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Reliability Centered Maintenance at King Fahad General Hospital in Jeddah City

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***Abstract*:** Reliability centered Maintenance is a methodology used to enhance systems and equipment operation, minimize their breakdown, and increase their Mean Time Between Failures (MTBF). The objective of this conceptual framework is to determine the right maintenance services for systems and to develop maintenance management strategies to be used for critical systems and equipment. RCM conceptual framework consists of seven major components. The most important two components of RCM are failure analysis and critical analysis. Failure Mode and Effect Analysis (FMEA) is trying to determine the functions and operational standards in each system; how they fail, causes of failure, their consequence and how to prevent or avoid these failures. Criticality analysis is concerned with determining critical equipment, estimates its criticality and assign its criticality index. In this study RCM was used to develop a maintenance program for three main utility systems at king Fahad General Hospital (KFGH) in Jeddah, Saudi Arabia. KFGH is 42 years old hospital with 707 beds, 17 operating theaters, 10 X-ray facility, a Laboratory and 38 OPD clinics. These systems are Boiler, chiller systems, Cooling Tower. In this study Failure Mode and Effect (FMEA) analysis were conducted to identify major failures and their causes in each of these systems. The maintenance labor force of these systems where revised and optimized which resulted in a reduction of 31.3% in total annual labor cost.

***Keywords*:** RCM, Reliability, Maintenance, Hospital

I. INTRODUCTION

Reliability Center Maintenance (RCM) way of thinking is based on the system update strategy, which allows management to recognize and improve financially sound maintenance and practical procedures. In such a way, the danger and disappointment in the framework can be monitored financially. The main objective of this analysis is the cost effectiveness when channeling the capital to high-need requests. RCM has a strategy in seven phases. This technique guarantees documentation that precisely records how maintenance tasks have been selected and why these are the best choices between the various competing options. Hospitals play a vital role in delivering health care services to communities. Hospitals are unique facilities that rely on numerous specialized and sometime complex systems to deliver health care services to patients [1-2]. In many instances, the hospital maintenance system is not standardized, but is observed by suppliers or administrative and professional specialists. A failure may not only occur because of the system itself; A system and its behavior can influence equipment performance. equipment failure due to delays would impact equipment's production capacity by decreasing performance, raising operational costs and interfering with customer service. To solve these problems, a conceptual framework is proposed to identify the correct maintenance program in the hospital using RCM to identify the cause of the breakdown. RCM is one of the effective maintenance solutions to minimize repair tasks and related costs without compromising overall equipment reliability, efficiency, environmental, and protection requirements. The RCM can be used for determining appropriate repair approaches based on the likelihood and impact of the experimental failure modes. Thus, RCM will improve the quality of maintenance and increase the reliability of medical equipment in service in the health industry. Most of the researchers have focused on classic

RCM. Some researchers used software and others didn't. All results lead to the importance of the planned maintenance and preference of RCM. These became important issues in situations when applied the proposed framework RCM instead of classic RCM to a real case study. Moreover, excel program is used to perform maintenance program that would minimize maintenance cost and improve system availability and reliability of industrial processes. It is used in criticality analysis, functional failure analysis, and Functional Mode Effect and Criticality Analysis (FMECA) [3-6].

This study will focus on the maintenance strategy of selected critical and high-risk system equipment. Elements of RCM will be used to analyze the current maintenance strategies used on the selected critical system equipment. Hospitals are relatively unique compared with other facilities because of the complexity of their systems and their criticality with respect to the communities they serve.

II. RESEARCH OBJECTIVES

The objectives of this study are to identify and document the type of maintenance management strategies to be used for critical equipment, such as Boilers, Chillers, Cooling Towers, KFGH. Also, to show how RCM can be an effective tool of maintenance in reducing failures in complex systems? What are the major factors that influence the selection of maintenance strategies for a critical system in the hospital? Finally, what are kind of maintenance management strategies that could be potentially used to increase equipment availability and decrease costs while achieving the desired level of patient services?

III. RESEARCH METHOD

This study uses Reliability-Centered Maintenance (RCM) as a methodology to measure the status of critical systems that have a high-risk level. Reliability Centered Maintenance is the application of quantitative measures appropriate to the nature of the data collected. Also provides data on the probability of failure of a critical system through the adoption of Failure Mode and Effect Analysis (FMEA). The objective of this conceptual framework is to determine the right maintenance services using RCM and to identify and document the type of maintenance management and strategies, for systems and equipment such as Boilers, Chillers, and Cooling Tower, in KFGH. The causes of breakdown need to be first identified for a solution to be suggested. RCM process is then to be implemented where the last step of RCM is to recommend new maintenance service program, by comparing with the current practice of maintenance service.

IV. RELIABILITY CENTERED MAINTENANCE

RCM is a resource optimization method that is used to develop and refine maintenance programs. The RCM process is a tool that allows a maintenance manager to focus scarce maintenance dollars on supporting only the critical functions of a piece of equipment required to ensure reliable operation. The main objective of applying RCM in an industrial plant is to increase the life of available plants, equipment, components and processes and reduce its maintenance cost. It is a corporate level maintenance strategy; these strategies are used for the plant to maintain it using cost effective maintenance techniques [4-8]. The seven steps below are the main steps of performing a streamlined RCM study as defined by Schwan (1999) [5]:

1. Establish the scope of the study. Boundaries are established to define the limits of the work.
2. Identify interfaces. Interfaces are identified to further define the limits of the study by specifically listing the required inputs or connections that will not be studied.
3. Specify important functions. RCM seeks to preserve only the most important functions of a system or equipment.

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4. Identify dominant failure modes. Dominant modes of failure, that fail an important function, are identified for evaluation.
5. Identify critical failure modes. The consequences of failure are evaluated for each dominant failure mode to determine their severity. If severe, then the failure mode is deemed critical. Non-critical failure modes are not considered further in the study.
6. Identify dominant failure causes. Dominant causes of failure are identified for only the modes of failure deemed critical. Only maintenance preventable causes of failure are considered.
7. Select maintenance tasks. Using decision logic, routine maintenance tasks are selected to address each dominant cause of failure directly and cost-effectively.

A. RCM Components

RCM framework includes four types of maintenance programs. These programs are: Reactive, Preventive, Proactive and condition-based maintenance. Figure 1 shows these four maintenance programs and their characteristics. The main goal of RCM is to preserve a system in its best operating conditions to minimize its failure and to extend its availability to provide its service. An RCM implementation usually consist of seven main steps. The main objective of RCM is to identify system main components/functions, their functional failures, failure modes, failure effects and causes of failure. The RCM steps are as follows [7]:

Step1: system selection and data collection.

Step2: system boundary definition.

Step3: system description and functional block.

Step4: system function functional failures.

Step5: failure mode effect analysis

Step6: logic tree analysis (LTA) diagram.

Step7: task selection.

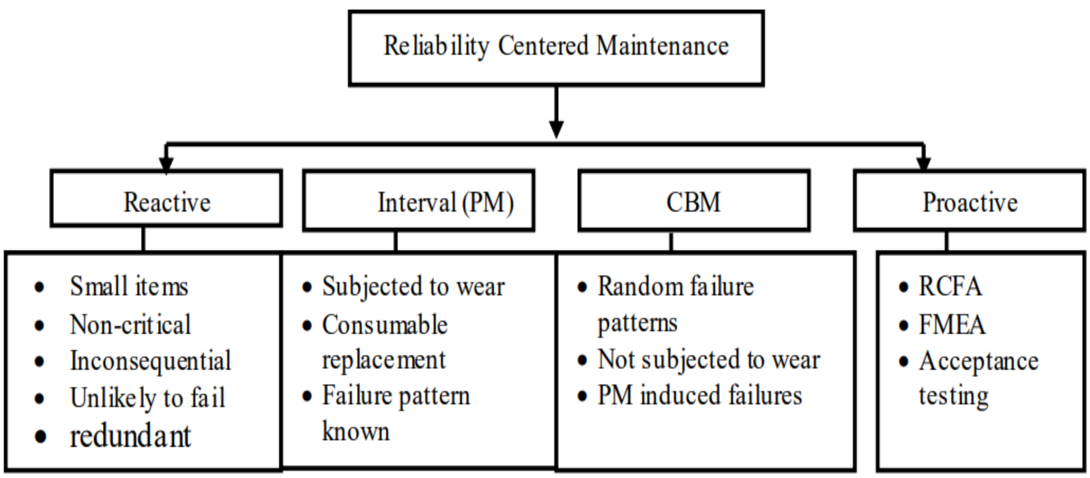

Figure 1: RCM Components

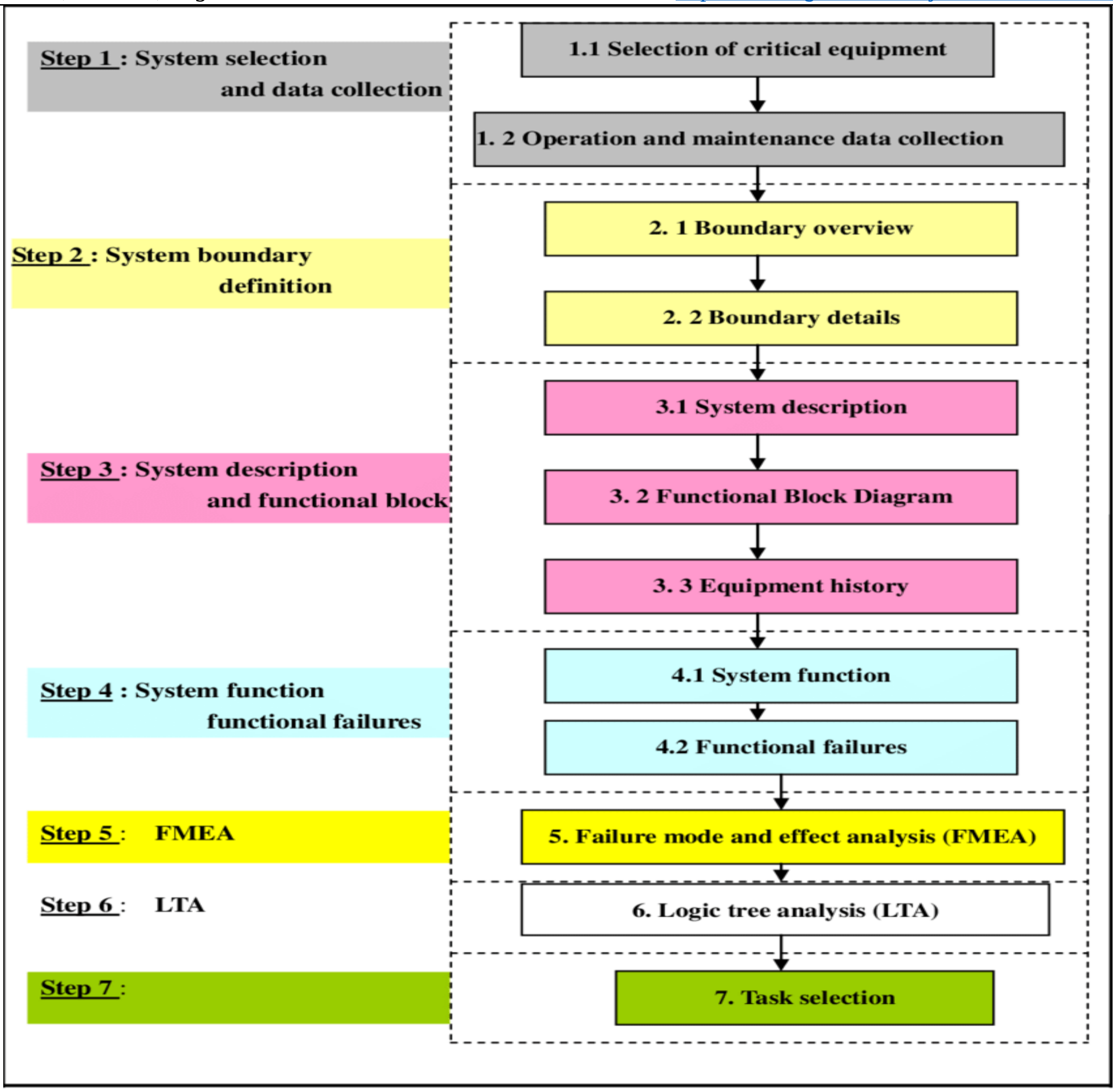

Figure 2: Main steps of the RCM

B. *System Selection and Data Collection*

In the RCM process, collection of data, and system selection has great importance. For this aspect, it is required to critically analyze various types of data to develop a system. It is important because there are great possibilities that the weak system or the failure of the systems major component might leave bad effects on the productivity of the system and greatly enhance the cost of the maintenance. Following is some of the significant factors that have direct impact on the system selection [3].

1. Mean Time between failure (MTBF).
2. Total cost of the maintenance.
3. Required time to repair. (MTTR)
4. Availability

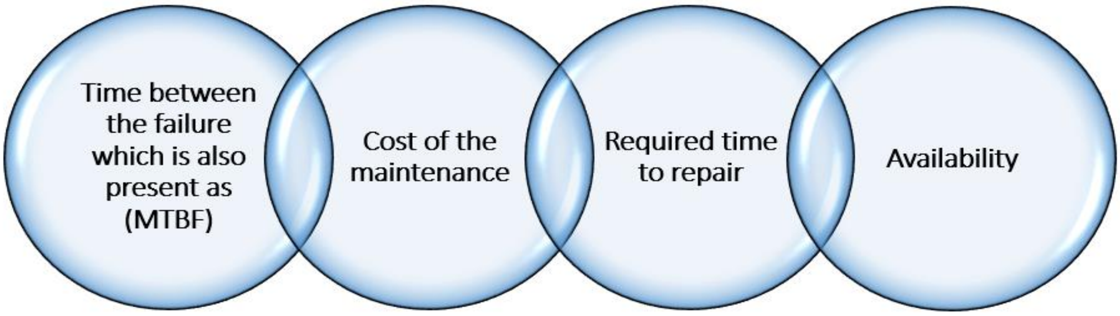

Figure 3: Significant Factors that impact System Selection

C. *Logic Tree Analysis (LTA)*

The basic (LTA) uses the decision tree structure shown in Figure 4, from this figure, decision bins: 1) safety related, 2) outage-related, or 3) economic-related were noticed. Each failure mode is entered into the top box of the tree, where the first question is posed: Does the operator, in the normal course of his or her duties, know that something of an abnormal or detrimental nature has occurred in the plant? It is not necessary that the operator know exactly what is awry or wrong for the answer to be yes [8-10].

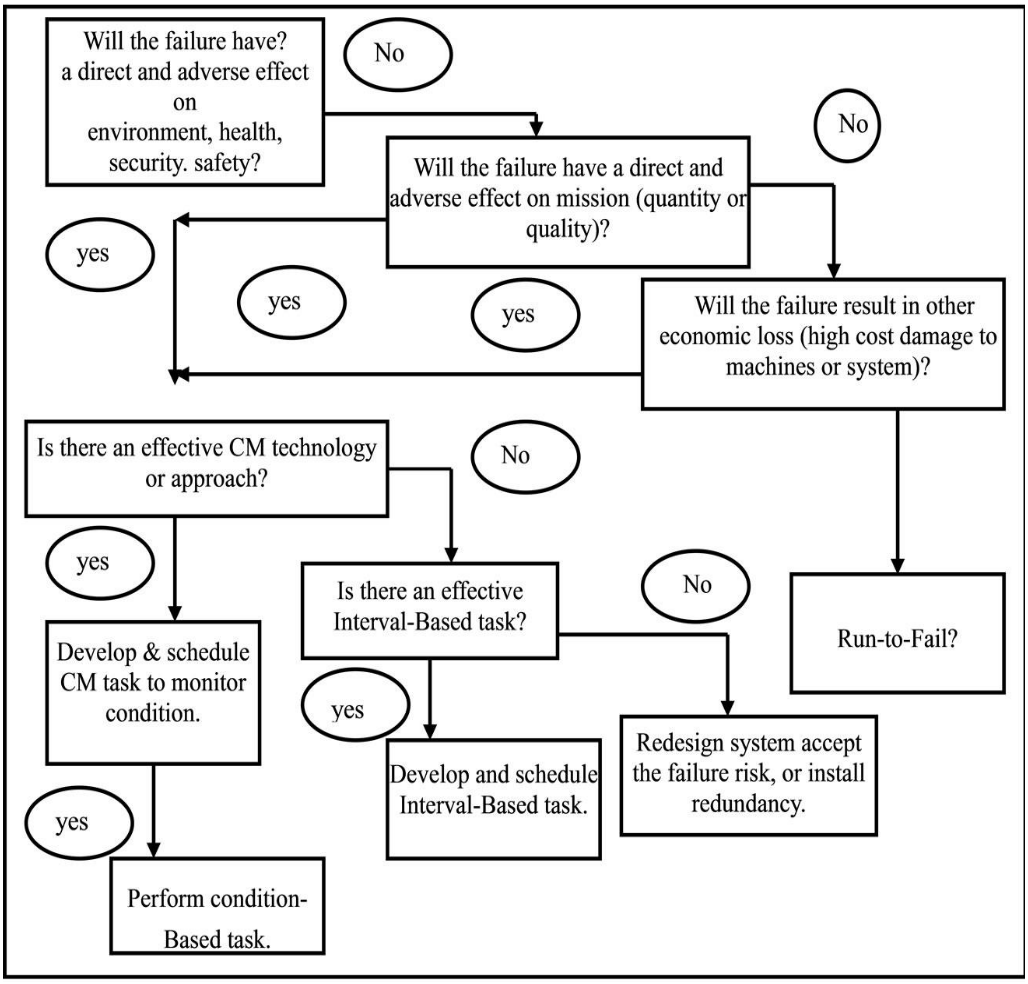

Figure 4: RCM logic tree.

D. RCM Process

According to the research conducted by [1] RCM is an essential part of the operation and maintenance program. The implementation of RCM involves any changes in the system of the established policies of the industry. These changes will be tested first, and its results should be monitored carefully to avoid future problems and issues. RCM efficiency depends on the time when it is implemented and in what steps are involved in its applications [1]. There are six basic steps in the RCM process:

1. Preparation
2. Analysis
3. Task selection
4. Task comparison
5. Task comparison review
6. Records

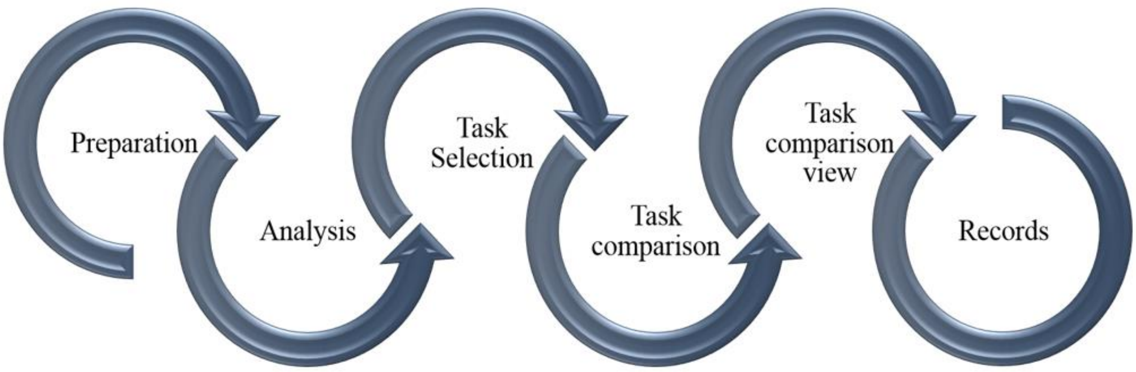

Figure 7: Process of RCM

V. CASE STUDY

King Fahd General Hospital built and operated by Ministry of Health a hospital located in Jeddah, will be used as a case study to demonstrate the capabilities of the developed model. The hospital was constructed in 1980 G (1400 H). The hospital contains 707 beds including regular rooms, emergency units, and intensive care units in addition to 17 operating rooms, 10 X ray facilities, a Laboratory, and 38 major OPD clinics. The hospital is equipped with the following systems: Fire & Safety, Communication & Alarms, Electrical, Water Sewerage, HVAC system, Boiler, Medical Gases, and others. This study focuses on the implementation of RCM for the maintenance of three main utility systems where the failure of these systems would severely negatively impact the health services rendered by the hospital to its patients. These systems are Boilers, chillers, Cooling Towers.

A. Information Collection

After determining the three utility systems that would be included in the RCM implementation study the data collection step started. Several data sets where the core of the data collection search; these are:

1. If Preventive maintenance programs for these systems is being developed and implemented.
2. If the manufacturer technical manuals are available and well kept in a good library on site.

3. If a formal maintenance records system whether manual or computerized system for these systems is maintained
4. If a set of critical spare parts of each system have been identified and an optimal stock has been carried on hand in a well-kept and managed inventory system.

Unfortunately, none of the above were found as expected or should be to ensure a good non-interrupted operation of these systems. This situation made the operation of these systems at high risk and the main health services of the hospital at very high risk also. This situation made the execution of this step extremely difficult. To complete this step, manuals were ordered from the vendors of these systems and properly kept in manual cabinets on site. Historical maintenance record was collected from engineers and technicians who were maintaining these systems. A new manual maintenance records was developed and implemented. A set of critical spare parts for each system was identified and a small warehouse was organized to keep these parts on hand at the site.

B. Failure Mode and Effect Analysis (FMEA)

Failure mode and effect analysis is a tool that examines potential product or process failures, evaluates risk priorities, and helps determine remedial actions to avoid identified problems. The spreadsheet format allows easy review of the analysis. Failure mode and effect analysis help on identifying and the creation of functional failure [11].

Failure Mode and effect analysis of the following systems were conducted.

1. Boiler System
2. Chiller System
3. Cooling Tower Systems

The analysis identified major components of the system that its failure would critically impact system operation. Then, the Functional Failure, Failure Mode, Failure Effects and Causes of Failures of each component were identified and described. Five major components were identified for the Boiler system, four components for the Chiller, five components for the Cooling Tower. The result of this analysis is shown in Tables 1 through 3.

C. Maintenance Labor Force

The labor force required for each system under study were revised and estimated. The labor force consisted mainly of Mechanical, Electrical, Electronic Engineers and Technicians. The required labor maintenance hours were estimated to perform maintenance on a weekly, monthly and semi-annually basis for each system. These estimates are shown in Table 4. Then, the number of staff in each job type was estimated for each of the proposed system under study. These estimates are shown in Table 5. From this Table, it can be observed that the current and proposed number of laborers required for the Boiler/Chiller Systems and their corresponding annual cost. An amount of saving of SR 206,400 was made in the maintenance labor force cost of the Boiler/Chiller representing a reduction of 34.12% from the current cost and a saving of SR28,800, representing 19.67%, for the Cooling Tower. The current total labor cost is SAR751,200 and the proposed total cost is SAR516,000. A total savings in annual labor force cost of SAR235,200 was realized, representing 31.3% reduction from the current annual cost.

Table 1: B FMECA of the oiler System

RCM Information Worksheet	General Maintenance Equipment RCM			
Boiler System				
Function	**Functional Failure**	**Failure Mode**	**Failure Effects**	**Causes Of Failures**
1.Water level control	Not responding (no output signal).	Circuit continuity is open	Feed water pump failed to operate	1.Water level control wire is not heat resistant it causes malfunction to the water level
2. Diesel Jet Pump	Discharge pressure is zero	Dirty fuel filter.	No combustion	1. Dirty filter 2. Diesel Jet pump is defective.
3. Feed Water pipe	Water leaking	Quality of pipe and water is not good	Loss process water.	1. Corroded pipe. 2. Piping was not coated with anti-rust paint. 3. Piping was not standard.
4. Manhole Gasket	Steam or water leaking.	Fastening bolt not tight / uneven tightness.	Operation of boiler will halt.	1. Improper material was installed. 2. In correct tightness torque of manhole cover
5. Blow down Valve	Water flows out.	Defective valve seal.	Low water level, will damage the boiler.	1. Boiler water quality was not maintained properly via chemical treatment .2. Unsuitable material was installed

Table 2: FMECA of the Chiller System

RCM Information Worksheet	General Maintenance Equipment RCM			
Chiller System				
Function	**Functional Failure**	**Failure Mode**	**Failure Effects**	**Causes Of Failures**
1. Condenser tube	Refrigerant leaking	Corroded tube	Low evaporator pressure.	Poor quality of water flowing in the condenser tube.
2. Mechanical shaft seal	Oil leaking	Sealing material deformed in hot condition.	Low oil level will shut down chiller.	1. Long time exposure to high temperature .2. Endurance of material strength fail.
3. Sensor	False reading	Sensor is defective.	Mislead monitoring parameters.	1. Low quality of material used. 2. Fastening bolts are slightly loose.
4. Oil Cooler	Oil leaking	Broken fittings.	Operation of chiller stop due to oil leak.	1. The quantity of cooling water flowing into the system was not sustained.
5. Compressor	Surging (noisy operation).	Chiller system has low refrigerant charge.	Safety controls will shut down the chiller.	1. Oil pipeline was subjected to tensile stress which causes oil cooler to break. 2. Internal stress in joints.

Table 3: FMECA of the Cooling Tower System

RCM Information Worksheet		General Maintenance Equipment RCM		
Cooling Tower Systems				
Function	**Functional Failure**	**Failure Mode**	**Failure Effects**	**Causes Of Failures**
1. Cooling water / process water	Rusty water flowing in the system.	Suspended solids in water.	Solid deposits in condenser tube and into piping system.	Dust from cooling air is carried by water to catch basin.
2. Fan unit.	Decrease number of working fans.	Fans totally broken / stopped.	Reduce the efficiency of cooling tower.	Safety control for vibration did not respond.
3. Fills	Widens space between fills.	Fills are torn / collapse.	Water can create rust in motors body and other components.	Dirt or scale deposits on fills increased its physical weight – hanging and aging condition
4. Chemical dosing	Adding chemical treatment to cooling water.	Manual dosing to chemical.	Unbalance chemical concentration in water.	Automated dosing was not provided to meet chemical control standard.

Table 4: Proposed Labor hours required for annual maintenance of the systems

System	PM Level	Frequency	Duration (Hours)	No. of Workers	Man-hour per PM level
Boiler	Six Month	2	20	2	80
	Monthly	12	3	3	108
	Weakly	52	2	2	208
	Total				***396***
Chiller	Six Month	2	48	4	384
	Monthly	12	8	3	288
	Weakly	52	2	2	208
	Total				***880***
Cooling Tower	Six Month	2	10	2	40
	Monthly	12	4	2	96
	Weakly	52	2	2	208
	Total				***344***

Table 5: Current and proposed Labor Cost estimates and savings

System	**Labor (SR/Month)**	**Type**	**Current Number**	**Proposed Number**
Boiler / Chiller	Engineers (SAR5000)	Mechanical	2	1
		Electrical	1	1
		Chemical	2	1
		Electronics	1	1
	Technicians (SAR1200)	Mechanical	8	6
		Electrical	5	3
		Chemical	2	1
		Electronics	2	1
	Total cost SAR/year		604,800	398,400
	Cost Savings/Year = SAR206,400 (34.12%)			
Cooling Tower	Engineers (5000)	Mechanical	1	1
	Technicians	Mechanical	6	4
	Total cost (SAR/year)		146,400	117,600
	Cost Savings/Year = 28,800 (19.67%)			

VI. SUMMARY

A full maintenace study was conducted on six main utility systems at KFGH in Jeddah. This study applied the RCM conceptual framework to improve the performance of these systems, minmize their failure and increase their availabilty in service to avoid any inturruption in hospital main operations.

FMECA was used to identify major failures and their causes in each of the three systems under study. The Current maintenace labor force was revised and a new reduced number was propsed. The current labor force cost was reduced by SAR235,200 representing a reduction of 31.3% in total maintenance labor cost. It is recommended that the proposed study should be implemented as soon as possible to improve the sevices of these systems and increase their availability to the hospital main operations and to caltivate the economic benifts that would be realized from the expected maintenace cost reduction of these systems. It is also recommended that a maintenace data base system be installed to manage all maintenace activities of these systems. Developing a preventive maintenace program based on manufacturer recommendations would definitely improve the performance of these sytems and their availabilty and would reduce reactive or breakdown maintenance. Finally, keeping all system manuals well organized on site and the continous training of the maintenace team would enhance the effectiveness of all maintenance activities.

Conflict of interest: We declare that we have no conflict of interest.

Ethical statement: we declare that they have followed ethical responsibilities.

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