Minimizing Preventive Maintenance Costs of An Equipment in Oil and Gas (O&G) Industry

by

Muhammad Farhan bin Aziz
13214

Dissertation submitted in partial fulfillment of the requirements for the

BACHELOR OF ENGINEERING (Hons)

(MECHANICAL ENGINEERING)

SEPTEMBER 2013

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Minimizing Preventive Maintenance Costs of An Equipment in Oil and Gas (O&G) Industry

by

Muhammad Farhan bin Aziz
13214

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirements for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

____

(Dr. Hilmi bin Hussin)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
Sept 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____

MUHAMMAD FARHAN BIN AZIZ

ABSTRACT

Preventive maintenance is required when there is an increased automation in industry. The more automated that the equipment is, the more components there are that fail and cause the entire piece of equipment to be taken out of service. In Oil and Gas (O&G) industry, many equipment are having their PM scheme set during plant design phase and generally follow recommendation from equipment manufacturer. After years of operation (operation and maintenance phase), the scheme/schedule might not be optimised due to various operating conditions such as operation, maintenance and others. Thus, the objectives of this project are to develop an appropriate model for minimizing preventive maintenance cost and also to apply the model to industrial data together with some recommendations for the optimised PM schedule. The project is initiated by identifying problem and objectives, study on literature review regarding various types of preventive maintenance model, and then come out with a model concept. The model is then applied on a plant data in order to make recommendations on how to minimize PM cost.

ACKNOWLEDGEMENT

First of all, I would like to express my utmost gratitude to Universiti Teknologi Petronas for allowing me to complete this project, providing facilities to me to finish up this project. I would also like to take this opportunity to direct my utmost indebtedness to my Final Year Project supervisor, Dr. Hilmi bin Hussin for his supervision and advices throughout the entire project. His provisions, tolerance, and willingness to assist me in the problem or complications that I confronted in my project have contributed tremendously to my project. His ideas and moral supports that make the project a success to achieve its objectives. I would also like to take this opportunity to acknowledge Mrs. Freselam, a post-grad student, who helped me a lot in guaranteeing the project is developed smoothly within the time frame specified. Last but not least, I would like to give my utmost gratitude and appreciation to my family and fellow colleagues who provide me a lot of helps during conducting this project, helps with software and other essential things. With their provision and inspiration, this project can be accomplished successfully.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATION

PM	Preventive Maintenance
O&G	Oil and Gas
JIT	Just-In-Time
U.S.	United States
RCM	Reliability Centered Maintenance
PMO	Preventive Maintenance Optimization
EPA	Environmental Protection Agency
OSHA	Occupational Safety and Health Administration
FYP	Final Year Project
SEDEX	Science and Engineering Design Exhibition
MTBF	Mean Time Before Failure
VBA	Visual Basic Application

CHAPTER 1

INTRODUCTION

1.1 Project Background

Preventive maintenance means all actions intended to keep durable equipment in good operating equipment and avoid failures. New technology has improved equipment quality, reliability and dependability by fault-tolerance, redundant components, self-adjustments, and replacement of hydraulic and mechanical components by more reliable electronic and optical operations. However, many components can still wear out, corrode, become punctured, vibrate excessively, become overheated by friction or dirt, or even be damaged by humans. For these problems, a good PM program will preclude failures, enable improved uptime, and reduce expenses.

Costs in terms of money and effort to be invested now must be evaluated against future gains. This means that the time-value of money must be considered along with business priorities for short-term versus long-term success. Data must be gathered over time and analyzed to assist with accurate decisions. The proper balance can be tenuous to achieve minimal downtime and costs between preventive and corrective maintenance.

PM can prevent failures from happening at a bad time, can sense when a failure is about to occur and fix it before it causes damages, and can often preserve capital investments by keeping equipment operating for years as well as the day it was installed.

However, in a few cases, PM still can cause problems. This is because humans are not perfect. Whenever any equipment is touched, it is exposed to potential damage. Parts costs increase if components are replaced prematurely. Unless the PM function is presented positively, customers may perceive PM activity as, “that machine is broken again.” An initial investment of time, materials, people, and money is required in a PM program. Payoff comes later. While there is little question that a good PM program will have a high return on investment, many people are reluctant to pay now if the return is not immediate. That challenge is particularly predominant is a poor economy where companies want fast return on their expenditures. The PM advantage is that we will pay less now to do planned work when production is not pushing versus very expensive emergency repairs that may be required under disruptive conditions and cause production to halt and lost revenue. Good PM saves money over a product’s life cycle.

In order to minimize the preventive maintenance costs, it is required to study the factors that affect the preventive costs maintenance and how to minimize it. These factors can affect the effectiveness and performance of PM and therefore yield bad performance results. With the proper technique, it is hoped that from this project we can better understand how much effect it has on the overall performance.

1.2 Problem Statement

Many equipment in the Oil and Gas industry are having their PM scheme set during plant design phase and generally follow recommendation from equipment manufacturer. PM schedules are generally integrated into the overall maintenance schedule, unless there are personnel dedicated only to performing the PMs. In either case, more accurate estimates and material requirements lead to more accurate schedules and, in turn, more successful PM programs. However, there is a need to review the scheme to minimize the operation and maintenance costs since after years of operation (operation and maintenance phase), the scheme/schedule might not be optimised due to various operating conditions such as;

- Scheduling
- Hiring
- Breakdown
- Training
- Insufficient Labour
- Maintenance Inventory

- Management Support
- Budget Cuts

1.3 Objectives

The objectives of this project are as follows:

1) To develop a practical and appropriate model for minimizing preventive maintenance (PM) cost and,
2) To apply the model to real industrial data and propose the optimised PM schedule.

1.4 Scope of Study

The input of this project will be obtained from the available equipment set-up in a plant (any plant) of Oil and Gas Industry. The variables that will be used are all of the existing tasks, preventive maintenance costs, loss performance costs and downtime costs. The output would be by inputting all the data obtained to the PM model in order to make recommendations for the minimized PM cost. The selected approach is to determine what factors affect the performance of the PM the most and how it can be optimized.

1.5 Significance of the Project

The study of preventive maintenance (PM) is important to the engineering world. This is because an engineer can make appropriate model design to eliminate all unplanned equipment failures and insure proper coverage of the critical equipment of the plant. Besides that, engineer able to carried out a study to minimize preventive maintenance costs of any equipment in Oil and Gas (O&G) industry. As a result, the failure frequency of an equipment due to lack concern in preventive maintenance can be reduced.

CHAPTER 2

LITERATURE REVIEW

Preventive Maintenance has varied definitions. For this project purposes, preventive maintenance is defined as any planned maintenance activity that is designed to improve equipment life and avoid any unplanned maintenance activity. In its simplest form, preventive maintenance can be compared to the service schedule for an automobile. Certain tasks must be scheduled at varying frequencies, all designed to keep the automobile from experiencing any unexpected breakdowns. Preventive maintenance for equipment is no different.

2.1 The History of Preventive Maintenance

Man has always felt the need to keep your computer, even the most fundamental tools and devices since the beginning of time. Most of the failures that were experienced were the result of abuse and it is still happening today. At first it was only when it was impossible maintenance continue using computers. That was called "Break or Reactive Maintenance"

It was until 1950 that a group of Japanese engineers began a new maintenance concept was simply following the recommendations of equipment manufacturers about the care that should be taken into the operation and maintenance of machines and devices.

This new trend is called "Preventive Maintenance". As a result, plant managers were interested in having their supervisors, mechanics, electricians and other technicians, to develop programs to lubricate and making key observations to prevent equipment from damages. Preventive maintenance helps reduce losses of time and money [1].

2.2 The Importance of Preventive Maintenance

Increased automation in industry requires preventive maintenance. The more automated the equipment, the more components that could fail and cause the entire piece of equipment to be taken out of service. Routine services and adjustments can keep the automated equipment in the proper condition to provide uninterrupted service.

Just-In-Time or people call it JIT manufacturing, which has become more common in a developing country like Malaysia today, requires that the materials being produced into finished goods arrive at each step of the process just in time to be processed. JIT eliminates unwanted and unnecessary inventory. However, JIT also requires high equipment availability. Equipment must be ready to operate when a production demand is made; it cannot break down during the operating cycle. If equipment does fail during an operational cycle, there will be delays in making the product and delivering it to the customer. In these days of intense competitiveness, delays in delivery can result in lost customers. Preventive maintenance is required so that equipment is reliable enough to develop a production schedule that, in turn, is dependable enough to give a customer firm delivery dates [2].

In most of the cases, companies will purchase another identical piece of equipment when equipment is not reliable enough to schedule to capacity. Then, if the first one breaks down on a critical order, they have a back up. With the price of equipment today, however, this back-up can be an expensive solution to a common problem. Unexpected equipment failures can be reduced, if not almost eliminated, by a good preventive maintenance program. With equipment availability at its highest possible level, redundant equipment will not be required.

Reducing insurance inventories has an impact on maintenance and operations. Maintenance carries many spare parts in case the equipment breaks down. Operations carry additional spare parts in process inventory for the same reason. Good preventive maintenance programs allow the maintenance departments to know the condition of the equipment and prevent breakdowns. The savings from reducing (in some cases, eliminating) insurance inventories can often finance the entire preventive maintenance program [3].

Each production process is dependent on the previous process in manufacturing and process operations. In many manufacturing companies, these processes are divided into cells whereby each cell is viewed as a separate process or operation. Furthermore, each cell is dependent on the previous cell for the necessary materials to process. An uptime of 97% might be acceptable for a stand-alone cell. But if ten cells, each with a 97% uptime, are tied together to form a manufacturing process, the total uptime for the process is only 71%.

However, this level is unacceptable in any process. Preventive maintenance must be used to raise uptime to even higher levels. Performing needed services on the equipment when required leads to longer equipment life. Returning to an earlier example, an automobile that is serviced at prescribed intervals will deliver a long and useful life. However, if it is neglected – for example, the oil is never changed – it will have a shorter useful life. Because industrial equipment is often even more complex than the newer computerized automobiles, service requirements may be extensive and critical. Preventive maintenance programs allow these requirements to be met, reducing the amount of emergency or breakdown work [2].

Moreover, preventive maintenance reduces the energy consumption for the equipment to its lowest possible level. Well-serviced equipment requires less energy to operate because all bearings, mechanical drives, and shaft alignment receive timely attention. By reducing these drains on the energy used by a piece of equipment, overall energy usage in a plant can amount to a 5% reduction.

Another cost reduction that helps justify a good preventive maintenance program is the quality. Higher product quality is a direct result of a good preventive maintenance program. Poor, out-of-tolerance equipment never produces a quality product. World class manufacturing experts recognize that rigid, disciplined preventive maintenance programs produce high quality products. To achieve the quality required to compete in the world markets today, preventive maintenance programs are required.

If operations or facilities were organized and operated the way the majority of maintenance organizations are, we would never get any products or services when we needed them. An attitude change is necessary to give maintenance the priority it needs. This change also includes management's viewpoint. U.S. management tends to sacrifice long-term planning for short-term returns. This attitude causes problems for maintenance organizations, leading to reactive maintenance with little or no controls. When maintenance is given its due attention, it can become a profit center, producing positive, bottom line improvements to the company.

No preventive maintenance program will be truly successful without strong support from the facility's upper management. Many decisions must be made by plant management to allow time to perform maintenance on the equipment instead of running it wide open. Without upper management's commitment to the program, PM will either never be performed, or it will be performed too little, too late. Thus, management support is the cornerstone for any PM program [2].

2.3 Types of Preventive Maintenance

There are many types of preventive maintenance. A good PM will incorporate all of these types, with the emphasis varying from industry to industry and from facility to facility. This list also provides a progressive step-by-step method for implementing a comprehensive preventive maintenance. The types of PM are as follows [3];

2.3.1 Basic Preventive Maintenance

Basic preventive maintenance is including lubrication, cleaning and inspection – is the first step in beginning a preventive maintenance program. These service steps take care of small problems before they cause equipment outages. The inspections may reveal deterioration, which can be repaired through the normal planned and scheduled work order system. One problem develops in companies that have this type of program: they stop here, thinking this constitutes a preventive maintenance program. However, it is only a start; a company can do more.

2.3.2 Proactive Replacements

Proactive replacements substitute new components for deteriorating or defective components before they can fail. This repair schedule eliminates the high costs related to a breakdown. These components are usually found during the inspection or routine service. One caution: Replacement should be only for components in danger of failure. Excessive replacement of components thought but not known to be defective can inflate the cost of the preventive maintenance program. Only components identified as defective or "soon to fail" should be changed.

2.3.3 Scheduled Refurbishing

Scheduled refurbishing is generally found in utility companies, continuous process-type industries, or cyclic facilities, such as colleges or school systems. During the shutdown or outage, all known or suspected defective components are changed out. The equipment or facility is restored to a condition where it should operate relatively trouble free until the next outage. These projects are scheduled using a project management type of software, allowing the company to have a time line for starting and completing the entire project. All resource needs are known in advance, with the entire project being planned.

2.3.4 Predictive Maintenance

Predictive maintenance is a more advanced form of the inspections performed in the first part of this section. Using the technology presently available, inspections can be performed that detail the condition of virtually any component of a piece of equipment. Some of the technologies include:

- Vibration analysis
- Spectrographic oil analysis
- Infrared scanning
- Shock pulse method

The main differentiation between preventive and predictive maintenance is that preventive maintenance is more of a basic task, whereas predictive maintenance uses some form of a technology.

2.3.5 Condition-Based Maintenance

Condition-based maintenance, it takes predictive maintenance one step further, by performing the inspections in a real-time mode. Sensors installed on the equipment provide signals that are fed into the computer system, whether it is a process control system or a building automation system. The computer then monitors and trends the information, allowing maintenance to be scheduled when it is needed. This eliminates error on the part of the technicians who would otherwise make the readings out in the field. The trending is useful for scheduling the repairs at times when production is not using the equipment.

2.3.6 Reliability Engineering

Reliability engineering is the final step in preventive maintenance, involves engineering. If problems with equipment failures still persist after using the aforementioned tools and techniques, engineering should begin a study of the total maintenance plan to see if anything is being neglected of overlooked. If not, a design engineering study should be undertaken to study possible modifications to the equipment to correct the problem. Incorporating all of the above techniques into a comprehensive preventive maintenance program will enable a plant or facility to optimize the resources dedicated to the PM program. Neglecting any of the above areas can result in a PM program that is not cost effective.

2.4 Issues Related to Preventive Maintenance

There are at least four different types of failures: infant mortality, random failures, abuse and normal wear out [2].

2.4.1 Infant Mortality

This type of failure is occurring in the first few hours of component life. It is understood by the electronics industry where burn-in of components is common. In this case, the failure occurs when initial voltage is applied to a circuit, but the component is not up to standard. It is impossible to design a PM program to prevent this type of failure.

2.4.2 Random Failures

Without notice or warning. This is what we called random failures. This type of failure, which is difficult to predict, is engineering or materials related. Because of their unpredictability, a PM program cannot be designed to prevent them.

2.4.3 Abuse Failures

Abuse or misuse failures generally result from a training or attitude problem. No preventive maintenance program can prevent this type of failure.

2.4.4 Normal Wear Out

This type of failure is where the preventive maintenance programs can be designed to prolong of prevents. These failures occur progressively over a relatively long period of time. PM programs can be designed to spot signs of wear and take appropriate measures to correct the situation. Normal wear is allowed to progress, either due to the fact there is no real consequence of a failure or a component is replaced just before normal wear causes a failure.

2.5 Available Methods of Performing a Review of Preventive Maintenance Activities

In many businesses, Preventive Maintenance activities have been established over time with little technical discipline supporting the decision process. This has resulted in Preventive Maintenance activities that:

- Are ineffective in detecting the onset of failure,
- Duplicate the effort of other preventive activities,
- Are missing for critical failures.

A review of Preventive Maintenance activities requires an assessment of the modes and consequence of failure contrasted with the effectiveness of the proposed or actual activity.

One method of performing a review of Preventive Maintenance activities is by hypothetical failure analysis. Analyses in this category develop Preventive Maintenance activities based on an analysis of failure risk. Analyses in this category are typified by RCM II after Moubray [4], however there are many derivatives of this approach in practice. This type of approach generally ignores the existing Preventive Maintenance activities and compares results with existing maintenance programs after the analysis is complete.

Hardwick and Winsor [5] describe the development of new maintenance standards for Energy Australia based on the application of RCM principles. Regarded as a successful technical and change management project, there were significant benefits estimated on 25000 Pole and Kiosk Substations. The traditional maintenance program had demanded an annual budget $6.875M per year. Typically $3.75M per year had been budgeted for, with the budget shortfall showing as work backlog. As a result of the project, new maintenance standards were developed. These changes did not affect the period or frequency of the preventive maintenance, but only the methodology or activities. The resulting maintenance program demanded a budget of $2M per year. With full implementation of the new program, a payback period for the project is estimated to be 4 months. This example clearly demonstrates the extent of the over-maintaining problem as well as the effectiveness of a successful review of preventive maintenance activities by hypothetical failure analysis.

Another method of performing a review of Preventive Maintenance activities is a “Reverse RCM” process in which each activity is reviewed and tested for its purpose, value and possible duplication against other activities. In this case the existing Preventive Maintenance activities are not ignored and provide the basis of the review process.

Turner [6] describes an approach called PMO that reviews Preventive Maintenance activities in a nine step process. The results of a typical PMO review are shown in Figure 2.1.

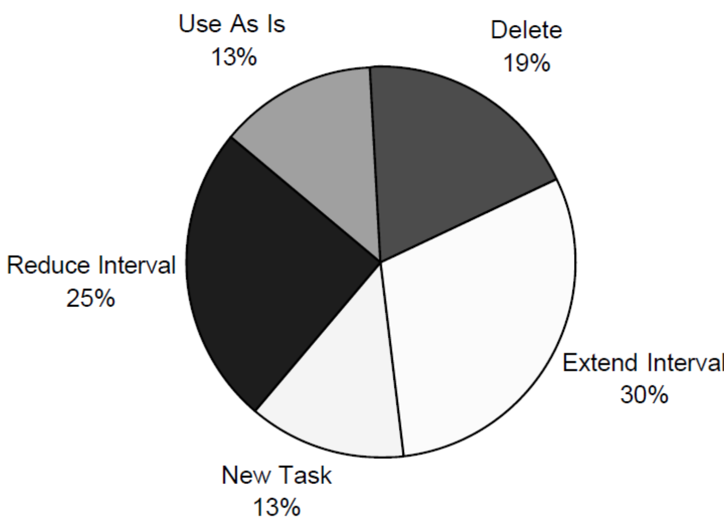


Figure 2.1: Results of a Typical PMO Review [6]

Figure 2.1 shows that:

- Only 13% of existing Preventive Maintenance activities were considered worthwhile
- 19% of Preventive Maintenance activities were a waste of time
- 30% of Preventive Maintenance activities were carried out too frequently

This example demonstrates the extent of the over-maintaining problem and shows the effectiveness of a review program in addressing the Preventive Maintenance activities. It also demonstrates that Preventive Maintenance activities have a significant impact on the effectiveness and cost of the Preventive Maintenance program. The review of Preventive Maintenance activities can be successful in terms of the technical activities developed, but face challenges in the selection of optimal activity frequencies.

2.6 Optimum Maintenance Intervals in RCM++ Software Tool (Application)

Preventive maintenance can give cost benefits by increasing the availability of a system and reducing the total costs of maintenance. The question of how often the task should be performed is important to consider. If the preventive maintenance interval is too short, then the maintenance costs associated with preventive maintenance can be too high. On the other hand, if the interval is too long, then the costs associated with corrective maintenance can be too high. Reliability Centered Maintenance or RCM++ provides calculations in order to determine the optimum maintenance interval, based on the probability of occurrence of a failure event and the costs of performing different types of maintenance [7].

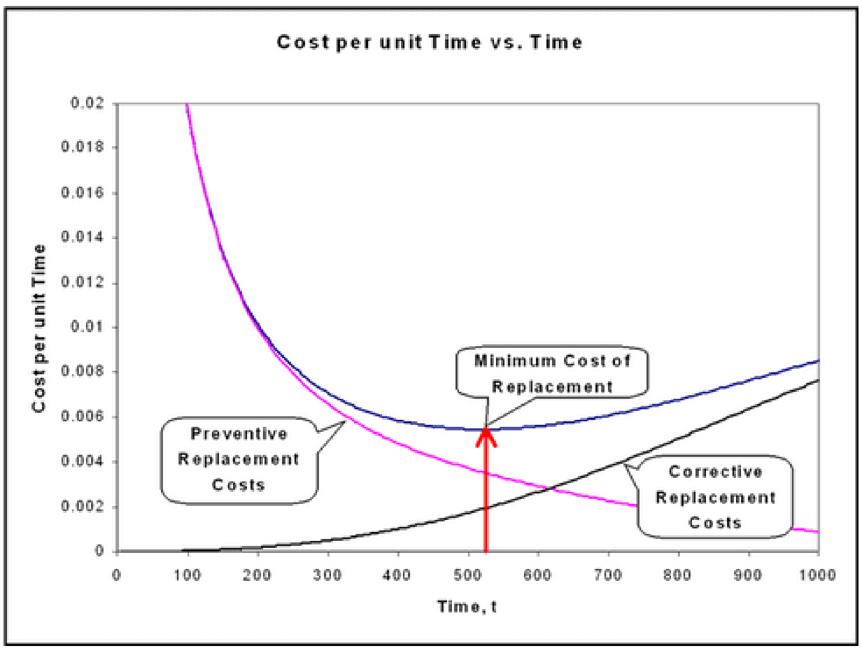


Figure 1.2: Cost vs. Time [7]

For preventive maintenance to be beneficial the failure rate of the system should be increasing over time and the cost of the preventive maintenance, which has been planned, must be less than the cost of the unplanned corrective maintenance. If both of those conditions are met, then the preventive maintenance should be performed. However, as shown in Figure 2.2 above, the time interval for performing preventive maintenance should be when the total maintenance costs are minimized. In order to do that, the time interval that minimizes the maintenance cost function must be found [7]. The maintenance cost per unit time function is given by:

$$CPUT(t) = \frac{C_P.R(t) + C_V.[1 - R(t)]}{\int_0^1 R(s)ds}$$

Where:

- R(t) is the reliability at time t.
- C_P is the preventive maintenance cost per incident (planned maintenance).
- C_U is the corrective maintenance cost per incident (unplanned maintenance).

The optimum replacement time interval, t, is the time that minimizes CPU(t). This can be found by solving for t such that:

$$\frac{\partial[CPUT(t)]}{\partial t} = 0$$

or by solving for a time, t, that satisfies:

$$\frac{\partial[\frac{C_P.R(t)+C_V.[1-R(t)]}{\int_0^1 R(s)ds}]}{\partial t} = 0$$

In Figure 2.3 below, it shows that the maintenance costs associated with the corrective maintenance of the machine. The typical task duration for repairing the machine is 5 hours. However, given that when the machine unexpectedly fails, there is a delay for the repair crew to arrive and the spare parts to be obtained and there is 7.7 hours, which is the total downtime per incident. Since the cost per hour of downtime is $1,000, this results to downtime costs of $7,700 per failure. With the other cost inputs, including the materials costs of $200 per incident and the calculated total labor cost of $250 (5 hours for the task multiplied by the labor rate of $50 per hour), the total cost per corrective maintenance incident is equal to $8,150.00 [7].

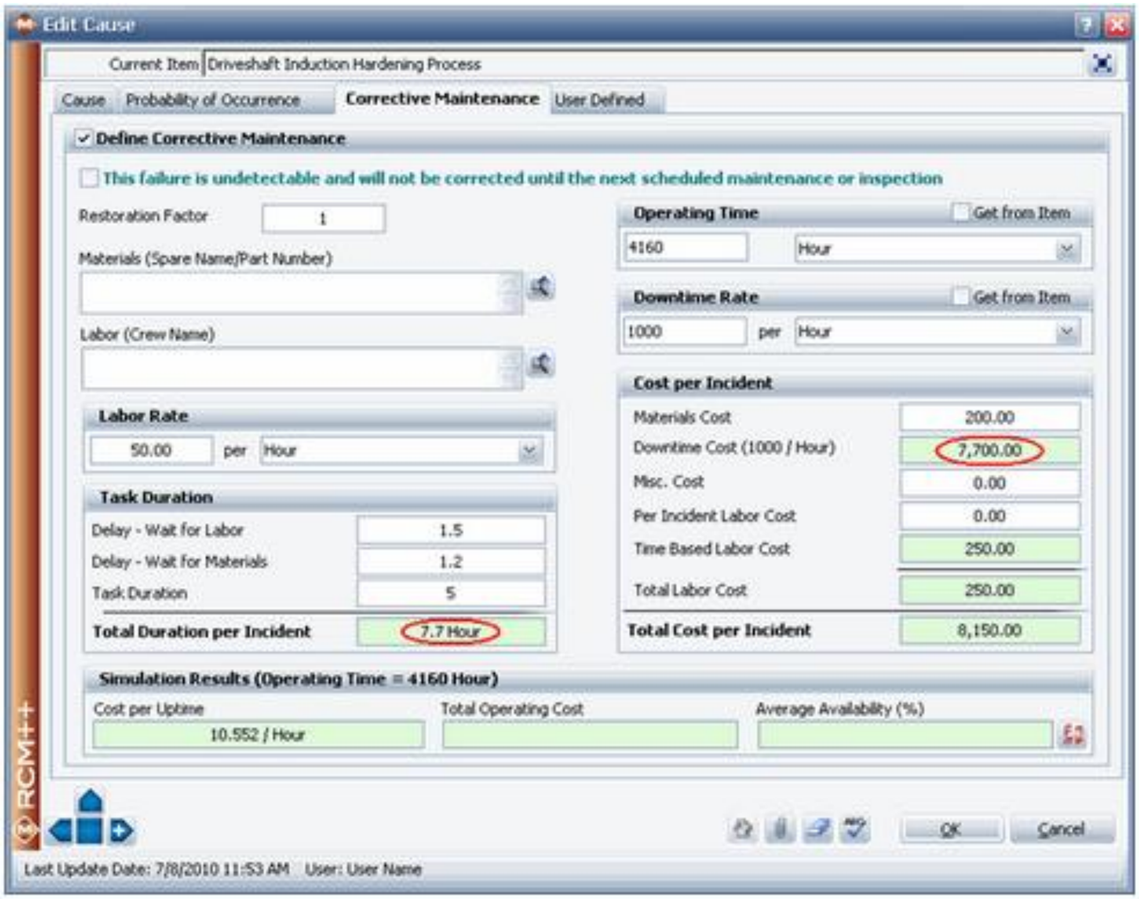


Figure 2.3: Corrective Maintenance Costs [7]

Using the failure probability of the machine and the associated corrective maintenance costs, we can run a simulation to determine the average availability of the machine for one year of operation (or 4,160 hours, given that the machine operates for 16 hours a day, 5 days a week) with a “run to failure” maintenance strategy. As shown in Figure 2.4, the average availability is 99.01% and the total operating cost is $43,463.95. These figures reflect the availability and cost assuming that no preventive maintenance is performed [7].

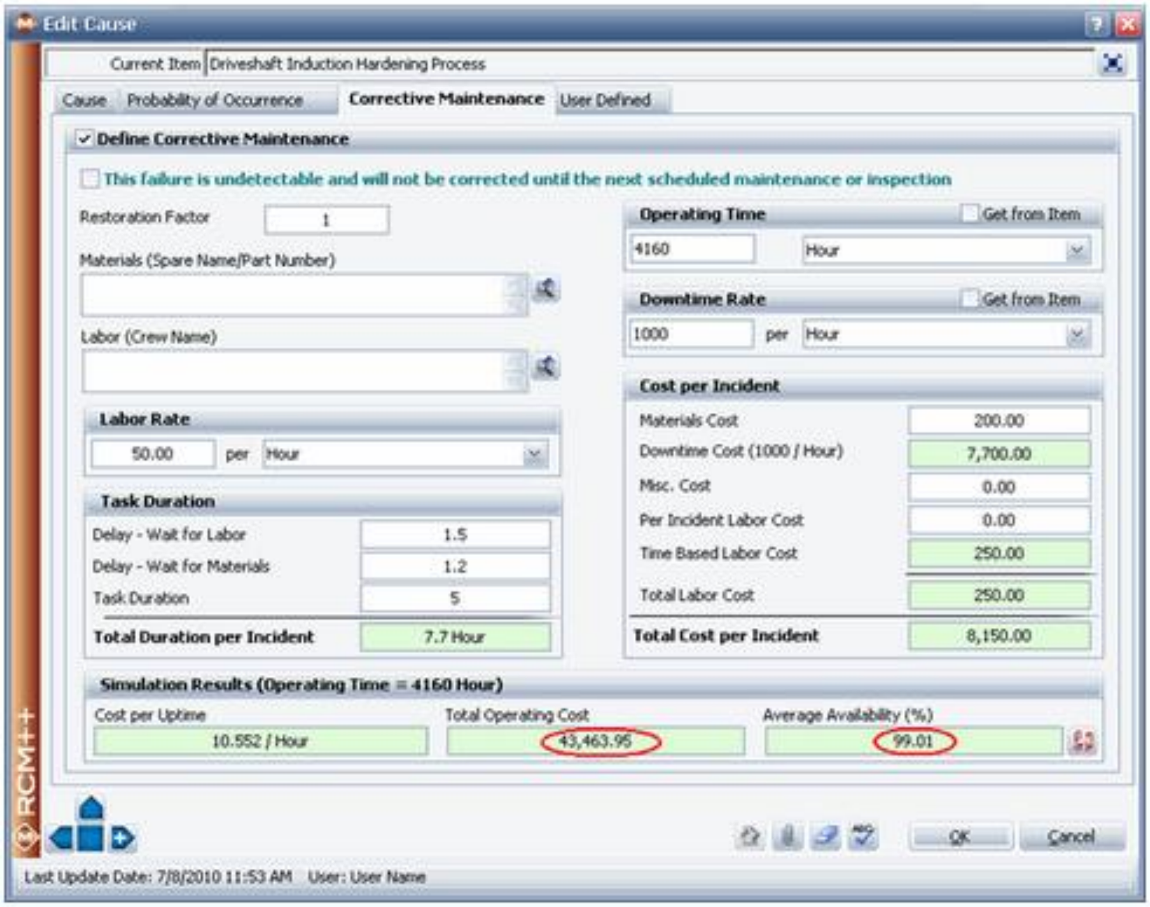


Figure 2.4: Calculated Average Availability and Total Operating Cost for Corrective Maintenance Only (no Preventive Maintenance) [7]

As shown above, it is determined that preventive maintenance should be performed on the machine. Only left is to determine how often the preventive maintenance should be scheduled. As seen, given the corrective and preventive maintenance costs and the probability of failure, we can find a time interval, which minimizes the total costs. Figure 2.5 below shows the costs associated with the preventive maintenance. Since preventive maintenance is a planned task, the total duration of the incident is considerably lower compared to the corrective maintenance. As a result, the total costs and the downtime cost per incident will also be lower [7].

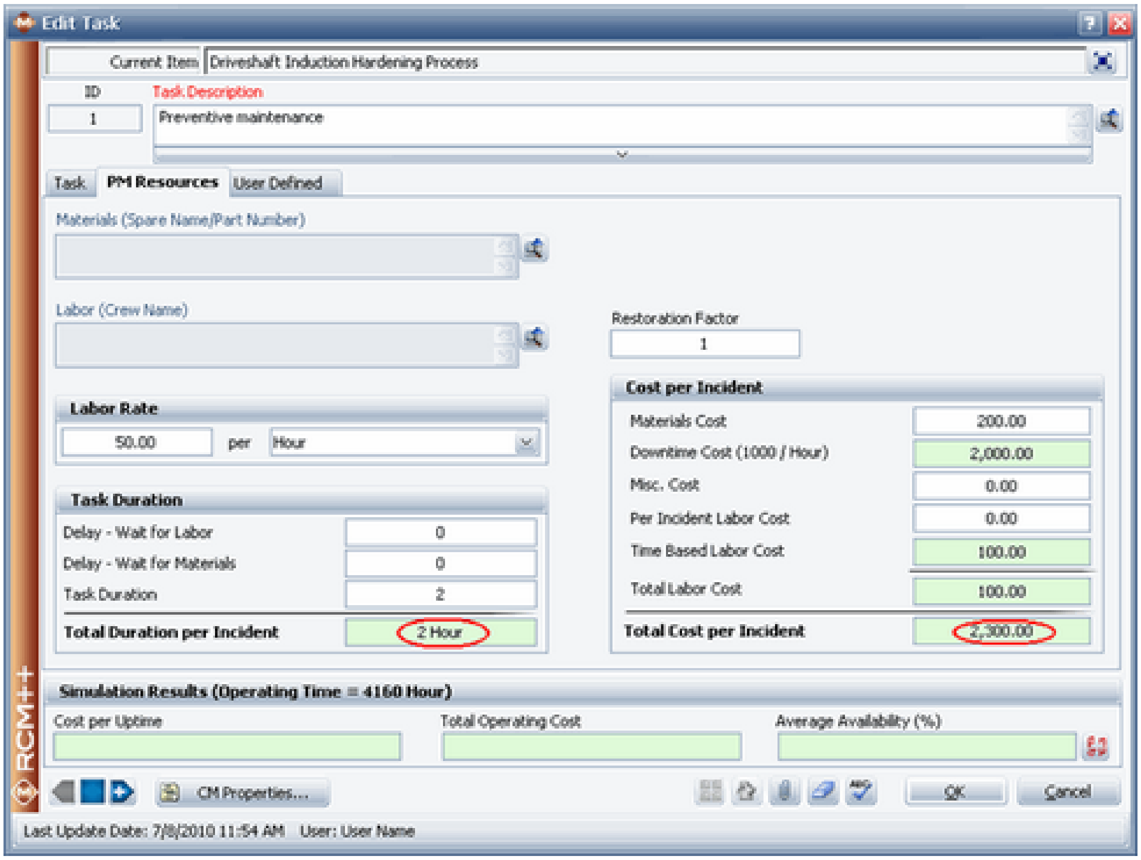


Figure 2.2: Preventive Maintenance Costs [7]

Now that the maintenance costs have been determined, the optimum interval for performing the preventive maintenance can be calculated. Figure 2.6 below shows that the optimum interval is stated to be 468.984 hours. RCM++ gives the option to set this as the assigned interval and use it in the calculations, set it as a proposed interval in order to keep it as a record without using it or not use it at all [7].

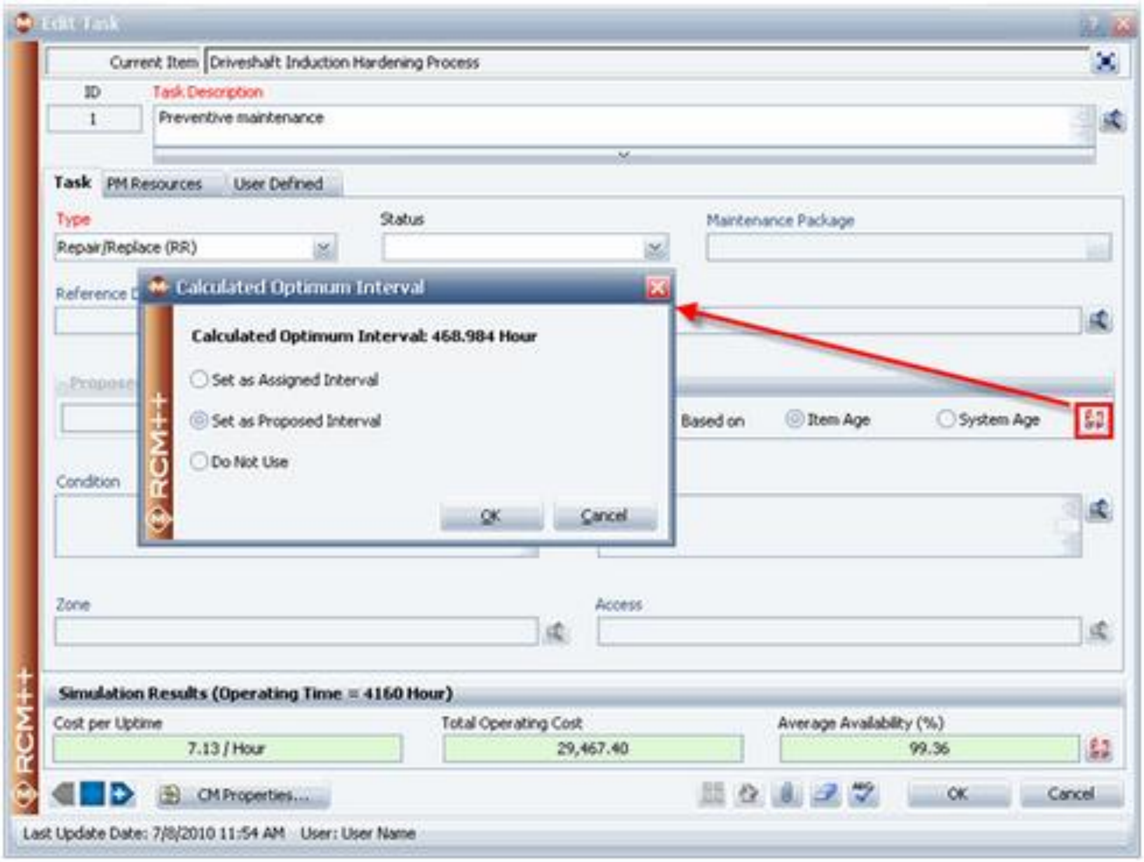


Figure 2.3: Calculation of Optimum Maintenance Interval [7]

The calculated figure is rounded to 470 hours for the actual assigned interval. Using this interval, a simulation can be run again to calculate the average availability and total costs for a year of operation. As shown in Figure 2.7, the average availability from implementing the preventive maintenance strategy is calculated as 99.36% and the total operating cost is $29,390.25. So it is clearly shows that by using the optimum maintenance interval to perform preventive maintenance, the availability is increased (99.36% compared to 99.01%) and the operating cost is reduced ($29,390.25 compared to $43, 463.95) [7].

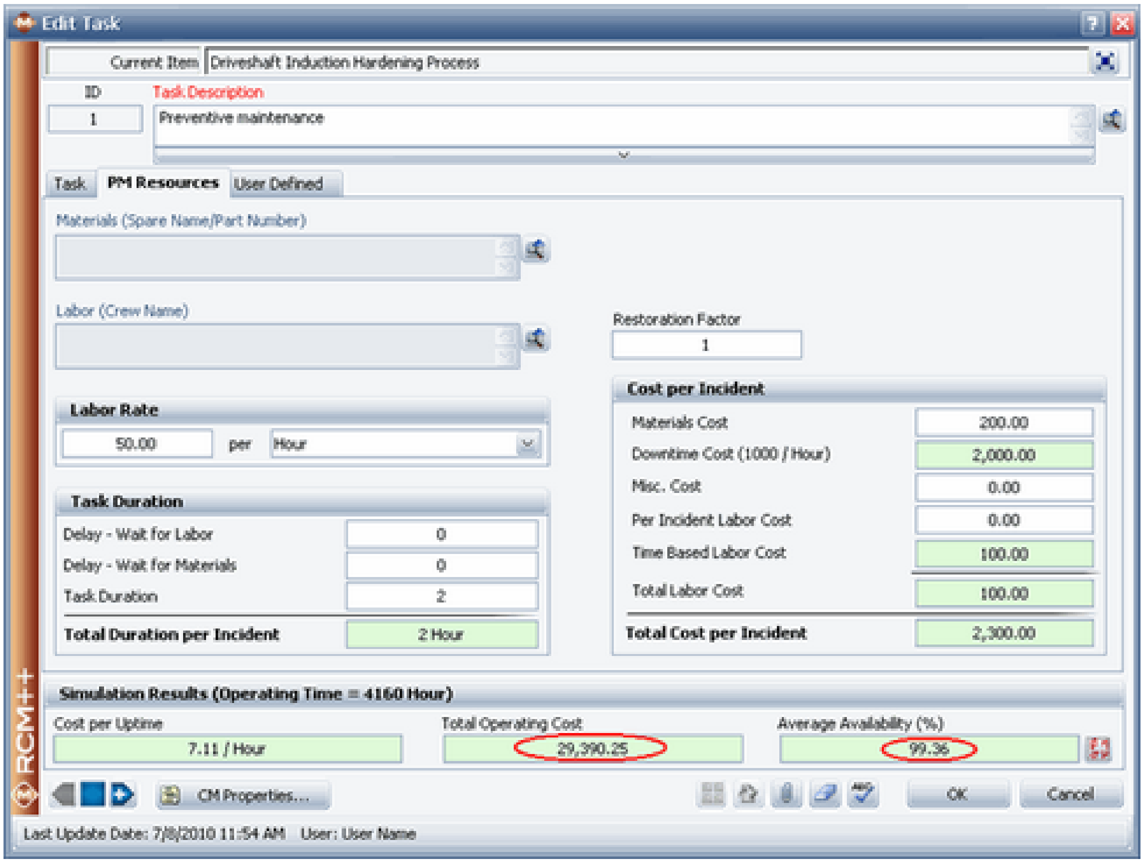


Figure 2.4: Calculated Average Availability and Total Operating Cost for Preventive Maintenance Strategy with Optimum Maintenance Interval [7]

2.7 Preventive Maintenance Cost Minimization Model (Conceptual Model)

This is a total cost strategy. This simple scheduling strategy involves the financial impact a preventive maintenance task has on the operation of the equipment. It is necessary to put the benefit vs. costs discussion in a form where all parties involved can understand it. The figure shows that the decision for scheduling a preventive maintenance task would be made, not on what is best for the operations group, nor on what is best for the maintenance group, but what is the lowest combined cost. This is the type of decision that companies must make if they are to optimize their resources.

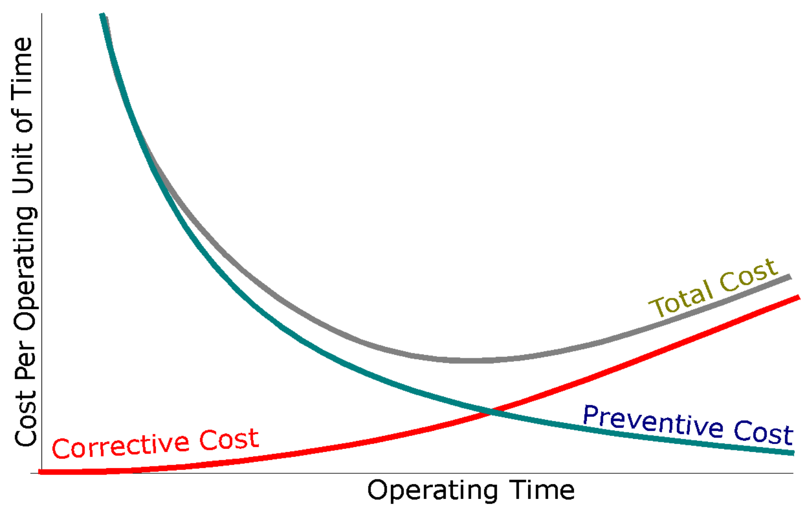


Figure 2.5: Preventive Maintenance Cost Minimization Model

Figure 2.8 as shown above is how the minimization model will look like. The intersection between both curves, which are corrective maintenance cost and preventive maintenance cost are actually the optimized result. It starts with assigning a cost to downtime. It may be useful to use the financial departments to find out what an hour or a shift of lost production is worth for a piece of equipment. This cost might include lost sales, employee salaries and overhead, the cost to make up lost production (if it can be made up), and any measurable depreciation to the assets. The figures coming from the financial department will usually be conservative, but will not be disputed by other parts of the organization.

2.7.1 Corrective Maintenance Cost

For CM cost, there are several parameters to be considered to estimate the cost of a failure, but all of them can be grouped in the following two groups: operational costs and non-operational costs.

2.7.1.1 Operational costs

Operational costs include costs related to the lost in the service operations due to the failure. If possible, it is good to know the average values associated to the failures for:

- Cost of opportunity loss (profit loss per hour)
- Cost of failure based on its frequencies (average no. of failures X cost per failure)

2.7.1.2 Non-operational costs (Direct maintenance costs)

Non-operational costs include costs related to the reparation of the failure. If possible, it will be good to know the average values associated to the failures for:

- Cost of labor (labor cost per hour)
- Cost of spare parts (average spare parts per failure X cost per unit of spare part)

2.7.2 Preventive Maintenance Cost

For preventive maintenance, there are no operational consequences. Maintenance should be scheduled to avoid service interruption, even extending the work time of the maintenance teams.

2.7.2.1 Non-operational costs (Direct maintenance costs)

- Cost of labor for inspection (labor cost per hour)

- Cost of spare parts or materials (average spare parts per failure X cost per unit of spare part)

With these figures agreed to, it is necessary to understand the maintenance costs involved. These costs may include the labor, material or supply, and miscellaneous costs that will be incurred due to the repair or the failure. Both costs may be needed to compare an overhaul to a run-to-failure approach to maintenance. Additional costs that may be incurred should also be calculated. These may include the hazardous materials, EPA, OSHA, or safety considerations [2].

CHAPTER 3

METHODOLOGY

3.1 Introduction

Methodology explains how the process of developing the PM costs minimization model. It includes the research methodology of the project and project activities in the given time that consists of phase 1 and phase 2.

3.2 Research Methodology

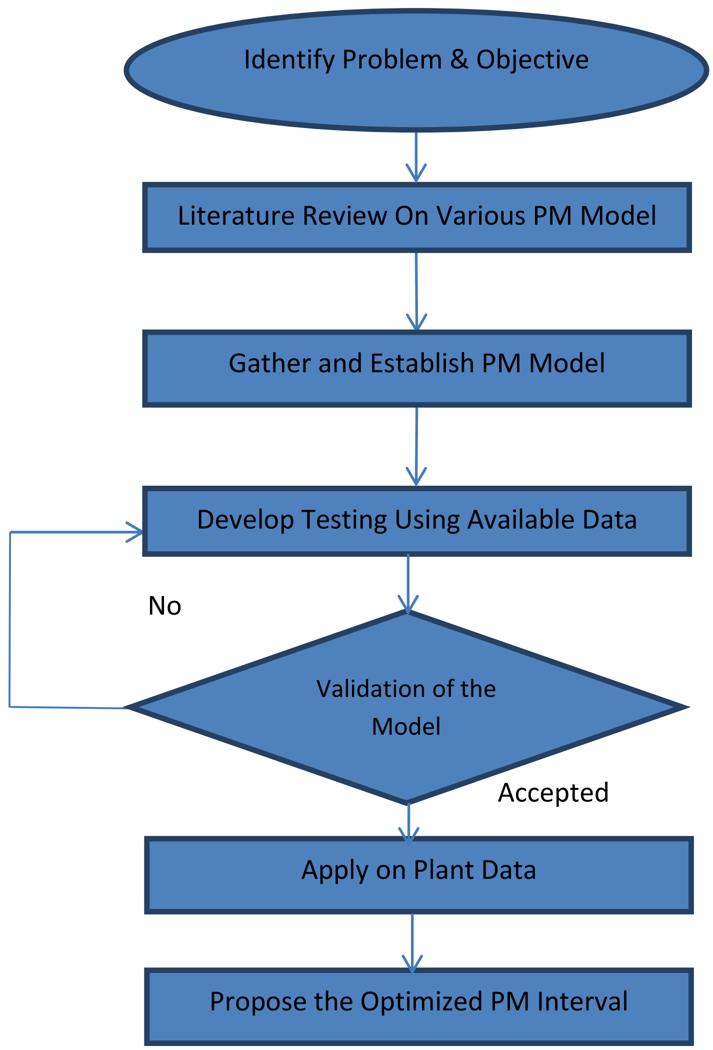


Figure 3.1: Flow Chart

The project initiated by defining the problem and identifies the objectives. Once done, the author carried out an extensive study on the project by gathering required data and information from available journals, articles, books and references. This enables the author to understand more on the project to be carried out and able to correlate the project with other previous researches done by researchers.

Experimental procedures are developed where preventive maintenance schemes or schedules data are gathered from an equipment of Oil and Gas Industry. The data is taken from a book, produced by Terry Wireman entitled ‘Preventive Maintenance’. In the book, it explains the decision for scheduling a preventive maintenance, but not on what is best for the operations group, nor on what is best for the maintenance group, but what is the lowest combined cost. In fact, this is the type of decision that companies must make if they want to optimize their resources. A model is then developed based on the data provided by the book in order to assess the existing PM schedules by inputting all the data obtained and propose ways to further reduce its operation and maintenance costs. Microsoft Office Excel is the main tool for the author to develop the PM minimizing model. After the testing produced no errors, the result then be discussed where the best decision is made.

PM schedules are generally integrated into the overall maintenance schedule, unless there are personnel dedicated only to perform the PMs. In other case, more accurate estimates and material requirements lead to more accurate schedules, which then lead to more successful PM programs.

3.5 Tools

The development of the model for minimizing preventive maintenance (PM) cost will utilize Microsoft Office Excel 2013.

CHAPTER 4

RESULT AND DISCUSSION

An example developed by Terry Wireman [2] is taken as the main reference for the developing of this model. The model developed is actually the enhancement of the data given in the book. An example equipment of oil and gas industry chosen is a Centrifugal Pump. This pump may be pumping a product or moving cooling water. Setting a price on the value gives a reference from which to start. The value of production cost is $100.00 per hour.

4.1 Data Input of the Model

Data to be input into the model are:

- Preventive Maintenance (PM) Cost
- Corrective Maintenance (CM) Cost
- Mean Time Before Failure (MTBF)
- Performance Lost
- Percentage of Performance Lost
- Downtime for PM
- Downtime for CM

Before these data input are obtained, some calculations are made. The following sub-topics will explain each and every of the calculation, step by step.

4.2 Preventive Maintenance (PM) Cost Calculation

Preventive Maintenance Cost = $1,500.00

If the pump is serviced once every 500 hours, the cost is: $1,500/500 = $3.00/hour

Table 1.1: Basic PM Cost

Service Frequency (Hours)	Preventive Maintenance Cost (Dollars)/hour
500	3.00
1000	1.50
1500	1.00
2000	0.75
2500	0.60
3000	0.50
3500	0.43
4000	0.38

For this centrifugal pump, it costs $1,500 dollars for labor and spare parts.

4.3 Performance Loss Calculation

The pump performance is measured, and it is found that it loses 5% of its capacity after 4000 hours of operation. An assumption is made where the drop is linear and continues to be so throughout the life of the pump. As shown in Table 4.2 below, if the PM is delayed, the amount of lost performance cost is increasing linearly.

The calculation at 4000 hours of operation is:

$$0.05 \times \$100 = \$5/hour$$

Table 4.2: Performance Lost

Time Since Last Service (Hours)	Lost Performance Cost (Dollars)/hour
500	0.63
1000	1.25
1500	1.88
2000	2.50
2500	3.13
3000	3.75
3500	4.38
4000	5.00

However, in Figure 4.1 below, it shows the understanding that the performance fall off is triangular and not the total area of the rectangle.

Figure 4.1: Percentage Drop of Performance Lost

Hence, the total loss is not the entire rectangle, but only half (1/2) of its area. As a result, the true total loss cost of the performance is half (1/2) of the calculated amount. The revised version of the table will be as shown in Table 4.3 below.

Table 4.3: True Performance Loss

Time Since Last Service (Hours)	Lost Performance Cost (Dollars)/hour
500	0.31
1000	0.63
1500	0.94
2000	1.25
2500	1.56
3000	1.88
3500	2.19
4000	2.50

4.4 Downtime Cost Calculation

Breakdowns are included when the maintenance intervals exceed a certain level. This means that the downtime needs to be factored in during the cycle. Hence, this will alter the results of the calculation. For this equipment, the breakdown will only occur if the preventive maintenance (PM) is not performed before 3000 hours of operation. If the PM frequency extends beyond that time, an additional cost $2,400.00 will be included, or as shown in the calculation below:

- Downtime for PM (at 500 or before 3000 hours of operation): 8 hours of downtime

$$\frac{\$100(production\ cost\ per\ hour) \times 8}{500} = \$1.60/hr$$

- Downtime for CM (at 3000 or above 3000 hours of operation): 24 hours of downtime

$$\frac{(\$\mathbf{100} \times \mathbf{8}) + (\$\mathbf{100} \times \mathbf{24})}{\mathbf{3000}} = \$\mathbf{1.07}/\boldsymbol{hr}$$

Table 4.4: Downtime Cost

Service Frequency (Hours)	Downtime Cost (Dollars)/hour
500	1.60
1000	0.80
1500	0.53
2000	0.40
2500	0.32
3000	1.07
3500	0.91
4000	0.80

As shown in Table 4.4 above, the downtime cost is decreasing when the service frequency increases. However, after 3000 hours of operation, the downtime cost increases back due to the occurrence of a breakdown.

4.5 Corrective Maintenance (CM) Cost Calculation

Corrective Maintenance Cost = $1,700.00

For this centrifugal pump, CM cost is $1,700 dollars for labor and spare parts. However, CM cost is calculated only after a breakdown occurs. In this case, the MTBF is at 3000 hours of operation. So, the calculation will be:

$$\frac{\$1{,}700}{3000} = \$0.57/hour$$

Table 4.5: CM Cost

Service Frequency (Hours)	Corrective Maintenance Cost (Dollars)/hour
500	0.00
1000	0.00
1500	0.00
2000	0.00
2500	0.00
3000	0.57
3500	0.49
4000	0.43

4.6 Total Cost Calculation

Continuing to consider all the calculations above, a decision then is made on the lowest total cost. The summary of the calculations is shown in Table 4.6 below.

Table 4.6: Total Cost

Time Since Last Service (Hours)	Preventive Maintenance Cost (Dollars) / Hour	Lost Performance Cost (Dollars) / Hour	Downtime Cost (Dollars) / Hour	Corrective Maintenance Cost (Dollars) / Hour	Total Cost (Dollars) / Hour
500	3.00	0.31	1.60	0.00	4.91
1000	1.50	0.63	0.80	0.00	2.93
1500	1.00	0.94	0.53	0.00	2.47
2000	0.75	1.25	0.40	0.00	2.40
2500	0.60	1.56	0.32	0.00	2.48
3000	0.50	1.88	1.07	0.57	4.01
3500	0.43	2.19	0.91	0.49	4.02
4000	0.38	2.50	0.80	0.43	4.10

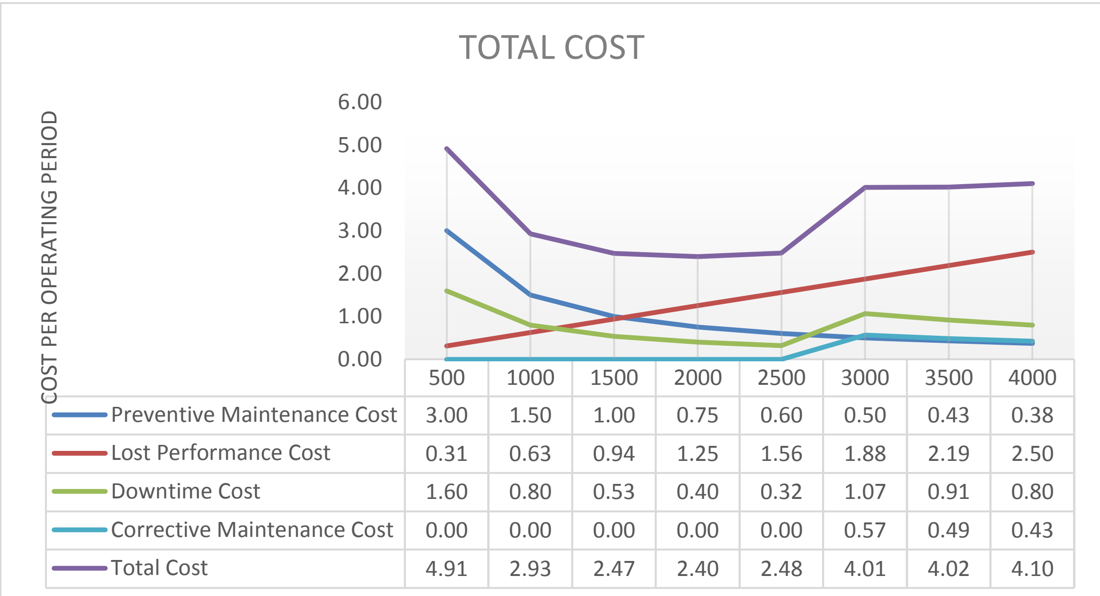


Figure 4.2: Minimized Preventive Maintenance Costs

Figure 4.2 above clearly shows that the lowest total cost will be around 2000 hours of operation, but definitely before 3000 hours of operation. However, the exact value of the optimized PM interval is at 1920 hours, which is shown in Appendix B.

4.7 Preventive Maintenance (PM) Cost Minimization Model in Excel

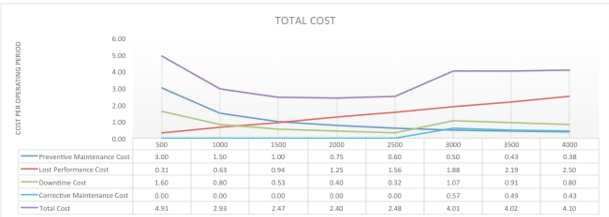
Figure 4.3 below shows how the PM Cost Minimization Model looks like in excel view.

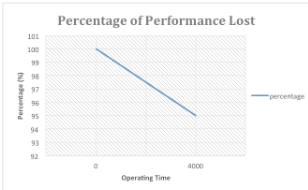
Time Since Last Service (Hours)	Preventive Maintenance Cost (Dollars) / Hour	Lost Performance Cost (Dollars) / Hour	Downtime Cost (Dollars) / Hour	Corrective Maintenance Cost (Dollars) / Hour	Total Cost (Dollars) / Hour
500	3.00	0.31	1.60	0.00	4.91
1000	1.50	0.63	0.80	0.00	2.93
1500	1.00	0.94	0.53	0.00	2.47
2000	0.75	1.25	0.40	0.00	2.40
2500	0.60	1.56	0.32	0.00	2.48
3000	0.50	1.88	1.07	0.57	4.01
3500	0.43	2.19	0.91	0.49	4.02
4000	0.38	2.50	0.80	0.43	4.10

Data Input	
Preventive Maintenance (PM) Costs ($)	1,500
Corrective Maintenance (CM) Costs ($)	1700
Production Cost ($) / Hour	100
MTBF (Hour)	3000
Performance Lost (Hours)	4000
Percentage of Performance Lost (%)	0.05
Downtime for PM (Hour)	8
Downtime for CM (Hour)	24
Hours Gap	500

Cost Involved for PM ($)	Total
Labour	750
Spare Parts	750
	1500

Cost Involved for CM ($)	Total
Labour	1200
Spare Parts	500
	1700





Optimum PM interval (Hours)	1920

Figure 6: Screenshot of PM Cost Minimization Model in Excel

4.8 Limitations

- This tool needs a very reliable data for a better and more precise data. If not, estimation of when the preventive maintenance activities will take place and not financially minimizing their resources
- This tool is only suitable for repairable systems
- The performance loss over time is assumed linear
- The failure frequency is not based on the distribution

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Preventive Maintenance performance has many advantages including increase in production revenue, reduction in overtime, increase in equipment availability, performed as convenient, balanced workload, consistency in quality, reduction in need for standby equipment, stimulation in reaction instead of reaction, reduction in parts inventory, improved safety, standardized procedures, times, and costs, scheduled resources on hand, and useful in promoting benefit and cost optimization [14,15].

The PM cost minimization model is successfully developed in this project and it is helpful to minimize preventive maintenance (PM) cost from continuous production. In addition, the developed model can be applied to real industrial data for determining the optimum schedule for PM internal.

5.2 Recommendation (Future Work)

Some recommendations for this project’s developments in the future are;

- Collecting real data of an equipment from any plant of oil and gas industry to make sure that the model, which is to be developed meet the expectation
- The tool can be further simplified by using Microsoft Excel’s VBA function as to make the spreadsheet more user friendly and more interesting
- To put probabilistic failure data (distribution) into the model
- To include stochastic performance lost model

REFERENCES

[1] Serna, O., *Maintenance History and Evolution*, April 2013, Retrieved from http://www.slideshare.net/alejandroserna71/maintenance-history-and-evolution

[2] Wireman, T. *Preventive Maintenance*, Volume 1. New York, NY: Industrial Press, Inc., 2008.

[3] Wireman, T. *Benchmarking Best Practices in Maintenance Management*, 2^{nd} Edition. New York, NY: Industrial Press, Inc., 2010, pp.141-155.

[4] Moubray J, *Reliability Centred Maintenance*, Butterworth-Heinemann, 2nd Edition.

[5] Hardwick J, Winsor G, RCM - *Making the Process More Cost Effective One Year Later*. ICOMS, 2002.

[6] Turner S, PMO Optimization Using PMO 2000 Reliability Software and Methodology, OMCS, 2002, Retrieved from http://www.pmoptimisation.com.au/downloads/pmo_for_assets_in_use.pdf

[7] Reliability Hotwire, Issue 113, July 2010, Retrieved from http://www.weibull.com/hotwire/issue113/hottopics113.htm

[8] Gross, J. M. *Fundamentals of Preventive Maintenance*. New York, NY: AMACOM, 2002.

[9] Marshall Institute, Preventive Maintenance – The Cost of Maintaining Equipment, 2010, Retrieved from http://info.marshallinstitute.com/bid/39146/Preventive-Maintenance-The-Cost-of-Maintaining-Equipment

[10] Author Unknown, February 2002, Reliability Goes Nonfat With Lean Maintenance, Retrieved from http://www.mt-online.com/current/0202_leanmaint.html

[11] Author Unknown, TE 5.2-25 OFF POST PREVENTIVE MAINTENANCE TASK AND FREQUENCY CHART– APPENDIX, Retrieved from http://www.mccoy.army.mil/A76/DSS/PWS/TE%205.2-25%20Off%20Post%20PM%20Task%20&%20Frequency%20-%20Appendix.doc

[12] Oniqua, Reducing The Cost of Preventive Maintenance, Retrieved from http://freepdfdb.org/pdf/reliability-centered-maintenance-by-john-moubray

[13] Machinery Management Solutions, Inc., Retrieved from http://www.machineryhealthcare.com/PMOptimization.html

[14] Levitt, J., Managing preventing maintenance, *Maintenance Technology,* February 1997, 20–30.

[15] Patton, J.D., *Preventive Maintenance,* Instrument Society of America, Research Tri- angle Park, North Carolina, 1983.

[16] Patton, J. D. *Preventive Maintenance*, 3rd Generation. Research Triangle Park, NC: ISA, 2004, pp.5-115.

APPENDIX A

Project Activities

Table 3.1: Project Activities of the Project (Phase I and Phase II)

Task	Activities
Project preparation	• Title Discussion • Title Approval • Preliminary Research Work
Extended Proposal	• Submission of Extended Proposal • Proposal Defense
Project Execution Phase 1	• Literature Survey - The Importance of Preventive Maintenance - Types of Preventive Maintenance - Issues Related to Preventive Maintenance - Available Methods of Performing a Review of Preventive Maintenance Activities - Benefit versus Costs (Optimizing Model) • Familiarization with Preventive Maintenance Cost Minimization Model • Gathering of Parameters for the Development of the Model • Preliminary Work on the Model Development
Project Break	• Submission of Interim Report
Project Execution Phase 2	• Development of Preventive Maintenance Cost Minimization Model
Progress Report	• Submission of Progress Report
Pre - SEDEX	• Poster Presentation
Project Closed Out	• Project Documentation – Dissertation (Soft Bound) – Technical Paper – Dissertation (Hard Bound) • Oral Presentation

Key Milestones

Table 3.2: Key Milestones in FYP 1

Deliverable	Target Date
Submission of Extended Proposal	Week 6
Proposal Defense	Week 8 – 9
Submission of draft Interim Report	Week 13
Submission of Interim Report	Week 14

Table 3.3: Key Milestones in FYP 2

Event or Deliverable	Target Date
Submission of Progress Report	Week 8
Pre - SEDEX	Week 11
Submission of Draft Report	Week 12
Submission of Dissertation (Soft Bound)	Week 13
Submission of Technical Paper	Week 13
Oral Presentation	Week 14
Submission of Dissertation (Hard Bound)	Week 15

Gantt Chart for FYP I and FYP II

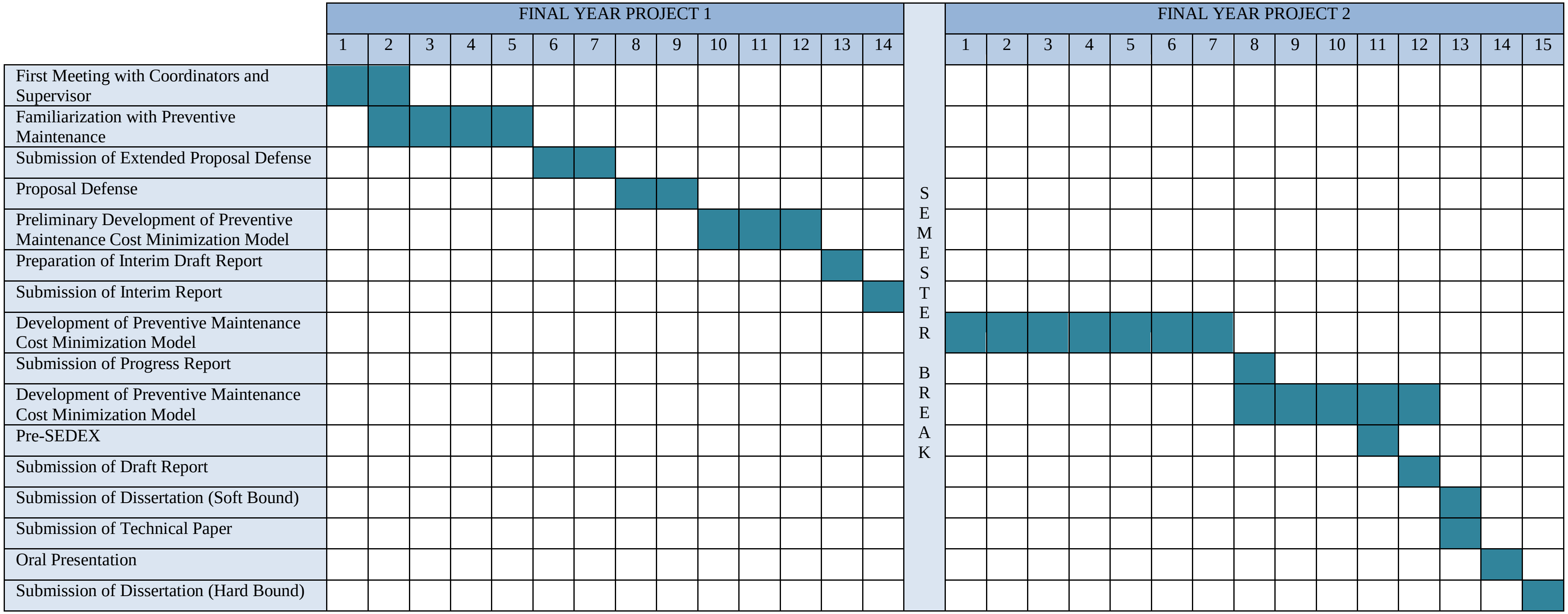


Figure 3.2: FYP Gantt Chart

APPENDIX B

Detailed Version of the Total Cost Calculation

Time Since Last Service (Hours)	Preventive Maintenance Cost (Dollars) / Hour	Lost Performance Cost (Dollars) / Hour	Downtime Cost (Dollars) / Hour	Corrective Maintenance Cost (Dollars) / Hour	Total Cost (Dollars) / Hour
20	75.00	0.01	40.00	0.00	115.01
40	37.50	0.03	20.00	0.00	57.53
60	25.00	0.04	13.33	0.00	38.37
80	18.75	0.05	10.00	0.00	28.80
100	15.00	0.06	8.00	0.00	23.06
120	12.50	0.08	6.67	0.00	19.24
140	10.71	0.09	5.71	0.00	16.52
160	9.38	0.10	5.00	0.00	14.48
180	8.33	0.11	4.44	0.00	12.89
200	7.50	0.13	4.00	0.00	11.63
220	6.82	0.14	3.64	0.00	10.59
240	6.25	0.15	3.33	0.00	9.73
260	5.77	0.16	3.08	0.00	9.01
280	5.36	0.18	2.86	0.00	8.39
300	5.00	0.19	2.67	0.00	7.85
320	4.69	0.20	2.50	0.00	7.39
340	4.41	0.21	2.35	0.00	6.98
360	4.17	0.23	2.22	0.00	6.61
380	3.95	0.24	2.11	0.00	6.29
400	3.75	0.25	2.00	0.00	6.00
420	3.57	0.26	1.90	0.00	5.74
440	3.41	0.28	1.82	0.00	5.50
460	3.26	0.29	1.74	0.00	5.29
480	3.13	0.30	1.67	0.00	5.09
500	3.00	0.31	1.60	0.00	4.91
520	2.88	0.33	1.54	0.00	4.75
540	2.78	0.34	1.48	0.00	4.60
560	2.68	0.35	1.43	0.00	4.46
580	2.59	0.36	1.38	0.00	4.33
600	2.50	0.38	1.33	0.00	4.21
620	2.42	0.39	1.29	0.00	4.10

640	2.34	0.40	1.25	0.00	3.99
660	2.27	0.41	1.21	0.00	3.90
680	2.21	0.43	1.18	0.00	3.81
700	2.14	0.44	1.14	0.00	3.72
720	2.08	0.45	1.11	0.00	3.64
740	2.03	0.46	1.08	0.00	3.57
760	1.97	0.48	1.05	0.00	3.50
780	1.92	0.49	1.03	0.00	3.44
800	1.88	0.50	1.00	0.00	3.38
820	1.83	0.51	0.98	0.00	3.32
840	1.79	0.53	0.95	0.00	3.26
860	1.74	0.54	0.93	0.00	3.21
880	1.70	0.55	0.91	0.00	3.16
900	1.67	0.56	0.89	0.00	3.12
920	1.63	0.58	0.87	0.00	3.08
940	1.60	0.59	0.85	0.00	3.03
960	1.56	0.60	0.83	0.00	3.00
980	1.53	0.61	0.82	0.00	2.96
1000	1.50	0.63	0.80	0.00	2.93
1020	1.47	0.64	0.78	0.00	2.89
1040	1.44	0.65	0.77	0.00	2.86
1060	1.42	0.66	0.75	0.00	2.83
1080	1.39	0.68	0.74	0.00	2.80
1100	1.36	0.69	0.73	0.00	2.78
1120	1.34	0.70	0.71	0.00	2.75
1140	1.32	0.71	0.70	0.00	2.73
1160	1.29	0.73	0.69	0.00	2.71
1180	1.27	0.74	0.68	0.00	2.69
1200	1.25	0.75	0.67	0.00	2.67
1220	1.23	0.76	0.66	0.00	2.65
1240	1.21	0.78	0.65	0.00	2.63
1260	1.19	0.79	0.63	0.00	2.61
1280	1.17	0.80	0.63	0.00	2.60
1300	1.15	0.81	0.62	0.00	2.58
1320	1.14	0.83	0.61	0.00	2.57
1340	1.12	0.84	0.60	0.00	2.55
1360	1.10	0.85	0.59	0.00	2.54
1380	1.09	0.86	0.58	0.00	2.53
1400	1.07	0.88	0.57	0.00	2.52
1420	1.06	0.89	0.56	0.00	2.51

1440	1.04	0.90	0.56	0.00	2.50
1460	1.03	0.91	0.55	0.00	2.49
1480	1.01	0.93	0.54	0.00	2.48
1500	1.00	0.94	0.53	0.00	2.47
1520	0.99	0.95	0.53	0.00	2.46
1540	0.97	0.96	0.52	0.00	2.46
1560	0.96	0.98	0.51	0.00	2.45
1580	0.95	0.99	0.51	0.00	2.44
1600	0.94	1.00	0.50	0.00	2.44
1620	0.93	1.01	0.49	0.00	2.43
1640	0.91	1.03	0.49	0.00	2.43
1660	0.90	1.04	0.48	0.00	2.42
1680	0.89	1.05	0.48	0.00	2.42
1700	0.88	1.06	0.47	0.00	2.42
1720	0.87	1.08	0.47	0.00	2.41
1740	0.86	1.09	0.46	0.00	2.41
1760	0.85	1.10	0.45	0.00	2.41
1780	0.84	1.11	0.45	0.00	2.4046
1800	0.83	1.13	0.44	0.00	2.4028
1820	0.82	1.14	0.44	0.00	2.4012
1840	0.82	1.15	0.43	0.00	2.4000
1860	0.81	1.16	0.43	0.00	2.3991
1880	0.80	1.18	0.43	0.00	2.3984
1900	0.79	1.19	0.42	0.00	2.3980
1920	0.78	1.20	0.42	0.00	2.3979
1940	0.77	1.21	0.41	0.00	2.3981
1960	0.77	1.23	0.41	0.00	2.3985
1980	0.76	1.24	0.40	0.00	2.3991
2000	0.75	1.25	0.40	0.00	2.4000
2020	0.74	1.26	0.40	0.00	2.4011
2040	0.74	1.28	0.39	0.00	2.4025
2060	0.73	1.29	0.39	0.00	2.4040
2080	0.72	1.30	0.38	0.00	2.41
2100	0.71	1.31	0.38	0.00	2.41
2120	0.71	1.33	0.38	0.00	2.41
2140	0.70	1.34	0.37	0.00	2.41
2160	0.69	1.35	0.37	0.00	2.41
2180	0.69	1.36	0.37	0.00	2.42
2200	0.68	1.38	0.36	0.00	2.42
2220	0.68	1.39	0.36	0.00	2.42

2240	0.67	1.40	0.36	0.00	2.43
2260	0.66	1.41	0.35	0.00	2.43
2280	0.66	1.43	0.35	0.00	2.43
2300	0.65	1.44	0.35	0.00	2.44
2320	0.65	1.45	0.34	0.00	2.44
2340	0.64	1.46	0.34	0.00	2.45
2360	0.64	1.48	0.34	0.00	2.45
2380	0.63	1.49	0.34	0.00	2.45
2400	0.63	1.50	0.33	0.00	2.46
2420	0.62	1.51	0.33	0.00	2.46
2440	0.61	1.53	0.33	0.00	2.47
2460	0.61	1.54	0.33	0.00	2.47
2480	0.60	1.55	0.32	0.00	2.48
2500	0.60	1.56	0.32	0.00	2.48
2520	0.60	1.58	0.32	0.00	2.49
2540	0.59	1.59	0.31	0.00	2.49
2560	0.59	1.60	0.31	0.00	2.50
2580	0.58	1.61	0.31	0.00	2.50
2600	0.58	1.63	0.31	0.00	2.51
2620	0.57	1.64	0.31	0.00	2.52
2640	0.57	1.65	0.30	0.00	2.52
2660	0.56	1.66	0.30	0.00	2.53
2680	0.56	1.68	0.30	0.00	2.53
2700	0.56	1.69	0.30	0.00	2.54
2720	0.55	1.70	0.29	0.00	2.55
2740	0.55	1.71	0.29	0.00	2.55
2760	0.54	1.73	0.29	0.00	2.56
2780	0.54	1.74	0.29	0.00	2.56
2800	0.54	1.75	0.29	0.00	2.57
2820	0.53	1.76	0.28	0.00	2.58
2840	0.53	1.78	0.28	0.00	2.58
2860	0.52	1.79	0.28	0.00	2.59
2880	0.52	1.80	0.28	0.00	2.60
2900	0.52	1.81	0.28	0.00	2.61
2920	0.51	1.83	0.27	0.00	2.61
2940	0.51	1.84	0.27	0.00	2.62
2960	0.51	1.85	0.27	0.00	2.63
2980	0.50	1.86	0.27	0.00	2.63
3000	0.50	1.88	1.07	0.57	4.01
3020	0.50	1.89	1.06	0.56	4.01

3040	0.49	1.90	1.05	0.56	4.01
3060	0.49	1.91	1.05	0.56	4.00
3080	0.49	1.93	1.04	0.55	4.00
3100	0.48	1.94	1.03	0.55	4.00
3120	0.48	1.95	1.03	0.54	4.00
3140	0.48	1.96	1.02	0.54	4.00
3160	0.47	1.98	1.01	0.54	4.00
3180	0.47	1.99	1.01	0.53	4.00
3200	0.47	2.00	1.00	0.53	4.00
3220	0.47	2.01	0.99	0.53	4.00
3240	0.46	2.03	0.99	0.52	4.00
3260	0.46	2.04	0.98	0.52	4.00
3280	0.46	2.05	0.98	0.52	4.00
3300	0.45	2.06	0.97	0.52	4.00
3320	0.45	2.08	0.96	0.51	4.00
3340	0.45	2.09	0.96	0.51	4.00
3360	0.45	2.10	0.95	0.51	4.00
3380	0.44	2.11	0.95	0.50	4.01
3400	0.44	2.13	0.94	0.50	4.01
3420	0.44	2.14	0.94	0.50	4.01
3440	0.44	2.15	0.93	0.49	4.01
3460	0.43	2.16	0.92	0.49	4.01
3480	0.43	2.18	0.92	0.49	4.01
3500	0.43	2.19	0.91	0.49	4.02
3520	0.43	2.20	0.91	0.48	4.02
3540	0.42	2.21	0.90	0.48	4.02
3560	0.42	2.23	0.90	0.48	4.02
3580	0.42	2.24	0.89	0.47	4.03
3600	0.42	2.25	0.89	0.47	4.03
3620	0.41	2.26	0.88	0.47	4.03
3640	0.41	2.28	0.88	0.47	4.03
3660	0.41	2.29	0.87	0.46	4.04
3680	0.41	2.30	0.87	0.46	4.04
3700	0.41	2.31	0.86	0.46	4.04
3720	0.40	2.33	0.86	0.46	4.05
3740	0.40	2.34	0.86	0.45	4.05
3760	0.40	2.35	0.85	0.45	4.05
3780	0.40	2.36	0.85	0.45	4.06
3800	0.39	2.38	0.84	0.45	4.06
3820	0.39	2.39	0.84	0.45	4.06

3840	0.39	2.40	0.83	0.44	4.07
3860	0.39	2.41	0.83	0.44	4.07
3880	0.39	2.43	0.82	0.44	4.07
3900	0.38	2.44	0.82	0.44	4.08
3920	0.38	2.45	0.82	0.43	4.08
3940	0.38	2.46	0.81	0.43	4.09
3960	0.38	2.48	0.81	0.43	4.09
3980	0.38	2.49	0.80	0.43	4.10
4000	0.38	2.50	0.80	0.43	4.10