 1998. The challenge of managing organizational change: Exploring the relationship of re-engineering, developing learning organizations and total quality management. *Total Quality Management*, *9*(1), 109–122. doi:10.1080/0954412989306

Dev G Raheja., and Louis J. Gullo, eds. 2012. *Design for reliability*. John Wiley & Sons

Devellis, R.F. 1991. Scale Development: Theory and Applications, Applied Social Research Methods Series, 26, Sage, Newbury Park, CA.

Donabedian, A. 1988. "The quality of care – how can it be assessed?", Journal of American Medical Association, Vol. 260 No. 12, pp. 1743-8.

Duffy, Francis.1990. "Measuring building performance." *Facilities* 8.5 , PP 17-20.

Pintelon, L., & Gelders, L. 1992. Maintenance managment decision making. *European Journal of Operational research, 58,* 301-317. http://dx.doi.org/10.1016/0377-2217(92)90062-E

Easterby-Smith, Thorpe, R. Lowe, A. 2002. Management Research.SAGE.CA Fink, A .1995b The Survey Hand Book. SAGE.CA

England, Stace, 2010. Lean practice: Value-added vs. non-value-added activity Southern Business Journal: http://thesouthern.com/business/local/article_eefc7186-5487-11df-8977-001cc4c002e0.html

Economist Intelligence Unit Limited .2009.The GCC in 2020 The Gulf and its People.[On line] Available at http://graphics.eiu.com/upload/eb/Gulf2020part2.pdf [accessed 12/2/2014].

EN 13306:2001. 2001. Maintenance Terminology. European Standard. CEN (European Committee for Standardization), Brussels.

Fazli, Idris and Ali Khairul Anuar Mohd.2008. "The impacts of leadership style and best practices on company performances: Empirical evidence from business firms in Malaysia." *Total Quality Management* 19, no. 1-2 : 165-173.

Feigenbaum, Armand Vallin 1961. *Total Quality Control*, McGraw-Hill

Freund, York P. 1988. "Critical success factors", Strategy & Leadership, Vol. 16 Iss: 4 pp. 20 - 23

Gallagher, M 1998. Evolution of Facilities Management in the Health care Sectors, Construction Paper No.86, The chartered Institute of Building, Ascot ,PP.1-8

Garg, A., & Deshmukh, S. G. 2006. Maintenance management: literature review and directions. *Journal of Quality in Maintenance Engineering*, *12*(3), 205–238. doi:10.1108/13552510610685075

Gamal Aboelmaged, M. 2011. Reconstructing Six Sigma barriers in manufacturing and service organizations: The effects of organizational parameters. *International Journal of Quality & Reliability Management*, *28*(5), 519-541.

Goldratt, E. 1992, An Introduction to Theory of Constraints: The Production Approach, Goldratt Institute, London.

Gu, Ning and Singh, Vishal and London, Kerry and Brankovic, Ljiljana and Taylor, Claudelle .2008. Adopting building information modeling (BIM) as collaboration platform in the design industry. In: CAADRIA 2008: Beyond Computer-Aided Design : Proceedings of the 13th Conference on Computer Aided Architectural Design Research in Asia, 9-12 April, 2008, Chiang Mai, Thailand.

Goldstein, S.M., Ward, P.T., Leong, G.K. and Butler, T.W. 2002. "The effect of location, strategy, and operations technology on hospital performance", Journal of Operations Management, Vol. 20 No. 1, pp. 63-75.

Gulf Cooperation Council. 2014. The cooperation Council for the Arab states of the Gulf. [Online] Available at http://www.gcc-sg.org/eng/ [accessed 23 May 2014]

Groene O, Kringos D, Sunol R on behalf of the DUQuE Project. 2014. Seven ways to improve quality and safety in hospitals. An evidence-based guide. DUQuE Collaboration, www.duque.eu

Green, M.E. 2000, "Beware and prepare: the government workforce of the future", Public

Personnel Management, Vol. 29 No. 4, pp. 435-44.

Hadfield, D. 2006 The lean Healthcare pocket guide: Tools for the Elimination of waste in Hospitals, Clinics and Other Healthcare facilities. MCS Media, INC.

Hanan, Al-Ahmadi. 2009. "Factors affecting performance of hospital nurses in Riyadh Region, Saudi Arabia",International Journal of Health Care Quality Assurance, Vol. 22 Iss: 1, pp.40 - 54

Hanan, AL-Ahmadi, and Martin Roland. 2005."Quality of primary health care in Saudi Arabia: a comprehensive review." *International Journal for Quality in Health Care* 17, no. 4 : 331-346.

Hamidi, Z. & Zamanparvar, A. 2008. Quality Management in Health Systems of Developed and Developing Countries: Which Approaches and Models are Appropriate? J Res Health, 8 (2), 40-50.

Hair, J.F., Black, W.C., Babin, B.J., Anderson, R.E. and Tatham, R.L. 2006. Multivariate Data Analysis, Pearson Prentice-Hall, Upper Saddle River, NJ

Hassanain MA, Froese TM, Vainer DdJ.2001 Development of maintenance management model based on IAI standards. Artificial Intelligence in Engineering volume15: PP177–93.

Hassanain, Mohammad A., Sadi Assaf, Khalaf Al-Ofi, and Abdullah Al-Abdullah.2013. "Factors affecting maintenance cost of hospital facilities in Saudi Arabia." *Property Management* 31, no. 4: 297-310.

Husby, P. 2007. "Competition or complement: Six Sigma", Material Handling Management, October, pp. 51-5.

Ho, S.K.M., Cicmil, S. and Fung, C.K. 1995. "The Japanese 5-S practice and TQM training", Training for Quality, Vol. 3 No. 4, pp. 19-24.

Hziegler. 2013. http://www.hziegler.com

Herbert, Robinson. Barry, Symonds. Barry, Gilbertson. Benedict, Ilozor. 2015. Design Economics for the Built Environment: Impact of Sustainability on Project Evaluation. John Wiley & Sons, Ltd.

Irani, Z., Beskese, a., & Love, P. E. D. 2004. Total quality management and corporate culture: constructs of organisational excellence. *Technovation*, *24*(8), 643–650. doi:10.1016/S0166-4972(02)00128-1

International Money Fund. 2013. Labor Market Reforms to Boost Employment and Productivity in the GCC. [online] Available: http://www.imf.org/external/np/pp/eng/2013/100513.pdf. [accessed 15 Aug 2014]

Jae-On Kim and Charles W. Mueller. 1978. *Factor Analysis: Statistical Methods and Practical Issues*, by, QASS No. 14

Joppe M. 2000. The research process [on line http://www.ryerson.ca/~mjoppr/rp.htm.access on 15 August 2015]

Juran, J.M. 1999. Juran's Quality Handbook, 5th ed., McGraw-Hill, New York, NY.
Sorqvist, L. 1998. "Poor quality costing", doctoral thesis, Norstedts tryckeri, Stockholm.

Jonsson, P. 1997. "The status of maintenance management in Maintenance Swedish manufacturing firms", Engineering Journal of Quality In Journal of Quality in Maintenance Engineering, Vol. 3 No. 4, pp. 233-58.

Joseph M.Juran. 1951.Quality Control Handbook, New York, New York: McGraw-Hill.

Kaplan, R.S. and Norton, D.P. 1992. "The balanced scorecard – measures that drive performance", Harvard Business Review, Vol. 70 No. 1, pp. 71-9.

Kaplan, R.S. and Norton, D.P. (1996), ``Using the balanced scorecard as a strategic management system'', Harvard Business Review, January-February, pp. 75-84.

Kravchuk, R.S., Leighton, R. 1993. "Implementing total quality management in the United States", *Public Productivity and Management Review*, Vol. 17 No.1, pp.71-82

Kotter, John P.1996. *Leading changes*. Harvard Business Press.

Khoja T, Kabbash I. 1997.Perception of mid-level health managers about primary healthcare implementation obstacles. *Tanta Med J* ; **26**: 841–861.

Khanna, V. K. 2009. 5 "S" and TQM status in Indian organizations. *The TQM Journal*, *21*(5), 486–501. doi:10.1108/17542730910983407

Kwon, S., Chun, C., & Kwak, R. 2011. Relationship between quality of building maintenance management services for indoor environmental quality and occupant satisfaction. *Building and Environment*, *46*(11), 2179–2185. doi:10.1016/j.buildenv.2011.04.028

Kometa, Simon T., Paul O. Olomolaiye, and Frank C. Harris. 1994. "Attributes of UK construction clients influencing project consultants' performance." *Construction management and economics* 12, No. 5 : 433-443.

Krippendorff, Klaus. 2004. Content Analysis: An Introduction to Its Methodology. Thousand Oaks, CA: Sage
Kym Fraser .2014,Facilities management: the strategic selection of a maintenance system. Journal of Facilities Management, Vol. 12 Iss 1 pp. 18 - 37

Kelly, G., Serginson, M., Lockley, S., Dawood, N., Kassem M., Dawood,N., and Kassem,

M. 2013. BIM for facility management: a review and a case study investigating the value and challenges. In: Proceedings of the 13th International Conference on Construction Applications of Virtual Reality, 30-31 October 2013, London, UK.

Lakhe, R.R., Mohanty, R.P., 1994. Total quality management: con-cepts, evolution and acceptability in developing economies. Inter-national Journal of Quality & Reliability Management 11 (9), 9–33.

Lee, W. S., Grosh, D. L., Tillman, F. A., & Lie, C. H. 1985. Fault Tree Analysis, Methods, and Applications, A Review. *Reliability, IEEE Transactions on*, *34*(3), 194-203.

Levitt, J. (1996), Managing Factory Maintenance, Industrial Press Inc., New York, NY.

Leflar, J.A. 2001. Practical TPM: Successful Equipment Management at Agilent Technologies, Productivity Press, Portland, OR.

Maggard, B. and Rhyne, D. 1992. "Total productive maintenance: a timely integration of production and maintenance", Production and Inventory Management Journal, Vol. 33, Fourth Quarter, pp. 6-10.

Martin, E.C., Terblanche, F. 2003. "Building organizational culture that stimulates creativity and innovation", European Journal of Innovation Management, Vol.6 No.1 pp64-74

MSD Magazine.2012. www.magazine.msd.med.sa on line <10/6/2012>

Mcdermott, R., Mikulak, R., & Beauregard, M. 1996. *The basics of FMEA*. New York: Productivity Inc.

Ministry of Health. 2012. Health Statistical Year Book. Saudi Arabia: MOH,.

Ministry of Health. 2014. A media Report on the MOH's Services. [0n line] Available at http://www.moh.gov.sa/en/Ministry/MediaCenterCentre/Publications/Pages/Publications-2014-04-20-001.aspx.[accessed on 10/6/2014]

Mueller, C. J., & Bezella, W. A. 1985. A reliability program approch to operational safety. *Nuclear ENGINEERING AND DESIGN*, *89*, 437–446.

Mukelas, E.M.A Zawawi , S.N. Kamaruzzaman , Z. Ithnin, S. H. Z. 2012. A Review of Critical Success Factors in Building Maintenance Management of Local Authority in Malaysia. *IEEE Symposium on Business, Engineering and Industrial Applications*, 653–657.

Myeda N.E., S.N. Kamaruzzaman, Z.A Samad, E.M.A Zawawi. 2009. Establishing the Key Factors in Measuring Maintenance Management Performance, Proceedings 1st

Regional Symposium on Sustainable Construction Material and Building System (SUCOMBS) 12th October 2009.Boulevard Hotel, Midvalley, Kuala Lumpur.

Motwani, Jaideep. 2001. "Critical factors and performance measures of TQM." *The TQM magazine* 13.4 : 292-300.

Milakovich, M.E. 1992. "Total quality management in the public sector", *National Productivity Review*, Spring, pp.195-213.

Michael Daragh Naughton, Peter Tiernan, 2012. "Individualising maintenance management: a proposed framework and case study", Journal of Quality in Maintenance Engineering, Vol. 18 Iss: 3 pp. 267 - 281

McKinsey & Company. 2012. Gulf Cooperation Council Health Care: Challenges and Opportunities. *Global Competitiveness Reports*.

Mubasher. 2015. Available at[online] http://www.mubasher.info/TDWL/news/2666703/%D9%82%D8%B1%D8%A7%D8%A1%D8%A9-%D8%A3%D9%88%D9%84%D9%8A%D8%A9-%D9%84%D9%84%D9%85%D9%8A%D8%B2%D8%A7%D9%86%D9%8A%D8%A9-%D8%A7%D9%84%D8%B3%D8%B9%D9%88%D8%AF%D9%8A%D8%A9-%D8%B9%D8%A7%D9%85-2015-%D9%88%D9%86%D8%B8%D8%B1%D8%A9-%D8%B9%D9%84%D9%89-%D8%A3%D9%87%D9%85-%D8%A7%D9%84%D8%A8%D9%86%D9%88%D8%AF#.VTQ0j63BzGc[accessed 12/2/2015]

Muthu, S., Devadasan, S.R., Mendonca, P.S. and Sundararaj, G. 2001. "Pre-auditing through a knowledge base system for successful implementation of a QS 9000 based maintenance quality system", Journal of Quality in Maintenance Engineering, Vol. 7 No. 2, pp. 90-104.

McIvor, R.T., Humphreys, P.K. and Aleer, W.E. 1997. "Strategic models for the formulation of an effective make or buy decision", Management Decision, Vol. 35 No. 2, pp. 169-78.

Motawa, Ibrahim. Almarshad, Abdulkareem 2013. A knowledge-based BIM system for building maintenance.

Nakajima, S. 1988. Introduction to TPM: Total Productive Maintenance, Productivity Press Inc, New York, NY.

Naughton, M. D., & Tiernan, P. 2012. Individualising maintenance management: a proposed framework and case study. *Journal of Quality in Maintenance Engineering*, *18*(3), 267–281. doi:10.1108/13552511211265802

Nesje, A.2002."Management, operation and maintenance costs of hospital buildings." *Proceedings of the International Federation of Hospital Engineering, Bergen*..

Nesreen, Alaloola, Waleed, Albedaiwi .2008. Patient satisfaction in a Riyadh Tertiary Care Centre. International Journal of Health Care Quality Assurance Vol. 21 No. 7, pp. 630-637

NIST. 2015. Baldrige quality award program, criteria for performance excellence. Washington, D.C.: National Institute of Standards and Technology (NIST).

Neuendorf, Kimbely 2002. The content analysis guidebook. Thousand Oaks, CA:Sage

ONS.2012. available at [online] http://www.ons.gov.uk/ons/rel/psa/expenditure-on-healthcare-in-the-uk/2012/info-healthcare-spending.html[accessed 12/2/2014].

Osada, T. 1991.The 5-S: Five Keys to a Total Quality Environment, Asian Productivity Organization, Tokyo.

O'Eocha, M. 2000. "Use of 5Ss for environmental management at Cooke Brothers", The TQM Magazine, Vol. 12 No. 5, pp. 321-30.

Palmer, R.H. 1991, "Considerations in defining quality of care", in Palmer, R.H. (Ed.), Striving for Quality in Health Care: An Inquiry into Policy and Practice, Health Administration Press, Ann Arbor, MI, pp. 1-59.

Parida, A. and Kumar, U. 2006. "Maintenance performance measurement (MPM): issues and challenges", Journal of Quality in Maintenance Engineering, Vol. 12 No. 3, pp. 239-51.

Pintelon, L. and Van Puyvelde, F. 1997. "Maintenance performance reporting systems: some experiences", Journal of Quality in Maintenance Engineering, Vol. 3 No. 1, pp. 4-15.

Porras, Jerry I. Stream Analysis. 1987. A Powerful Way to Diagnose and Manage Organizational Change, Prentice Hall.

Pallant, J. F. 2007. SPSS survival manual: A step-by-step guide to data analysis with SPSS.

PSMMS. 2014 available at [online] http://www.psmmc.med.sa/EN/Aboutus/Pages/Vision.aspx[accessed 12/2/2014]

Prince Sultan Military Medical City .2014.Vision and Mission [Online]. Available at: http://www.psmmc.med.sa/AR/pages/default.aspx [Accesses 23 September.2014].

Powell, T.C., 1995. Total quality management as competitive advantage: A review and empirical study. Strategic Man- agement Journal 16 (1), 15–37.

Porwal, Atil. Hewage, Kasun. 2013.Building Information Modeling (BIM) partnering framework for public construction projects. Automation in Construction 31 pp 204–214.

Raouf, A. and Ben-Daya, M. 1995. "Total maintenance management: a systematic approach", Journal of Quality in Maintenance Engineering, Vol. 1 No. 1, pp. 6-14.

Rodrigues, M. and Hatakeyama, K. 2006. "Analysis of the fall of TPM in companies", Journal of Materials Processing Technology, Vol. 179 Nos 1-3, pp. 276-9.

Rosqvist, T., Laakso, K. and Reunanen, M. 2009. "Value-driven maintenance planning for a production plant", Reliability Engineering & Safety System, Vol. 94, pp. 97-110.

Riyadh chamber. 2010. Foreign works in GCC. [Online] Available at http://www.riyadhchamber.org.sa/mainpage/Machinery/Pages/default.aspx

Robson, C. 2002 Real world Research Blackwell. Oxford

Robson, Colin. 2011 Real Work Research. Wiley.UK

Roy Bhaskar. 1989. Reclaiming Reality: A Critical Introduction to Contemporary Philosophy, by. London, UK: Verso,. 218pp. ISBN:086091951X.

Rebekka Volk,. Julian Stengel, Frank Schultmann. 2014. Building Information Modeling (BIM) for existing buildings — Literature review and future needs. Automation in Construction. Issue 38 pp.109–127

RICS, RICS BIM Survey Results, The Royal Institute of Charted Surveyors, 2013.

Robert Eadie,. Tim McLernon, Adam Patton,.2015. AN INVESTIGATION INTO THE LEGAL ISSUES RELATING TO BUILDING INFORMATION MODELLING (BIM)

Sadi, Assaf. Mohammad A. Hassanain, Abdul-Mohsen Al-Hammad, and Ahmed Al-Nehmi. 2011."Factors affecting outsourcing decisions of maintenance services in Saudi Arabian universities." *Property Management* 29, no. 2 : PP195-212.

Salonen, A., & Deleryd, M. 2011. Cost of poor maintenance. *Quality in Maintenence Enginering*, *17*(1), 63–73. doi:10.1108/13552511111116259

Sharma, R. K., & Sharma, P. 2010. System failure behavior and maintenance decision making using , RCA , FMEA and FM. *Journal of Quality in Maintenance Engineering*, *16*, 64–88. doi:10.1108/13552511011030336

Sharp, J.V., Kam, J.C. and Birkinshaw, M. 1993. "Review of criteria for inspection and maintenance of Donabedian, A. (1988). Quality assessment and assurance: Unity of purpose, diversity of means. Inquiry, 25(1), 175–192. North Sea structures", OMAE Conference, Glasgow, 20-24 June.

Saraph, J.V, Benson, G, Schroeder, R.G .1989. "An instrument for measuring the critical factors of quality management", Decision Sciences, Vol.20 No.4 pp810-29

Sharp, John M., Zahir N. Irani, T. Wyant, and N. Firth. .1997."TQM in maintenance to improve manufacturing performance." In *Innovation in Technology Management-The Key to Global Leadership. PICMET'97: Portland International Conference on Management and Technology*, pp. 811-814. IEEE.

Shohet, Igal M., Sarel Lavy-Leibovich, and Dany Bar-On. 2002. Integrated maintenance management of hospital buildings in Israel. Proceedings of the 17th International Symposium of the international Federation of Hospital Engineering.

Shohet Igal M., Sarel Lavy, 2004."Healthcare facilities management: state of the art review", Facilities, Vol. 22 Iss: 7 pp. 210 – 220

Shohet, Igal M.2006. "Key performance indicators for strategic healthcare facilities maintenance." *Journal of Construction Engineering and Management* 132.4 PP 345-352.

Swanson, L. 1997. "An empirical study of the relationship between production technology and maintenance management", International Journal of Production Economics, Vol. 53 No. 2, pp. 191-207.

Smith, Ricky, and R. Keith Mobley.2011. *Rules of thumb for maintenance and reliability engineers*. Butterworth-Heinemann.

Shingo, Shigeo. 1989. *A study of the Toyota production system: From an Industrial Engineering Viewpoint*. Productivity Press.

Santos, J. R. A. 1999. Cronbach's alpha: A tool for assessing the reliability of scales. *Journal of extension*, *37*(2), 1-5.

Saunders, M., Lewis, P, & Thornhill, A. 2003. Research method for business students, 3rd edition. New York: Prentice Hall.

Scheinkop, Lisa J.1999. Thinking for a Change: Putting the TOC Thinking Processes to Use. St. Lucie Press. New York

Stewart, D.W. and Shamdasani, P.N.1990. Focus Groups: Theory and Practice. Newbury Part, CA:Sage.

Sarah Delany2015. Building Information Modelling: the holy grail?http://www.thenbs.com/topics/bim/articles/buildingInformationModelling.asp

Stephen Hamil.2015. What BIM is and how it is being used. http://www.thenbs.com/pdfs/What_BIM_is_and_how_it_is_being_used.pdf
Bedrick, J. 2008. Organizing the development of a building information model, AECbytes Feature

Todinov, M.T. 2006. "Reliability analysis based on the losses from failures", Reliability Analysis, Vol. 26 No. 2, pp. 311-35.

Tsang, A.H.C., Jardine, A.K.S. and Kolodny, H. 2002. “Measuring maintenance performance: a holistic approach”, Journal of Quality in Maintenance Engineering, Vol. 19 No. 7, pp. 691-715.

Takata, S., Kimura, F., Van Houten, F. J. A. M., Westkamper, E., Shopitalni, M., Ceglarek, D., & Lee, J. 2004. Maintenance: changing role in life cycle management. *CIRP Annals - Manufacturing Technology Volume 53, Issue 2, 2004, Pages 643–655*, *53*(2), 643–655. Retrieved from http://www.sciencedirect.com/science/article/pii/S000785060760033X

Tanmia-Idaria. 2013. Foreign works risk trapped Gulf Society.

Tabachnick, B.G., Fidell, L.S., 2001. Using Multivariate Statistics. Allyn and Bacon, Boston, MA.

The Economist Intelligence Unit Limited, 2009. The GCC in 2020

Teicholz, P. 2013. *BIM for Facility Managers*. New Jersey, U.S.: John Wiley & Sons.

UNDP. 2011. Human Development Report, Sustainability and Equity: A Better Future for All United Nations Development Program 1 UN Plaza, New York, NY 10017, USA

US-SABC. 2015 available at] http://www.us sabc.org/i4a/pages/index.cfm?pageid=4251[online] [accessed 12/2/2013]

Vasseur, D. and Llory, M. 1999. “International survey on PSA figures of merit”, Reliability Engineering & System Safety, Vol. 66 No. 3, pp. 261-74.

Vanneste, S.G. and van Wassenhove, L.N. 1995. “An integrated and structured approach to improve maintenance”, European Journal of Operational Research, Vol. 82, pp. 241-57.

Vatn, J., Hokstad, P. and Bodsberg, L. 1996. “An overall model for maintenance optimization”, Reliability Engineering and System Safety, Vol. 51, pp. 241-57.

Viera Wardhani, Adi Utarini, Jitse Pieter van Dijk, Doeke Post, and Johan Willem Groothoff. 2009. "Determinants of quality management systems implementation in hospitals." *Health policy* 89, No. 3. PP239-251.

Zawawi, E. M. A., Kamaruzzaman, S. N., Ithnin, Z., & Zulkarnain, S. H. 2011. A conceptual framework for describing CSF of building maintenance management. *Procedia Engineering*, *20*, 110-117.

Waeyenbergh, Geert, and Liliane Pintelon. 2002."A framework for maintenance concept development." *International journal of production economics* 77.3 : 299-313

Wireman T. 1998. Developing performance indicators for managing maintenance. New York: Industrial Press; .

Willmott, P. (1994), “Total quality with teeth”, The TQM Magazine, Vol. 6 No. 4, pp. 48-50.

Walston, Stephen L., Badran A. Al-Omar, and Faisal A. Al-Mutari. 2010. “Factors affecting the climate of hospital patient safety: a study of hospitals in Saudi Arabia.” International journal of health care quality assurance 23.1: 35-50.

World Bank. 2013. Population Growth Annual available at http://data.worldbank.org/indicator/SP.POP.GROW [online] [accessed 12/2/2013]

WHO.2008: The World Health Report

WHO.2013 The World Health Report

Yamane, Taro. 1967. *Statistics: An Introductory Analysis*, 2nd ed’n., New York: Harper and Row.

Youngsoo Jung. Joo, Mihee. 2011 "Building information modelling (BIM) framework for practical implementation." Automation in Construction 20.2 (2011): 126-133

Yusuf Arayici, Timothy Onyenobi, Charles Egbu,.2012. Building Information Modelling (BIM) for Facilities Management (FM): The Mediacity Case Study Approach . 56 International Journal of 3-D Information Modeling, 1(1), 55-73

Appendix I

Questionnaire 1

To what extent Implementing of Total productive Maintenance(TPM) in a Hospital could improve maintenance procedures

General information

1) What is your department?

- Maintenance
- Operator

2) What is your job title?

- Manager
- Engineer
- Supervisor
- Technician
- Helper

3) Are you happy in your work?

- Yes
- No
- satisfy

4) Do you deal with equipment?

- Yes
- No

5) Do you negotiate with a group of technician to solve a problem?

- Always
- Sometimes
- Rarely
- Never

6) Is there any kind of support the supervising provides it to you?

- Yes
- No
- When I ask
- If there is a big problem

7) Is there a cooperation between Maintenance and Operation Department?

- ◯ Always
- ◯ Sometimes
- ◯ Rarely
- ◯ Never

8) Is there a promotion or increment give to operation to do regular maintenance?

- ◯ Yes
- ◯ No

9) Is there a training program for operators to understand how to maintain equipment?

- ◯ ALL equipment
- ◯ Most equipment
- ◯ The critical one
- ◯ Never

Maintenance policy and procedure

10) Is there a standardisation for maintenance jobs?

- ◯ Yes
- ◯ No

11) Are your responsibilities clear?

- ◯ Yes
- ◯ No
- ◯ To an extents

12) As you are one of the maintenance team, do you have full information about the equipment you are going to fix?

- ◯ Yes
- ◯ No
- ◯ Sometimes

13) If you operate equipment, Do you have knowledge to maintain it ?

- ◯ Yes
- ◯ No
- ◯ To an extent

14) Which type of maintenance program use ? select more than one answer if need

- Corrective Maintenance
- Periodic Maintenance
- Preventive Maintenance
- Other

15) Is there a cooperation between Maintenance, Operation and Technical Affair Departments?

- Formal
- Informal
- Formal/Informal
- None

16) Is there any cooperation between Technician and Engineers?

- Yes
- No

17) Is there any cooperation between Technician and Managers?

- Yes
- No

18) Is there any cooperation between Manager and Engineers?

- Yes
- No

19) Is there a time need to prepare the equipment before it is operated again?

- Yes
- No

20) Do sometimes equipment faults recur frequently?

- No
- Yes

21) Is there a quick response to repair an equipment fault?

- Always
- Sometimes
- Rarely
- Never

Maintenance and Operation Responsibilities

22) Can you recognise any fault earlier before breakdown?

- ◯ Yes
- ◯ NO
- ◯ Sometimes
- ◯ Rarely

23) If you identifying a problem change the usual operating condition such as a change in the speed, noise, etc, do you stop the equipment immediately?

- ◯ Yes
- ◯ NO

24) As you are one of maintenance team, do you often repair the fault and run the equipment or check the cause of breakdown?

- ◯ Only repair the fault
- ◯ check the cause of the breakdown and repair the cause

25) Do you able to recognize any fualt earlier?

- ◯ Yes
- ◯ NO
- ◯ Sometimes
- ◯ Rarely

26) If you one of the maintenance team, Do you have any problem if an operator does minor maintenance to an equipment?

- ◯ Yes
- ◯ NO
- ◯ NO if he ask
- ◯ No if he Knows to do that?

27) if you one of maintenance team, do you feel that there it is waste of time to do a simple maintenace task for an equipment rather than postpone important tasks?

- ◯ Yes
- ◯ No

28) As you an operator, do you often leave the equipment to run with a fault or stop it immediately?

- ◯ Yes

No

29) As you an operator, equipment has a breakdown: do you repair the fault direct or search what is the main cause?

Repair it only

Check what is the causes

30) Do you often run equipment in abnormal satiation e.g. guards left off machine?

Always

sometimes

Rarely

Never

Maintenance Facilites

31) Are spare parts available in the warehouse?

Always

sometimes

Rarely

Never

32) Do you have drawings and catalogues of all equipment?

Yes

Most of them

Some of them

None

33) In any emergency, do you reach to these drawings easily?

Yes

No

34) Do you have history log book for all organisation equipment ?Tick more than one answer?

Yes

No

Not all, the critical one

not all, the expensive one

35) Do you use a computerised system in maintenance tasks?

- ○ Yes
- ○ No

36) Is that system up to date?

- ○ New
- ○ More than a year
- ○ More than 3 years
- ○ More than 5 years
- ○ others

37) Do you have a suitable tool in maintenance department?

- ○ Yes
- ○ No
- ○ almost

38) What is the condition of these tools?

- ☐ New
- ☐ Like new
- ☐ Old
- ☐ Broken

39) Do you keep these tools in a suitable location?

- ☐ Yes
- ☐ No
- ☐ Take long time to find it
- ☐ a special box

Thank You!

Thank you for taking our survey. Your response is very important to the research.

Appendix II

Questionnaire 2

The effect of Organisational Culture & Leadership Behaviours in improving Maintenance Management effectiveness in Healthcare Organisations

General information

You are invited to participate in a study of organisational culture and leadership behaviours conducted by a doctoral student of Nottingham Trent University in partial fulfilment of degree requirements. In this survey, questions about the Goal and objectives in their organisation as well as behaviours of mangers and hospital engineer in dealing with maintenance action in a hospital. It will take only a few minutes to complete the questionnaire. All survey responses recorded are anonymous. Data from this survey will only be reported in the aggregate. You do not have to give your home or reveal any information which makes you directly identifiable. Your participation in this study is completely voluntary. You have not been coerced into completing the survey associated with this project. If you feel uncomfortable answering any questions, you can withdraw from the survey at any point. Remember, your responses are anonymous. It is very important for us to learn your opinions. Completion of the survey will have no direct individual impact either in gain or loss as all data collected is to be aggregated and reported only in summarised form. If you have questions at any time about the survey or the procedures, you may contact Hesham alzaben, principal researcher for this study at 00966505154329 or by email at n0240543@ntu.ac.uk. Thank you very much for your time and support. The survey is in three parts and will only take a few minutes of your time. Please start with the survey now by clicking on the Continue button below.

1) Age Group:

- ☐ Under 21
- ☐ 21-29
- ☐ 30-35
- ☐ 36-40
- ☐ 41-50
- ☐ 46-50
- ☐ 51-55
- ☐ 56+

2) Education

- ○ Did not Finish High School
- ○ High School
- ○ Diploma
- ○ Some College, No Bachelor's Degree
- ○ Bachelor's Degree

Some Graduate Work

Graduate Degree

3) Tenure: Please enter the number of years of work experience you have in the following categories. With your current employer:

4) Tenure: Please enter the number of years of work experience you have in the following categories: With your previous employer:

Organizational culture and leadership behaviours

5) I always retain the final decision making authority within my department or team.

Never True   Rarely True   Sometimes True   Always True
Not Applicable

6) I always try to include one or more employees in determining what to do and how to do it. However, I maintain the final decision making authority.

Never True   Rarely True   Sometimes True   Always True
Not Applicable

7) My employees and I always vote whenever a major decision has to be made.

Never True   Rarely True   Sometimes True   Always True
Not Applicable

8) I do not consider suggestions made by my employees, as I do not have the time for them

Never True   Rarely True   Sometimes True   Always True
Not Applicable

9) I ask for employee ideas and input on upcoming plans and projects.

Never True   Rarely True   Sometimes True   Always True
Not Applicable

10) For a major decision to pass in my department, it must have the approval of each individual or the majority.

Never True   Rarely True   Sometimes True   Always True
Not Applicable

11) I tell my employees what has to be done and how to do it.

Never True   Rarely True   Sometimes True   Always True
Not Applicable

12) When things go wrong and I need to create a strategy to keep a project or process running on schedule, I call a meeting to get my employee's advice

Never True Rarely True Sometimes True Always True Not Applicable

13) To get information out, I send it by email, memos, or voice mail

Never True Rarely True Sometimes True Always True Not Applicable

14) When someone makes a mistake, I tell him or her not to do that again and make a note of it.

Never True Rarely True Sometimes True Always True Not Applicable

15) I allow my employees to determine what needs to be done and how to do it

Never True Rarely True Sometimes True Always True Not Applicable

16) My workers know more about their jobs than me, so I allow them to carry out the decisions to do their job.

Never True Rarely True Sometimes True Always True Not Applicable

17) I delegate tasks in order to implement a new procedure or process.

Never True Rarely True Sometimes True Always True Not Applicable

18) My employees can lead themselves just as well as I can.

Never True Rarely True Sometimes True Always True Not Applicable

19) I would let the members do their work the way they think best

Never True Rarely True Sometimes True Always True Not Applicable

20) I would refuse to explain my actions

Never True Rarely True Sometimes True Always True Not Applicable

21) I would encourage the use of uniform procedures

Never True Rarely True Sometimes True Always True Not Applicable

---

Organisational Behaviour

22) I get enough support to complete my task

◯ Never True ◯ Rarely True ◯ Sometimes True ◯ Always True
◯ Not Applicable

23) I know the organisation strategy?

◯ Never True ◯ Rarely True ◯ Sometimes True ◯ Always True
◯ Not Applicable

24) I understand the vision and the mission of my organisation

◯ Never True ◯ Rarely True ◯ Sometimes True ◯ Always True
◯ Not Applicable

25) You need to be supervised closely or you are not likely to complete the work

◯ Never True ◯ Rarely True ◯ Sometimes True ◯ Always True
◯ Not Applicable

26) You need to be supervised closely for you to preform satisfyingly

◯ Never True ◯ Rarely True ◯ Sometimes True ◯ Always True
◯ Not Applicable

27) You want to be part of the decision making process

◯ Never True ◯ Rarely True ◯ Sometimes True ◯ Always True
◯ Not Applicable

28) In complex situation, your boss lets subordinates work problems out in their work

◯ Never True ◯ Rarely True ◯ Sometimes True ◯ Always True
◯ Not Applicable

29) Leadership requires staying out of the way of subordinates as they do their work

◯ Never True ◯ Rarely True ◯ Sometimes True ◯ Always True
◯ Not Applicable

30) As a rule, employees must be given rewards or punishments in order to motivate them to achieve organisational objectives

◯ Never True ◯ Rarely True ◯ Sometimes True ◯ Always True
◯ Not Applicable

31) You want frequent and supportive communication from your boss

◯ Never True ◯ Rarely True ◯ Sometimes True ◯ Always True
◯ Not Applicable

32) Your boss gives you complete freedom to solve problems on your own

◯ Never True ◯ Rarely True ◯ Sometimes True ◯ Always True
◯ Not Applicable

33) You have clear responsibility and clear procedures.

○ Never True ○ Rarely True ○ Sometimes True ○ Always True
○ Not Applicable

34) In most situations, you prefer to receive precise orders rather than little input from the leader.

○ Never True ○ Rarely True ○ Sometimes True ○ Always True
○ Not Applicable

35) In this organisation, people protect themselves above all else.

○ Never True ○ Rarely True ○ Sometimes True ○ Always True
○ Not Applicable

36) There is no encouragement for innovation

○ Never True ○ Rarely True ○ Sometimes True ○ Always True
○ Not Applicable

37) There is no room for one's own personal morale

○ Never True ○ Rarely True ○ Sometimes True ○ Always True
○ Not Applicable

38) People here are expected to do anything to provide the best service to the patient, regardless of the consequences.

○ Never True ○ Rarely True ○ Sometimes true ○ Always True
○ Not Applicable

39) Successful people in this hospital are those who follow legal or professional standards.

○ Never True ○ Rarely True ○ Sometimes True ○ Always True
○ Not Applicable

40) My supervisor would use my mistakes to attack me personally.

○ Never True ○ Rarely True ○ Sometimes True ○ Always True
○ Not Applicable

41) My supervisor would risk me to protect himself / herself in work matters.

○ Never True ○ Rarely True ○ Sometimes True ○ Always True
○ Not Applicable

42) My supervisor would allow me to be blamed for his / her mistakes.

○ Never True ○ Rarely True ○ Sometimes True ○ Always True
○ Not Applicable

43) My supervisor avoids coaching me because he / she wants me to fail.

Never True   Rarely True   Sometimes True   Always True
Not Applicable

44) My supervisor deliberately makes employees angry at each other.

Never True   Rarely True   Sometimes True   Always True
Not Applicable

45) My supervisor would limit my training opportunities to prevent me from advancing

Never True   Rarely True   Sometimes True   Always True
Not Applicable

46) My organization is willing to help me when I need a special favour.

Never True   Rarely True   Sometimes True   Always True
Not Applicable

47) I am proud to tell others I work at my organization

Never True   Rarely True   Sometimes True   Always Tru
Not Applicable

48) My organization gives recognition for good work

Never True   Rarely True   Sometimes True   Always True
Not Applicable

49) Meetings are frequently held to discuss work problems with my co-workers and me.

Never True   Rarely True   Sometimes True   Always True
Not Applicable

50) My supervisor shows very little concern for me.

Never True   Rarely True   Sometimes True   Always True
Not Applicable

51) There is a clear link between departments

Never True   Rarely True   Sometimes True   Always True
Not Applicable

52) There is a clear Path for advancement on my organization structure

Never True   Rarely True   Sometimes True   Always True
Not Applicable

53) Emergency work is always more than Scheduled work,

Never True   Rarely True   Sometimes True   Always True
Not Applicable

54) There is a clear timetable

○ Never True ○ Rarely True ○ Sometimes True ○ Always True
○ Not Applicable

55) Long-term plan is always more than Short-term plan,

○ Never True ○ Rarely True ○ Sometimes True ○ Always True
○ Not Applicable

56) There is always over time, or cover others' shifts, because of Shortage of staff

○ Never True ○ Rarely True ○ Sometimes True ○ Always True
○ Not Applicable

57) Delay in service happens as a consequence of :

☐ Shortage of Staff

☐ Uncertainty of Instructions

☐ Unclear Policy & Procedure

☐ No motivation

☐ Shortage of Resources (Medicine, spare part, Linen, Tool, etc,)

58) My organization provide access to the data when ever it needs

○ Never True ○ Rarely True ○ Sometimes True ○ Always True
○ Not Applicable

59) Standby power, contingency plan, emergency plan, and/or evacuation plan are available in case of emergency

○ Never True ○ Rarely True ○ Sometimes True ○ Always True
○ Not Applicable

60) Budget limitation affects my job or performance

○ Never True ○ Rarely True ○ Sometimes True ○ Always True
○ Not Applicable

61) Different maintenance regimes are used

○ Never True ○ Rarely True ○ Sometimes True ○ Always True
○ Not Applicable

62) Most of our maintenance staff is qualified

○ Never True ○ Rarely True ○ Sometimes True ○ Always True
○ Not Applicable

63) Maintenance staff has the skills to accomplish their duties.

- Never True
- Rarely True
- Sometimes True
- Always True
- Not Applicable

64) Maintenance staff co-operate with workers to accomplish routine or emergency work

- Never True
- Rarely True
- Sometimes True
- Always True
- Not Applicable

65) A worker gets quick support from other colleagues or any one in higher position?

- Never True
- Rarely True
- Sometimes True
- Always True
- Not Applicable

66) A worker gets quick support from other colleagues or any one in lower position?

- Never True
- Rarely True
- Sometimes True
- Always True
- Not Applicable

67) The current process meets the organization's objectives / department

- Never True
- Rarely True
- Sometimes True
- Always True
- Not Applicable

68) The current processes lead to added value

- Never True
- Rarely True
- Sometimes True
- Always True
- Not Applicable

69) The current processes lead to redundancy reduction

- Never True
- Rarely True
- Sometimes True
- Always True
- Not Applicable

70) The current processes lead to waste elimination

- Never True
- Rarely True
- Sometimes True
- Always True
- Not Applicable

71) I have the capability, ability and knowledge to perform the work?

- Never True
- Rarely True
- Sometimes True
- Always True
- Not Applicable

72) The organizations I work with follow the safety procedures effectively and do not allow any one to harm himself/herself.

- Never True
- Rarely True
- Sometimes True
- Always True
- Not Applicable

Thank you for taking our survey. Your response is very important to the research.

Appendix III

Interview Questions

Q1: What's your assessment of the existing level of maintenance?

Q2: From your opinion how can maintenance procedures be developed? and how can faults be minimized?

Q3: The existence of cooperation between departments would help in raising the morale of the maintenance crew as a whole. Do you see that as important?

Q4: Many managers believe that the lack of interest in departments is the top cause of deterioration of maintenance, what are the issues you see as obstacles in maintenance improvement?

Q5: As part of the maintenance department team, do you see the need for the operators to conduct minor maintenance jobs? Would you be willing to be responsible for their training to achieve that?

Q6: In order to have identified ranking of factors affecting on providing a maintenance management system, could you choose which options reflect your answer?

Q7: Factoring affecting on hospital maintenance management system

Choose of the following answer:
Extremely important, Very important, Important, Some what important, Not important

- Top management support leads to provide high maintenance services to hospital facilities and patients
- Need for organization structure to show department connection clearly
- Clarity of policies and procedures
- Having employees with high technical skills
- The clarity of the maintenance contract
- The existence of frequent training programmes
- Promoting teamwork and sharing of information and experiences
- Maintenance strategies compatible with the organization's goals.
- Employees working according to their qualifications and job descriptions
- Good performance management indicators
- A good motivation system
- The need to respect the efforts of maintenance workers
- Achieving customer satisfaction
- Attention to the mental well-being of staff and their morale
- Need to pay attention to change management
- Good modern information systems
- Limit out-sourcing of maintenance work

Factors affeting hospital maintenanace managenet system

Page One

1. دعم الادارة العليا ضروري لنجاح تطوير نظام الصيانة وتذليل عقبات التطبيق وايضاح اهمية وجود نظام صيانة ذوكفاءة عاليه لتحقيقاهداف المنظمة من ناحية التاكد من ايصال الرعاية الصحية للمريض و تقليل الاعطال والتكاليف *

Extremely important	Very important	Important	Some what important	No important
○	○	○	○	○

2. وجود هيكل اداري للمنظمة يحدد التسلسل الهرمي او الافقي للادارات *

Extremely important	Very important	Important	Some what important	No important
○	○	○	○	○

3. وضوح السياسيات والاجراءات لكل قسم مع وجوب معرفة كل موظف بالعمل المناط به ومسؤلياتة *

Extremely important	Very important	Important	Some what important	No important
○	○	○	○	○

4. وجود نظام تدريبي مستمر لجميع افراد الصيانة اما خارجي او داخلي *

Extremely important	Very important	Important	Some what important	No important
○	○	○	○	○

5. ضرورة الاهتمام بادارة التغير وكيفية تطبيقها لتقليل مقاومة التغير وان هذا التغير يحقق مصلحة المنظمة وان الظروف الحاليه تتطلب التحسين والتطوير *

Extremely important	Very important	Important	Some what important	No important
○	○	○	○	○

6. وجود خطة استراتيجة للصيانه تتماشى مع اهداف المنظمة *

- ○ Extremely important
- ○ Very important
- ○ Important
- ○ Some what important
- ○ No important

7. وجود موظفين يتمتعون بمهارات فنية عالية ويملكون القدرة على ادارة الصيانة واصلاح الاعطال *

- ○ Extremely important
- ○ Very important
- ○ Important
- ○ Some what important
- ○ No important

8. وجوب وجود العدد الكافي من الموظفين والتاكد بانهم يعملون وفق امكانيتهم والوظفية التي يشغرونها بما يتاسب مع مؤهلاتهم *

Extremely important	Very important	Important	Some what important	No important
○	○	○	○	○

9. عدم الاعتماد على عمالة خارجية لاصلاح الاعطال وتنمية مهارتة الموظفين الموجودين وتوظيف موظفين يحققون اهداف الصيانة *

Extremely important	Very important	Important	Some what important	No important
○	○	○	○	○

10. الاهتمام بالنواحي النفسية والمعنوية للموظفين *

Extremely important	Very important	Important	Some what important	No important
○	○	○	○	○

11. وجود نظام حوافز يشجع على الابداع والتحسين يشمل زيادات سنوية ومكافئات *

Extremely important	Very important	Important	Some what important	No important
○	○	○	○	○

12. وجود انظمة معلومات حديثة تساعد على التواصل بين الموظفين (اجهزة اتصال سلكية ولاسلكية) ومراقبة الاجهزة والتحكم بها وادارة اعمال الصيانة كنظام ادارة المباني *

Extremely important	Very important	Important	Some what important	No important
○	○	○	○	○

13. ضرورة احترام جهود اعمال الصيانة وتوفير الدعم لهم من قبل الادارة العليا ودعم رؤساء الاقسام والاطباء *

Extremely important	Very important	Important	Some what important	No important
○	○	○	○	○

14. وجود مقاييس لمؤشرات الاداء بحيث يمكن قياس اداء الموظفين والاعطال وكفاءة الاجهزة والعمل على تحسينها *

Extremely important	Very important	Important	Some what important	No important
○	○	○	○	○

15. التشجيع على العمل الجماعي وتبادل المعلومات والخبرات *

Extremely important	Very important	Important	Some what important	No important
○	○	○	○	○

16. تحقيق رضاءالزبون بمايشمل المرضى والمرافقين والموظفين من اطباء وممرضين واداراين *

Extremely important	Very important	Important	Some what important	No important
○	○	○	○	○

17. وضوح عقد الصيانة بمايشمل عدد موظفي العقد ورواتبهم ومؤهلاتهم

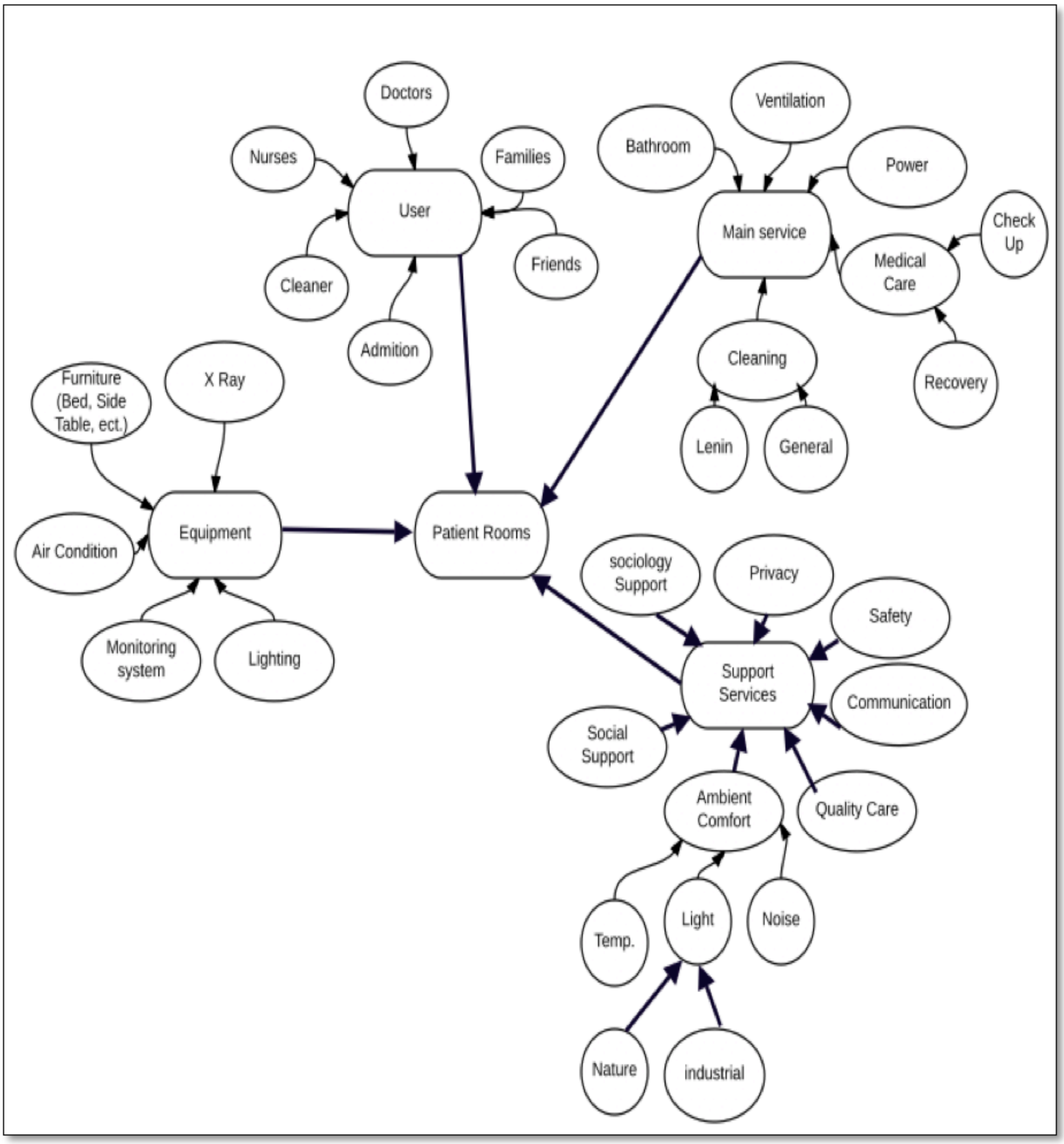
Extremely important	Very important	Important	Some what important	No important
○	○	○	○	○

Thank You!

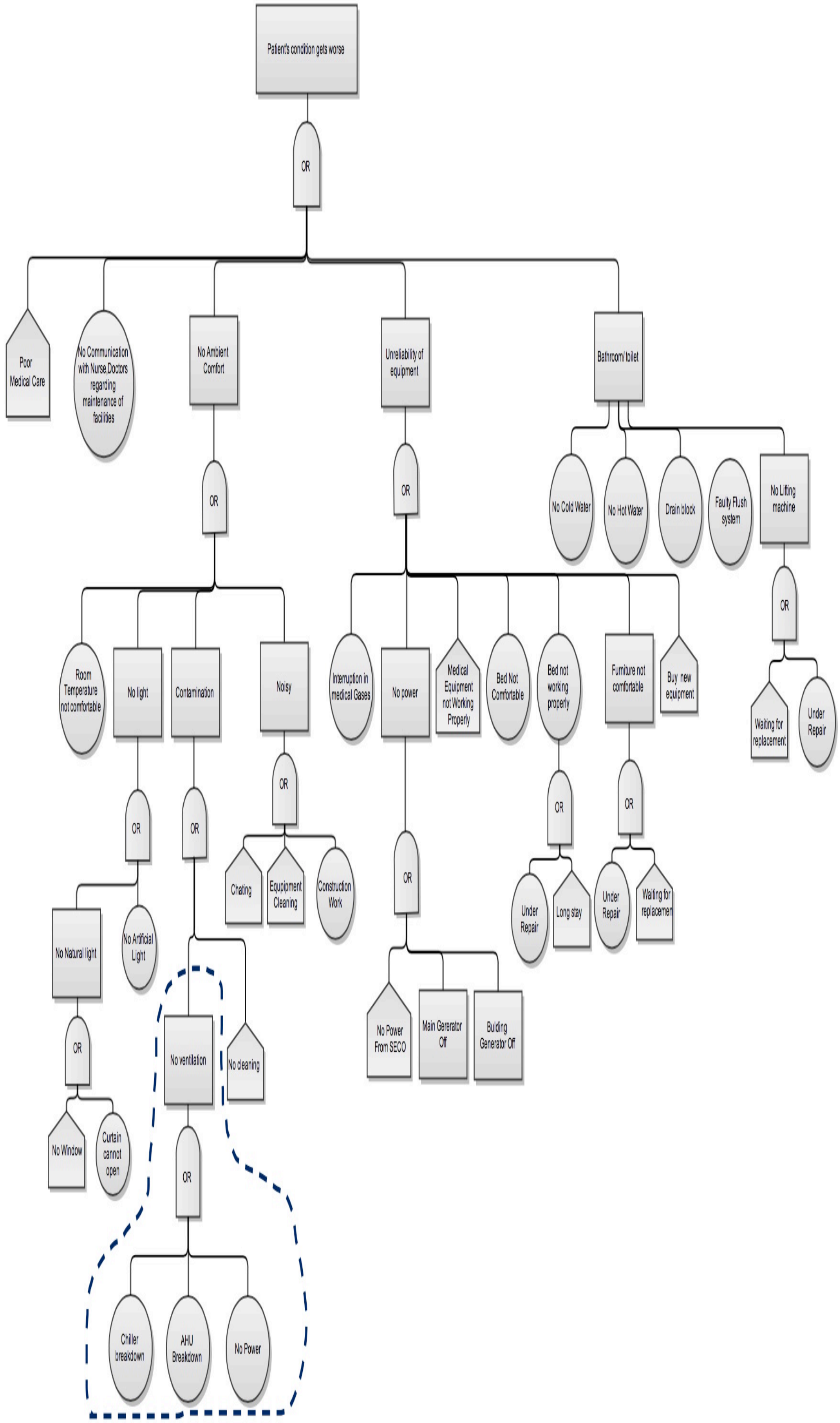
Thank you for taking our survey. Your response is very important to us.

Appendix IV

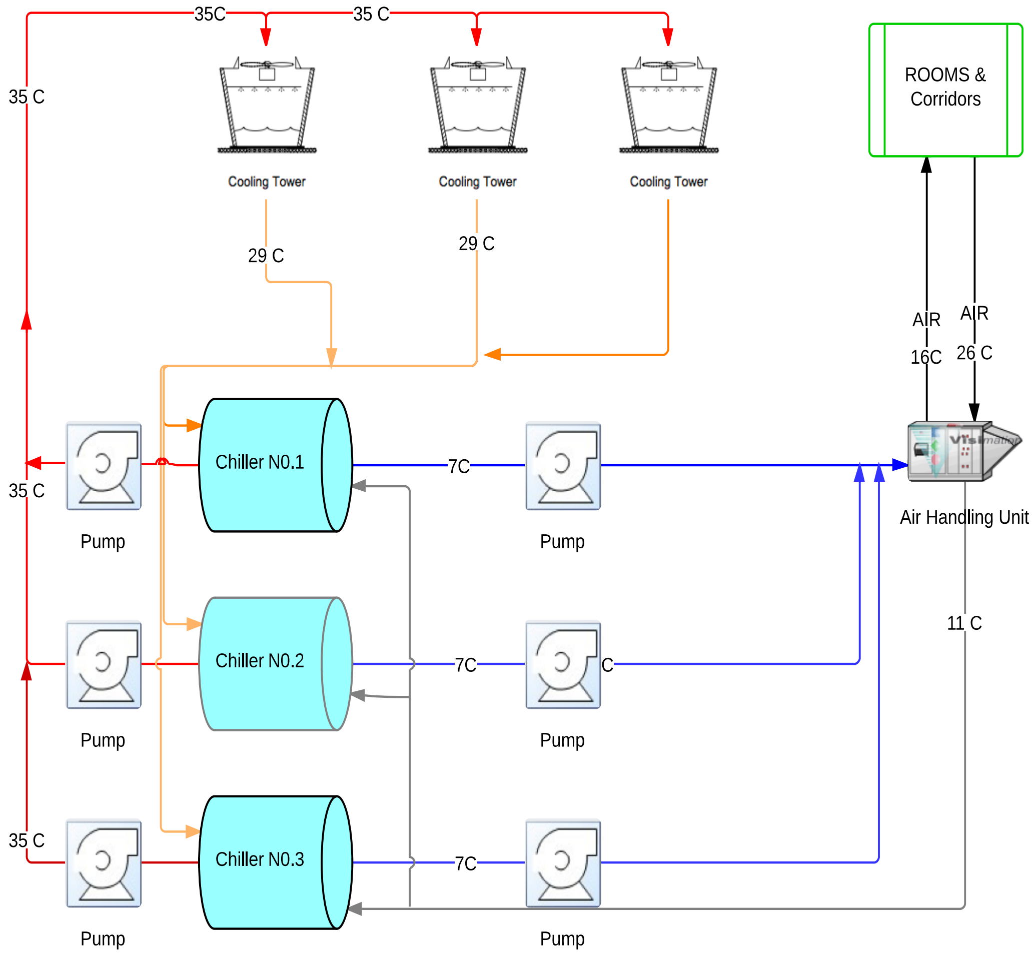
Reliability tools and calculation



Requirements for patients' rooms



Fault Tree Analysis of factors affecting the wellbeing of patients



A block diagram of the ventilation system at RMH

DATE		15/03/2014	20/02/2014	23/01/2014	16/03/2014	16/03/2014	20/03/2014	23/03/2014
LOCATION	Building	100	120	44	1	70	100	100
	AREA	THEATER	PARKING	GF	ONCOLOGY	A&E	W33 /R2	1F ENDESCOPEY
DOCKET		146776	142176	136497	146864	146891	148292	148511
DESCRIPTION OF WORK		PVC TILES BROKEN	POLE BROKEN	FLOOR TILES	INSTAL NEW WATER MIXER	FIX DRAIN LINE PIPE		REPAIR WATER MIXER
TIME	Complaint SEND To CCS	11.58.	09.05.	10.44.	08.00.	08.20.	13.00.	08.05.
	Complaint SEND TO SUPERVISOR	12.02.	09.10.	10.46.	08.05.	08.25.	13.05.	08.07.
	GOING TO REPAIR THE FUALT	12.18.	09.15.	10.49.	08.10.	08.30.	13.07.	08.10.
	CHECK WORK	12.35.	09.25.	10.51.	08.15.	08.35.	13.10.	08.15.
	TECHNICIAN TELL SUPERVISOR WORK NEED SPARE PARTS	12.50.	09.40.	10.55.	08.20.			08.20.
	SPARE PARTS TAKES FROM STORE			13.00.	08.25.			08.25.
	SUPERVISOR WRITE MSR		09.20.	11.10.	08.30.			08.30.
	MSR SEND TO BUYER		09.50.	11.20.	08.35.			09.30.
	PARTS ARRIVEL			12.55.	09.30.			09.35.
	START WORK	01.40.	07.30.	13.15.	09.35.	08.40.	13.12.	09.45.
	Complete Work	16.00.	09.20.	10.10.	10.30.	09.00.	13.32.	10.05.
	Back to workshop	16.15.	09.35.	10.25.	10.40.	09.10.	13.40.	10.15.
Name			2 TECH	4 TECH	1 TECH	2 TECH	2 TECH	1

Work Order	Description	Date Created	Status	Work Order Type	Requestor	Asset/ Equip/ Loc	Building No
100002	A/C IS COLD	23/06/14	Completed	Corrective Maintenance	NIL	B08-F1	BUILDING 08
100003	A/C IS HOT	23/06/14	Completed	Corrective Maintenance	NIL	B08-F1	BUILDING 08
100005	SINK BLOCKED	23/06/14	Completed	Corrective Maintenance	NIL	B13-F4	BUILDING 13
100007	WATER COOLER PUMP NOT WORKING	23/06/14	Completed	Corrective Maintenance	UMESH	B72-GF	BUILDING 72
100009	FIX PROJECTOR	23/06/14	Completed	Corrective Maintenance	NIL	B05-F2	BUILDING 05
100017	AC IS HOT	23/06/14	Completed	Corrective Maintenance	NIL	B37-F3	BUILDING 37
100019	CHECK DIMMER LIGHT	23/06/14	Completed	Corrective Maintenance	NIL	B07-B1	BUILDING 07
100020	DRAIN BLOCKED	23/06/14	Completed	Corrective Maintenance	NIL	B05-B1	BUILDING 05
100021	REPLACE CEILING TILES(msr#12428)	23/06/14	Completed	Corrective Maintenance	ENG. ALI	B05-F1	BUILDING 05
100022	FIX WOODEN BOX	23/06/14	Completed	Corrective Maintenance	NIL	B05-F4	BUILDING 05
100023	FIX METAL CABINET	23/06/14	Completed	Corrective Maintenance	NIL	B05-F4	BUILDING 05
100024	CHECK LIGHTS	23/06/14	Completed	Corrective Maintenance	NIL	B05-F1	BUILDING 05
100032	REPLACE FL.LIGHT	23/06/14	Completed	Corrective Maintenance	NIL	B13-GF	BUILDING 13

Process	Time (min.)	Time (Average time min.)	Man-Hours	No. of man	cost/ man-hour (£)	total	Total process cost/ man-hours	maintenance flow	Man-Hours	No .of man	cost/ man-hour (£)	total	Total process cost/ man-hours
Request wasmade	3 TO 20	7.35	8	3	20	60	489.8	7.35	8	3	20	60	489.8
Complaint control system receive a request	1 TO 5	3.34	18	3	15	45	808.4	3.34	18	3	15	45	808.4
Hospital engineer receives the request	5 TO 10	7.5	8	2	25	50	400.0	x	x	x	x	x	x
Work order Clerk contact H.E & Supervisor	1 TO 5	3.3	18	2	15	30	545.5	x	x	x	x	x	x
Hospital Engineer supervisor review work order	10 TO 15	12.5	5	2	20	40	192.0	x	x	x	x	x	x
Docket issue to Supervisor	2 TO 16	2.12	28	2	15	30	849.1	2.12	28	2	15	30	849.1
Supervisor check the fault	2 TO 27	7.32	8	2	20	40	327.9	7.32	8	2	20	40	327.9
Dispose the equipment	5 TO 20	12	5	3	15	45	225.0	x	x	x	x	x	x
Amend the inventory	20 TO 30	25	2	1	25	25	60.0	x	x	x	x	x	x
Supervisor full Material Service Request form (MSR)	5 TO 8	6.5	9	1	15	15	138.5	6.5	9	1	15	15	138.5
Project manager sings MSR	3 TO 7	5	12	2	30	60	720.0	5	12	2	30	60	720.0
H.E signs MSR	3 TO 180	20	3	2	25	50	150.0	20	3	2	25	50	150.0
Head of facility Dep. Sings MSR	5 TO 150	45	1	2	40	80	106.7	x	x	x	x	x	x
Need One quotation	120 TO 4320	360	0	3	15	45	7.5	x	x	x	x	x	x
Need Three quotations	2880 TO 7200	4320	0	3	15	45	0.6	4320	0	3	15	45	0.6
Procurement orders parts	240 TO 36000	7200	0	3	15	45	0.4	7200	0	3	15	45	0.4
Parts arrives at store	840 TO 37440	7200	0	5	15	75	0.6	7200	0	5	15	75	0.6
Supervisor full pre-issue Form check to take the part from store.	5 TO 10	8	8	1	15	15	112.5	8	8	1	15	15	112.5
H.E sings the Form	3 TO 180	20	3	2	25	50	150.0	20	3	2	25	50	150.0
Supervisor takes the part	10 TO 20	25	2	2	25	50	120.0	25	2	2	25	50	120.0
Supervisor assigns a tech. to do the job	5 TO 1320	101.5	1	1	15	15	8.9	101.5	1	1	15	15	8.9
Technician complete WO and return it to Supervisor	5 TO 1315	104.37	1	3	10	30	17.2	104.37	1	3	10	30	17.2
Supervisor review WO and close the docket	5 TO 30	9.4	6	1	15	15	95.7	9.4	6	2	15	30	191.5
Purchase orders (P.O.) send to Financial dep.	2896 TO 7545	4320	0	8	15	120	1.7	4320	0	8	15	120	1.7
Supervisor signs PO	5 TO 8	6.5	9	1	15	15	138.5	6.5	9	1	15	15	138.5
Project manager sings PO	3 TO 7	5	12	2	30	60	720.0	5	12	2	30	60	720.0
H.E signs PO	3 TO 180	20	3	2	25	50	150.0	20	3	2	25	50	150.0
Head of facility Dep. Sings PO	5 TO 150	20	3	2	40	80	240.0	20	3	2	40	80	240.0
Total Time		23876.7						23411.4		52	415	980	
Man-hour cost													
man hours			174										
Total man				66									
total cost/ man hours						1280							
total cost of process man-hours							6776.3						5335.4