Mechanical Seal Cost Saving by Preventive Maintenance: A Case Study of STC.

by

Mr. Mondop Somsoi

A Final Report of the Three-Credit Course
CE 6998 Project

Submitted in Partial Fulfillment
of the Requirements for the Degree of
Master of Science
in Computer and Engineering Management
Assumption University

March 2004

Mechanical Seal Cost Saving by Preventive Maintenance: A Case Study of STC.

by
Mr. Mondop Somsoi

A Final Report of the Three-Credit Course
CE 6998 Project

Submitted in Partial Fulfillment
of the Requirements for the Degree of
Master of Science
in Computer and Engineering Management
Assumption University

March 2004

Project Title	Mechanical Seal Cost Saving by Preventive Maintenance
Name	Mr. Mondop Somsoi
Project Advisor	Dr. Chamnong Jungthirapanich
Academic Year	March 2004

The Graduate School of Assumption University has approved this final report of the three-credit course, CE 6998 PROJECT, submitted in partial fulfillment of the requirements for the degree of Master of Science in Computer and Engineering Management

Approval Committee:

(Dr. Chamnong Jung irapanich)
Dean and Advisor

(Prof.Dr. Srisakdi Charmonman)
Chairman

(Assoc.Prof. Somchai Thayarnyong)
CHE Representative

March 2004

ABSTRACT

This project concentrates on the design and implementation of preventive maintenance program for assisting manufacturer in improving the performance of plant maintenance system and also reducing maintenance cost simultaneously.

The mechanical seal is the equipment that's considered to be the main part of this program. Thai Kraft Industry Co., Ltd. (TKIC), one of the major companies in pulp and paper industry of Thailand, decided to implement the preventive maintenance instead of the traditional one for mechanical seal repairing. Sealing Technology Co., Ltd. (STC), the reliable mechanical seal supplier of TKIC, proposed the 3-year preventive maintenance contract to TKIC. Before signing the contract, plant survey has been done by the project team of STC. By information from plant survey record, retrofit technique and John Crane mechanical seal specification, the quotation can be developed. After several negotiations, the mechanical seal preventive maintenance program is implemented. In order to develop this program, the maintenance document such as Tag. No., mechanical seal history card, and maintenance schedule must be designed.

The evaluation of the STC maintenance service was done by the customer. TKIC monitors the project by considering monthly report from STC project team. Besides, Mean Time Between Failure (MTBF) has been calculated and compared with the traditional one. This index can help TKIC to decide to continue implementing preventive maintenance program after the existing contract was expired. Considering STC side, the payback period, yearly cash flow, process time of bidding and resigning the optional additional 2-year contract have been developed so as to track the project cost and prepare the project life extension proposal for the customer.

ACKNOWLEDGEMENTS

I am thankful to the following people and organizations. Without them, this project would not have been possible.

I wish to express sincere appreciation to my advisor and dean of MS(CEM) program, Dr. Chamnong Jungthirapanich. His patient assistance, guidance, and constant encouragement has led me from the project inception to the project completion. I would like to express gratitude to my chairman, Prof.Dr. Srisakdi Charmonman and CHE representative, Assoc.Prof. Somchai Thayarnyong for their constructive comments and advice throughout the project.

I would like to thank Mr.Anuthep Punyakhum, Mr.Uchat Withuworachat and the staff at the Department of Engineering, Sealing Technology Co., Ltd. for their help in engineering data support.

Special appreciation is due to my family for their continuous encouragement. Above all, I am forever grateful to my parents whose willingness to invest in my future has enabled me to achieve my educational goal.

TABLE OF CONTENTS

Chapter		Page
ABSTRACT		
ACKNOWLEDGEMENTS		ii
LIST OF FIGURES		
LIST OF TABLES		viii
I.	INTRODUCTION	1
	1.1 Introduction	1
	1.2 Objective	2
	1.3 Scope	3
	1.4 Methodology	3
II.	LITERATURE REVIEW	4
	2.1 Key Question	4
	2.2 Economic Factors	6
	2.3 Economics Methods of Comparison	7
	2.4 Depreciation Concepts and Terminology	14
	2.5 Controlling Cost and Schedule	18
	2.6 Maintenance and Reliability	28
III.	MECHANICAL SEAL	41
	3.1 What Is a Seal?	41
	3.2 Leakage	43
	3.3 Main Factors Influencing the Sealing Process	44
	3.4 Types of Seals	45
	3.5 Seal Performance Ranking	45

Chapter		Page
	3.6 Mechanical Seals	51
IV.	THE TKIC PREVENTIVE MAINTENANCE CONTRACT	60
	4.1 TKIC Traditional Maintenance Program	60
	4.2 Preventive Maintenance Service Proposal	62
	4.3 Contract Signing	71
V.	THE PREVENTIVE MAINTENANCE PROGRAM	72
	5.1 Maintenance Document	72
	5.2 Stock Management	82
	5.3 Data Flow Diagram	84
VI.	CONCLUSIONS AND RECOMMENDATIONS	88
	6.1 Conclusions	88
	6.2 Recommendations	90
APPENDIX A RELIABILITY PARTNERSHIP AGREEMENT		94
BIBLIOGRAPHY		107

LIST OF FIGURES

Figure	Page
2.1 Payback Period of Project S and L	8
2.2 Discounted Payback Period of Project S and L	10
2.3 Gantt Chart of House Project	20
2.4 Example of Master Schedule (in Line-bubble Format)	21
2.5 Gantt Chart Drawn by Harvard Project Manager 3.0	22
2.6 Arrow (Network) Diagram of House Project	24
2.7 Activity-on-node, (Network) Diagram of House Project	25
2.8 Normal Probability Distribution of Project Critical Path	27
2.9 Good Maintenance and Reliability Strategy Requires Employee Involvement and Good Procedures	29
2.10 Overall System Reliability as a Function of Number of Components and Component Reliability with Components in a Series	31
2.11 Maintenance Costs	36
3.1 Static Seal	41
3.2 Flange Coupling	41
3.3 Dynamic Seal	42
3.4 Example of a Dynamic Seal Application	42
3.5 Decreasing the Gap by Using a Seal	43
3.6 Influencing Parameters	44
3.7 Fixed Bush	46
3.8 Floating Bush	47
3.9 Floating Segmented Bush	48
3.10 Gland Packing	48

Figure	Page
3.11 Elastomer Lip Seal	49
3.12 FS Lip Seal	49
3.13 Metal Cased Lip Seal	50
3.14 Approximate Leakage Rates for Various Secondary Containment Device Sealing Aqueous Fluids	50
3.15 Mechanical Seal	51
3.16 Illustrates How the Two Radial Surfaces Retain the Liquid, which also Lubricates and Cools the Contacting Faces	52
3.17 Mechanical Seal Components	53
3.18 Externally Mounted Seal for Corrosive Liquid Sealing Purpose	54
3.19 Three Common Way to Prevent Overheating	54
3.20. Back to Back Arrangement	56
3.21 Tandem Arrangement	57
3.22 Adding a Second Seal to a Normally Externally Mounted PTFE Bellows Seal	58
3.23 Face to Face Arrangement	59
4.1 John Crane Seal Selection Process	66
4.2 John Crane Mechanical Seal Cost Estimation for TKIC Store	68
4.3 The 3-year Preventive Maintenance Quotation	69
5.1 Mechanical Seal History Card	73
5.2 Mechanical Seal Life and Performance Upgrading Card	74
5.3 Sample of Monthly Report for TKIC	77
5.4 Job Description for Completed Works in October	79
5.5 Context Diagram of TKIC Preventive Maintenance Service	84

Figure		Page
5.6	First Level Data Flow Diagram of TKIC Preventive Maintenance Service	85
5.7	Second Level Data Flow Diagram of TKIC Preventive Maintenance Service: Develop Maintenance Bid	86
5.8	Second Level Data Flow Diagram of TKIC Preventive Maintenance Service: Implement and Track Project Cost	87
6.1	Traditional Mechanical Seal MTBF-Last 6 Months	88
6.2	MTBF After Implementing Preventive Maintenance Program	89
6.3	Arrow Diagram of STC Preventive Maintenance Project	92
6.4	Arrow Diagram of STC Optional Addition of 2-Year Preventive Maintenance Project	93

LIST OF TABLES

Table		Page
2.1.	Information for Planning House Project	19
4.1.	List of Mechanical Seal Maintenance Expense in Wangsala Mill	60
4.2.	Sample of Plant Survey Form	64
4.3.	TKIC Rotating Equipment Summary	65
5.1.	Sample of TKIC Mechanical Seal Preventive Maintenance Schedule	75
5.2.	TKIC Plant Categories	76
5.3	Sample of Preventive Maintenance Report for PM#4, PM#5	80
5.4.	Sample of TKIC Stock Inventory	82
6.1.	Net Cash Flows of TKIC Preventive Maintenance Project	90
6.2.	PERT of STC Preventive Maintenance Project Bidding	92
6.3.	PERT of STC Optional Addition of 2-Year Preventive Maintenance Project	93

I. INTRODUCTION

1.1 Introduction

Most of the machines that are used for transferring or mixing the fluid products are necessary to have the dynamic seals. Pumps, agitators, mixers are the good example of the machines that need dynamic seals to prevent the leakage of the fluid from them to the atmosphere. There are two main reasons to prevent the leakage from those machines. The first reason is commercial concern, which concentrates on the value of the products especially, the costly products such as pulp, food and beverages, medicine, etc. The second is environmental concern, which focuses on the pollution and the hazard that might be caused by the leakage from products such as petrochemical products, acid, etc.

Typically, there are so many kinds of the dynamic seals. In the past, metal bush was used as the seal for the space between rotating shaft and the machine housing. Because of its hardness and design, the damage of the machine's shaft was happened and also the leakage. The second generation of dynamic seal was gland packing, which was developed by changing the material from the metal to synthetic fiber in order to make itself softer. Besides, the additives such as Polytretafluoroethelene (PTFE) graphite were filled in the synthetic fiber to reduce the friction between seal and shaft. However, it still has the wear on the shaft which is one cause of leakage. Nowadays, the hi-technology product named mechanical seal becomes the solution of sealing technology. It can prevent the leakage perfectly and at the same time get rid of the shaft wear problem.

Sealing Technology Company, subsidiary of Econosto (Thailand) Ltd., was established for mechanical seal problem solution. The company serves the clients by giving engineering consultation about the mechanical seal selection and supplies the "John Crane" mechanical seal products. Because of the reliability of the company, Thai Kraft Industrial Company Limited (TKIC), one of the company's potential pulp and paper industrial group customers was interested to implement the mechanical seal service contract with the company for 3 years period. The objectives of this contract are the mechanical seal life extension, breakdown time minimization, seal failure analysis and mechanical seal standardization. By implementing this project, the customer believed that the maintenance cost of mechanical seal will be decreased and simultaneously, plant reliability will be increased.

Before TKIC decided to sign the contract, the corrective maintenance had been implemented. At that time, TKIC faced a lot of unsolved problems, because the machine repairing record was not collected and they've never done seal failure analysis. When the mechanical seal failed, they just threw it away though some parts of it can be reused. Therefore, the company tried to eliminate those problems by using preventive maintenance.

Sealing Technology expects to gain the profit from this project by applying the lapping technique, which is one of the preventive maintenance methods to prolong the mechanical seal life, refurbishment and the spare part replacement. From these actions, the maintenance cost will be reduced.

1.2 Objective

The objective of the project is to show how to develop and implement the preventive maintenance program and also to illustrate the benefits of the preventive maintenance which are as follows:

(1) Maintenance cost saving.

(2) Reliability maximization.

(3) Mean time between failure (MTBF) increasing.

1.3 Scope

The project scope is aimed to study and apply the preventive maintenance concept to the mechanical seals which are installed in the rotary equipment of TKIC. The project will concentrate on developing and implementing of preventive maintenance program. In order to develop this program, the maintenance documents such as Tag. No., Mechanical Seal History Card are designed for collecting the machine data while TKIC Mechanical Seal Preventive Maintenance Schedule, TKIC Stock Inventory and monthly report are developed for the maintenance program implementation. The payback period, NPV and MTBF are calculated in order to evaluate the 3-year preventive maintenance program.

1.4 Methodology

The project methodologies are as follows:

(1) Identifying the specific industrial firm's maintenance information to consider the traditional maintenance program situation.

(2) Comparing the advantage of preventive maintenance with the traditional corrective maintenance program.

(3) Selecting the most appropriate maintenance method.

(4) Implementing the preventive maintenance program.

(5) Evaluating the performance of the program by calculating the financial and maintenance index.

II. LITERATURE REVIEW

Each Project Life Cycle starts with an examination of the feasibility of the project for the client. The feasibility study could be a discrete phase of the project. Thus prior to the decision to proceed with the development of an engineering project, a preliminary investigation or feasibility study should be made to determine whether the project is worthwhile and if so, what is the best option or alternative to adopt. Usually a feasibility study considers a project from a 'whole-of-life' perspective. The 'whole-of-life' considers the project from beginning until it is de-commissioned. These studies normally require a range of input including technical, economic, political, social and environmental considerations. A study that concentrates only on technical considerations could be inadequate and could result in a report that will not be approved or worse will cause ramifications during the life of the project.

Clients seek feasibility studies for different reasons. A study that identifies that the client's concept is achievable is not a guarantee that a project will be sanctioned or funded. Accordingly, there tend to be more feasibility studies than projects. Interestingly you should note that some multi-million feasibility studies are projects in their own right and the organization preparing the feasibility study may possibly be a specialist firm with no relationship to the Project Management group assuming a project eventuates.

2.1 Key Question

The key question that must be answered is whether the project will be worthwhile, in other words 'will it pay'. To start, you will need to formulate the essential features of the project and then determine whether it should be done now, later or never. If the project is identified as being worthwhile all the various alternatives or options of executing the proposal must be analyzed. A logical process is necessary and a suggested approach is as follows:

(a) Identify the requirement (the client's goals)

(b) Identify the limitations (time, funds, location, use, life, political influences) resolve the unknowns (site information, maintenance factors, lobby groups, silent partners)

(c) Identify and analyze the project options, considering:

(1) The need - undertake or amend existing procedures (phases)?

(2) The timing - do all now, part only to satisfy current demands?

(3) The cost - what is the best investment strategy?

(4) The method - are there alternative ways to achieve the same result? develop the preferred option (this may become the project plan).

At the outset there must be discussion with the client to determine the 'whole-of-life' requirement for the proposal. Some clients may be vague on the eventual use of the product that will be provided by the project so it is essential that positive discussion occur. Hence the feasibility study leader must be prepared to take the initiative. If immediate responses are not forthcoming, options can be presented to the client in the study. This may appear convoluted but remember that clients do not have all the expertise (remember you are there to provide the client with the best solution). Once the client has identified the project requirements, discussion should lead to answers or directions on the following questions:

(a) What is the required time frame to deliver the project?

(b) How will the project be funded during execution and beyond?

(c) How will the project be executed - client's organization, contractors engaged by the client, project manager or another?

(d) Are there any restrictions - location, political, cultural, security?

(e) What does the client intend to do with the project on completion - sell it, rent it, use it, develop it further, other (overseas aid project where the product is given to host country may delete the need for economic considerations)?

(f) How will the project be maintained on completion? Who will pay (this may influence options for the project - higher initial investment and lower maintenance versus lower initial investment and higher maintenance)?

(g) Does the client have any initial studies or reports that are available?

All the above assumes a relationship (contractual or otherwise) has been reached between the client and the organization preparing the feasibility study. This is often an exchange of letters where requirements, report time-frames and fees are agreed. The feasibility study can be a time consuming activity and you should establish the operating framework before the investigation is commenced.

2.2 Economic Factors

Most engineers are able to address the technical requirements (design, construction or production) of a feasibility study but often do not appreciate the economic factors - an essential management skill for engineering managers. The level of economic study required is dependent on the project. In some cases, all that may be required is an estimate; others will require a full economic analysis. Often this will become apparent during the discussion period with the client.

There are a number of ways of conducting an economic analysis. Engineering economic studies are concerned with both the initial capital cost of the project including debt as well as the continuing operation and maintenance and the benefits to be gained from its existence. When the assessment of various factors of relative significance presents some difficulty estimates are made, with the basis of reasoning also listed. This can also apply to the prediction of future trends; however, the use of external authoritative sources can assist. When making assumptions that may critically affect the project path, you must also determine what other actions may be necessary should the assumption prove incorrect.

Most economic studies aim to reduce factors to common units of money and time-scale so that alternatives can be compared. This leads to a cost-benefit analysis where a project can be economically justified if its benefit to cost ratio is greater than one. The benefits are defined as the total gain to the owner arising from the project; costs are the amounts to create and sustain the project. These are usually expressed in the same units such as dollars/annum, dollars/hectare, dollars/litre. Costs should include interest, depreciation, training, operation, maintenance, government charges, foreign exchange rates and any other directly attributable charges.

The status quo option (do nothing) should always be considered. If the construction of a new school will cost $100 000/annum, but the estimated community saving is $150 000/annum then the project is worthwhile as the benefit to cost is greater than one (1.5). There could be a number of alternatives to develop the school (total completion/partial completion now, open/closed layout) and this will vary the benefits and costs. Cost-benefit ratios should be developed for each option, with the best option being preferred.

2.3 Economics Methods of Comparison

During Engineering Economics, different economic comparison methods were introduced. Feasibility studies can use a variety of methods to assess a project's potential worth. These will normally include:

2.3.1 Payback Period and Discount Payback(Brigham 1997)

The payback period, defined as the expected number of years required to recover the original investment, was the first formal method used to evaluate capital budgeting projects. The payback calculation is diagrammed in Figure 2.1, and it explained below for Project S

Project S:	0	1	2	3	4
Net cash flow	-1000	500	400	300	100
Cumulative NCF	-1000	-500	-100	200	300

Project L:	0	1	2	3	4
Net cash flow	-1000	100	300	400	600
Cumulative NCF	-1000	-900	-600	-200	400

Figure 2.1. Payback Period of Project S and L. (Brigham 1997).

(1) Cumulative cash flow of year 0 equals to net cash flow of year 0 (CF0) which is -1000

(2) Now add CF 1 = 500 to find the cumulative cash flow at the end of Year 1. This is -500.

(3) Now add CF2 = 400 to find the cumulative cash flow at the end of Year 2. This is -100.

(4) Now add CF3 = 300 to find the cumulative cash flow at the end of Year 3. This is +200.

([5]) You see that by the end of Year 3 the cumulative inflows have more than recovered the initial outflow. Thus, the payback occurred during the third year. If the $300 of inflows come in evenly during Year 3, then the exact pay back can be found as follows:

$$\text{Payback}_s = \text{Year before full recovery} + \frac{\text{Unrecovered cost at start of year}}{\text{Cash flow during year}}$$

$$= 2+100/300 = 2.33 \text{ years.}$$

Applying the same procedure to Project L, we find Payback_i, = 3.33 years.

The shorter the payback the better. Therefore, if the firm required a payback of three years or less, Project S would be accepted but Project L would be rejected. If the projects were mutually exclusive, S would be ranked over L because S has the shorter payback. Mutually exclusive means that if one project is taken on, the other must be rejected. Independent projects are projects whose cash flows are independent of one another.

Some firms use a variant of the regular payback, the discounted payback period, which is similar to the regular payback period except that the expected cash flows are discounted by the project's cost of capital. Thus, the discounted payback period is defined as the number of years required to recover the investment from discounted net cash flows. Figure 2.2 contains the discounted net cash flows for Projects S and L, assuming both projects have a cost of capital of 10 percent. To construct Figure 2.2, each cash inflow is divided by $(1 + k)^t = (1.\ 10)^t$, where t is the year which the cash flow occurs and k is the project's cost of capital. After 3 years, Project S will have generated the $1,000 cost plus an extra $11, or $1,011 in discounted cash inflows. Since the cost is $1,000, the discounted payback is just under 3 years, or, to be precise, 2 + ($2 14/$225) = 2.95 years. Project L's discounted payback is 3.88 years:

Discounted paybacks = 2.0 + 214/225 = 2.95 years.

Discounted $payback_L$ = 3.0 + 360/410 = 3.88 years.

Project S:	0	1	2	3	4
Net cash flow	-1000	500	400	300	100
Discounted NCF	-1000	455	331	225	68
Cumulative discounted NCF	-1000	-545	-214	11	79

Project L:	0	1	2	3	4
Net cash flow	-1000	100	300	400	600
Discounted NCF	-1000	91	248	301	410
Cumulative discounted NCF	-1000	-909	-661	-360	50

Figure 2.2. Discounted Payback Period of Project S and L.(Brigham 1997).

For Projects S and L, the rankings are the same regardless of which payback method is used; that is, Project S is preferred to Project L, and Project S would still be selected if the firm were to require a discounted payback of three years or less.

2.3.2 Net Present Value (NPV) (Brigham 1997)

The net present value (NPV) method relies on discounted cash flow (DCF) methodology. To implement this approach, we proceed as follows:

(1) Find the present value of each period's net cash flow; including both inflows and outflows, discounted at the project's cost of capital.

(2) Sum these discounted net cash flows; this sum is defined as the project's NPV

(3) If the NPV is positive, the project should be accepted. If the NPV is negative, it should be rejected. And if two projects are mutually exclusive, the one with the higher positive NPV should be chosen.

The NPV is found using this equation:

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+k)^t}$$

Here CF_t, is the expected net cash flow at Period t, and k is the project's cost of capital. Cash outflows (expenditures on the project, such as the cost of buying equipment or building factories) are treated as negative cash flows. In evaluating Projects S and L, only CF0 is negative, but for many large projects such as a new automobile model, an electric generating plant, or a new steel mill, outflows occur for several years before operations begin and cash flows turn positive. Also, note that the above equation is quite general, so inflows and outflows could occur on any time basis, say, quarterly or monthly, in which case t would represent quarters or months rather than years.

At a 10 percent cost of capital, the NPV of Project S is $78.82:

	0	k = 10% 1	2		
Cash Flows ($1,000)		$500	$400	$300	$100

454.55 <
330.58
225.39 <
68.30 <
$ 78.82 = NPV_s

•By a similar process, we find NPVL = $49.18. On this basis, both projects should be accepted if they are independent, but S should be the one chosen if they are mutually exclusive.

2.3.3 Internal Rate of Return(Brigham 1997)

The IRR is defined as that discount rate which equates the present value of a project's expected cash inflows to the present value of the project's expected costs or; equivalently, forces the NPV to equal zero:

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1 + IRR)^t} = 0.$$

Here is the setup for Project S:

	0	IRR = ? 1	2	3	4
Cash Flows	($1,000)	$500	$400	$300	$100
Sum of PVs for CF_{1-4} =	$1,000				
Net present value	$ 0				

IRR_S = 14.5% = Discount rate which forces the sum of the PVs of CF 1.4 to equal the project's cost, $1,000, i.e., which forces the NPV to equal zero.

Internal rates of return can be calculated with financial calculators and computers, and most firms have computerized their capital budgeting processes and can quickly generate IRRs, NPVs, and paybacks for all projects. Thus, business firms have no difficulty whatsoever with the mechanical side of capital budgeting. Project S has IRRs

= 14.5%, while IRRL = 11.8%. If both projects have a cost of capital of 10 percent, then the internal rate of return rule indicates that if the projects are independent, both should be accepted - they both are expected to earn more than the cost of the capital needed to finance them. If they are mutually exclusive, S ranks higher and should be accepted, while L should be rejected. If the cost of capital is more than 14.5 percent, both projects should be rejected.

2.3.4 Profitability Index(Brigham 1997)

Another method used to evaluate projects is the profitability index (PI), or the benefit/cost ratio, as it is sometimes called:

$$PI = \frac{PV\ benefits}{PV\ costs} = \frac{\sum_{t=0}^{n} \frac{CF_t}{(1+k)^t}}{\sum_{t=0}^{n} \frac{COF_t}{(1+k)^t}}$$

Here CIF_t represents the expected cash inflows, or benefits, and COF_t represents the expected cash outflows, or costs. The PI shows the relative profitability of any project, or the present value of benefits per present value dollar of costs. The PI for Project S, based on a 10 percent cost of capital, is 1.079:

PIs = $1,078.82 /$1,000 = 1.079.

Thus, on a present value basis, Project S is expected to produce $1 .079 for each $1 of investment. Project L, with a PI of 1.049, should produce $1 .049 for each dollar invested.

A project is acceptable if its PI is greater than 1.0, and the higher the PI, the higher the project's ranking. Therefore, both S and L would be accepted by the PI criterion if they were independent, and S would be ranked ahead of L if they were mutually exclusive.

2.4 Depreciation Concepts and Terminology(Dergarmo 1997)

Depreciation is the decrease in value of physical properties with the passage of time and use. More specifically, depreciation is an accounting concept that establishes an annual deduction against before-tax income such that the effect of time and use on an asset's value can be reflected in a firm's financial statements. The actual amount of depreciation can never be established until the asset is retired from service. Because depreciation is a noncash cost that affects income taxes, we must consider it properly when making after-tax engineering economy studies.

Depreciable property is property for which depreciation is allowed under federal, state, or municipal income tax laws and regulations. To determine if depreciation deductions can be taken, the classification of various types of property must be understood. In general, property is depreciable if it meets the following basic requirements:

(1) It must be used in business or held to produce income.

(2) It must have a determinable useful life and the life must be longer than one year.

(3) It must be something that wears out, decays, gets used up, becomes obsolete, or loses value from natural causes.

(4) It is not inventory, stock in trade, or investment property.

Depreciable property is classified as either tangible or intangible. Tangible property can be seen or touched, and it includes two main types called personal property and real property. Personal property includes assets such as machinery, vehicles, equipment, furniture, and similar items. In contrast, real property is land and generally anything that is erected on, growing on, or attached to land. Land itself, however, is not depreciable because it does not have a determinable life.

Intangible property is personal property such as a copyright, patent, or franchise. We will not discuss the depreciation of intangible assets because engineering projects rarely include this class of property.

A company can begin to depreciate property it owns when the property is placed in service for use in the business or for the production of income. Property is considered to be placed in service when it is ready and available for a specific use, even if it is not actually used yet. Depreciation stops either when the cost of placing it in service has been recovered or it is retired from service. The Classical Depreciation Methods are as follows

2.4.1 Straight-Line (SL) Method(Brigham 1997)

Straight-line depreciation is the simplest depreciation method. It assumes that a constant amount is depreciated each year over the depreciable (useful) life of the asset. The following definitions are used in the equations below. If we define

N = depreciable life of the asset in years

B = cost basis, including allowable adjustments

dk = annual depreciation deduction in year k (1 k N)

BVk = book value at end of year k

SVN = estimated salvage value at end of year N

d_k* = cumulative depreciation through year k

then

dk = (B - SVN)/N

dk* = kdk for 1 k N

$BV_k = B - dk^*$

2.4.2 Declining Balance (DB) Method(Brigham 1997)

In the declining balance method, sometimes called the constant percentage method or the Matheson formula, it is assumed that the annual cost of depreciation is a fixed percentage of the BV at the beginning of the year. The ratio of the depreciation in any one year to the BV at the beginning of the year is constant throughout the life of the asset and is designated by R (0 R 1). In this method, R = 2/N when a 200% declining balance is being used (i.e., twice the straight line rate of 1/N), and N equals the depreciable (useful) life of an asset. If the 150% declining balance method is specified, then R = 1.5/N. The following relationships hold true for the declining balance method.

$$d_1 = B(R)$$

$$dk = B(1 - R)^{k-i}(R)$$

$$dk^* = B[1- (1 - R)^k]$$

$$BVk = B(1- R)^k$$

$$BVN = B(1 - R)^N$$

2.4.3 Sum-of-the-Years-Digits (SYD) Method(Brigham 1997)

To compute the depreciation deduction by the SYD method, the digits corresponding to the number for each permissible year of life are first listed in reverse order. The sum of these digits is then determined. The depreciation factor for any year is the number from the reverse-ordered listing for that year divided by the sum of the digits. For example, for a property having a depreciable (useful) life of five years, SYD depreciation factors are as follows:

Year	Number of the Year in Reverse Order (digits)	SYD Depreciation Factor
1	5	5/15
2	4	4/15
3	3	3/15
4	2	2/15
5	1	1/15
Sum of the digits	15	

The depreciation for any year is the product of the SYD depreciation factor for that year and the difference between the cost basis (B) and the estimated final SV. The general expression for the annual cost of depreciation for any year k, when N equals the depreciable life of an asset, is

$$d_k = (B\text{-}SVN) \cdot \left|\frac{k +}{N(N+1)}\right|$$

The book value at the end of the year k is

$$BV_k = B - \frac{2(B\text{-}SVN)}{N} \; \underline{k} \; \frac{(B\text{-}SVN)}{N(N+1)} \; k(k+1)$$

and the cumulative depreciation through the year k is simply

$$dk^* = B - BVk$$

2.5 Controlling Cost and Schedule(Kerzner 1979)

The essential management function of control has been defined simply as "compelling events to conform to plans". There we found that the first step in control was to establish standards, and that this was done in the planning process. The project planning methods such as the Gantt (bar) charts, and network scheduling systems such as PERT can help you to achieve the project.

2.5.1 Gantt (Bar) Charts(Agarwal 1995)

Henry L. Gantt, one of the pioneers of the scientific management movement, is generally credited with initiating the concept of a class of charts in which the progress of some set or sequence of activities or resources in the vertical dimension is plotted against time in the horizontal dimension. The first reported application was in 1915, when Gantt was keeping track of the time between ordering and delivery of each lot of ammunition produced in the United States for Allied forces in World War I.

Gantt charts have found many other applications. In the job-shop or batch-production environment, Gantt charts are used to schedule the use of production machines, and elsewhere for the planning and control of work crews. In project management, it is tasks or activities (project performance) that must be charted against time (project schedule). Three things must be established in the project planning process before Gantt charts can be created:

(1) The tasks (activities) needed to complete the project

(2) The precedence relationships of the tasks (which tasks must be complete before other specified tasks can begin)

(3) The expected duration of each task

Table 2.1. Information for Planning House Project.(Agarwal 1997).

Task	Follows Task(s)	Weeks Duration	Task Description	Manning Level
A	Start	1.0	Clear site	3
B	Start	0.6	Obtain lumber and other basic materials	1
C	Start	2.0	Obtain other materials and components	1
D	B	2.0	Prefabricate wall panels	4
E	B	0.9	Prefabricate roof trusses	3
F	A, B	1.0	Form and pour footings and floor slab	3
G	D, F	0.3	Erect wall panels	4
H	E, G	0.2	Erect roof trusses	4
J	C, H	0.5	Complete roof	3
K	J	2.0	Finish interior	4
L	J	1.0	Finish exterior	2
M	L	0.4	Clean up site	1
N	K, M	0.2	Final inspection and approval	1

Table 2.1 illustrates these three items (plus a "manning level" for later use) for a simple project: building a single-story residence on a concrete slab by first prefabricating wall panels (with electrical wiring and plumbing inside) and roof trusses. Time durations have been given in weeks assuming a five-day work week, so that an 8-hour day is 0.2 week. Given these durations and precedence relationships, a simple bar chart can be drawn in which each task is represented by a solid bar (Figure 2.3).

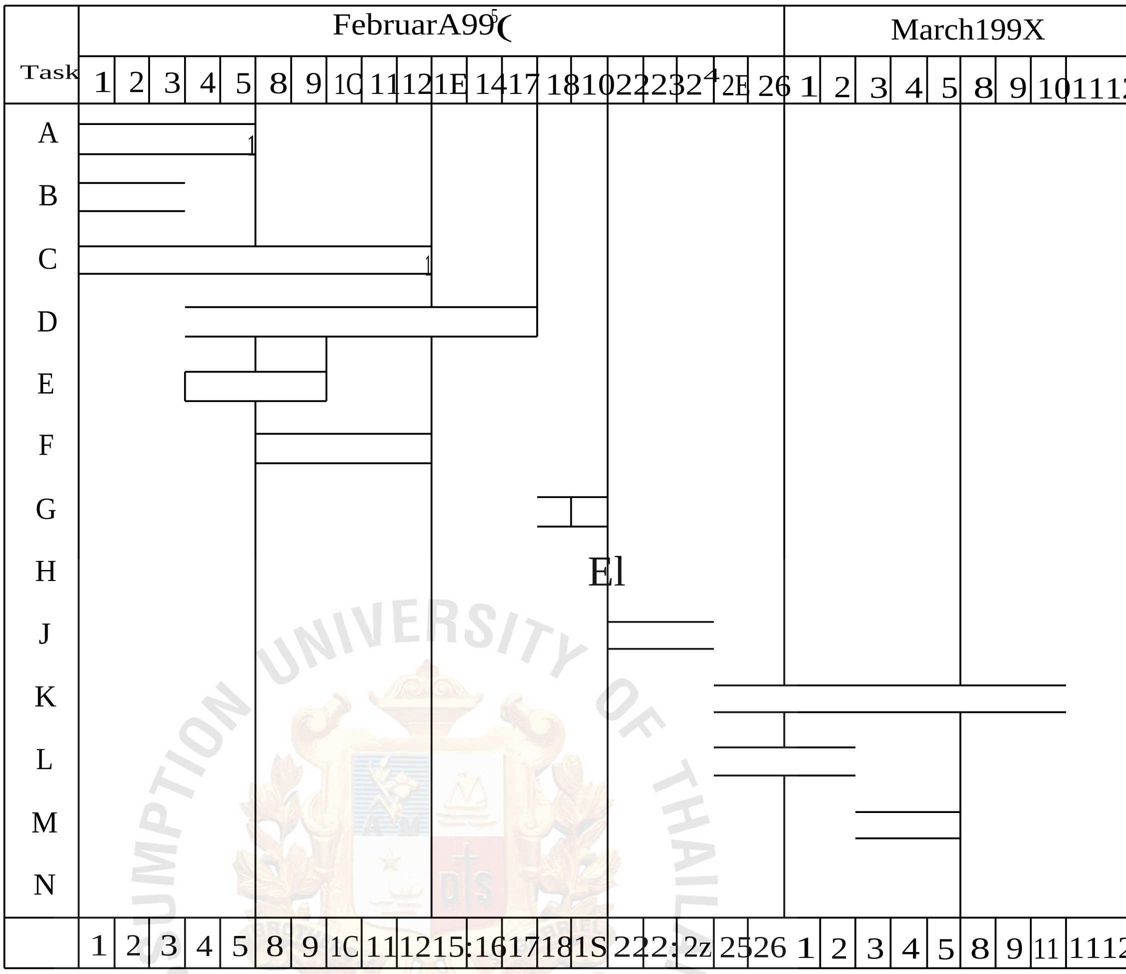


Figure 2.3. Gantt Chart of House Project.(Agarwal 1997).

Bar charts can be elaborated with symbols and arrows above and below the bars to indicate significant points within the task or relationships to other tasks. A bar chart showing only the major subdivisions of project activity (composite tasks) is often known as a master schedule. Figure 2.4 illustrates such a schedule in "line-bubble" format for a minicomputer development project; symbols above the lines (bars) give the originally scheduled start and finish dates for each task; open symbols below each line show the latest reschedule, and solid symbols show that the date tasks were actually begun and completed.

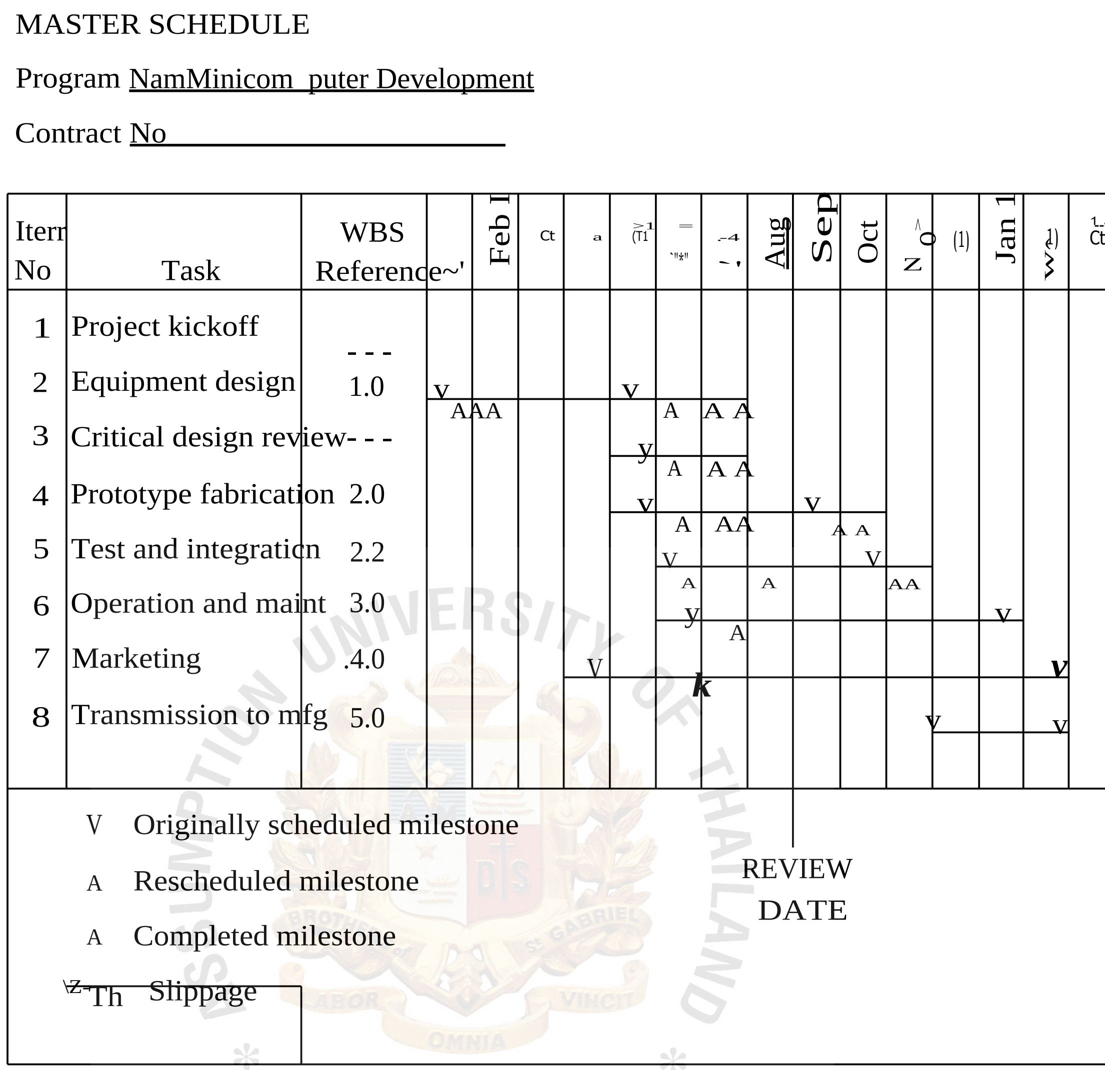


Figure 2.4. Example of Master Schedule (in Line-bubble Format). (Agarwal 1997).

Gantt charts are easy to understand and use, and they provide a good tool for managing small projects without an excessive number of tasks. Bars can be filled in with a felttip pen to show the extent of task completion, making obvious the tasks that are behind or ahead of schedule. At one time Gantt charts were considered an inflexible tool, since a schedule change in some critical task might make it necessary to redraw many charts by hand. This disadvantage has been eliminated by project management software packages.

Figure 2.5 shows a simple Gantt chart as it would appear on a computer screen drawn by Harvard Project Manager 3 .0, an early personal computer software. Task A on Figure 2.5, for example, was planned (top solid bar) to begin October 7 and end before October 14, but it could be permitted to end as late as October 16 (thin extension of top bar). The task actually began October 9, but finished as originally scheduled (bottom solid for task A). If delays or changes in the project make replanning necessary, one simply changes a few parameters of computer input, and the computer completely replans the project and can reproduce a new set of Gantt charts and schedule reports at minimal cost.

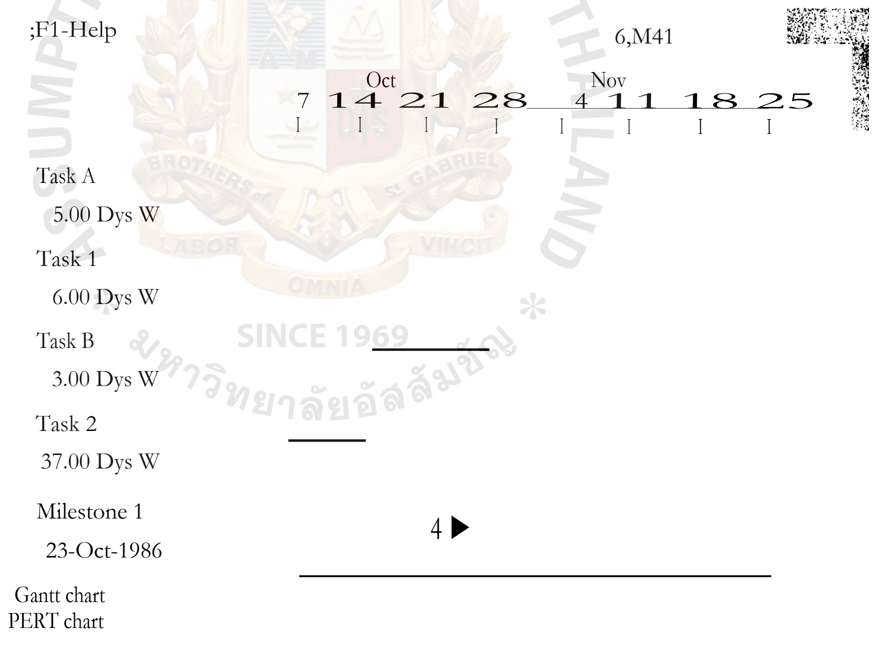


Figure 2.5. Gantt Chart Drawn by Harvard Project Manager 3.0.(Kerzner 1979).

2.5.2 Network Scheduling Systems(Kerzner 1979)

About 1958 two similar systems for network-based project scheduling were devised: the program evaluation review technique (PERT) was created by Booz, Allen, and Hamilton (management consultants) and Lockheed Aircraft Corporation for use in development of the Polaris ballistic missile, and the critical path method (CPM) was developed by the DuPont Company for chemical plant construction. In the intervening years the features of each have been added to the other, but the terminology "PERT" is still used in aerospace and related industry, and "CPM" is preferred in the construction industry.

A network can be portrayed using either of two graphical techniques: the arrow or the circle diagram. Figure 2-6 is the arrow diagram for the house project, based on the same data (Table 2-1) used for the bar chart in Figure 2.3. The arrows represent activities or tasks, which have time durations and consume resources (dollar cost and use of people and equipment); the circles represent events, which indicate the start and/or end of one or more activities. An activity may be given its own symbol (such as A in Figure 2.6), or it can be designated by its predecessor and successor events (activity 1,2 or 1-2 instead of A). No activity may begin until all activities ending in its predecessor event have been completed. Dummy activities, shown by dashed arrows such as 3-2 in Figure 2.6, simply show a precedence relationship between events in an arrow diagram, and they consume neither time nor any other resource. For example, activity F (2-4) cannot start until both A and B (1-2 and 1-3) are complete, whereas activity D (3-4) or E (3-5) depends only on the completion of activity B (1-3). Durations (here in weeks) are shown below each arrow.

The critical path is the longest path through the network, calculated by a computer software algorithm (or, in this simple case, by hand). In our house problem the critical path, shown with heavier arrows, is B-D-G-H-J-K-N (1-3-4-5-6-7-9-10) and has a duration of 5.8 weeks. Activities not on the critical path allow a degree of scheduling flexibility (called slack or float) that the project manager can use in obtaining the best use of resources. For example, activity E (3-5) has a duration of 0.9 week, whereas the parallel path D-G (3-4-5) has a duration of 2.3 weeks; activity E therefore has a slack of 1.4 weeks, and its start may be delayed that much without affecting the ending date of the project. Similarly, activity C (1-6) has a duration of 2.0 weeks, and the parallel path 1-3-4-5-6 has a duration of 3.1 weeks; the start of activity C may therefore be delayed up to 1.1 weeks without penalty.

Exactly the same relationships can be shown on a circle diagram (also known as an activity-on-node (AON) diagram), in which activities are shown within the circles and the arrows simply show dependency relationships between activities. Figure 2.7 shows the AON equivalent for the house project. All paths must begin with the "start" symbol and terminate at the "end." No equivalent to the dummy activity of the arrow diagram is required.

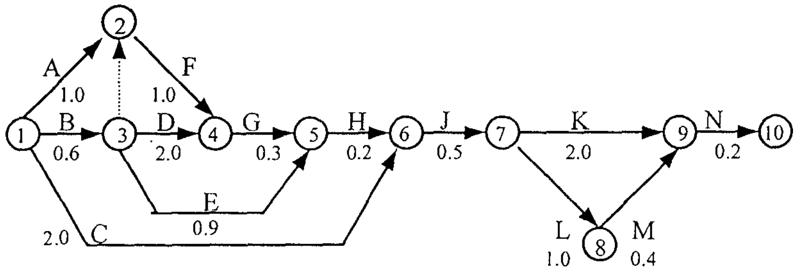


Figure 2.6. Arrow (Network) Diagram of House Project.(Agarwal 1997).

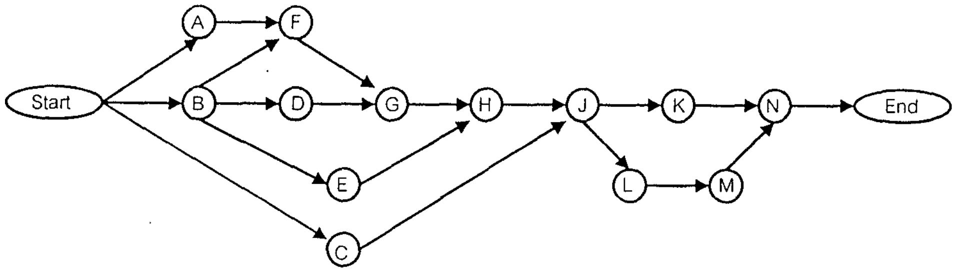


Figure 2.7. Activity-on-node, (Network) Diagram of House Project. (Agarwal 1997).

2.5.3 PERT Treatment of Uncertainty(Agarwal 1995)

A special feature developed with PERT is the treatment of activity durations (and therefore total project duration) as variables rather than constants. To use this feature, estimators are asked to provide three estimates of the duration of any activity that might vary:

(1) An optimistic time (a) that would only be improved upon once in 100 attempts

(2) A most likely time (m) that would occur most often if the activity were repeated many times (statistically, the mode)

(3) A pessimistic time (b) that would only be exceeded once in 100 attempts

The developers of PERT assumed that the probability distribution of possible durations of an activity fits a beta distribution, which need not be symmetrical (m need not be equidistant between a and b). The expected time (or mean value) t_o in the beta distribution can be approximated by

$$t_e = \frac{a + 4m + b}{6}$$

For example, if an activity were estimated to have an optimistic time of 10 weeks, a most likely time of 13 weeks, and a pessimistic time of 19 weeks, one would predict an expected (mean) time of

$$t_o = \frac{10+4(13)+19}{6} = 13.5 \text{ weeks}$$

Assuming the optimistic (a) and pessimistic (b) estimates for duration of an activity are three standard deviations on either side of the mean t_e, the standard deviation for the activity becomes

$$= \frac{b - a}{6} = \frac{19 - 10}{6} = 1.5 \text{ weeks}$$

The expected length of the critical path T_e for the entire project is obtained simply by adding the expected times t_e for (only) those activities lying on the critical path. Standard deviations cannot be added in the same way-only variances (the squares of standard deviations) can. The standard deviation 6r of the total project duration therefore becomes the root mean square of the standard deviations of activities lying along the critical path:

$$\sigma_T = \sqrt{\Sigma (\sigma^2)}$$

According to the central limit theorem of statistics, the probability distribution of the average or sum of a set of variables tends toward (approaches) the symmetrical normal distribution, even though the original variables fit other distributions. Knowing the expected time (mean) and standard deviation for the critical path permits us to draw a normal distribution fitting those two criteria.

project in 61.0 weeks (which is (61.0 - 58.0)/3.0, or 1.0, standard deviation longer than the mean of 58.0 weeks), you would estimate an 84% probability (50% + 34%) of completing the project within that time. The probability of completion within a 52-week year, 2.0 standard deviations (6.0 weeks) less than the mean T_e, on the other hand, would only be (50.0-34.1 - 13.6=) 2.3%.

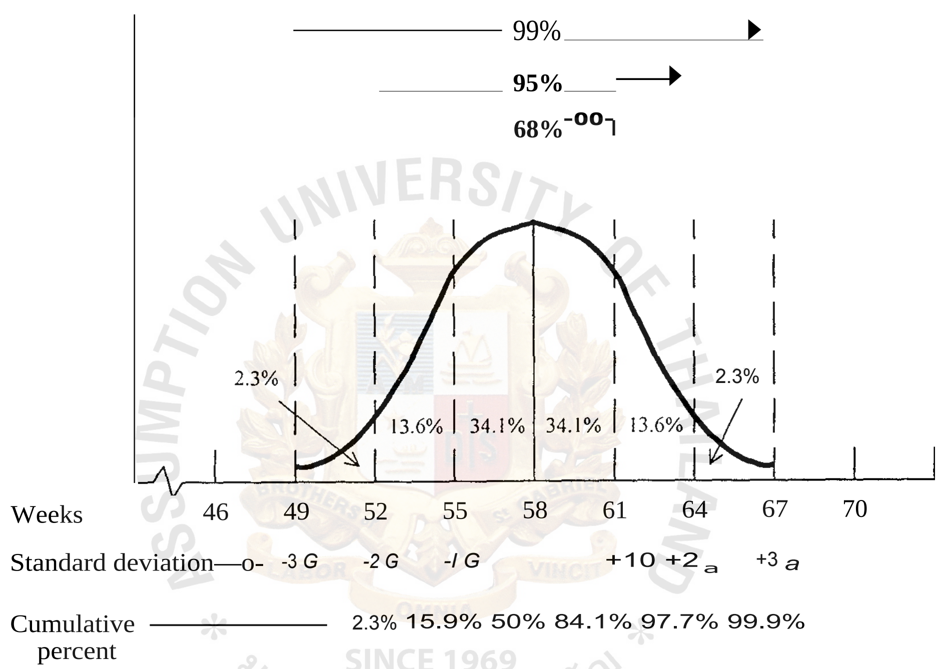


Figure 2.8. Normal Probability Distribution of Project Critical Path.(Agarwal 1995).

2.6 Maintenance and Reliability(Heizer 2001)

The results of failure can be disruptive, inconvenient, wasteful, and expensive in dollars and in lives. Machine and product failures can have far-reaching effects on an organization's operation, reputation, and profitability. In complex, highly mechanized plants. an out-of-tolerance process or a machine breakdown may result in idle employees and facilities, loss of customers and goodwill, and profits turning into losses. In an office, the failure of a generator, an air-conditioning system, or a computer may halt operations. A good maintenance and reliability strategy protects both a firm's performance and its investment.

The Objective of maintenance and reliability is to maintain the capability of the system while controlling costs. A good maintenance system drives out system variability. Systems must be designed and maintained to reach expected performance and quality standards. Maintenance includes all activities involved in keeping a system's equipment in working order. Reliability is the probability that a machine part or product will function properly for a specified time under stated conditions.

Two firms that recognize the strategic importance of dedicated maintenance are Walt Disney Company and United Parcel Service. Disney World, in Florida, is intolerant of failures or breakdowns. Disney's reputation makes it not only one of the most popular vacation destinations in the world but also a mecca for benchmarking teams that want to study its maintenance and reliability practices.

Likewise, UPS's famed maintenance strategy keeps its delivery vehicles operating and looking as good as new for 20 years or more. The UPS program involves dedicated drivers who operate the same truck every day and dedicated mechanics who maintain the same group of vehicles. Drivers and mechanics are both responsible for the performance of a vehicle and stay closely in touch with each other.

The interdependency of operator, machine, and mechanic is a hallmark of successful maintenance and reliability. As Figure 2.9 illustrates, it is not only good maintenance and reliability procedures that make Disney and UPS successful. but the involvement of their employees as well.

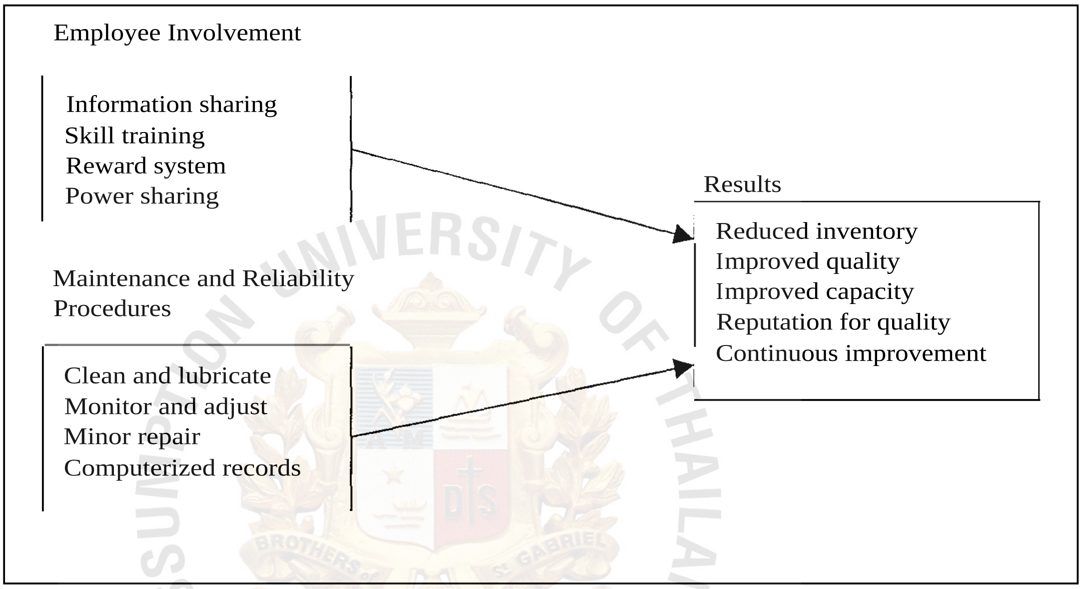


Figure 2.9. Good Maintenance and Reliability Strategy Requires Employee Involvement and Good Procedures.(Heizer 2001).

The tactics for improving the reliability and maintenance not only of products and equipment but also of the systems that produce them. The four tactics are organized around reliability and maintenance.

The reliability tactics are

(1) Improving individual components.

(2) Providing redundancy.

The maintenance tactics are

(1) Implementing or improving preventive maintenance.

(2) Increasing repair capabilities or speed.

2.6.1 Reliability(Heizer 2001)

Systems are composed of a series of individual interrelated components, each performing a specific job. If any vie component fails to perform for whatever reason, the overall system (for example. an airplane or machine) can fail.

(1) Improving Individual Components

Because failures do occur in the real world, understanding their occurrence is an important reliability concept. We will now examine the impact of failure in a series. Figure 2.10 shows that as the number of components in a series increases, the reliability of the whole system declines very quickly. A system of n = 50 interacting parts, each of which has a 99.5% reliability, has an overall reliability of 78%. If the system or machine has 100 interacting parts. Each with an individual reliability of 99.5%, the overall reliability will be only about 60%.

To measure reliability in a system in which each individual part or component may have its own unique rate of reliability. We cannot use the reliability curve in Figure 2.10.

However, the method of computing system reliability (R_s) is simple. It consists of finding the product of individual reliabilities as follows:

$$R_S = RI \ X \ R2 \ X \ R_3 \ X \ . . . \ X \ R_n$$

where R1 = reliability of component 1

R_2 = reliability of component 2

and so on.

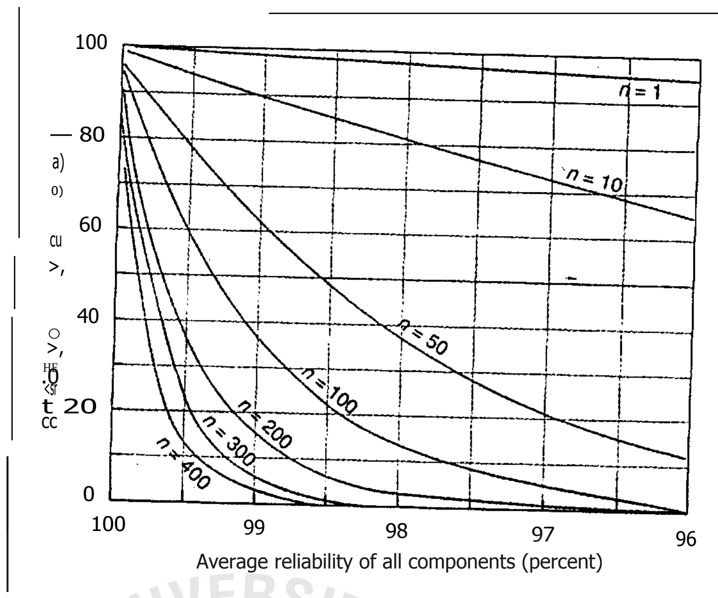


Figure 2.10. Overall System Reliability as a Function of Number of Components and Component Reliability with Components in a Series.(Heizer 2001).

According to the above equation, we assume that the reliability of an individual component does not depend on the reliability of other components (that is, each component is independent). Additionally, in this equation as in most reliability discussions, reliabilities are presented as probabilities. Thus, a 0.90 reliability means that the unit will perform as intended 90% of the time. It also means that it will fail 1 - 0.90 = 0.10 = 10% of the time. We can use this method to evaluate the reliability of a service or a product.

The basic unit of measure for reliability is the product failure rate (FR). Firms producing high-technology equipment often provide failure-rate data on their products. As shown in the following equations the failure rate measures the percentage of failures among the total number of products tested, FR(%), or a number of failures during a period of time, FR(N):

$$FR(\%) = \frac{\text{Number of failures}}{\text{Number of units tested}} \times 100\%$$

$$FR(N) = \frac{\text{Number of failures}}{\text{Number of units-hours of operating time}}$$

Perhaps the most common term in reliability analysis is the mean time between failures (MTBF), which is the reciprocal of FR(N).

Mean time between failures (MTBF) is the expected time between a repair and the next failure of a component machine, process, or product.

$$MTBF = \frac{1}{FR(N)}$$

(2) Providing Redundancy

To increase the reliability of systems, redundancy is added. The technique here is to 'back up" components with additional components. This is known as putting units in parallel. Redundancy is provided to ensure that if one component fails, the system has recourse to another. For instance, say that reliability of a component is 0.80 and we back it up with another component with reliability of 0.80. The resulting reliability is the probability of the first component working plus the probability of the backup (or parallel) component working multiplied by the probability of needing the backup component (1 - 0 .8 = 0.2).

Therefore, the new reliability is 0.96 (0.8 + [0.8 x (1 - 0.8)]).

2.6.2 Maintenance(Agarwal 1997)

The mainstream activities of maintaining plant equipment can be divided into corrective, preventive, and predictive maintenance; each is considered below.

(1) Corrective Maintenance

Corrective maintenance is simply repair work, made necessary when something breaks down or is found to be of order. This is the activity that most of us think of when maintenance is mentioned. When equipment breaks down, especially machinery on which an integrated production line depends, the costs of lost production mount and pressure is on the maintenance team to get equipment fixed and back into operation. Effective maintenance engineering requires thinking through the most likely types of breakdowns, assuring an adequate inventory of the most commonly needed or critical replacement parts, and providing spare capacity where break-downs cannot reasonably be avoided.

(2) Preventive Maintenance

Many mechanical systems wear out. Their failure rates increase with time and the quality of performance falls off because bearings become loose, gears wear, 0-rings and belts deteriorate, and grease hardens. These types of problems are reduced by periodic inspection, lubrication, and identification and replacement of worn parts. Efficient preventive maintenance requires documentation of all equipment to be included in the program and establishment of the most cost-effective schedule for inspection. Inspection checklists need to be established for each type of equipment, and inspectors trained to make simple repairs when problems are observed. Computers are useful to print out lists of inspection tasks that are due and maintain data on the time and material costs of inspection to support periodic analysis and revision of the preventive maintenance plan.

(3) Predictive Maintenance

Predictive maintenance is a preventive type of maintenance that involves the use of sensitive instruments (e.g., vibration analyzers, amplitude meters, audio gages, optical tooling, and pressure, temperature, and resistance gages) to predict trouble. Critical equipment conditions can be measured periodically or on a continuous basis. This approach enables maintenance personnel to establish the imminence of need for overhaul. Where diagnostic systems are built into equipment, production workers can observe warning signs during operation, catching incipient failures long before maintenance workers would see them.

(4) Implementing Preventive Maintenance

Preventive maintenance implies that we can determine when a system needs service or will need repair. Therefore, to perform preventive maintenance, we must know when a system requires service or when it is likely to fail. Failures occur at different rates during the life of a product. A high initial failure rate, known as "infant mortality", may exist for many products. This is why many electronic firms "burn in" their products prior to shipment: That is to say, they execute a variety of tests detect "start-up" problems prior to shipment. Firms may also provide 90-day warranties. We should note that many infant mortality failures are not product failures per se, but rather failure due to improper use. This fact points up the importance in many industries of operations management's building an after-sales service system that includes installing and training.

Once the product, machine, or process 'settles in," a study can be made of the MTBF (mean time between failure) distribution. Such distributions often follow a normal curve. When these distributions exhibit small standard deviations, then we know we have a candidate for preventive maintenance, even if the maintenance is expensive.

Once our firm has a candidate for preventive maintenance, we want to determine when preventive maintenance is economical. Typically, the more expensive the maintenance, the narrow must be the MTBF distribution (that is have a small standard deviation). Additionally, if the process is no more expensive to repair when it breaks down than the cost of preventive maintenance, perhaps we should let the process break down and then do the repair. However, the consequence of the breakdown must be fully considered. Even some relatively minor breakdowns have catastrophic consequences. At the other extreme, preventive maintenance costs may be so incidental that preventive maintenance is appropriate even if the MTBF distribution is rather flat (that is, it has a large standard deviation). In any event, consistent with job enrichment practices, machine operators must be held responsible for preventive maintenance of their own equipment and tools.

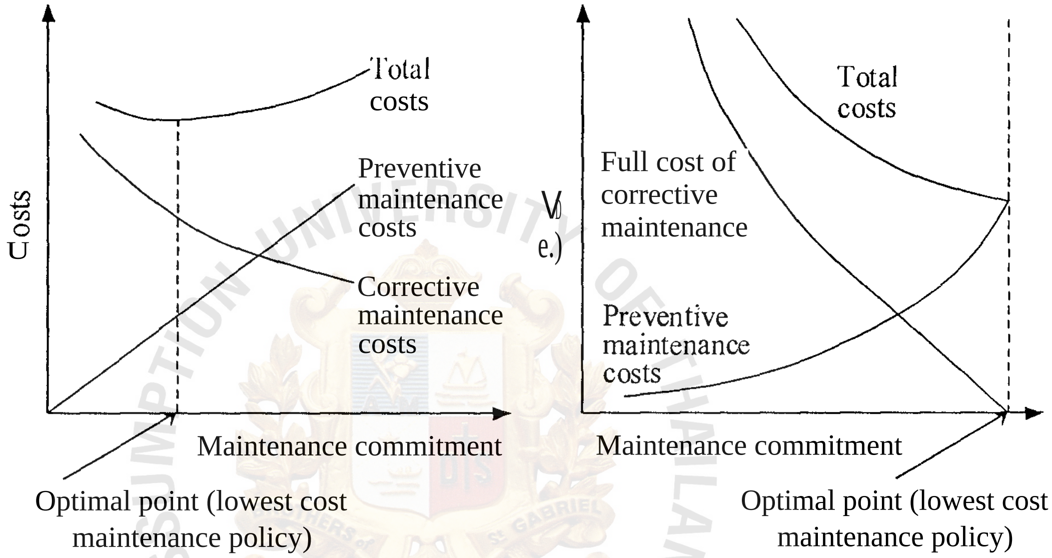
With good reporting techniques, firms can maintain records of individual processes, machines, or equipment. Such records can provide a profile of both the kinds of maintenance required and the timing of maintenance needed. Maintaining equipment history is an important part of a preventive maintenance system, as is a record of the time and cost to make the repair. Such records can also contribute to similar information about the family of equipment as well as suppliers.

Record keeping is of such importance that most good maintenance systems are now computerized.

Figure 2.1 1(a) shows a traditional view of the relationship between preventive maintenance and corrective maintenance. Under this view, operations managers consider a balance between the two costs. On the one hand, allocating more resources to preventive maintenance will reduce the number of breakdowns. At some point, however, the decrease in corrective maintenance costs may be less than the increase in preventive maintenance costs. At this point, the total cost curve will begin to rise. Beyond this optimal point, the firm will be better off waiting for breakdowns to occur and repairing them when they do.

Unfortunately, cost curves such as in Figure 2.11(a) seldom consider the full costs

of a breakdown. Many costs are ignored because they are not directly related to the immediate breakdown. For instance, the cost of inventory maintained to compensate for downtime is not typically considered.



(a) Traditional View of Maintenance (b) Full Cost View of Maintenance

Figure 2.11. Maintenance Costs.(Agarwal 1997).

Moreover, downtime can have a devastating effect on morale: Employees may begin to believe that performance to standardize and maintaining equipment are not important. Finally, downtime adversely affects delivery schedules, destroying customer relations and future sales. When the full impact of breakdowns is considered, Figure 2.11(b) may be a better representation of maintenance costs. In Figure 2.1(b), total costs are at a minimum when the system does not break down.

Assuming that all potential costs associated with downtime have been identified, the operations staff can compute the optimal level of maintenance activity on a theoretical basis. Such analysis, of course, also requires accurate historical data on maintenance costs, breakdown probabilities, and repair times. The example shows how to compare preventive and corrective maintenance costs in order to select the least expensive maintenance policy as follows.

Huntsman and Associates is a CPA firm specializing in payroll preparation. The firm has been successful in automating much of its work, using high-speed printers for check processing and report preparation. The computerized approach, however, has problems. Over the past 20 months, the printers have broken down at the rate indicated in the following table:

Number of Breakdowns	Number of Months That Breakdowns Occurred
0	2
1	8
2	6
3	4
	Total: 20

Each time the printers break down, Huntsman estimates that it loses an average of $300 in time and service expenses. One alternative is to purchase a service contract for preventive maintenance. If Huntsman contracts for preventive maintenance, it expects an average of only one breakdown per month. The price for this service is $150 per month. To decide whether Huntsman should contract for preventive maintenance, we will follow a 4-step approach:

Step 1: Compute the expected number of breakdowns (based on past history) if the firm continues as is, without the service contract.

Step 2: Compute the expected breakdown cost per month with no preventive maintenance contract.

Step 3: Compute the cost of preventive maintenance.

Step 4: Compare the two options and select the one that will cost less.

1.

Number of Breakdowns	Frequency	Number of Breakdowns	Frequency
0	2/20 = 0.1	2	6/20 = 0.3
1	8/20 = 0.4	3	4/20 = 0.2

Expected number of breakdowns

[(Number of breakdowns) x (Corresponding frequency)]

(0)(0.1) + (1)(0.4) + (2)(0.3) + (3)(0.2)

0 + 0.4 +0.6 +0.6

1.6 breakdowns/month

2. Expected breakdown cost

Expected number of breakdowns x Cost per breakdown

(1.6)($300)

$480/month

3. Preventive maintenance cost

Cost of expected breakdowns if service contract signed x Cost of service contract

= (1 breakdown/month)($300) + $150/month

= $450/month

4. Because it is less expensive to hire a maintenance service firm ($450) than suffer a breakdown ($480), Huntsman should hire the service firm.

(5) Increasing Repair Capabilities(Agarwal 1995)

Because reliability and preventive maintenance are seldom perfect, most firms opt for some level of repair capability. Enlarging or improving repair facilities can get the system back in operation faster. A good maintenance facility should have these six features:

(a) Well-trained personnel.

(b) Adequate resources.

(c) Ability to establish a repair plan and priorities.

(d) Ability and authority to do material planning.

(e) Ability to identify the cause of breakdowns.

(f) Ability to design ways to extend MTBF.

(6) Some Maintenance Management Considerations

There are some maintenance management considerations are as following.

(a) Size of maintenance staff

(b) Work orders.

(c) Work scheduling.

(d) Repair parts inventory.

<u>Size of maintenance staff.</u> Production supervisors naturally would like maintenance specialists of all types available immediately when a breakdown occurs, since the cost of idle maintenance time does not come out of their budget. When a plant is in full production and profits are high, it is easy to build the maintenance staff to a "comfortable" level, but when demand slows and costs are being trimmed, shortsighted

managers will find maintenance an easy target for drastic cuts. Good management balances the cost of additional maintenance personnel against the probable costs of production loss and equipment damage if adequate maintenance is not maintained.

Work orders. To maintain control over maintenance costs, work is not ordinarily performed without a supporting work order signed by a foreman or supervisor. The work order states the problem and estimated the cost of repair, and provides space for workmen to document the time they spent on the problem and any materials or parts they used in solving it. Completed work orders provide data to analyze maintenance costs of each type of equipment, so that cost-saving decisions such as redesign or replacement can be made.

Work scheduling. In larger plants, maintenance scheduling is the responsibility of a separate unit of the maintenance organization; in smaller plants, this is done directly by the foreman. Schedules are only estimates, and may have to be changed if a breakdown emergency takes place.

Repair parts inventory. As industry becomes more automated, it has more complex operating equipment with more parts that can fail and require replacement. Like any other inventory, this can tie up large sums of money that might be put to more productive use, and good judgment and periodic review are required. Where equipment vendors will provide prompt repair service at an acceptable price, this eliminates the need for parts inventories as well as for specialized training, so that after-sale service is a real consideration in purchasing equipment.

III. MECHANICAL SEAL

3.1 What Is a Seal?

A seal is an element which separates two spaces. It is meant to avoid a product transport between these two spaces. We can classify it in two major types as follows.

3.1.1 Static Sealing Systems

Static seals are used to seal the gap between stationary components.

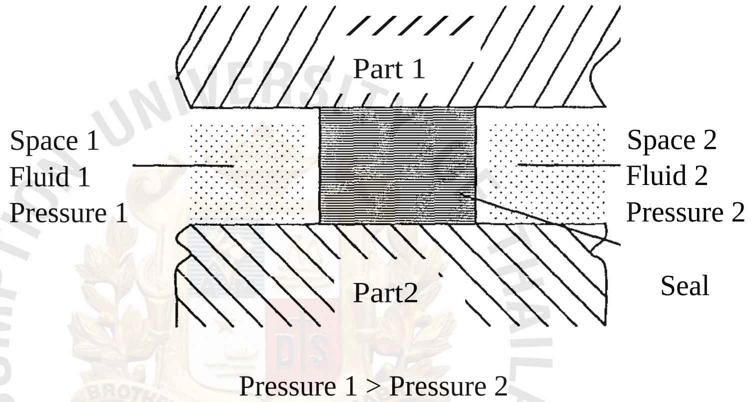


Figure 3.1. Static Seal. (Crane 1997).

A typical application of a static seal is for example the connection between flanges.

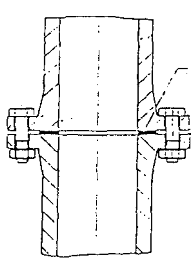


Figure 3.2. Flange Coupling. (Crane 1997).

3.1.2 Dynamic Sealing Systems

Dynamic seals are used to seal the gap between two parts moveable to each other.

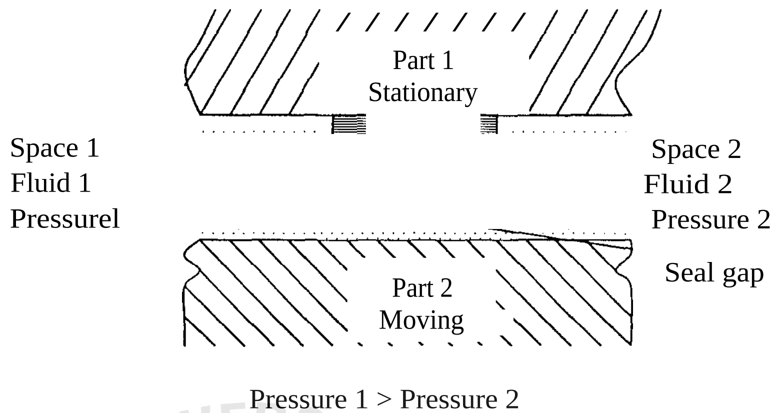


Figure 3.3. Dynamic Seal.(Crane 1997).

With the majority of applications of a dynamic seal the moving component is a rotating shaft, the static component is a housing wall.

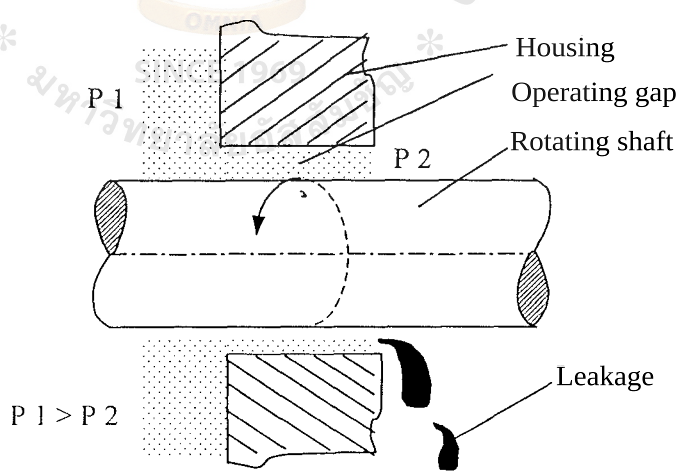


Figure 3.4. Example of a Dynamic Seal Application. (Crane 1997).

3.2 Leakage

Only with very high technical expenditure it is possible to prevent any transport of product through the seal. Even most of the static sealing elements have minimum leakage due to diffusion. Usually you may proceed from the assumption that static seals are leakproof for practical applications.

In applications with dynamic seals, there is a gap between the moving part and the static part due to constructive reasons. As the gap is too big to ensure a tightness of the system, it has to be equipped with a seal forming thus the required narrow gap.

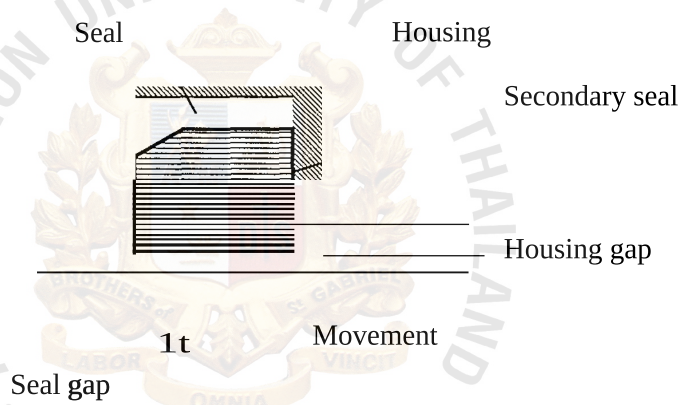


Figure 3.5. Decreasing the Gap by Using a Seal. (Crane 1997).

The leakage of a dynamic seal can thus be minimized, yet, not completely prevented.

A minimum seal gap is only possible if all shaft movements are compensated by the seal. This means that the seal can move in all directions. A secondary sealing element closes the gap between seal and housing.

3.3 Main Factors Influencing the Sealing Process(Crane 1997)

Influences on the sealing. process can derive from the medium to be sealed or from the seal itself. The influences from the medium are as follows:

(a) pressure density

(b) viscosity

(c) temperature

(d) steam pressure

(e) pH values

The influences from the seal:

(a) elasticity and ductility of the materials

(b) heat conductibility of the seal body

(c) chemical resistance

(d) roughness of the sliding faces

Important is that all these factors somehow influence the seal gap and thus the leakage behavior.

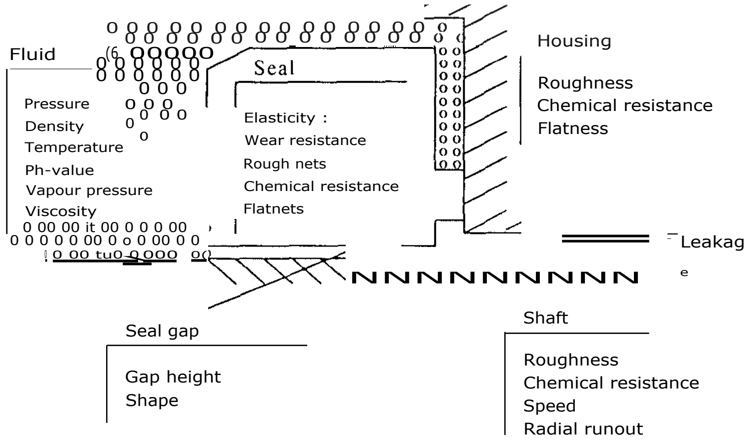


Figure 3.6. Influencing Parameters.(Crane 1997).

3.4 Types of Seals(Crane 1997)

3.4.1 Static Seals

There are several kinds of static seals as follows.

(1) Pure graphite standard gaskets

(2) Serrated gaskets

(3) Boiler and manhole gaskets (usually made of asbestos)

(4) Gasket sheets

(5) PTFE seals

3.4.2 Dynamic Seals

Dynamic seals can be categorized by considering the movement of the sealed parts.

(1) Reciprocating movement seals which are

(a) Lip seals

(b) Bellows seal

(c) Diaphragms

(2) Rotating movement seals or Rotary shaft seals which are

(a) Shaft lip seals

(b) Stuffing box packings

(c) Mechanical seals

3.5 Seal Performance Ranking(Crane 1997)

In the past, the engineers tried to solve the leakage problem by design the device to seal the space between the moving part and the stationary part of the machine. The first generation of the seal was the fixed bush, which made by metal such as bronze, brass, cast iron. However, the leakage was still high, so the seals have been continuously developed. At the present, the mechanical seal is the most popular rotary shaft seal because it can prevent the leakage product almost 100%. The seal performance ranking for the rotary shaft seal are as follow.

(a) Fixed bush

(b) Floating bush

(c) Floating segmented bush

(d) Gland packing

(e) Elastomer lip seal

(f) FS lip seal

(g) Metal cased lip seal

(h) Mechanical seal

Fixed bush. A one piece, non-contacting throttle bush.

This device prevents a mass escape of the service fluid to atmosphere in the event of complete failure of the primary seal.

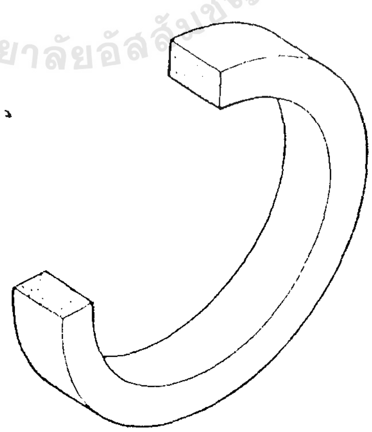


Figure 3.7. Fixed Bush. (Crane 1997).

Floating bush. A one piece, non-contacting, spring loaded throttle bush.

This device prevents a mass escape of the service fluid to atmosphere in the event of primary seal failure, operating on the same principle as the fixed bush but giving reduced leakage through closer diametrical clearance. The flexible mounting allows a limited degree of self-alignment of the bush in service.

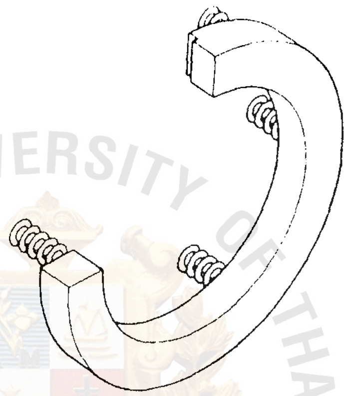


Figure 3.8. Floating Bush. (Crane 1997).

Floating segmented bush. A segmented, non-contacting, spring loaded throttle bush.

This device prevents a mass escape of the service fluid to atmosphere in the event of primary seal failure. Supplied in segments, the device works on the same principle as a fixed bush, but very close clearances are possible due to the segments being spring energized on the outside diameter. The flexible mounting allows a limited degree of self-alignment of the bush in service.

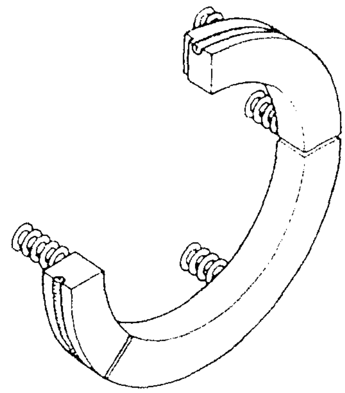


Figure 3.9. Floating Segmented Bush. (Crane 1997).

Gland packing. The gland packing can be classified in two types, which are compressed and non-compressed gland packing. The compressed gland packing is for use with continuous quench only but for the non-compress type, continuous is not required.

Packing clearances will progressively increase with time if not compressed at regular intervals. If on compressed packing, the gland runs "dry" for a period of time, a clearance will be rapidly worn.

Gland packing gives closer control than fixed bushes, but is less convenient to install and may need a greater frequency of replacement.

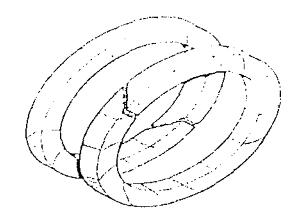


Figure 3.10. Gland Packing. (Crane 1997).

Elastomer lip seal.Usually termed "oil seals", many different designs are available.

Generally used for low duty applications, and requires a lubricating quench. The lip of the device may be secured by a radially acting garter spring.

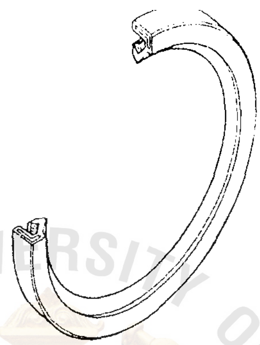


Figure 3.11. Elastomer Lip Seal. (Crane 1997).

FS lip seal. This device offers a high level of primary seal back-up at low cost. During normal (unpressurized) operation, the device runs with a small clearance from the shaft. On primary seal failure, the device will energize, closing down onto the shaft at pressures greater than 0.5 bar gauge.

Under certain thermal conditions the device should be used in conjunction with a support ring.

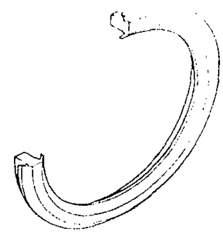


Figure 3.12. FS Lip Seal. (Crane 1997).

Metal cased lip seal. A metal cased, carbon or glass loaded PTFE lip seal.

An elastomer gasket acts as a seal between the metal case and lip.It's highest cost lip seal option.

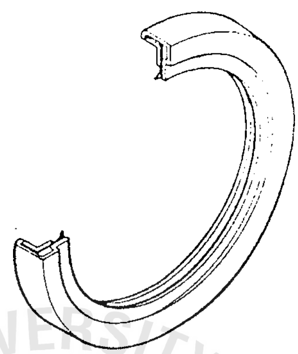


Figure 3.13. Metal Cased Lip Seal. (Crane 1997).

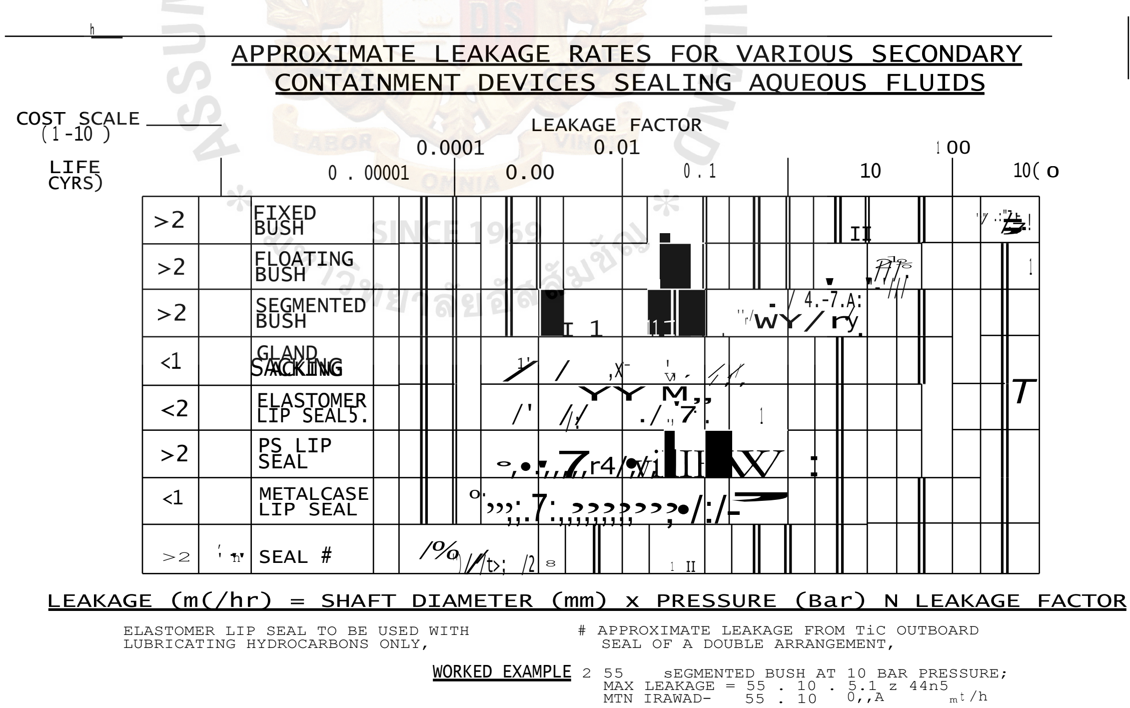


Figure 3.14. Approximate Leakage Rates for Various Secondary Containment Device Sealing Aqueous Fluids. (Crane 1997).

3.6 Mechanical Seals(Crane 1997)

The original concept of a mechanical seal was a device for use on rotating shafts only. It sealed more effectively than gland packing, used replaceable parts and, during the life of the seal did not wear or in any other way affect the equipment to which it was fitted.

Generally speaking this is true of today's mechanical seals which are made and fitted as individual items into surroundings very similar to those in which gland packing would formerly have been used.

By far the greatest use of mechanical seals is made in the pump industry, and the following comments, while open to broader interpretation, apply mainly to pumps and pumping.

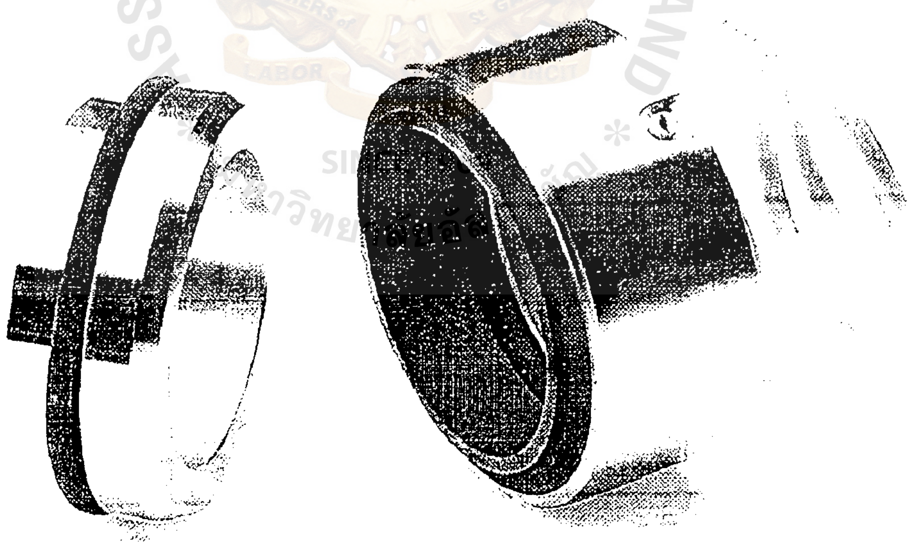
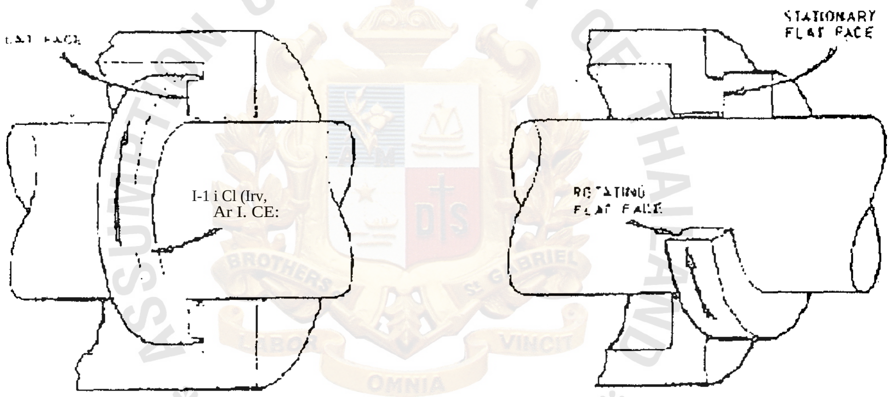


Figure 3.15. Mechanical Seal. (Crane 1997).

3.6.1 Sealing Principle

A mechanical seal consists of two radial fiat surfaces, one mounted so that it rotates with the shaft. The second surface is stationary, and the seal is formed by one surface making contact with the other. One of the surfaces, known as the seat, is usually fixed in position but the other is given some axial and radial flexibility to compensate for shaft movements which inevitably occur in practice. This axial flexibility also makes it possible to fit a seal to practical limits without being too precise. How precise depends upon the seal design.



(a) Internally Mounted (b) Externally Mounted

Figure 3.16. Illustrates How the Two Radial Surfaces Retain the Liquid, which also Lubricates and Cools the Contacting Faces.

Figure 3.17 shows how one of the radial surfaces usually known as the face or washer, is flexibly mounted, lightly loaded against the seat with a spring, and driven with the shaft. The face is also sealed to the shaft and it is this feature which, with the spring, provides much of the variety in mechanical seal designs.

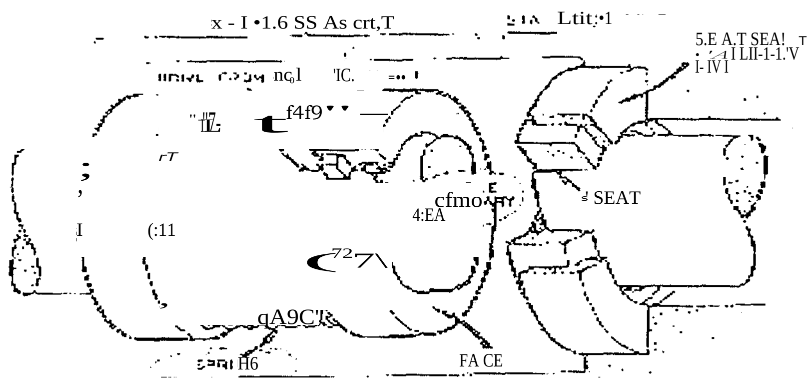


Figure 3.17. Mechanical Seal Components. (Crane 1997).

3.6.2 Seal Arrangement(Crane 1997)

In order to install the mechanical seal with the most effectiveness, the user has to understand the principle of seal arrangement, which are single seal and double seals arrangement

(1) Single Seal Arrangement

Except for certain specialized applications, mechanical seals are designed for internal mounting with the flexible unit mounted on the shaft. The flow of liquid around the seal can be controlled effectively, and the outside pressure on the seal parts provides a very high inherent degree of operational safety.

For high speeds, generally above 4,000 rpm, the position of the flexible unit and the seat are interchanged so that the parts of the unit are not influenced by centrifugal forces.This installation is now often used with metal bellows seals at lower speeds, particularly when sealing hot hydrocarbon liquids on refinery duties.

Seals designed for highly corrosive duties in which no metal parts can be allowed in contact with the pumped liquid are more conveniently designed for external mounting. Figure 3.18 illustrates how the surfaces in contact with the liquid can be minimized and made in suitably corrosion resistant materials with a PTFE bellows seal.

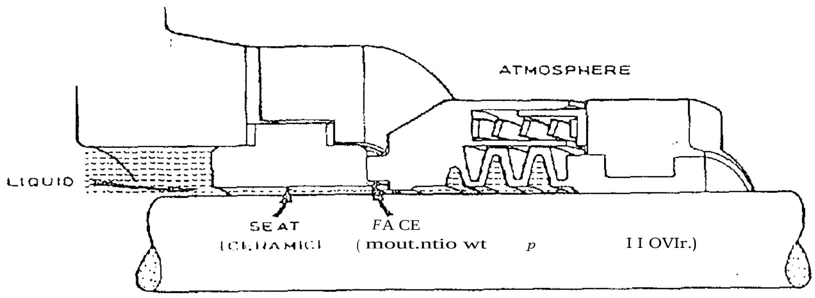


Figure 3.18. Externally Mounted Seal for Corrosive Liquid Sealing Purpose. (Crane1997).

As the radial faces rub together, heat is produced which must be removed if eventually the liquid around the seal is not to boil away, and eventually destroy the seal. So the liquid around the seal is replaced by bleeding a small quantity of the pumped liquid to the seal (recirculation) or from the seal (reverse circulation). Pumps with open housings need neither as the fluid around the seal is constantly changing anyway.

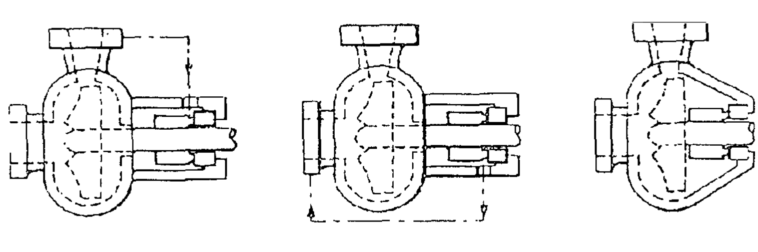


Figure 3.19. Three Common Way to Prevent Overheating. (Crane 1997).

(2) Double Seals Arrangement

In a few cases seals are fitted in pairs. These two seals are fitted with the rotating units. The arrangements are as follow.

(a) Back to back

(b) Tandem

(c) Face to face.

Back to back. This arrangement solves a number of difficulties for a single seal, and is offered for very abrasive duties, gases and also thick viscous liquids.

Besides these applications double back to back seals can be considered one way of seal cooling, and are particularly effective in handling hot solutions which can be very abrasive to single seals. The presence between the double seals of a pressurized liquid also makes the back to back arrangement ideal for handling and containing hazardous liquids.

One more feature of this arrangement derives from the reversed inner seal where only the inner surfaces of the seal unit and seat are in contact with the sealed liquid. In nearly all seal designs, the metal parts are in the sealed liquid when normally used as single seals. In the double back to back arrangement the metal parts are taken out of the sealed liquid and this makes it possible to use seals in back to back installations which do not need metal parts which are fully corrosion resistant.

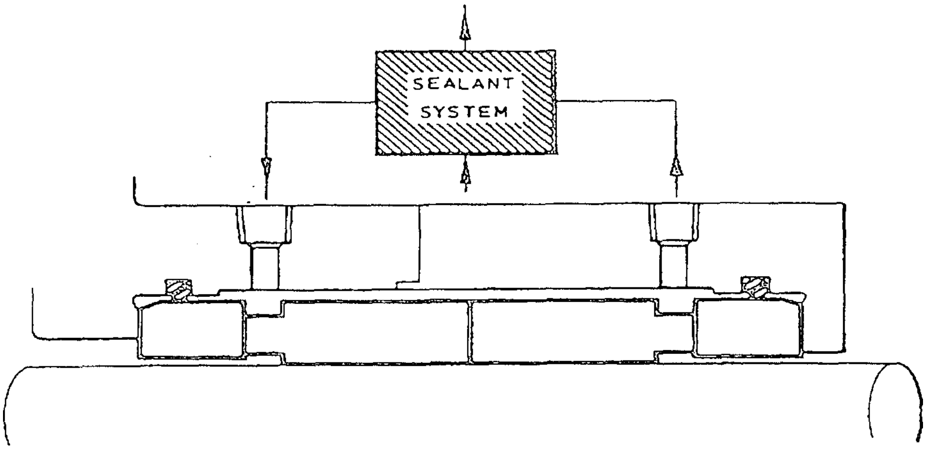


Figure 3.20. Back to Back Arrangement.(Crane 1997).

To 'make a double back to back seal work requires a pressurized liquid, termed the sealant, to flow through the formed space between the inner and outer seals. The pressure is normally not less than 1 to 2 bar above the sealed pressure so that effectively both seals are preventing the escape of sealant. It is this feature which makes it possible to seal non-lubricating fluids such as gas, and abrasive liquids, because the pressurized sealant provides the lubrication and cooling the seal faces.

The sealant is normally a clean cool stable liquid, provided from an external source. This may simply be water taken from a header tank or be provided by a purpose designed sealant system. In all the possible ways of providing a sealant, the object is to provide sufficient flow to cool the seals effectively, and sufficient pressure so that at all times the sealant pressure is higher than the sealed pressure. If the pressure falls below the sealed pressure, the inner seal will open and contaminate the sealant system.

Tandem. In this arrangement the inner unit is mounted exactly as it would be as a single seal. The duty must therefore be suitable for a single seal and this is the first major difference from back to back seals. The second is that the sealant is at lower than sealed pressure, and the outer seal is again mounted as a single seal would be to seal the sealant.

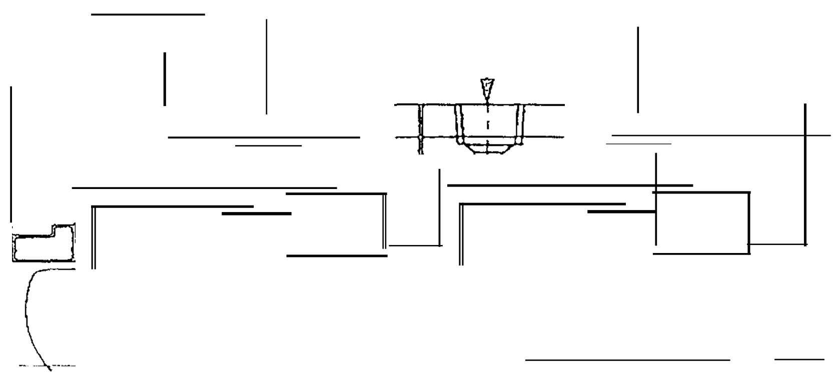


Figure 3.21. Tandem Arrangement.(Crane 1997).

A tandem seal can therefore be used to provide extra operating safety or as a means of breaking down the sealed pressure to bring it within the operating capability of the seals to be used. For instance, PTFE bellows seals have a more limited pressure and temperature range than most other types. This can be extended by adding another seal in an arrangement which looks at first sight to be a back to back installation but which works like a tandem seal with a sealant pressure lower than sealed pressure.

The pressure over the inner seal is controlled within the seal's operating range and sealant cooling can allow it to operate in a higher temperature than would normally be permitted.

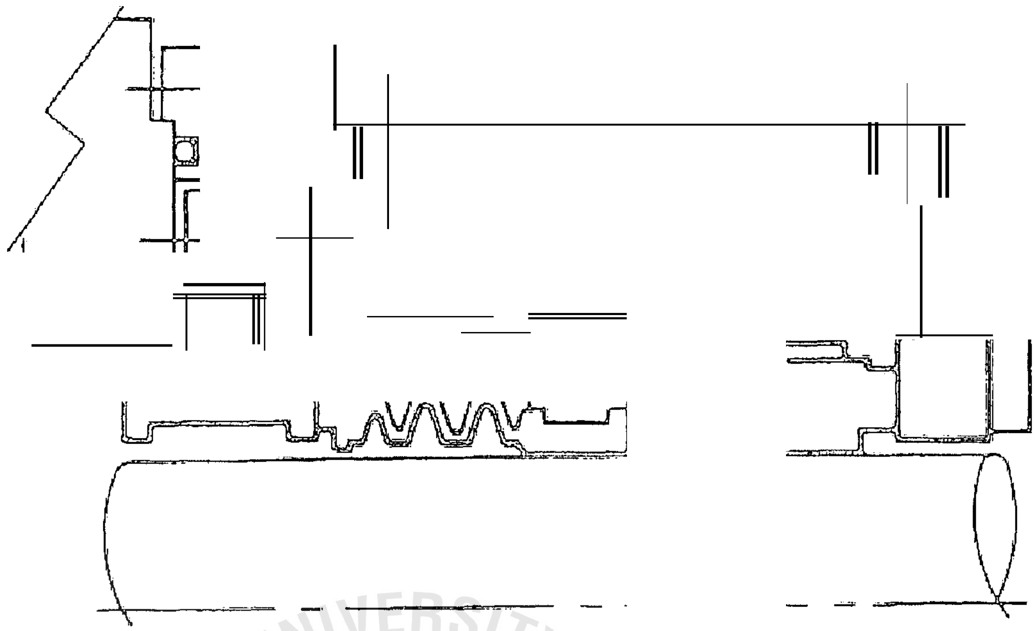


Figure 3.22. Adding a Second Seal to a Normally Externally Mounted PTFE Bellows Seal .

Face to Face. This is a special form of tandem seal in which the outer seal is reversed and therefore limits the sealant pressure to roughly no more than 1 bar unless a PTFE or metal bellows seal is used. This arrangement should be considered as a single seal with an effective quench bush, and is sometimes recommended when a water or other solvent quench is required to prevent crystal formation on the atmospheric side of a single seal or for safety reasons.

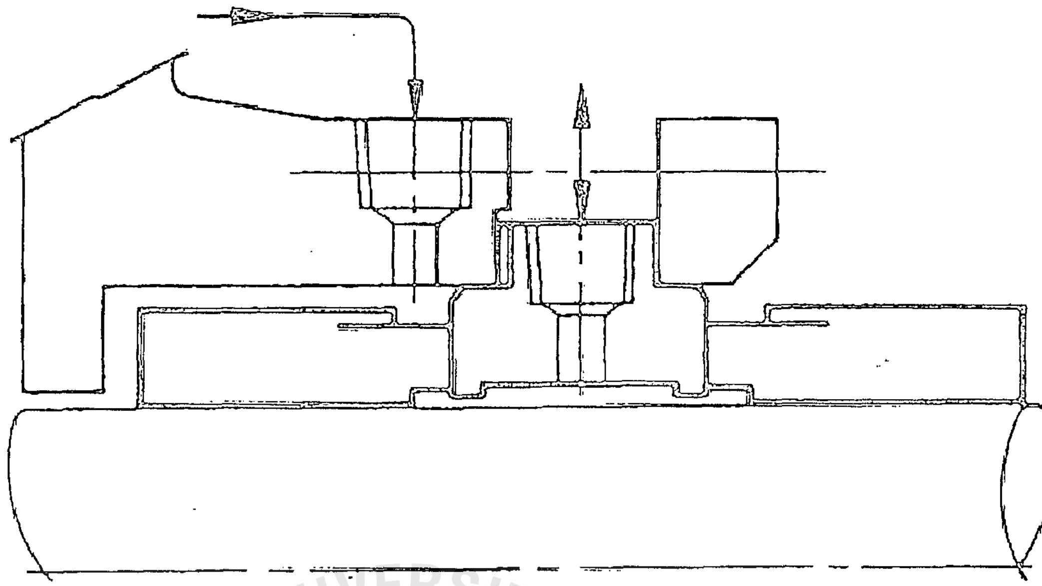


Figure 3.23. Face to Face Arrangement.(Crane 1997).

IV. THE TKIC PREVENTIVE MAINTENANCE CONTRACT

4.1 TKIC Traditional Maintenance Program

Thai Kraft Industry Company Limited (TKIC) is a pulp and paper manufacturing company located in Wangsala, Karnchanaburi province. TKIC has a lot of machines that the factory must monitor and repair in order to maintain the continuous productivity.

Most of the machines that are used for transferring or mixing the fluid in pulp and paper manufacturing are pumps, agitators, and mixers. These kinds of machines need dynamic seals to prevent the leakage of products and the most popular dynamic seal that TKIC and other pulp and paper manufacturers choose is the mechanical seal.

Although TKIC applies the mechanical seals for the rotating equipments in the production lines, the production cost is still high. Because of implementing only corrective maintenance, the yearly maintenance cost of mechanical seals is high and affects the total cost of the company. Table 4.1 shows the annual mechanical seal maintenance expense of TKIC.

Table 4.1. List of Mechanical Seal Maintenance Expense in Wangsala Mill.

ITEM	MAKER	SIZE	APPLICATION	QTY	TOTAL 1997	TOTAL 1996
1	JOHN CRANE	33	Hydrauchlorite pump no 1,2,3	3	-	-
2	JOHN CRANE	40 MM	Recovery boiler regitifies pump	2	-	-
3	JOHN CRANE	40 MM	Raw condense for recovery boiler	4	-	
4	JOHN CRANE	40 MM	Hyprochotride pump	4	-	-
5	JOHN CRANE	28 MM	Turbine condenses pump	3	15,240.00	-
6	JOHN CRANE	33	Hydrocholride pump no 1,2,3	3	-	-
7	NSO	55	Recovery boiler crusher pump	1	-	-
8	JOHN CRANE	65	CIP pump for chip pack adjust	1	-	75,723.98
9	JOHN CRANE	100	High pressure cooking pump no.1,2,3	3	455,641.20	227,820.60
10	JOHN CRANE	55	Naocl Pump no.1,2	2	147,723.01	590,892.04
11	SEALOL	60	MC Pump	2	-	-

Table 4.1. List of Mechanical Seal Maintenance Expense in Wangsala Mill.(Continued)

ITEM	MAKER	SIZE	APPLICATION	QTY	TOTAL 1997	TOTAL 1996
12	SEALOL	-	White Liquor pump	2	-	-
13	JOHN CRANE	38 MM	Black Liquor pump	2	-	31,672.16
14	N/A		Vacuum Pump for steam	1	-	-
15	N/A		Vacuum Pump for steam	1	-	-
16	JOHN CRANE	38 MM	Oil Heat pump	2	63,344.32	63,344.32
17	N/A	28	Condensate pump	1	5,573.84	-
18	N/A	32	Condensate pump	2	35,184.84	23,456.56
19	N/A	38	Separater	0	14,137.80	42,413.40
20	JOHN CRANE	3 3/4"	Culor mixer	1	156,791.00	313,582,00
21	PULLEN PUMP		Vertical Mectistroe pump	1	-	-
22	PULLEN PUMP		Vertical Mectistroe pump	1	-	-
23	PULLEN PUMP		Vertical Mectistroe pump			-
24	DURA	100	Scan Submersible pump	14	150,754.86	753,774.30
25	DURA	100	Scan Submersible pump	14	182,368.98	151,974.15
26	DURA	75	Scan Submersible pump	2	182,078.66	-
27	DURA	70	Scan Submersible pump	2		69,034.29
28	DURA	55	Scan Submersible pump	21	235,146.24	235,146.24
29	PACSEAL	40	SangFiUarpump	2	18,260.12	18,260.12
30	PACSEAL	35	Pre sed pump	4	36,752.52	24,501.68
31	PACSEAL	45	Gorman Rupp	4	7,315.66	-
32	DURA	35	Scan Submersible pump	4	-	97,658.26
33	DURA	55	Condensate pump	2	-	18,173.04
34	TORISHIMA	95	Boiler water pump	4	292,336.12	
35	DURA	80	Mill water supply pump	4		-
36	NSO	70	Waste water pump	4	-	-
37	DURAMATALLIC	55	Ahlstrom Pump (APP5) (WPA4)	31	440,245.98	391,329.76
38	DURAMATALLIC	85	Ahlstrom Pump (APP5) (WPA4)	1	-	96,235.77
39	DURAMATALLIC "MOTT"K73..TM DWG 1A-43003	Honda Pump (chemical)	24	3	47,000.22	
40	DURAMATALLIC	48	Scan Pump (2B) (PM#5)	10	132,030.24	308,070.56
41	DURAMATALLIC	75	Scan Pump (2B) (PM#5)	6	76,001.58	304,006.32
42	DURAMATALLIC	48	Scan Pump (2B) (PM#4)	5	88,020.16	-

Table 4.1. List of Mechanical Seal Maintenance Expense in Wangsala Mill.(Continued)

ITEM	MAKER	SIZE	APPLICATION	QTY	TOTAL 1997	TOTAL 1996
43	JOHN CRANE	75	Scan Pump (2B) (PM#4)	2	46,013.18	-
44	JOHN CRANE	78	Scan Pump (2B) (PM#4)	5	144,484.29	48,161.43
45	DURAMATALLIC	73	Scan Pump (2B) (PM#4)	3	61,544.44	-
46	DURAMATALLIC	75	Selective (12) (PM#4,5)	5	95,451.44	47,725.97
47	DURAMATALLIC	100	Selective (24.30) (PM#4,5)	6	178,478.90	267,718.35
48	N/A	125	Selective (36) (PM#4)3	3	655,584.45	-
49	DURAMATALLIC	75	Scan Pump (4D) (PM#4)	11	413,857.35	183,936.60
50	DURAMATALLIC	65	Scan Pump (38) (PM#4)	13	249,426.00	249,426.00
51	DURAMATALLIC	65	Scan Pump (3B) (PM#4)	4	360,905.88	180,452.94
52	DURAMATALLIC	65	Ahistrom Pump (APP2) (WP#4,5)	3	73,388.85	146,777.70
53	DURAMATALLIC	65	Ahistrom Pump (APP3) (WP#4,5)	10	807,277.35	587,110.80
54	DURAMATALLIC	65	Scanpump (3B) (PM#5)	13	513,721.95	1,467,777.00
55	JOHN CRANE	95	Used for Brg. Unit 3D	66	-	-
56	JOHN CRANE	38	Used for Brg. Unit 1R	10	-	
57	JOHN CRANE	75	Used for Brg. Unit 4D	2	-	-
58	JOHN CRANE	45	Used for Brg. Unit 2D	20	-	-
59	DURAMATALLIC	2.625"	Brg. Unit App4	8	410,870.88	-
60	DURAMATALLIC	2.250"	Brg. Unit App3	18	-	-
61	DURAMATALLIC	3.375"	Brg. Unit App5	2	-	-
62	DURAMATALLIC	1.750"	Brg. Unit App2	6	307,223.28	-
63	JOHN CRANE	45	Pump (Frame 1)	5	-	-
64	JOHN CRANE	55	Pump (Frame 1)	12	-	
65	JOHN CRANE	45	Pump (Frame 2)	2	-	
66	JOHN CRANE	35	Pump (Frame 1)	1	-	
67	JOHN CRANE	35	Pump (Frame 1)	2	11,263.78	11,263.78
68	JOHN CRANE	35	Pump (Frame 1)	5	31,149.62	-
				445	7,031,809.5	7,355,492.7

4.2 Preventive Maintenance Service Proposal

As shown in Table 4.1, TKIC had to spend around 7 million Baht annually in order to replace the broken mechanical seals with the brand new ones. Moreover, the production process had been stopped for changing mechanical seals very often, which created opportunity cost from loss of production. Hence, it costs TKIC more than 7 million Baht a year to pay for the traditional maintenance program.

Sealing Technology Company, "John Crane" mechanical seal product authorized dealer, one of the major mechanical seal suppliers of TKIC, proposes the solution by giving TKIC the engineering consultation about implementing preventive maintenance and seal standardization in order to minimize maintenance cost, opportunity cost and maximize plant reliability.

4.2.1 Plant Survey

In order to let TKIC make decision to sign the preventive maintenance contract with Sealing Technology Company (STC), the best price must be quoted to TKIC. STC must first determine how many mechanical seals there are in the plants and what models there are. Besides, STC has to convert the seals that aren't John Crane brand to the John Crane mechanical seals that have the closest specification to the original models.

Table 4.2 shows the data that must be recorded in plant survey form so as to implement seal selection and standardization.

Table 4.2. Sample of Plant Survey Form.

Sealing Technology (THAILAND Co.,Ltd.)

[illegible]	[illegible]	[illegible]	Type	Model	Shaft	Dial	rpm.	Fluid Process	[illegible]	[illegible]	[illegible]	[illegible]	Pressure		[illegible]			[illegible]	Remark
	[illegible]	[illegible]	NB 80/5-20	MKB 0.3, 5				[illegible]						[illegible]					DRAIN PUMP P4
			Scan Pump			38	1450								[illegible]				
	[illegible]	[illegible]	NB 80/5-20	MKB 0.3, 5				[illegible]						[illegible]		DURA			DRAIN PUMP P5
			Scan Pump			38	1450								CBR				
	[illegible]	[illegible]	AB 200/150-40					Pulp						[illegible]	[illegible]				PERSS PIT P.
			Scan Pump			65	1450	0309228								[illegible]	a.		
	[illegible]	[illegible]	[illegible]					[illegible]						[illegible]	[illegible]				COUCH PIT P.2
			Scan			48	1470									[illegible]	a.		
	[illegible]	[illegible]	BA 200/150-40	MKB 24				Pulp						[illegible]	J/C				COUCH PIT P.2
			Scan	I Pump		65	1485	0309226							IA	I GSIS1/BP			
	00							[illegible]							[illegible]				FAN PUMP
			SCAN PUMP				I 100												
	01							[illegible]							[illegible]				
			SCAN PUMP				I 100												
	[illegible]							[illegible]							[illegible]				FAN PUMP
			SCAN PUMP				100												
	[illegible]	[illegible]	NB 150/125-32	MKW 26				0307218						04	[illegible]				[illegible]
			Scan	I Pump		65	1470	Pulp								[illegible]	a.		

After STC has collected the necessary data, the company will know the number of mechanical seals that need to be installed inside the machines, their applications, and operating conditions such as fluid pressure, fluid temperature, speed of the machines, etc.

From this information, STC is able to summarize the number of needed John Crane mechanical seals and seal selection.

Table 4.3. TKIC Rotating Equipment Summary.

ITEM	PLANT	PUMP (UNITS)	AGITATOR (UNITS)	PUMP PACKING	AGITATOR PACKING	M/S JOHN CRANE	M/S DURA	M/S BURGMANN	NSO
1	PM #4	104	30	5	30	22	77	-	
2	PM#5	76	34	5	34	20	51		
3	WASTE PLANT#5	14	4	14	4	-	-		-
4	PM#6	76	55	13	55	43	20		
5	PM#7	50	50	7	50	37	6		
6	PM#8	143	42	96	42	20	19	8	
7	WASTE WATER (TKIC)	32	-	-		-	32		-
8	WASTE WATER (SCL)	20					20		
9	POWER PLANT	25	-	15		4	4	2	-
10	SCL	73	7	55	-	11	-	2	5
TOTAL		613	222	210	215	157	229	12	5

4.2.2 Seal Selection

From Table 4.3, the competitors' mechanical seals such as Dura and Burgmann mechanical seals must be considered for converting to use John Crane mechanical seals. By using the information from plant survey records and John Crane seal selection manual, high performance seals have been selected.

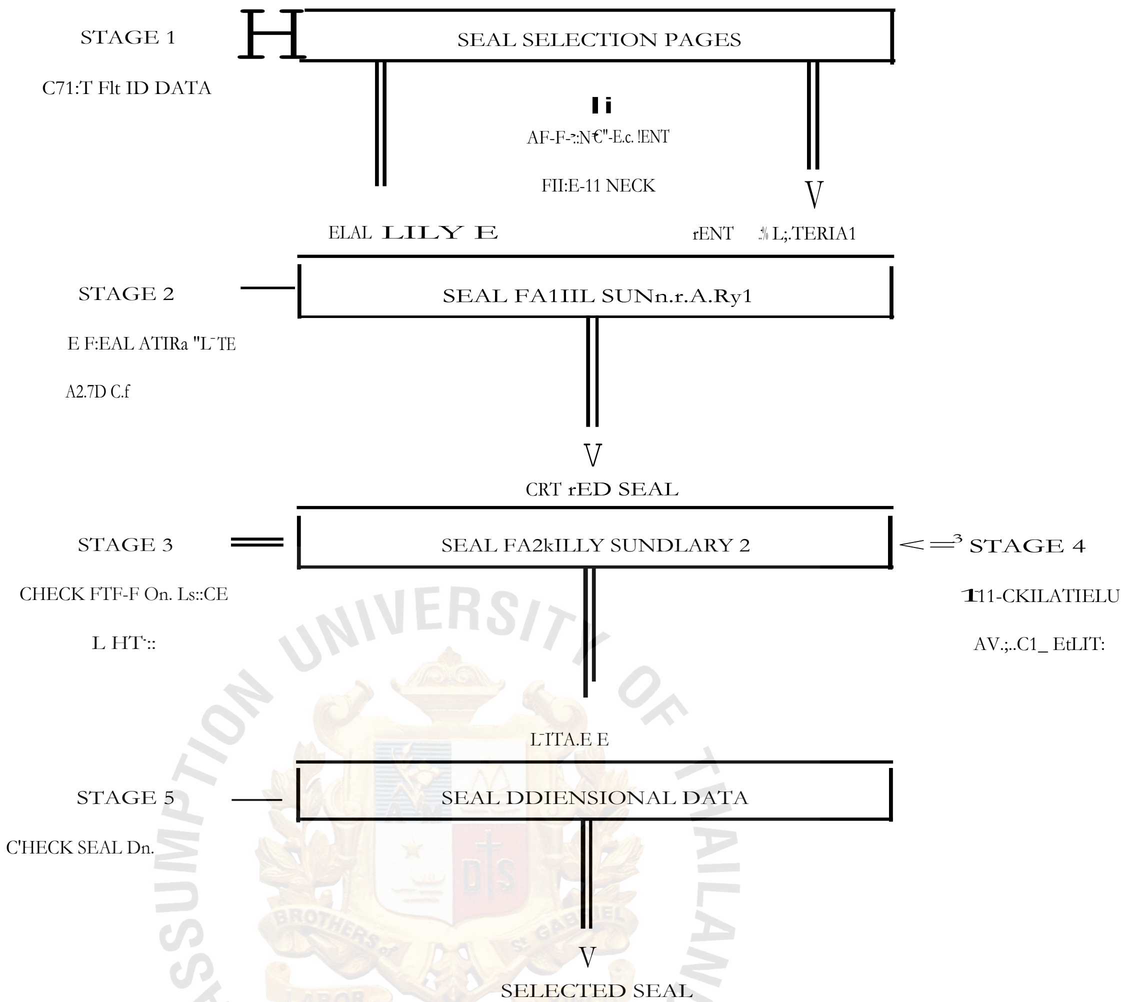


Figure 4.1. John Crane Seal Selection Process.(Crane 1997).

After seal selection and retrofit- the conversion of a sealing system from other manufacturers to John Crane or from gland packings to mechanical seal, have been implemented, STC has to check the available mechanical seal stock of the customer in order to develop the reasonable quotation for TKIC.

ITEM 6:0E1140.	132i	0/002:4	.201414C8.311111.41.3 AEC0661,1151413.4.21C011	{ITT 4.3'13CE (F1	3OTAL. 11,
7 :2- TIX1 35M:	41	CS(VAT% CCUE 76.37 1.2-3	461.4 '32 -56.4C.,,r ,..3 *-.0..-	2 SOTS •.:C4 7:-	6.2:14 54 i
:36 7 13 3315'102	3:	'2241.E ti.SOE ROT/63.1L 11.7.10E 3TS-1'1	55 WA TS54.102t 1243.1.1116	I 131 47 1723 1:	4710C 22 !
• 06-71.31710231	25	S1SE-.11/N6,40E	TS NM 1315E'POOLiCi.SP	1 1733T 66,011 It	44.013.1.11
• 2/3,7 1=15231	15	C1C....41..E RAO *MAIL* cODE	'75 *14,1 1502 3111C1753,7A1C3rEC*	. 2 6111 50 6 *3) 20*	7C1106 AE
06-7331150:235	1E3	:10263E 14510E 038 14A3t °COE	1:03 *IAA* T332Atticveriuticiao	; 3 sirs Er 4:41 56	:C12125 TY 1
▮:6?5..v413316	11'5	445:1:E GM i4 031 61-7LSTRC611 FRANZ 5	033.14 1112.521G5 :SI	SET :22 :to	724 06' 1 –
.6'1334._ • 4!	7C7/1	-054 2.•r.. 373. 77-N	10.1 4/34 T71 51/230,...0.,..489	4 stlz 153.754 Al	5:3 C15 **44**
E	11 111:4.: • 4	vca P1-7.40	1011264 75.1.,11 17,40	SETS x: 134 1113	114 .%
01 7 155200752.	33	TB VAT% FF7-	P.22 T171.7:17 CAN	• SET 73 744 5::	7415:
33	TrIC44303•1	IwAsTE %NATO(up)	11.4•3i_IC,:24	7 Sf t • 5' .1 16	**454324**
I	32. 11311141.14.1	frPf	2.177 T'.45R C '34	r 21,- 145- r'l	• **575** 24
11 36-7371565114		TYPE 11-4115176/	**751034** 71.1 53.1 131.84	7 621 15.723 44	12 (30 41
1 /6-'323523126	44	**11*1 144.5 55.M.P**	4112371 111.23.1. 131 04	1 KT 42.112223	41.312.I6
)5		:34.4044 Ec.TF tk	15 5.232 !..1.114.! 'EA Er	' SET 1'2 S:5 '75.	2.2 *11! it*
2 36 ".131:$i)7 1	2	511.1).E. 171513E 523	n7Fs	I CC' 117 31 • ..4	.21 01 2.2
,136 -1 1112.S 41		PRESS.	1St 1432 If..24_1135 7/7	r.4 5 '3 1321.1	154'64 14
1 11 136. 1,1.3 7-12234		13 5352--EE	71 LAU T+10 2	71 :44 42	11 544 aS
16 -36.7 53.33.8223;		75 sP:. vCRo E.As-W	7514.5 75032.21 ` 5 t,'EP	2 SE15- **.4 5.54 15**	**51 6M** 34 !
		35.6;.53.314 15.110 FILTER K1/F	160/73.1 T501114.1 :51 r.p	I SET '1 .12'... 7 2	i4.2ec 12 1
71.3. 11:.7,...'41	35	43.140 5415S20	115 Ian 75C3634 1C1700	1 X1 61'.•:	3.1
21 04-1134132111	**53**	**'724klitlClfte**	**•53 neAlt 753144**	**WA 7.344.65**	**14,4102.311.**
27 44-72.1.7540214	**45**	**75151.,011G205-06.r**	**41104** 1515371 GRE5.261 . 34-	1 11E7 **73,746 46 .**	**21,741.K**
23 06 11.3007C1•1	0 2.1	• I .4 335_6	117 .4XF	1E.EIS 5 3434 •	**1 1. 012 14**
06/12853414E	**34**	-54-.1151184	**341E54 712.:G5 15.1. teP**	**I LIT 63.553.**44	42.511304
11141 1		771.	:6143 156.4.4.* 11"5 1	• SE'S 745 11:E	24.
14-	' 12	.2132 • S. REFS		'c	*&Li 7.4*
(4 -237:142 -, Si	•	7.11.7-4; 4636	*45 kW 5 10P*	1 5.4.1 *1'. `Lt*	*.±,.1*
:e	11.21.53:((1 1	tiE). 1)X :.SABCFS.	55 *460 715::*	**1.410 3.5** 1:2::	
71 1 1312 - 7.4	13	.1.75.11)01:		C **:4J;** CC i.t.t	**413:L1:**

;atm 3713CKs4o. seE		0000EL	1J01511•01.114i SEALE FICCC1.151115111.1.TAOK	OTT Tf FoCE(e.j	t3TAL IBI
32X4.3377	41	CaR 42-.N	411451 1 5/1.7.0,1-7.1.,21;	t SET a t 2.-14.E	47 ;151 40
33 06.123t57531-2	73	71330$ 1548)	**75** Itiol 35/1465 **551'84**	**1E7 15 730.41**	11,734240
25 .3..71.30534132	35	351420313.110	35 Mil TAAL	6eT S2,212.14	53.11.114
)) 7.0.--73.1:125112.2	55	P C7 FAZE	155 **1W '15.58a.) 1SVEI 9**	- ' SET rwco:	t9.3i0
5. .34-'33.1.52133	5.•	s.,53.1fXxt:	,50 *MO* 1507.'AR IC1'130	• 3.41 244 1 51	54 47 ;.5
5. Z.5-7 3333662 1 32	63	6g7:	:15 65.5 T$331.1.; $•/3?	3 3£13 1 61 Le 31	:21 734 35
33 :4 1 31.7 1 53 1 32	45	7 0 F-A-4 417	14 5 41 7363.1333 131,EP	1 351 1 2 '45 15	77 1.5 **:4**
3' 26.2.2:27.5.121S1	33	••••TS 9C-200,15:	3,3434 7502.1'54 1c1150	1 543 5 1 **i.i 44**	
34 :)-73115157:7		:5'.6.C.4.4105,/,#) LPM.5.211530N	**44** UM T5 21)R 1C1150	I 541 6.483 5 1	ifsit 21
• :05-33115.22721	4.5	N• 6435.1.1P1.5.5P."1..P15.55•111111t.	**'43** 6+1- 1C1r80	– 1 SET 5.516: 2	*!443* 21
• 55-7311511M		5YP1 62 53Y3E 52-11f3C004	21 144 '1502:55 1011e0	' 3C1 :.5.7 3 64	3 7:3/6
z6-73115 35323	32	1 S PE 52 ICC 0131SATE *PUJP1* STYLE 5:3430X35	3, 1 is 750:AAR IC1160	2 5E 1 5 5 154 14	11 321 34
4: 34- 31 • :•4:3••;::		r'PE 52 Srf..E 6141=6	35 **41. 1307.14.7.** 10 1 730	4 SETS 6:125;1	:4 Ea CC
41 01-'3 34703521	33	Ta	40.4 TIOT C6.1C31:	2 5515 *21 • ti 2*	293 04 •
44 .04.1354/551.11	53	C Po 5.52-193	53 MK 1KIPAC SEAL 312	13T 142,17101	14.2.721.11
41 cA6•73530.33141	11	TS2tARic1420	3) 148111 732141.4 1C 1•10	2131$ 3,133	11, 1/ 1.22
44 04-73524115/ 1		2SilwE101C171i0 2,3	31 0:44 IS14.1334 1E 1.11P	2 **0.7.75 3,41363**	22.027. 2 **1**
47 136-2251tI5522	100	u0115-105'115 /L306= K20 10 1	150101 /1053.E UE115.1(8,115	**I %EI** *777.320* 6,3	221_021)60
.4 *A*-7158044377	45	14212153.0371035) PACK PLOW'	65 WM T1643 131 EP	1 SET 13.2/3	1 5.71116
			TOTAL	91 442!3	5,TK342.73
			11 J0'4'2 CO2.2.(111€C1 17.4 CAL SEAL	16CET5	934.114.1$
			3r.-44 SEA..	VS	53' .5345

Figure 4.2. John Crane Mechanical Seal Cost Estimation for TKIC Store.

4.2.3 Developing Quotation

From all information that STC has researched from the customer such as the number of the machines in each plant, the suitable models of the seal that fit to the machines, the old stock of the seal, etc., STC is able to quote the best price of the three year maintenance contract to TKIC. Some important parts of the quotation are as follows:

Sealing Techonology (Thailand) Co., Ltd.
99/30, Soi Wat Ladprao (Chokechai 4)
Ladprao Road, Bangkok 10230, Thailand

Tel.:(662) 931-6868-79

Fax.:(662) 931-6880

Mechanical seal partnership/maintenance contract bases on a period of three years. The following are the details.

(a) According to stock planning, 50% of mechanical seal stock will be ready in 45 days and the real in 90 days upon signing the contract.

(b) Workshop facility will be ready in 15 days upon signing the contract.

(c) Service fee does not include the cost of mechanical seal.

Figure 4.3. The 3-year Preventive Maintenance Quotation.

Item	Description	Qty	Price in Thai Baht		
			1998	1999 Estimate	2000 Estimate
1	Refurbishment of uses mechanical seal (Only John Crane mechanical seal), change new part & new mechanical seal		1,500,000		
2	Retrofit to John Crane seal		3,500,000		
3	Overhead & service fee & etc.		1,500,000		
4	Total (1+2+3)		6,500,000	5,500,000	5,000,000
5	Estimated cost of mechanical seals in TKIC store	16 sets	934,814		
6	Net price (4-5)		5,565,186		

Conditions and term of payment

First year Two-month down payment of "mechanical seal partnership contract" upon signing the contract, and 30-day credit will be allowed for monthly payment.

Second year The meeting between "The company" and "John Crane" should kick off in October 1998 in order to streamline and fine tune 1998's partnership activities to meet 1999's objective.

Third year The meeting between "The company" and "John Crane" will be held in October 1999 in order to review the benefits and efficiency achieved to reduce Meantime Between Failure (MTBF).

Figure 4.3. The 3-year Preventive Maintenance Quotation. (Continued).

There are our responses to your queries are as follows:

(1) Personnel available during normal operating time

(a)	Sales Engineer Supervisor	2 days a week
(b)	Senior Technical Service	Monday to Saturday
(c)	Technical Service	7 days a week
(d)	John Crane Technical Support	4 times a year

(2) Maximum personnel available on site during shutdown is 5 persons

(3) 24-hour service is available.

(4) Our personnel will reach the site within 2 hours upon receipt of emergency call from TKIC.

(5) Pick up car

Figure 4.3. The 3-year Preventive Maintenance Quotation. (Continued).

4.3 Contract Signing

After TKIC has considered the quotation, the negotiation process has been implemented. Finally, TKIC decides to sign up contract with STC, because the annual maintenance cost is reduced from 7 million Baht to around 5 million Baht by applying the maintenance contract (see Appendix A. for the detail of the contract).

V. THE PREVENTIVE MAINTENANCE PROGRAM

After the customer signed up the 3-year maintenance contract, STC has to manage the maintenance program effectively. Because STC must reduce the annual maintenance cost of mechanical seal from 7 million Baht to within 5 million Baht budget, STC considers to implement setting up the preventive maintenance program.

5.1 Maintenance Document

First of all, sonic maintenance documents must be designed in order to record the important data of the machine. This information can help the STC service team a lot to monitor the physical status of mechanical seals. The mechanical seal history cards are developed for this purpose. They contain necessary mechanical seal information such as pressure, temperature, speed of the pump that is needed when the maintenance time comes. Sometimes, the traditional model of the mechanical seal that is installed in the machine is not the most suitable model. This situation may cause the problem of seal failure before the life time comes and the plant will be shut down unexpectedly.

Therefore, STC will change it immediately and record the new data of the replacement seal in the mechanical seal life and performance upgrading card. In this card, the user may find the update information of the newly installed seal such as the new mechanical seal design, accessories, pump chamber modification, etc.

In order to avoid the confusion, the name of the equipment is represented by the specific code that the service team attaches to all equipments which have the mechanical seals installed inside or needed to replace from gland packing to the mechanical seal. This code is called "Tag. No.".

B. THAI KRAFT PAPER INDUSTRY CO.,LTD.
Mechanical Seal History Card

SEALING TECHNOLOGY (THAILAND) CO.,LTD.
99/30 SOI WAT LADPRAO, (CHOKECHAI 4)
LADPRAO ROAD., BANGKOK 10230 THAILAND

TEL. : (662) 931-6260-79
FAX. : (662) 931-6367, 6320
E-MAIL : [illegible]

- Equipment Tag. No. :
- Equipment Brand :
- Equipment Model :
- Mechanical Seal Brand :
- Code :

Liquid Service :
Temperature :
Specific Gravity :

Concentration :
Pressure :
Speed :

Installation Date	Alignment Data	Vibration Data	Failure Analysis	Comments	Reconditioning	Parts Change

Prepared by.: ____________________

Mechanical Seal History Card.

......-•,.et:111N-1
:1;74;-7Al'il r
dgidilii.910: . 1
,_,,...Zl•t-,.-=.1.l. '

.7"tly.
-1
-...11̈4
il...•"%t
...e.r....

SC.I wAILADFIR.J.C. :CFEZ.I.MCKAI
LA DF RA C. ROAD EANCIZC IC ...... tit:411A ND
'CIL : :SS:: ;::-C.:$:• ;
F.A:!;.. : :Si:: ;:L•i:S' S:::
E•:•LAIL

C. THAI hTAFT PAPER INDUSTRY CO.J.T.P.
.)IEc'...)13:lical SEal Li..:E and PErfOrIllanCE Uporadino

ira2., No.
Exi:tin: Seal Brand :
Seal Code

1. Technical de:cription to exi:tin: failure

1. New Propoial
Seal (A.A. :

?ridii :
Delivery r..irh.g..

Technical de:cription of new mechanical :hal '1 :i;u...

Adaptive hardware or acce.ssories required.

Niodif cation required.

Figure 5.2. Mechanical Seal Life and Performance Upgrading Card.

When the records of all machines have been collected, the next step for STC is to create the maintenance schedule. The maintenance schedule consists of the information of the target machine that needs the mechanical seal inspection. By referring to the Tag. No., and plant layout of TKIC, it is very easy to find the location of each pump and agitator.

Normally, the John Crane mechanical seals that are used in pulp and paper industry have life time around 2-3 years. It depends on many factors such as type of sealed fluid, operating temperature, operating pressure, installation, vibration, etc. With the customer record and technical data of John Crane mechanical seal, the preventive maintenance schedule can be developed.

Table 5.1. Sample of TKIC Mechanical Seal Preventive Maintenance Schedule.

Plant	Equipment Tag. No.	Plant Layout No.	John Crane Model	Inspection Date	Next Due
PM#4	103201/4	PL401	T1A/GS1 S 1/BP	15/10/99	15/04/00
	103202/4	PL401	T502/BR171/ORS	15/10/99	15/04/00
	103203/4	PL401	T2001/AS1S1/M(L3)	15/10/99	15/04/00
	103204/4	PL401	T521/BRICl/B0	15/10/99	15/04/00
	103205/4	PL401	T59U/QR1S I/BP	15/10/99	15/04/00
	103206/4	PL401	T1A/GJ1SI/BP	15/10/99	15/04/00
	103207/4	PL401	T58U/ARICl/B0	15/10/99	15/04/00
	103208/4	PL402	T2/AR1C1/B0	15/10/99	15/04/00
	103209/4	PL402	TIA/GS1S[1]/3P	15/10/99	15/04/00
	103210/4	PL402	T502/BR171/ORS	16/10/99	16/04/00
	103211/4	PL402	T502/BR17I/ORS	16/10/99	16/04/00
	103212/4	PL403	T521/BRICl/B0	16/10/99	16/04/00
	103213/4	PL403	T2001/AS1S1/M(L3)	16/10/99	16/04/00
	103214/4	PL403	T1A/GJ1S1/13P	16/10/99	16/04/00
	103215/4	PL403	T1A/GESI/BP	16/10/99	16/04/00
	103216/4	PL403	T59U/QRI SI/BP	16/10/99	16/04/00
	103217/4	PL403	T2/GJI S I /BP	17/10/99	17/04/00
	103218/4	PL403	T502/BR171/ORS	17/10/99	17/04/00
	103219/4	PL403	T521/BR1C1/130	17/10/99	17/04/00
	103220/4	PL403	T59U/QR1S1/BP	17/10/99	17/04/00
	103221/4	PL404	T1A/GSISUBP	17/10/99	17/04/00
	103222/4	PL404	T2001/AS1S1/M(L3)	17/10/99	17/04/00
	103223/4	PL404	T2001/AS1S 1 /M(L3)	17/10/99	17/04/00

Table 5.1 illustrates some parts of the maintenance program of the whole plant that can be categorized into 10 plants as follows:

Table 5.2. TKIC Plant Categories.

Item	Plant	Pumps (Units)	Agitators (Units)	Total (Units)
1	**PM#4**	104	30	134
2	PM#5	76	34	110
3	WASTE PLANT#5	14	4	28
4	PM#6	76	55	131
5	PM#7	50	50	100
6	PM#8	143	42	185
7	WASTE WATER	32		32
	(TKIC)			
8	WASTE WATER	20		20
	(SCL)			
9	POWER PLANT	25		25
10	SCL	73	7	80
	Grand Total	**613**	**222**	**835**

For the preventive maintenance program, some machines have to be inspected every month while the others have to be checked every 6 months. This condition depends on many factors such as the task of those machines, machine hour per day, etc. The machines with heavy duties for 24 hours running must be inspected more often than batch process machines.

When the service team implements the maintenance program as shown in the schedule, the progress must be reported to the customer. In this service contract project, both parties agree to develop monthly report in order to monitor the status of the machine and the work progress. Monthly report of the month October 1999 is shown in Figure 5.3.

TKIC SERVICE MONTHLY REPORT

For October 1999

SEALING TECHNOLOGY CO., LTD.

Brief Summary

Since the first October 1999 until now, we have done 6 jobs of mechanical seal retrofit and reconditioning and some pump maintenance.

From all the jobs that are done, there are 2 cases that are being still tried to solve. The one in SCL plant, PHEINHUTTE pump, which is a modified one can not be fitted with a standard John Crane seat in the gland plate because the seat socket is over size and a shaft sleeve is also sliped on the shaft. So, a new gland plate and a shaft sleeve are necessary for the solution.

The other One is COLOR MIXER AGITATOR TK31 for TUPI waste plant. There is a badly scratched inside of the stuffing box especially the o-ring position. The shaft sleeve is also the same and we are finding out what the cause is or whether it will take a maintenance period. As a solution, all of the repairing is in process.

Figure 5.3. Sample of Monthly Report for TKIC.

Preventive Maintenance

We have done preventive maintenance for PM # 4, 5 completely and some of PM # 6, 7. For the PM # 6,there are some problems with plant layout. We need the one that is completed and matches the equipment tag.

Further Action

We have to do the job that will form the step of work processing and also include preventive maintenance for the whole plant within a period of 8 weeks.

More details of the work of October 1999 are as shown attachments.

Figure 5.3. Sample of Monthly Report for TKIC. (Continued)

shy Co., Ltd. Plant *.el [redacted]

2/10/99	Lapping and new seat				2/10/99
5/10/99	New seal (SE1-P-50-QREO)				5/10/99
13/10/99	Lapping/Cleaning		sion on shaft sleeve		13/10/99

onthly Rep

Custom sty Co., Ltd. P

Service Date	Item No.	Job Description	Failure Analysis	Comments	Reconditioning	Finish Date
6/10/99	MP0203	Lapping				8/10/99
7/10/99	MP0305	Installation Mechanical seal T59U				7/10/99
7/10/99	MP0203	Lubricating				7/10/99

Sample of Preventive Maintenance Report for PM#4, PM#5.

[illegible]

Sample of Preventive Maintenance Report for PM#4. PM#5.(Continuedl

5.2 Stock Management

After all maintenance documents or forms had been prepared, the inventory planning must be prepared. By considering the mechanical seal standard life time, operating conditions and engineering supported data, the product specialist is able to forecast- the expiration date of each model of the TKIC's seals. This information brings us to develop the inventory planner for the effective preventive maintenance program.

Table 5.4. Sample of TKIC Stock Inventory.

John Crane (Thailand) Limited.
Stock inventory - TKIC
For month: October 1999

Size	Type	Description	Balance Qty.	Coming Qty.	Due coming	price
0320/902/059		SEAT 'BO' C/W 0-RING NBR	1			4,391.00
0330/58^{4}/$_{1}$38		WEDGE	1			2,395.00
0380/500/277		BP SEAT WITH SPRING	1			14,660.00
0650/006/001		DRIVE RING	5			
0750/500/277		SEAT BP	1			37,594.00
0750/500/277		SEAT BP SILICON CARBRIDE	3			37,594.00
1.375" (21165060)	SB2A	QRMG-1.375-302705	1			69,080.00
100 MM	T2	AR1-1	2			103,348.00
100 MM	ROPAC	UB115-105/115	1			288,000.00
100 MM (21120820)	SAB	TREN-100-300777	1			168,740.00
100 MM (21280067)	SBE	QRVO-100	1			79,024.00
1016/D99/277		SEAT `PG'	1			60,000.00
1143/094/138		WEDGE PTFE FOR T109	1			5,117.00
1143/095/277		FACE	1			85,000.00
14 MICRON		DR1MOND COMPOUND	2			
16 MM	T IA	BRICl/N	1			6,169.00
16 MM	T502	BRI71/ORS	0			5,625.00
20 MM	T502	GRICl/BO		2	November	5,652.00
20 MM	T58U	ARICI/BO	1			21,265.00
25 MM	T502	ARICl/BO	3			6,641.00
28 MM	T2100	ASISI/M(L3)	3			1,852.00
31/4"	T2	BFIC1/ORS	1			74,753.00

Table 5.4. Sample of TKIC Stock Inventory. (Continued)

John Crane (Thailand) Limited.
Stock inventory — TKIC
AS OF:
For month: October 1999 (cont.)

Size	Type	Description	Balance Qty.	Coming Qty.	Due coming	price
38 MM	SBE	QREO		2	November	29,568.00
38 MM		KIT REPAIR	2			
38 MM (21150145)	SB I	GREO-38-302464	1			41,008.00
38 MM (21160140)	SB2	QN-38-7454	1			05,658.00
40 MM	SEM)!	QREO	2			27,544.00
40 MM (21270680)	SE2-P1	QRMG-40-301170	2			55,440.00
40 MM (21270746)	SE2	QREG-40-304711	1			55,400.00
43 MM	T2100	GS I S I /M(L3)		2	November	6,028.00
45 MM	T2100	GS I SI/M(L3)		2	November	7,305.00
45 MM	T502	BJ 45	1			24,059.00
48 MM	SBE	QREO		3	November	34,936.00
48 MM	T2100	AS I S I /M(L3)	1			5,105.00
48 MM	T502	GRIST/BP	1			25,148.00
48 MM	SB2	QN-48-301089	1			52,146
50 MM	SBE	QREO	1			46,464.00
50 MM	SBE	QREO	4			46,464.00
50 MM	SEI-PI	QREO	1			35,728.00
50 MM	SE2-PI	QRMG-50-301171		4	November	35,728.00
50 MM (21270747)	SE2	QREG-50-304621	1			35,728.00
50 MM (21397023)	SE2	QREG-50-304621	1			35,728.00
50 MM (21399070)	SE2	QREG-HARDWARE	1			35,728.00
50 MW21465028)	SE2	QREG-304621	1			35,728.00
53 MM	T502	AR1-1	1			3,593.00
53 MM (2160361)	SB2	QRMN-53-303657	1			110,440.00
55 MM	T58U/SPC	AX1X 1 /AR1 Cl/BP	2			75,000.00
55 MM (21150426)	SB1	QREO-55-304468	3			52,184.00
55 MM (21280021)	SBE	QREO	3	2	November	46,464.00
60 MM	SE2-PI	QRMG-50-301172		4	November	113,432.00
65 MM	T515E	PG RXS/BP	2			59,014.00
65 MM	T1 A	GJISI/BP		10	November	45,500.00
65 MM	T680	ABD-YSD		5	November	3,492.00
65 MM		GSISI/BP	1			45,500.00
65 MM		515	2			59,014.00
65 MM (21150580)	SB I	GREO-65-30441	1			67,672.00
65 MM (21150610)	SBI	QREO-65-303677	1			67,672.00
65 MM (21280032)	SBE	QREO-403879	5			57,112.00

5.3 Data Flow Diagram

For understanding the whole system of preventive maintenance service, there are several developed diagrams as shown below:

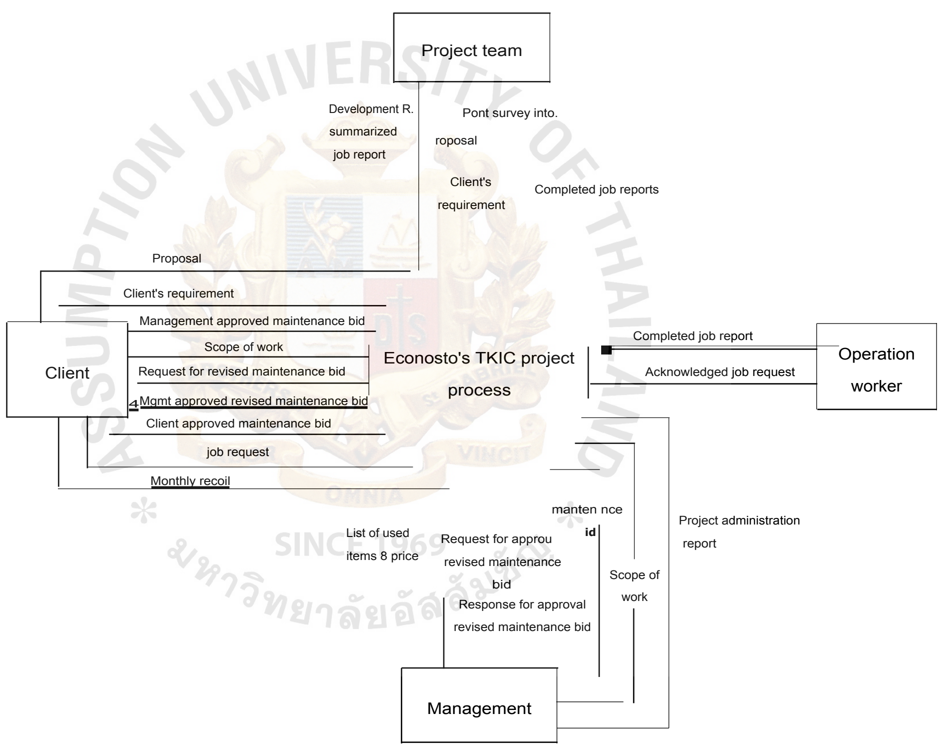


Figure 5.5. Context Diagram of TKIC Preventive Maintenance Service.

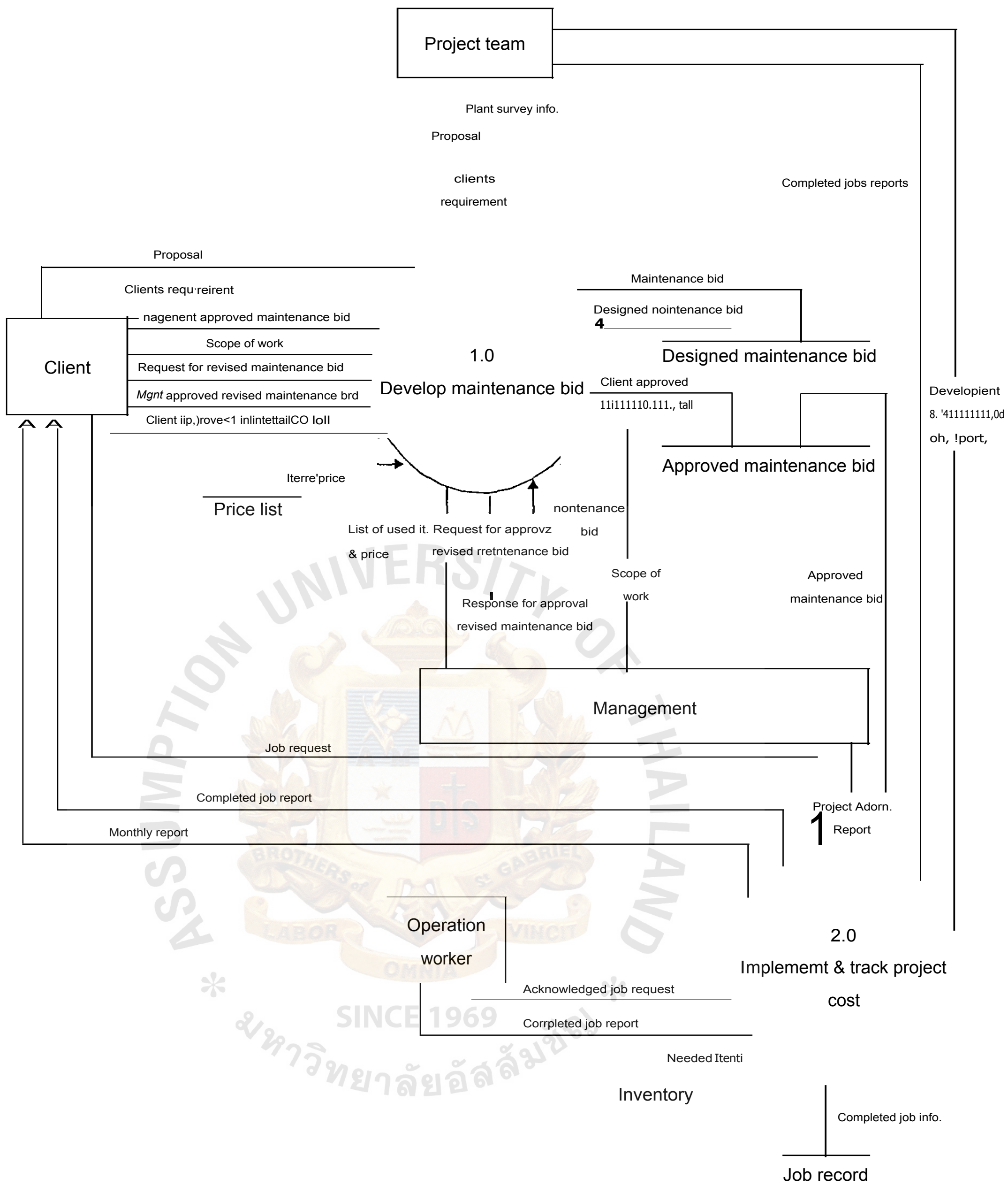


Figure 5.6. First Level Data Flow Diagram of TKIC Preventive Maintenance Service.

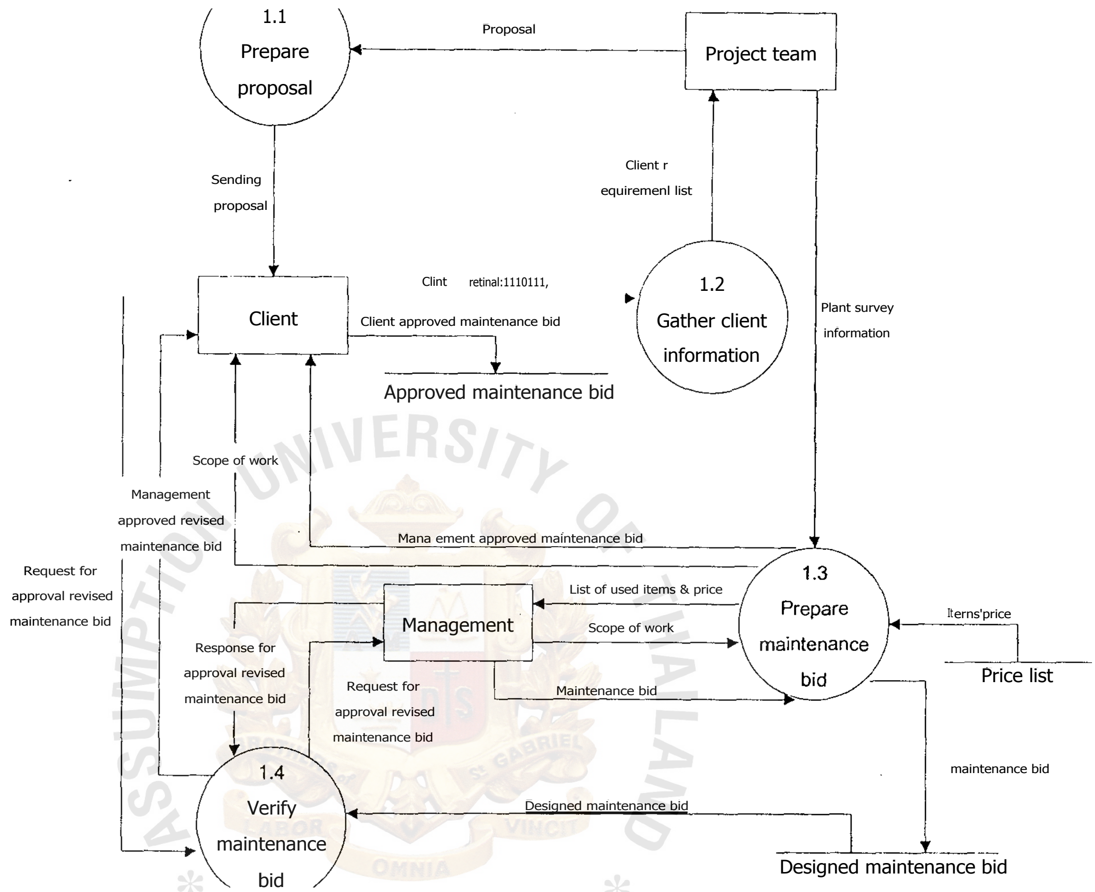


Figure 5.7. Second Level Data Flow Diagram of TKIC Preventive Maintenance Service : Develop Maintenance Bid.

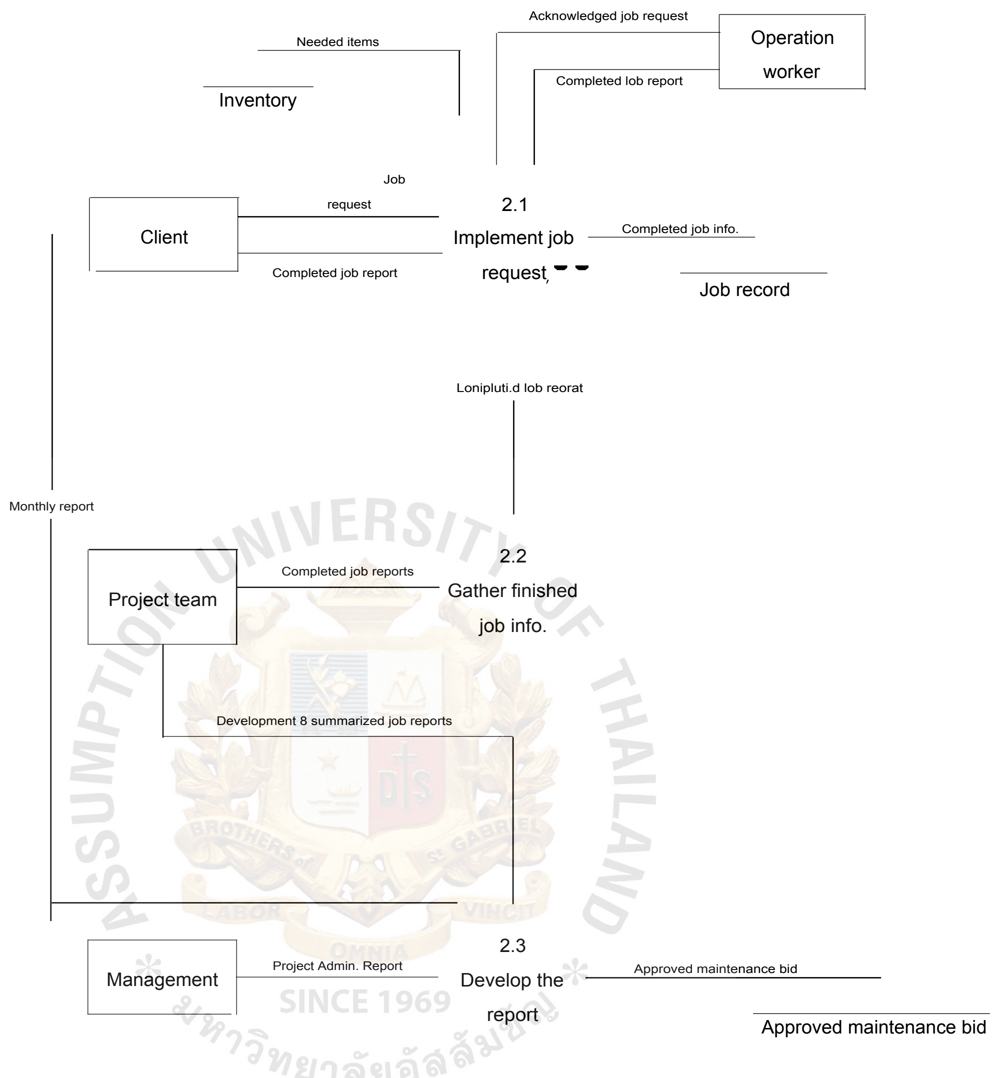


Figure 5.8. Second Level Data Flow Diagram of TKIC Preventive Maintenance Service: Implement and Track Project Cost.

VI. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

By signing the mechanical seals preventive maintenance contract with Sealing Technology Co., Ltd. (STC), the maintenance cost of Thai Kraft Industry CO., Ltd. (TKIC) is reduced from 21 million Baht to 15 million Baht over 3 year period. It is very convenient for TKIC maintenance department to solve the leakage problem in pumps and other equipments by applying STC maintenance service. Because of this contract, TKIC maintenance staff have much more time to deal with other maintenance jobs. Therefore, the whole maintenance performance is automatically higher.

With the purpose of mechanical seal preventive maintenance performance measuring, mean time between failure (MTBF) is the popular index that can be used. The comparison between the traditional MTBF and the new MTBF is shown below.

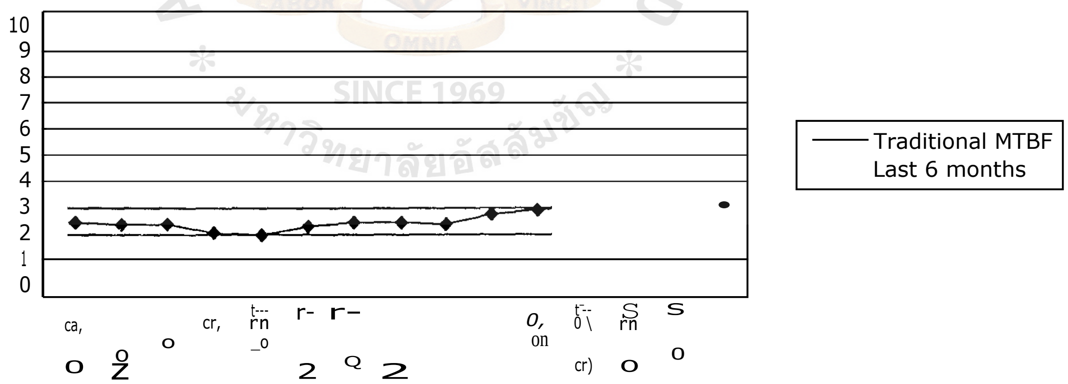


Figure 6.1. Traditional Mechanical Seal MTBF-Last 6 Months.

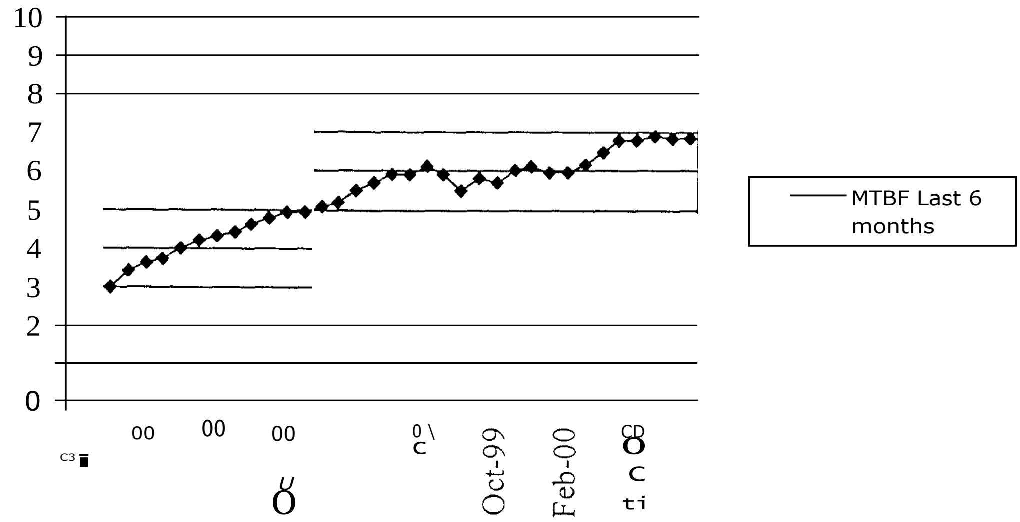


Figure 6.2. MTBF After Implementing Preventive Maintenance Program.

By considering both figures, TKIC found that MTBF index is going higher after implementing the preventive maintenance program. That means the efficiency of the new mechanical seal maintenance approach is better than the traditional program.

For STC side, STC gains not too much profit from this project but the company has got the credit and reliability from the customers not only TKIC, but also other pulp and paper manufacturers. Because this is the pioneer project of John Crane mechanical seal service contract in Thailand, STC can use this maintenance project as a reference to propose next contract to other customers such as Advance Agro Co.,Ltd. (AA) which is also a pulp and paper company.

The financial profit and payback period are calculated by using the information from Table 6.1.

Table 6.1. Net Cash Flows of TKIC Preventive Maintenance Project.

	1999	2000	2001
Net sales	5000000	5000000	5000000
Variable costs	4400000	2800000	3000000
Fixed costs (overhead)	950000	950000	950000
Depreciation (truck)	100000	100000	100000
Depreciation(equipment)	110000	110000	110000
Earning before taxes	-560000	1040000	840000
Taxes(30%)	0	312000	252000
Projected net operating income	-560000	728000	588000
Add back noncash expenses	210000	210000	210000
Cash flow from Project	-350000	938000	798000
Cumulative cash flow	-350000	588000	1386000

From Table 6.1, the payback period and NPV of this project can be found as follows:

Payback = 1+350,000/938,000

= 1.37 years

NPV = -350,000+938,000/(1+0.1)+798,000/(1+0.1)^2

= 1,162,231.41 Baht

According to payback period and NPV value, STC begins to receive the profit at the beginning of the second year and the financial profit is 1,162,231.41 Baht.

6.2 Recommendations

TKIC should consider to continue mechanical seal preventive maintenance program after the expiration date of the contract, because this program can reduce failure of the seal effectively and also save the cost of maintenance. There are two alternatives to choose to continue the program.

The first one is to decide to extend the contract with an optional addition of two years as STC has offered. This might be the most convenient way for TKIC. However, TKIC must negotiate again with STC because the price of mechanical seal or service charge may be changed. The other important subject that TKIC must consider is the new scope of work of STC.

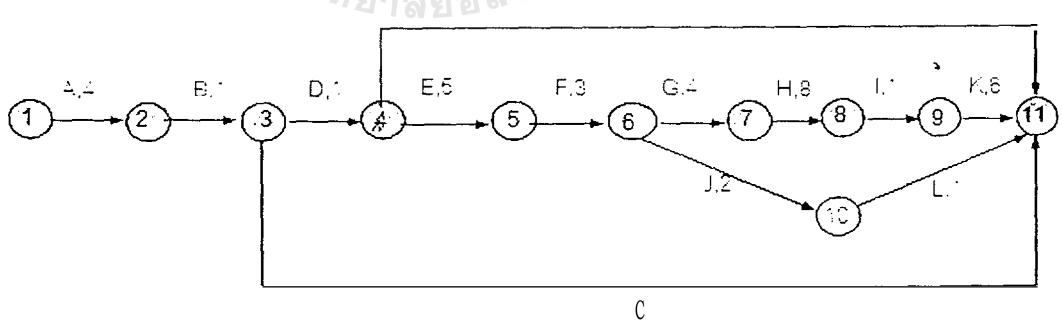
Another option is implementing preventive maintenance program by TKIC maintenance persons. This way might be more difficult but TKIC will save more money than extending the contract. During three year service, TKIC should train their own maintenance staff about implementing preventive maintenance. They might be trained by applying on the job training technique or by assisting the professional. By working with STC service team, TKIC maintenance staff will acquire skills and experiences of seal repairing. Moreover, TKIC should apply preventive maintenance program not only for the mechanical seal, but also for other equipments in their plants.

For STC, the company should try to convince the customer to extend the contract, because STC has the opportunity to gain more profit from this extended contract. However, STC should mark up the price of the optional addition two year service. It should be higher than 10 million Baht because the previous net profit is quite low and some mechanical seals which have 3 years life might be changed by the new completed set in the forth year.

In order to let the customer to continue using maintenance service or propose the new service contract to other customers, STC must have future plan for running the project. PERT can help STC to achieve that goal as shown below.

Table 6.2. PERT of STC Preventive Maintenance Project Bidding.

Activity	Designation	Immediate Predecessors	Duration (weeks)	ES	EF	LS	LF	Slack
Propose idea	A	-	4	0	4	0	4	0
Set project team	B	A	1	4	5	4	5	0
Schedule project	C	B	2	5	7	31	33	26
Survey plant	D	B	1	5	6	5	6	0
Co-operate with oversea	F	D	5	6	11	6	11	0
Negotiate price and spec.	F	E	3	11	14	11	14	0
Develop preliminary proposal	G	F	4	14	18	14	18	0
Negotiate with client	H	G	8	18	26	18	26	0
Sign contract	I	H	1	26	27	26	27	0
Select office location	J	F	2	14	16	30	32	16
Purchase equipment & machine	K	I	6	27	33	27	33	0
Set up office	L	J	1	16	17	32	33	16
Prepare Seal Recommendation	M	D	4	6	10	29	33	23

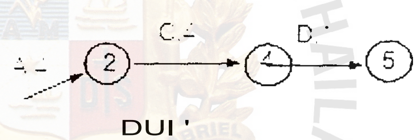


n = Critical Path

Figure 6.3. Arrow Diagram of STC Preventive Maintenance Project.

Table 6.3. PERT of STC Optional Addition of 2-Year Preventive Maintenance Project

Activity	Designation	Immediate Predecessors	Duration(weeks)				ES	EF	LS	LF	Slack
			a	m	b	to					
Prepare the previous project-benefit report	A		2	4	6	4	0	4	0	4	0
Develop preliminary proposal	B		1	2	3	2	0	2	2	4	2
Negotiate with client	C	A,B	2	4	6	4	4	8	4	8	0
Sig contract	D	C	I	I	I	I	8	9	8	9	0
	Dummy	B	0	0	0	0	2	2	4	4	2



= Critical Path

Figure 6.4. Arrow Diagram of STC Optional Addition of 2-Year Preventive Maintenance Project.

From the tables and figures above, the process time of implementing the new project arid project extension are 8.25 and 2.25 months respectively. Therefore, STC must have at least 8.25 months for bidding preparation and also 2.25 months for project life extension proposal.

APPENDIX A

RELIABILITY PARTNERSHIP AGREEMENT

A.1 RELIABILITY PARTNERSHIP AGREEMENT

1. Introduction

The key to successful mechanical seal operation in the pulp & paper industry is to have a range of seals that have been designed for the specific needs of that industry and to engineer the seal's installation environment correctly.

John Crane's active participation in this industry for many years has yielded the necessary experience and seal designs which are not only highly reliable but also simple to install and operate.

Sealing paper stock is the predominant and one of the most demanding application in this industry. John Crane had developed special nonclogging seal designs and sealing techniques to ensure effective and reliable sealing for all types of services in this industry. With the acquisition of Safematic Seals and Sealol Seals, John Crane is the only seal manufacturing company that has the most comprehensive sealing capabilities in the pulp and paper industry.

Today the usage of water in any process is becoming a main concern and drastic actions have been taken by both authorities and environmentalists to minimize this. In contrast most plant operators are striving to avoid unnecessary injection of water into the process. In most cases, to operate a packed gland and some mechanical seal installation effectively, a flush of water is required, thus contaminating the process resulting in the unnecessary usage of water. For those reasons John Crane has designed cartridge type seals for easy installation and do not require any flush water and use a minimal flow of quench where conditions allow.

Unflushed seals give substantial savings in water and water treatment costs as well as lower evaporation costs in certain areas. Mechanical seals used and maintained correctly helps to reduce environmental problems caused by toxic effluent outflows.

The mechanical seal is the most critical component of a rotating equipment system and the rotating equipment is the most critical component of the entire plant. Improved seal integrity and reliability provide benefits in terms of reduced emissions, plant efficiency and higher productivity.

2. Definitions

(1) **THE COMPANY** refers to Thai Kraft Paper Industry Co., Ltd.

(2) **John Crane** refer to sole distributor Sealing Technology (Thailand) and John Crane Singapore

(3) **Mechanical Seals** refer to all components related to mechanical sealing systems and its directly-related accessories.

(4) **Equipment** refers to the production machinery (pumps, agitators, screens, etc.).

(5) **Refurbishment /Reconditioning** refers to the maintenance of used seals, fault finding, dismantling, cleaning, relapping of contact faces and replacement of elastomers.

(6) **Retrofit** refers to the conversion of a sealing system from other manufacturers to John Crane or from gland packings to mechanical seal.

3. Objective of THE COMPANY

THE COMPANY is seeking to optimize the management and maintenance of all mechanical seals on-site. **John Crane** is proposing to take over the entire responsibility for the refurbishment, retrofitting and maintenance of all mechanical seals on site be it of any make or manufacture, with a view to reducing the overall cost of maintenance and unnecessary downtime due to unplanned shutdowns caused by mechanical seal failures. John Crane will draw up implement and execute the following.

(1) A condition based maintenance plan.

(2) A systematic preventive maintenance plan.

(3) The refurbishment of used mechanical seals.

(4) Daily on-site attendance of a fully trained technician.

(5) On-site seal refurbishment facilities and basic workshop.

(6) Management of on-site spares and stocks.

Further improvement may be proposed by both parties outside the scope of this contract with a view to improving our service and the plant's sealing system efficiency and/or the environment. With this in mind, both parties should work together towards a common goal and that is " to a more reliable and efficient production facility". To achieve this goal, total cooperation between both parties is very vital for the effective performance of this contract.

4. Objectives

The main objective of this contract is the provision of John Crane's expertise in sealing solution for 'THE COMPANY' to maximize the usage of their mechanical sealing systems and for John Crane to provide the valuable on-site service and training all technical staff and management of "THE COMPANY" to maximize on achieving a reliable and efficient production facility.

5. Scope of Work

5.1 On-Site Consultancy Services / Complete Detail of Mill Survey

John Crane has a wide network of service centres throughout the world, THE COMPANY'S technical staff and management will benefit from this as they would be able to communicate via e-mail with most of our service and design centres and the various JC manufacturing plants globally. These would include Safematic and Sealol technical and engineering support capabilities. A John Crane Asia Pacific Pulp & Paper Technical Engineer will provide on-site consultancy service at least 4 times a year.

5.2 Proposal to Improve Seal-Life and Seal Upgrade

A detailed proposal for sealing improvements will be made on completion of a detailed plant survey to be done by a John Crane personnel. The improvements will be formally recommended in writing to 'THE COMPANY' and an order may be placed by 'THE COMPANY' with John Crane to have recommended proposal carried out. Any proposals recommended will state clearly the benefits and savings -to 'THE COMPANY'. As it is still pre-mature to ascertain the specific areas to improve Mean Time Between Failure (MTBF) until a more detailed study is jointly carried out with 'THE COMPANY'. John Crane will strive to provide benefits and savings as follows.

(1) Correct seal selection for each item of rotating equipment throughout the mill.

(2) Cost saving benefits achievable by application of correct sealing solutions.

(3) Standardization where possible to reduce 'THE COMPANY' inventory cost.

(4) Achieve significant water savings.

(5) Reliability.

5.3 Mechanical Seal Taken Over

Under this contract John Crane shall take over all the John Crane mechanical seals on site and at which time the other mechanical seal (non-John Crane mechanical seal) fails or fails to perform, John Crane will propose a retrofit at the price quoted to 'THE COMPANY' as attached. In the long term this will benefit both parties as a standardization of mechanical seals in a plant will mean interchangability between equipment in similar processes with the same shaft dia meters, specifications and a better control of spares inventory.

5.4 Recommendation of Seat in New Projects and New Equipments

John Crane will make recommendation to 'THE COMPANY' so that when an equipment selection is made, the selected equipment will already be fitted with seals for which replacements and spares are already in stock on site.

5.5 Preventive Maintenance Services

As our motto says "Provide Powerful Solutions with Common Goals for Mutual Benefits", we will stand by 100%. Since we will have a technician on site daily with full facilities, ready available stocks and spares, one of his main duties would be to constantly check the seals on critical rotating equipment and report to the engineer concerned his findings and take the necessary action before a major breakdown takes place. The preventive maintenance program will also include a survey history of each rotating equipment as attached appendix and this will be kept on 3.5" disks, updated regularly and is available to 'THE COMPANY' when requested.

5.5.1 Implementation of a Preventive Maintenance Program

This program will be a joint effort between technicians from both companies and the John Crane technician will take instructions from 'THE COMPANY's' engineers, supervisors or planners before proceeding with a scheduled task. A signed authorized work order has to be issued before the commencement of the job.

5.6 Exclusions In the Process of Removal and deal Installation (Dismantle and Assemble)

The John Crane technician will not strip or install the equipment in question. He may assist 'THE COMPANY's' personnel if requested but will take full responsibility in the removal and installation of the mechanical seal and the support system if any. He is to make sure that all flush and quench lines are clogged free. He will not be responsible for alignment, vibration analysis of the equipment but will stay to make sure that all of the necessary procedures are met and proper start-up procedures are followed. To avoid any confusion in the process of seal installation and removal, the John Crane technician must be utilized for this purpose unless circumstances prevail.

5.7 Management of On-Site Stocks and Spares

Complete seal stocks and break-down spares will be available on site and stored in a John Crane facility near TKIC together with lapping machines, flatness calibration equipment and basic workshop equipment and will remain the property of John Crane. A procedure will have to be agreed on between 'THE COMPANY' and John Crane as to the best way to the benefit of both parties and with the least of obstructions. This is the assurance of John Crane upon confirmation of contract.

6. 'THE COMPANY' access to John Crane Reliability Program.

(a) Sealing Technology (Thailand) Co., Ltd.

(1)	Anuthep Punyakhum	Sales Supervisor
(2)	Tananya Tantrapras	Sales Manager
(3)	Uchat Witchuworach	Product Specialist
(4)	Somsak Leekasem	Senior Technician
(5)	Sarawut Chanakano	Technician

(b) John Crane Singapore

(1)	Anthony Goh	Country Manager
(2)	John B. Dhanaraj	Pulp & Paper Manager — Asia Pacific
(3)	Nigel Jenkins	Senior Application Engineer
(4)	Krisada Klai-ngern	Senior Technical Service Engineer

7. Obligations of 'THE COMPANY'

'THE COMPANY' should give full cooperation to John Crane personnel to work as a team to achieve a common goal. 'THE COMPANY' should make available the equipment in question without delay if a job arise so that the necessary repair can be done immediately. Non-urgent breakdowns happening after normal work hours or at night should be repaired the following morning. The John Crane technician will reside within 5 km from the mill.

8. Response Time

Since John Crane will be setting up a workshop within 5 km from the mill, the response time will, depend on the urgency of each job. After hours callout, a response time will be no more than 1 hour. John Crane will carry stocks and spares to service as the contract to the best of its ability.

9. Monitoring of the Activity and Performance

9.1 Performance Indicators

To calculate the efficiency of the plant and to monitor the performance of the mechanical seals, the indicators chosen to serve as the reference basis are as the followings

(1) The number of seal breakdowns causing unscheduled shuts and breaks in production.

(2) The downtime connected with these unscheduled shuts.

(3) The data used for this will be collected over a period of the first 12 months of the contract and will be set on a graph to record the progress and the efficiency.

9.2 Regular Maintenance Meetings

Personnel from John Crane is obliged to attend regular maintenance meetings if required by 'THE COMPANY's' maintenance team. At these meetings personnel from both parties should work together to solve problems and difficulties encountered and improve plant efficiency.

10. Guarantees

10.1 John Crane Products

John Crane will give 100% warranty on all its products and this includes labour and services. However, the guarantee will not be applicable in the following cases.

(1) Mishandling of the mechanical seal by persons other than authorised John Crane personnel.

(2) Wrong installation of a mechanical seal done by persons other than authorised John Crane personnel or not being supervised by John Crane technical personnel.

(3) If there is a process malfunction or the process goes out of tolerance.

(4) Rotating equipment duty changes and seal operates outside of specifications.

(5) Seal failures caused by rotating equipment failure.

(6) Seal running dry due to lack of lubrication of coolant.

(7) Seal failures due to misalignment of rotaing equipment

10.2 Non-John Crane Seals guarnteed 100%

Used seals from all vendors shall be guaranteed for at least 6 months after refurbishment and re-installation of the seal to the equipment. However, John Crane will not provide warranty on the mechanical seal materials as this is beyond John Crane's control and quality standards.

John Crane will abide by reconditioning and refurbishing non-John Crane seals when spare parts and seal specifications are available ex-stock from TKIC. John Crane will give full warranty on the work carried out but will not give warranty on the reliability and performance of the repaired non-John Crane seals. In the event where spare parts are not available and it causes delay in a job, John Crane has the authority to retrofit to an equivalent or better seal at the prices attached.

11. Pricing

11.1 Payment

A monthly maintenance fee (not including cost of mechanical seal) of Baht 100,000 will be charged and payable every month by 'THE COMPANY' for the duration of one calendar year (12 months) of the first year of the contract.

This will cover the setting-up cost and maintenance of full service facility with a daily attendance of one experience service technician and another technician to call in 3 times a week to assist the on-site based technician. In the case of major shutdown of the plant, full concentration will be put with a total attendance of at least 3 technicians and 1 supervisor will be on-site to carry out all necessary maintenance on mechanical seals and sealing systems. This will also cover the maintenance of the sophisticated machinery and calibration equipment used in the proper maintenance of mechanical seals including the stock of mechanical seals and spare parts.

11.2 Price List of Mechanical Seals

At the request of 'The COMPANY', John Crane may be occasionally asked to convert other non-mechanical sealing system, namely gland packing, etc., to mechanical sealing system. Under this circumstance THE COMPANY' will be charged for mechanical seal replacement. For this purpose, John Crane will submit a one-year fixed price list. An annual inflation adjustment will apply and modification of this adjustment will be notified by official letter. All prices will be quoted in Thai Baht.

11.3 Taxes

The monthly service fee as stated in clause 11.1 does not include value add tax (VAT) or any other tax which may be applicable to this oonrtract. All taxes including but not limited to VAT shall be borne by'THE COMPANY'.

12. Term and Condition of Payment

12.1 Terms of Payment

Invoicing of the service fee as stated in clause 11.1 will be monthly and due payment in 30 days. All other mechanical seals will be the subject of separate invoicing and payment will be as per our normal trading terms of 30 days. On signing of the contract, a 2 month advance of the fixed service fee amounting to Baht 200,000.- will be paid in full and the remainder to follow accordingly.

12.2 Due Date and Method of Payment

Unless stipulated otherwise on the order, all prices are considered firm and final. The initial payment as stated in clauses 11.1 and 12.1 will be paid signing the contract. Payment of other goods and services will be carried out on the 1 st of the following month.

13. Duration of Contract

The contract duration would be a period of 3 (three) years with an optional addition of 2 (two) years, and will be effective on **DD day of MMMMM 1998,** and will expire on **DD day of MMMMM 2001.**

14. Suspension and Recission

14.1 Normal Rescission

Both parties have the possibility of rescinding this contract at anytime by sending a registered letter with a return of receipt to the other party giving 3 months' notice. This contract will be rescinded in the event of bankruptcy or liquidation of assets of either party.

14.2 In The Event of a Dispute

In the event of any serious or repeated shortcomings in the fulfillment of their obligations by either one of the parties, this contract may be suspended immediately on the initiative of the other party, after a registered letter of termination has been sent to the other party setting out the grounds, with a request for a receipt. In this instance, both parties undertake to organize a meeting at an appropriate level of seniority within 14 days to examine the arguments of the party which has taken the initiative of suspending the contract.

Signatures

This contract was sign at ____

On the ________________ day of ________________________ 1998

By

From'THE COMPANY' being Thai Kraft Paper Industry Co., Ltd.

Name in full

Designation

Signature | Company Stamp

For our local representatives being Sealing Technology (Thailand) Co., Ltd.

Name in full

Designation

Signature | Company Stamp

For the principle being John Crane Sin:a.ore Pte Ltd.

Name in full

Designation

Signature | Company Stamp

BIBLIOGRAPHY

1. Agarwal, L. N. and K. C. Jain. Production Planning Control and Industrial Management: Khanna Publishers, 1997.

2. Agarwal, L. N. and K. C. Jain. Production Management: Khanna Publishers, 1995.

3. Brigham, F. Eugene and Louis C. Gapenski. Financial Management: Theory and Practice, Eighth Edition. Florida: The Dryden Press, 1997.

4. Crane John. Seal Selection Manual: John Crane UK Ltd. 1997.

5. Degarmo, Paul E., William G. Sullivan, James A. Bontadelli, and Elin M. Wicks. Engineering Economy, Tenth Edition. Upper Saddle River, New Jersey 07458: Prentice-Hall, Inc.,1997.

6. Hawryszkiewycz, I. T. Introduction to Systems Analysis and Design, Fourth Edition. Australia: Prentice Hall Australia Pty Ltd., 1998.

7. Heizer, Jay and Barry Render. Operations Management, Sixth Edition. Upper Saddle River, New Jersey 07458: Prentice-Hall, Inc.,2001.

8. Kerzner, Harold. Project Management: A System Approach to Planning, Scheduling, and Controlling. New York: Van Nostrand Reinhold,1979.