Risk Based Integrity Modeling of Offshore Process Component Piping

by

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14865

Dissertation submitted in partial fulfilment of

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

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January 2015

CERTIFICATION OF ORIGINALITY

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

(THEVI SREETHARAN)

ABSTRACT

This paper discusses on the methodology to develop a risk-based integrity model of offshore process piping (surface flowlines) which degrades due to corrosion. Gas processing plants are highly hazardous which deals with chemicals at extreme conditions such as high temperature and high pressure. These facilities should be going through the right maintenance and inspection from time to time to ensure a safe environment, continuous and fault-free operation. Deterioration of gas facilities gives a major impact on the continuous operation of the facilities. This paper proposes a risk-based integrity modelling methodology to have a fault-free operation for the facility's piping (also known as surface flowlines). The risk-based integrity model is to develop the model of offshore surface flowlines' corrosion mechanism efficiently to obtain an optimum replacement plan. The economic consequences of offshore surface flowlines corrosion mechanism are developed in terms of the cost of failure, inspection and maintenance. The optimal replacement strategy is obtained by combining the collective posterior probability of failure and the corresponding rate of corrosion. Risk-based integrity's assessments use the structural corrosion data which are modelled using the prior probability information. This prior probability information can be restructured to posterior probability using Bayesian Theorem and ASME B31.3 prediction method with the support of the inspection data of the facility. Posterior probability will then be used to estimate the likelihood of the piping failures in the facility. This can then lead to quantify the possible ageing hazards to the facility and identify the replacement interval of the components to avoid hazards. The consequence will be measured by cost as a function of time. This paper focuses mainly on general corrosion on the surface flowlines (topside pipeline).

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ABBREVIATIONS AND NOMENCLATURES

ABRREVIATIONS	**MEANING**
RBIM	Risk-Based Integrity Modeling
FYP I	Final Year Project (Semester 1)
FYP II	Final Year Project (Semester 2)
ASME	American Society of Mechanical Engineers
PoF	Probability of Failure
HSE	Health Safety and Environment
CS	Carbon Steel
CAPEX	Capital Expenditure
OPEX	Operational Expenditure
NDT	Non-destructive test
RBI	Risk based integrity
USD	United States Dollar
MATLAB	Matrix Laboratory Software
AEC	Annual Equivalent Cost

CHAPTER 1

INTRODUCTION

1.1 Background

Maintenance in terms of engineering is defined as the optimization of equipment, procedures, and departmental budgets to achieve better maintainability, reliability, and availability of equipment, where it can perform a requisite function (Thodi et al. 2009). Reputable maintenance should be steered to lessen the production hazards and maintenance methodology such as Reliability Centred-Maintenance, Condition-Based Maintenance and Total Productive Maintenance. These maintenance methods can only be used based on the component's Probability of Failure (PoF) where the approaches will turn out to be more useful with the data about the failure discovery, component, repair, budgets, maintenance plan and management policies (Khan et al. 2006). While the consequences of failure, inspection and maintenance is not applicable through these maintenance strategies.

Risk-based Integrity Modeling has become a very valuable method and a recognized tool based on the life-cycle risks in enhancing the maintenance activities. (Saharuddin et al. 2011) mentioned that the selection of a risk analysis method has a key effect on the identification of risk causes and in developing a true (Backlund, 2002) decision making in maintenance process. Cautious requirement identification and an efficient method with proper goals are required while performing risk analysis. Gerhardus (2012) has stated that integrity maintenance of offshore process piping lines has been a subject of exploration for many years, yet needed to be justified. This paper discusses about the importance of Risk-Based Integrity to measure the risk posed by the offshore surface flowlines.

1.2 Problem statement

Offshore process components reducing its life span earlier than predicted durability. This is because the facility is going through high failure rate due to improper replacement strategy, which causes relatively high unplanned maintenance cost due to unexpected failures. Ensuring continuous and failure free operations of offshore components such as pipeline is paramount, taking into account the production deferment and additional cost incurred due to unplanned maintenance activities. There is a great need to avoid this situation from stirring and to minimize the environmental and cost impact. To ensure a fault-free operation throughout the assets life, a risk-based integrity model (RBIM) can be used to obtain an optimal replacement strategy for the corrosion of the surface piping. This model will be developed in terms of the cost of failure, inspection and maintenance.

1.3 Objective

The purpose of this paper is about the importance of Risk-Based Integrity, which is:

- To measure the risk posed by corrosion in offshore piping (only surface lines)
- To develop a risk-based integrity model for the optimal replacement of offshore process piping.
- To develop the failure consequences of offshore process piping corrosion in terms of the cost of failure, inspection and maintenance.

1.4 Scope of study

The scope of this study will be focusing on the topside surface flowlines downstream of separator at offshore process facility. The scope of this project is within the offshore gas processing facility, focusing on carbon dioxide system of the facilities, study will be on corrosion of the piping in the facility. The study of the thesis is confined to develop a risk-based integrity model for the optimal replacement of offshore process piping. Throughout the study failure consequences of the piping corrosion are developed in terms of the cost of failure, inspection and maintenance. This study will measure the combination of collective posterior PoF and the corresponding cost of corrosion for an optimum replacement strategy. This study also will show that in order to develop RBIM, Bayesian theorem model and corrosion rate prediction method in ASME B31.3 are used.

CHAPTER 2

LITERATURE REVIEW

This paragraph represents literature review on the areas related to the Risk-Based Integrity Modeling (RBIM). There has been an issue of research going on for voluminous years regarding the integrated maintenance of the process components because lack of maintenance will cause deterioration of assets where it has a very critical effect on the operation of gas processing platforms (Kallen, 2002). Assets are subjected to corrosion which will eventually degrade (Straub, 2004).

RBI involves an optimal maintenance process (involves cost) which will be used to test the corrosion of equipment or components in industrial plants. Health, Safety and Environment (HSE) and risk of business will be examined by ranking failure probability and consequence through the RBI assessment. Maintaining the integrity of offshore process facility is a prime concern for the oil and gas industries in the world. An optimal methodology is necessary to avoid any failure consequences from occurring.

2.1 Carbon Dioxide, CO_2, Effect on Corrosion

Carbon dioxide is an acidic oxide (covalent compound) and it reacts with water which will result in carbonic acid. CO_2 corrosion is also known as “sweet corrosion” (Barker et al, 2013). Majority oil and gas industry is facing failures due to CO_2 corrosion on carbon steel (CS) and has lack of knowledge to overcome this problem.

Kermani et al. (2003) has commented that CO_2 corrosion is the most widespread type of risk faced by oil and gas sector. In search for more oil and gas source, the operational activities have moved to a deeper and high risk environment, thus, it is moving to a higher pressure and higher temperature condition. These have evolved to more challenges faced by the industry, where the project development and the operation cost is also increasing. In addition, there will be needs to identify the facilities integrity and accurate estimation of materials performance to avoid major failures and risk. The effect of corrosion in this industry can be observed in terms of CAPEX and OPEX, and HSE (Kermani, 2003).

2.2 Corrosion Type: General or Uniform Corrosion

General corrosion is common among CS. General Corrosion focuses on surface of the pipe and easily estimated by good inspection because of its uniform rate of corrosion. There is always excess material thickness will be provided to allow the corrosion to thin the material to a certain allowable amount of minimum thickness (based on ASME B31.3, 2011); if it falls below the minimum allowable thickness, the pipe will start to leak and eventually will fail. Thus, brings risk to the safety of the surrounding.

General corrosion is also known as uniform corrosion, which occurs moderately and evenly distributed over the surface, leading to a relatively uniform thickness reduction (Cicek, 2009). It is the most common form of corrosion and responsible for most of the material loss. Prediction test of thickness reduction (corrosion rate) for this form of corrosion is simple with availability of proper inspection data (Winston, 2007). This also will lead to the prediction of probability of failure (PoF), and life expectancy of the product.

Winston (2007) has mentioned that there are two fundamental criteria must be considered to determine the PoF, which are:

- The form of corrosion and the corrosion rates.
- The possible effectiveness of corrosion inspection and monitoring.

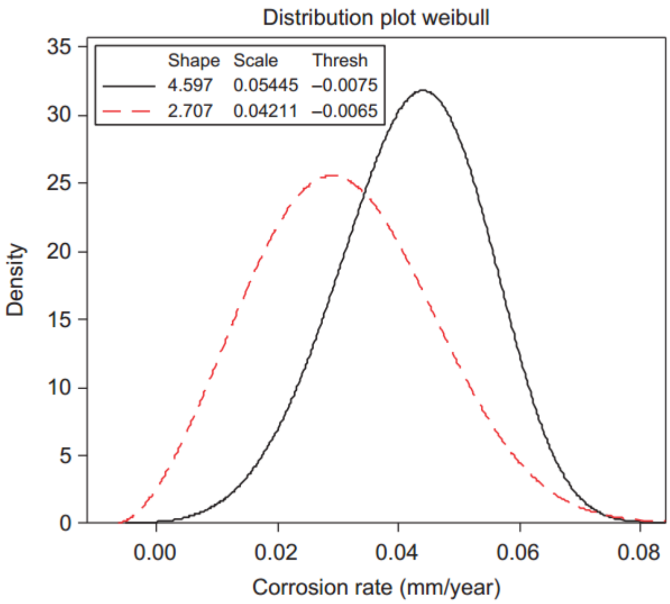


Figure 1: Weibull distribution analysis for corrosion

Figure 2 refers to the Weibull distribution plot which was obtained by (Thodi et. al, 2013). This is the posterior samples and was used to estimate their parameters of risk. This is then lead to the prediction of failure time of the piping.

2.3 Bayes' Theorem

Reliability engineering measure the failure due corrosion which can be observed for a period of time before the failure happens (Park & Padgett, 2006). Thodi et al. (2009, 2010) has discussed about estimating the probability of structural deterioration-related failure, which can be related to the present condition of the component. Corrosion standards and failure observations data reflect when conducting inference on the statistical factors of the components' lifespan distribution. Rate of failure is determined through the NDT data and the professional's knowledge and can be obtained during the inspection. NDT data can be used to derive the likelihood probability. Based on the data collected from the facility, inspection and piping lines, Bayesian theorem model and ASME B31.3 prediction analysis will be used to model the system.

Prior probability will be a part of the research where it is studied through judgmental and by analyzing the standard database. The simulation-based Metropolis-Hastings (M-H) algorithm method was used to make estimation on the posterior models because the prior-likelihood combinations were non-related to each other (Khan et al. 2006). Posterior model must be developed for the corrosion in piping.

Conditional probability of an event is known as a probability achieved with additional data that some other event has already occurred (Mario,n.d.). Bayes' theorem deals with sequential events, whereby new data is obtained for a subsequent event. The new data that was obtained will be used to revise the probability of the initial event.

Prior probability and posterior probability models are used commonly in Bayes' Theorem. Probability is a degree of acceptance of how far that it is true based on the data obtained. According to Chienet al. (2009), these models are reliable to predict the future failure probability of failing components in the process facility. As seen from Figure 1, Bayesian uses population parameters which are associated with a posterior probability which quantifies the degree of acceptance from the obtained data [*refer to Equation (1)*].

2.4 Risk-Based Integrity Modeling (RBIM)

The primary concern in engineering field is to manage risk, reduce and abolish it to a certain acceptable levels. Combination of the probability of a failure event and the severity resulting from the failure is known as risk in engineering field. According to Thodi et al. (2013) RBIM is a methodology to measure the risk to life modelled by the deteriorating components and to mitigate that in an economical method. Components will deteriorate if there's any physical breakage, leaks, and environmental effects. These deteriorations are stochastic processes. Therefore, the main concept in RBIM is to do estimation of the probability of structural failures and their consequences. Probability of failure is determined through stochastic modeling of the corrosion (Selvik J.T. et al. 2011). Through Bayesian prior-posterior analysis, the probability distribution function can be achieved, which can also be used to model a realistic inspection data.

The failure occurrence, inspection and the maintenance tasks can be used to do the consequence analysis which is focused on estimating the cost sustained (Khan et al. 2013) the consequence analysis is done to estimate the consequence of undesirable failure occurrences in terms of the cost of failure, corrective maintenance and preventive maintenance. Failures can lead to perform replacement for the components which will result in high cost corrective maintenance and unplanned shutdown in oil and gas process component facilities. These will cause a very large impact on maintenance tasks done and the cost to replace the component. Thus, an organization needs an optimal policy which aims to avoid large replacement cost and to minimize the total operating cost. According to Gerhardus (2012), the cost of maintenance includes cost of attaining access to the site, cost of preparation before inspection and maintenance and cost of detecting and sizing of defects using the non-destructive tests (NDT), cost of conveyance of equipment and cost of qualified technicians. Failure costs include breakdown loss, shutdown loss and environmental damage and liability loss.

2.5 Prior Probability Modeling

A prior probability is an primary probability value initially obtained before any additional information is received (Mario, n.d.). For any type of component degradation, the prior probability refers to the initial knowledge about each type of degradation processes. The corrosion data for the prior distribution can be obtained by few methods, such as frequency graphs, by conducting statistical investigations and plotting probability graphs. A rational agreement of results can be made by analyzing the historic data of the same or the similar piping lines installations (Congdon, 2006), even though the prior probability data is subjective.

2.6 Estimation of Likelihood Probability

Estimation of likelihood probability (Montgomery et al. 2002) is the process of estimating the parameters of statictical models. This method selects the parameters from the model which maximizes the likelihood function, and thus, it maximizes the probability of the observed data under the resulting distributionwhich gives a unified approach to estimation. Estimation theory is the division in statistics which deals by estimating the values of parameters on measured data which has random element. Estimation theory uses the measured data to approximate the unknown parameters.

The failure rate of an undesirable event in RBI is called likelihood. American Bureau of Shipping, ABS, (2003) has mentioned that likelihood is considered to be the most important factor in the evaluating risk since it directly affects the selection of inspection frequency. Pipe lines that has relatively high-risk will be prioritized during the screening and more detailed analysis on corrosion and frequency will be performed, e.g. NDT inspection data will be used to estimate the likelihood probability of different time of corrosion processes.

2.7 Posterior Probability Modeling

Posterior probability is known as Bayesian statistics, where the model is treated as another unknown parameter of a random event (also known as conditional probability) that is done after the background condition is measured (Congdon, 2006). The word ‘posterior’ is defined as the condition that was taken into account after obatining the relevant results related to the particular process which is being measured. It is treated as a random variable from the evidence that was resulted from the test done on the same or similar processes (ABS, 2003). A range of approximate methods must be proposed in order to select the Bayesian model. After the observation of data, Bayesian model is related to prior model probabilities and posterior model probabilities. A M-H algorithm approximation needed to be used to identify the posterior probability (Berger et al. n.d.).

2.8 Economic Consequences analysis

RBIM is done to minimize the risk level by preventing faliures caused by the corrosion and thus will maximize the profit due to less risk and failure (Purnell, 1999). Consequences analysis is done to measure the risk level and consequences is represented in USD unit because risk is evaluated as the expected loss of business due to certain failures. Analysis of economic consequences is further explained.

Cost analysis of corrosion for inspections is built on posterior functions as shown in Figure 2. Based on the corrosion analysis graph, it has a preventive replacement time of approximately 14 years and failure period of 26 years approximately. There are 2 minimum point found on the corrosion cost analysis graph, one is at year 10 and another one at year 22 approximately. The pipeline studied in this research paper was operating for 5 years and inspection was done for only once, then the next inspection should be due in 5 years' time. The minimum expected results for the replacement period for this study will be around 10 years as well.

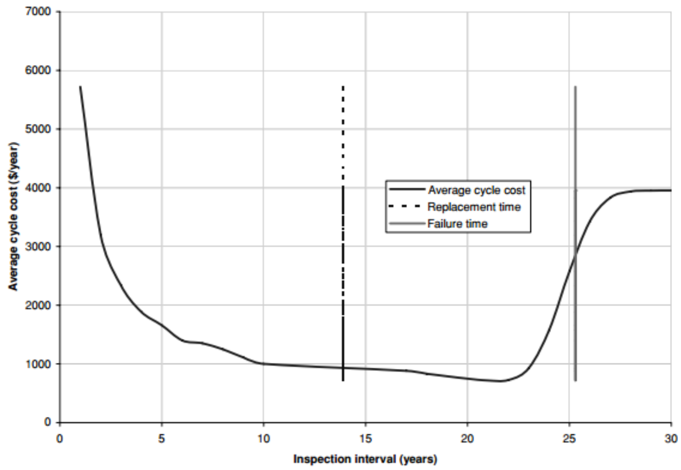


Figure 2: Average inspection (cost/year) for corrosion degradation on pipeline; Courtesy of (Khan, 2006)

Figure 3 shows that the failure cost is decreasing over time. While the inspection and maintenance cost is increasing over time during its service life. The increase for the maintenance and inspection cost are assumed to occur due to the corrosion which affects material strength of the pipeline.

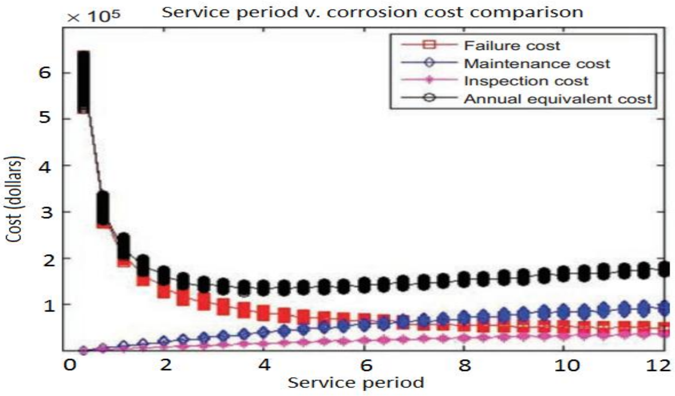


Figure 3: Sample of economic analysis from (Thodi et al., 2013)

CHAPTER 3

METHODOLOGY/PROJECT WORK

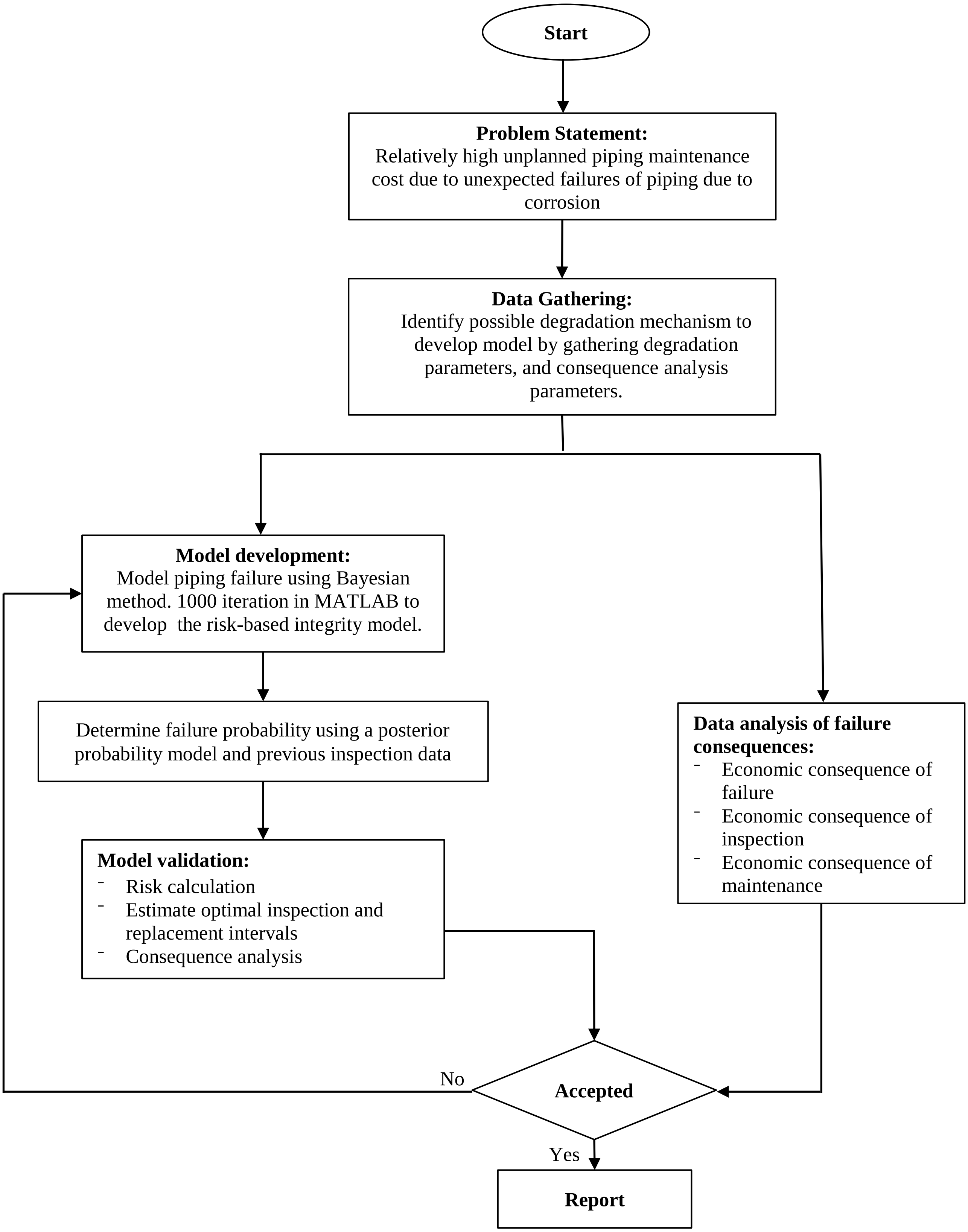


Figure 4: Flow chart of the activities

Data analysis of failure consequences should be conducted to quantify the economic impact on failures, inspection and maintenance before the RBIM is developed. The analysis is crucial to validate the RBI model if it can maximize the profit and minimize the risk by preventing failures associated with corrosion. The criteria of an effective RBIM is to have the total cost of failure reduced after its implementation. The results are valid if the Annual Equivalent Cost (AEC) is in a convex function as shown in Figure 4 and if the replacement time of both results are approximately equivalent (if valid the graph should be convex).

3.1 Bayesian Theorem Model

Bayesian Theorem is evaluated through calculating posterior probability distribution,$p(\theta/y)$, where $p(\theta)$, is prior probability,$p(y/\theta)$ is the likelihood function, $[\int p(\theta)p\left(\frac{y}{\theta}\right)d\theta]$ is the evidence (normalization constant useful for Bayesian model selection)(Thodi et al., 2013).

$$p\left(\frac{\theta}{y}\right) = \frac{p(\theta)p(\frac{y}{\theta})}{\int p(\theta)p\left(\frac{y}{\theta}\right)d\theta} \tag{1}$$

Thodi et al. (2013) has proven that posterior density, $p(\theta/y)$, summarizes the whole figures, after attaining the data and conveys a root for inference regarding the corrosion parameters.

3.1.1 Pressure Design Thickness of Process Piping

Based on ASME B31.3, (2011), pressure design thickness in straight pipe under internal pressure

$$t = \frac{PD}{2(SEW+PY)} \tag{2}$$

Where pressure design thickness, t, is the product of internal design gage pressure, P and outside diameter of pipe, D, divided by stress value for material, S, quality factor, E, weld joint strength reduction factor, W, and coefficient, Y.

$$t_m = t + c \tag{3}$$

Where t_m is the minimum require thickness including corrosion and mechanical allowance, and c is the sum of the mechanical allowances.

3.2 Economic Consequences analysis

(ABS, 2003; Thodi et al. 2013)

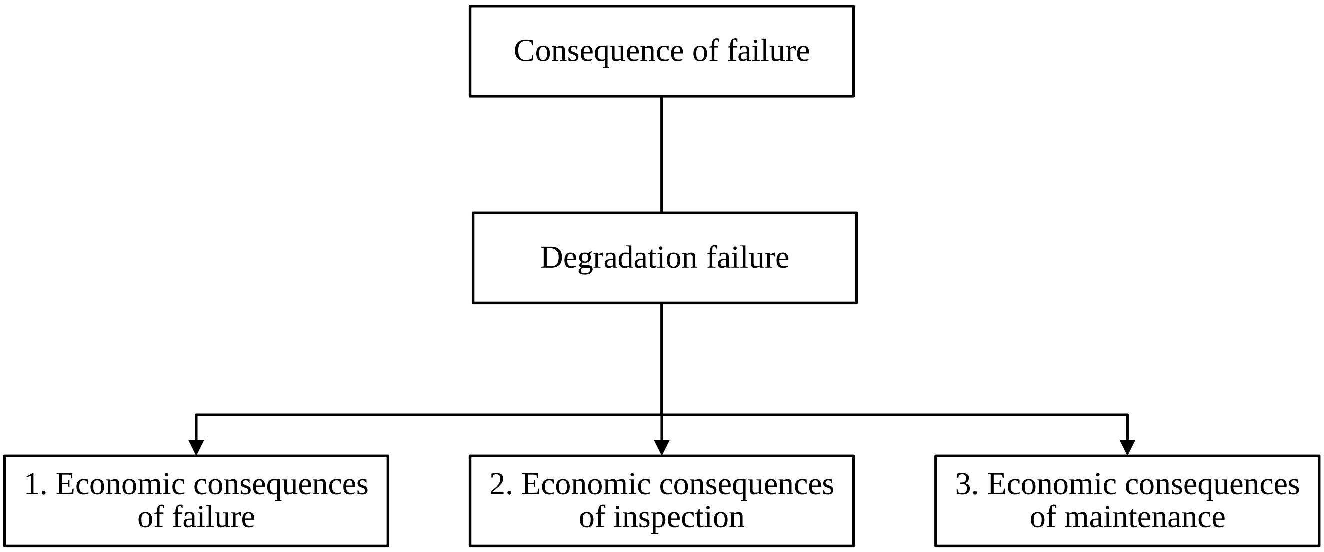


Figure 5: Economic consequence analysis chart

3.2.1 Economic consequences of failure

(Thodi et al. 2013)

3.2.1.1 Loss due to breakdown The mass flow rate, Q_m is obtained from the area of pipe hole, A is given by (Crowl and Louvar, 2002), where discharge coefficient, C_o, fluid density, ρ, gravitational constant, g_c, and gauge pressure, P_g.

$$Q_m = AC_o\sqrt{2\rho g_c P_g} \qquad (4)$$

3.2.1.2 Cost of breakdown due to corrosion, C_{lc} is measured by multiplying the average number of critical failures in the piping, E_{cf}, failure and loss of commodity probability, P_{ofl}, the duration of the commodity loss, T_{cl}, quantity of commodity loss, Q_{cl}, and cost of downtime, C_{dt}.

$$C_{lc} = E_{cf} \times P_{ofl} \times T_{cl} \times Q_{cl} \times C_{dt} \qquad (5)$$

3.2.1.3 Cost of shutdown due to degradation (USD), C_{sd}, is measured using the shutdown cost, C_p multiplied with unit cost of product (USD/barrel),Q, and total delay of maintenance (days), T_{md}.

$$C_{sd} = C_p \times Q \times T_{md} \tag{6}$$

3.2.1.4 Cost of spill clean-up due to corrosion,C_{sc} is measured by multiplying loss of product, Q_p, duration of spillage, T_{ds},and cost of spill cleanup, C_{scs}.

$$C_{sc} = Q_p \times T_{ds} \times C_{scs} \tag{7}$$

3.2.1.5 Cost of damage in nature due to corrosion, C_{nd}, is the product of the multiplication of the discharge of product due to degradation (ton/hour), Q_{rp} and the duration of discharge (hour), T_{dr}.

$$C_{nd} = Q_{rp} \times T_{dr} \times C_{dnr} \tag{8}$$

3.2.1.6 Total cost due to corrosion failure

$$C_{Tf} = C_{lc} + C_{sd} + C_{sc} + C_{nd} + C_{li} \tag{9}$$

3.2.2 Economic consequence of inspection

(Thodi et al. 2013)

The cost of inspection for degradation calculations are:

3.2.2.1 Cost to gain access for corrosion inspection,C_{gam}, is calculated by multiplying the cost of inspection technician per hour,C_{isl}, with total duration of work done to inspect, t.

$$C_{gam} = C_{isl} \times t \tag{10}$$

3.2.2.2 Cost of the preparation to inspect, C_{spi}, is the product of multiplication of cost of inspection labour per hour,C_{isl}, with the duration of work done to prepare for inspection (surface preparation) (hours) t.

$$C_{spi} = C_{isl} \times t \tag{11}$$

3.2.2.3 Inspection technician cost. This cost is measured by defining which type of inspection is done to inspect the piping and how many personnel is involved for how long (t), which involves the cost of:

Visual and radiographic inspection of piping,$C_{vi} = C_{isl} \times t$ (12)

UT piping (thickness and defect), $C_{UTtd} = C_{isl} \times t$ (13)

3.2.2.4 Technical expert, $C_{te} = C_{tecf} \times t$ (14)

C_{tecf} stands for technical expert consultancy fees (calculated hourly)

3.2.2.5 Logistics, $C_{log} = C_c + C_{ier} + C_{st}$ (15)

C_c stands for cost of consumables, C_{ier} is the cost of equipment for inspection, and C_{st} is the cost for storage and transportation done during inspection.

3.2.2.6 Total inspection cost involved to inspect the corrosion of piping is:

$$C_{Ti} = C_{gai} + C_{sp} + C_{vi} + C_{UTtd} + C_{te} + C_{log} \quad (16)$$

3.2.3 Economic consequences of maintenance

(Thodi et al. 2013)

Few categories are considered to measure the cost of maintenance for corrosion, which are:

3.2.3.1 Cost to gain access for corrosion maintenance, C_{gam}, is calculated by multiplying the cost of inspection technician per hour, C_{mp}, with total duration of work done to inspect, t.

$$C_{gam} = C_{mp} \times t \quad (17)$$

3.2.3.2 Cost of the preparation to inspect, C_{spm}, is the product of multiplication of cost of expert labour per hour, C_{mp}, with the duration of work done to prepare for inspection (surface preparation) (hours) t.

$$C_{spm} = C_{mp} \times t \quad (18)$$

3.2.3.3 Maintenance technician cost. This cost is measured by defining which type of maintenance is done to inspect the pipelines and how many personnel is involved for the period of time involved to do maintenance, t.

Gauging defects personnel cost, $C_{gd} = C_{mp} \times t$ (19)

Logistics cost, C_{mlog}

Total cost of gauging defects for corrosion maintenance,

$$C_{dgm} = C_{gd} + C_{mlog} \tag{20}$$

3.2.3.4 Reparation process cost for corroded piping:

Repair, $C_{rp} = C_{mp} \times t$ (21)

Weld quality test and coating restoration, $C_{wqt} = C_{wp} \times t$ (22)

C_{wp} stands for cost of weld quality test personnel (calculated hourly)

Technical assistance, $C_{mta} = C_{mp} \times t$ (23)

Other minor repair, $C_{mir} = C_{ms} + C_{mc}$ (24)

C_{ms} stands for cost of parts or spare and C_{mc} consists of cost of consumables.

3.2.3.5 Total maintenance cost of corrosion degradation,

$$C_{Tm} = C_{gam} + C_{spm} + C_{gd} + C_{mir} \tag{25}$$

Annual equivalent cost (AEC) due to corrosion failure, inspection and maintenance, will be calculated for the service period of total years, n, by using annual worth, present worth analysis with an annual interest rate of *i* percent.

3.3 Tools Required

Throughout the project, several tools will be used to compile and analyze relevant data. The tools required during the project consist of the following software’s as shown in the table in APPENDIX I.

3.4 Gantt Chart and Key Milestone

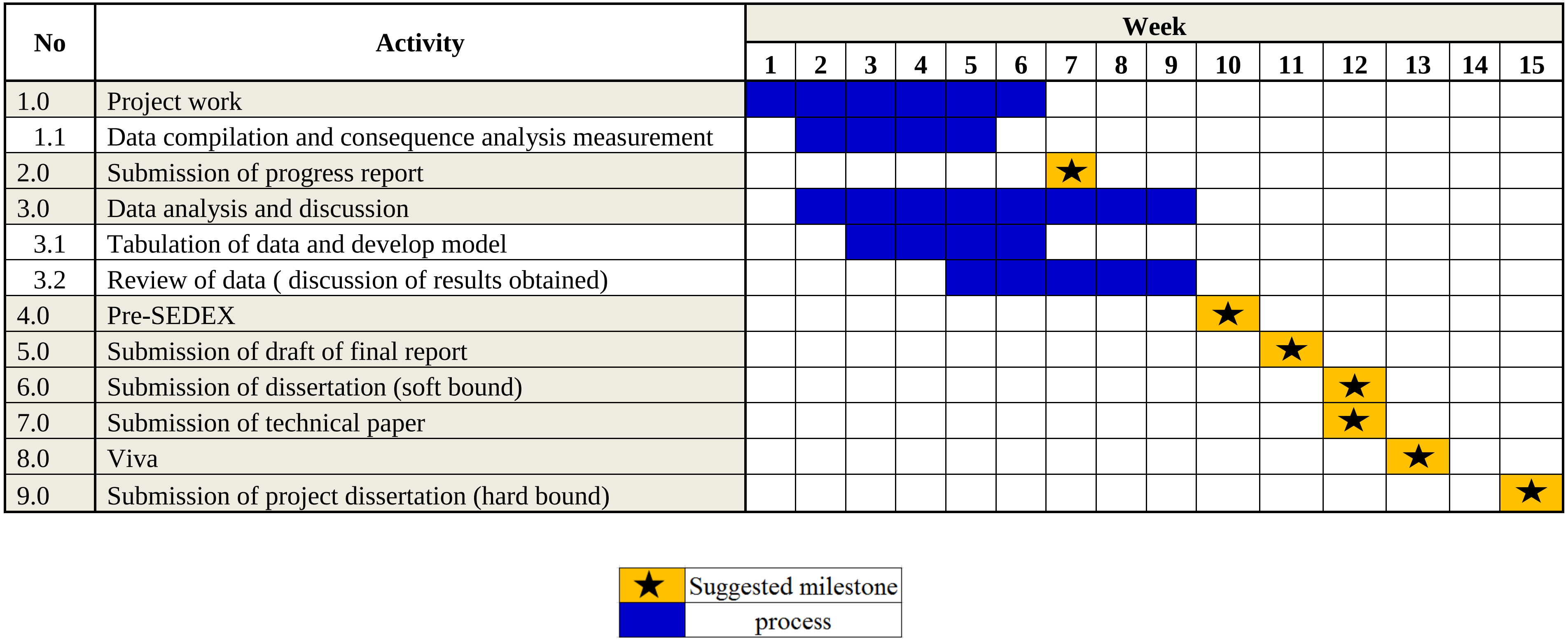
FYP I

No	Activity	Week													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1.0	Selection of project topic	🟦	🟦												
2.0	Preliminary research work		🟦	🟦	🟦	🟦									
2.1	Literature review		🟦	🟦	🟦	🟦									
2.1.1	Obtain equations and probability distributions				🟦	🟦									
2.1.2	Methodology				🟦	🟦									
3.0	Submission of extended proposal						★								
4.0	Design of experiment						🟦	🟦	🟦	🟦					
4.1	Identifying component that is affected with degradation						🟦	🟦							
4.2	Selection of degradation processes							🟦	🟦						
4.3	Identifying & obtaining standards and parameters needed							🟦	🟦						
5.0	Proposal defence								🟦	🟦					
6.0	Project work							🟦	🟦	🟦	🟦	🟦	🟦		
6.1	Measure and test the probability distribution models										🟦	🟦	🟦		
7.0	Submission of interim draft report													★	
8.0	Submission of interim report														★

★	Suggested milestone
🟦	process

Figure 6: Gantt chart of FYP I

FYP II



No	Activity	Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1.0	Project work	🟦	🟦	🟦	🟦	🟦	🟦									
1.1	Data compilation and consequence analysis measurement		🟦	🟦	🟦	🟦										
2.0	Submission of progress report							★								
3.0	Data analysis and discussion		🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦						
3.1	Tabulation of data and develop model			🟦	🟦	🟦	🟦									
3.2	Review of data (discussion of results obtained)					🟦	🟦	🟦	🟦	🟦						
4.0	Pre-SEDEX										★					
5.0	Submission of draft of final report											★				
6.0	Submission of dissertation (soft bound)												★			
7.0	Submission of technical paper												★			
8.0	Viva													★		
9.0	Submission of project dissertation (hard bound)															★

★	Suggested milestone
🟦	process

Figure 7: Gantt chart of FYP II

CHAPTER 4

RESULTS AND DISCUSSION

Offshore component that was selected in this study are gas surface lines. Table 1 below is the case study of this project which was obtained from a gas processing company.

Table 1 : Data obtained for the simulation process

Design Parameters	**Separator Pipeline**
Design temperature	140˚F/-20˚F
Design pressure	840 Psig
Operating temperature	99 ˚F
Operating pressure	730 Psig
Pipe dimensions	Diameter = 24in
	Wall thickness = 22.61mm
Material of construction	Carbon steel
Active damage mechanism for pipeline	corrosion, erosion, cracking due to stress
Other Parameters Values	
Tensile strength	90 MPa (min)
Yield strength	50 MPa (min)
Inspection cost	RM5,000
Preventive replacement cost	RM100,000
Failure cost	RM500,000

These data was used to resolve to get the replacement interval of the piping by doing simulation in MATLAB software to obtain the Risk-Based Integrity Model.

This project involves CS piping segment of 24 inch diameter with the wall thickness of 35.61 mm. This research is done based on a straight piping with the length of 200 m after the separator. This pipe is used to illustrate the Bayesian Theorem model to get the replacement interval of the piping. Based on Figure 8, the peaks of prior and posterior probability density distribution are very much attached to each other. Both the functions are evenly spread in the figure below. Peak of posterior probability distribution functions are at 0.14 mm/year, while for prior probability distribution is at 0.12 mm/year. Prior density distribution is based on real time data, which is obtained from inspection data. The posterior density distribution is simulated and estimated based on the information obtained from prior density distribution. This density distribution functions will assist to obtain the Bayesian Theorem model's wall thickness prediction.

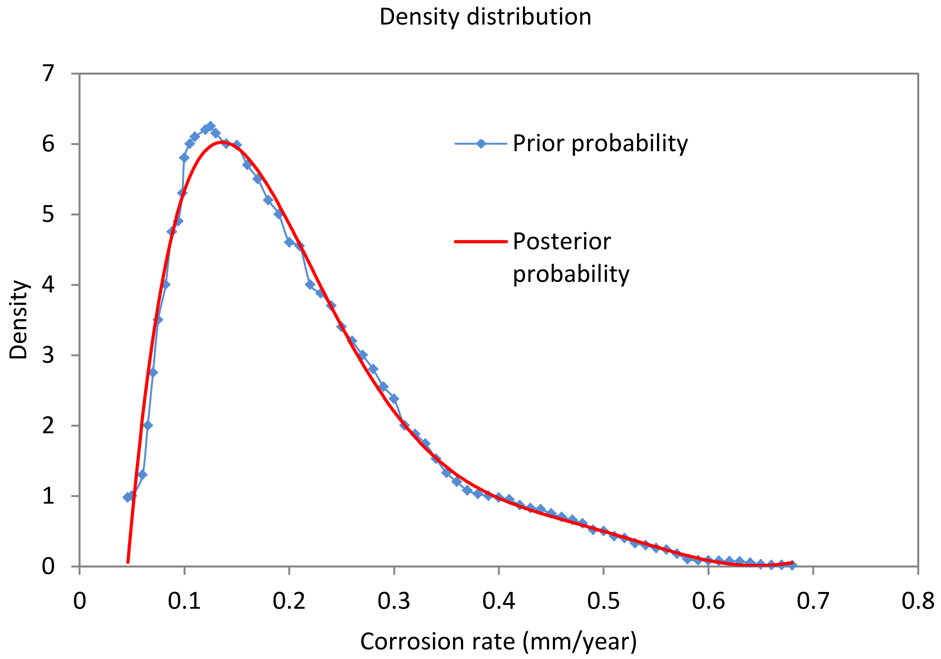


Figure 8: Prior and posterior probability density distribution for corrosion degradation in the piping.

Table 2: Results obtained from calculation based on ASME B31.3

Unit	**Results obtain**
Internal design gage pressure, P	840 psig
Outside diameter of pipe, D	24 inch
Stress, S	90 ksi
Quality factor, E	1
Weld joint strength reduction factor, W	1
Coefficient, Y	0.4
Sum of the mechanical allowances, c	0.2
Pressure design thickness, t	23.66 mm
Minimum allowable thickness, t_m	24.16 mm
Difference in t	9.09 mm
Number of years pipe operated	11 years
Corrosion rate	0.8263 mm/year

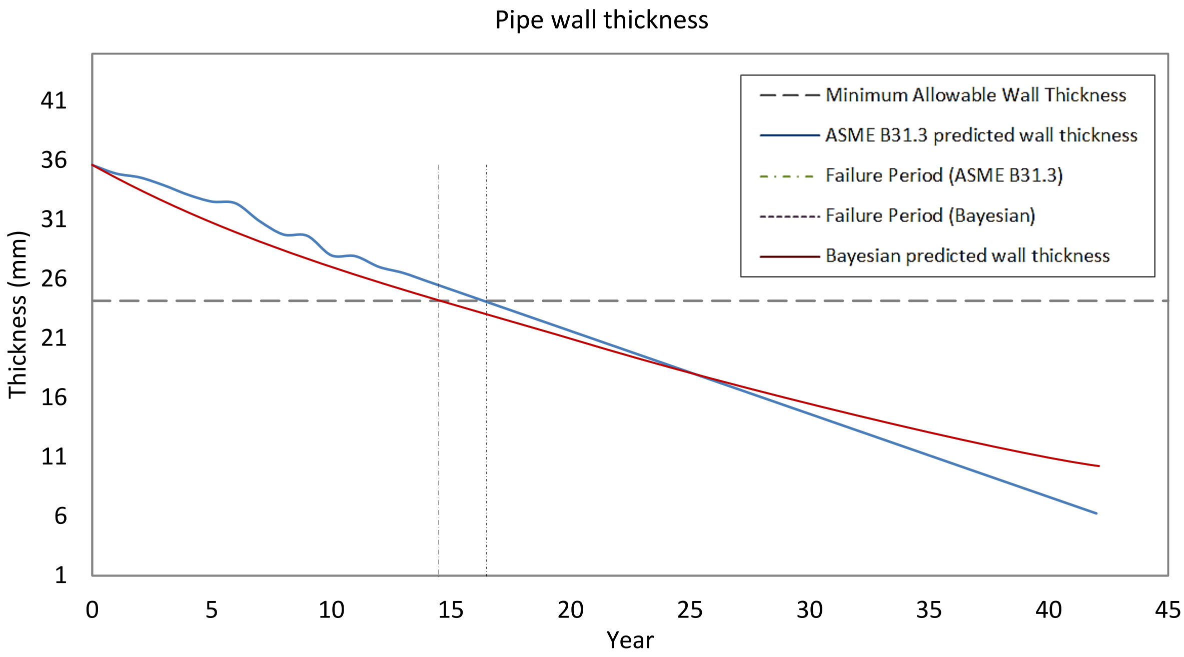


Figure 9: Average corrosion rate for corrosion degradation mechanism

Figure 9 is consists of 2 main graphs, which are the prediction of wall thickness by using ASME B31.3 and the prediction of wall thickness by using Bayesian Theorem model. ASME B31.3 wall thickness prediction is widely used in oil and gas industry to predict the failure period of pipe by measuring the internal pressure design of the pipe and the wall thickness. This paper is comparing the Bayesian Theorem wall thickness prediction with ASME B31.3. The pipe would fail when the predicted wall thickness lines interferes with the minimum allowable thickness line which is 24.16 mm. Thus, the piping failure period predicted by using ASME B31.3 is at the midyear of 16 (16.5 years)[the calculation method is shown in APPENDIX II], while the failure period predicted using the Bayesian Theorem is at the end of year 14 (14.8 years). The optimal replacement interval is the interval which corresponds to minimum risk, thus, taking into account the minimum risk, based on Figure 9, the replacement interval should be before year 14 (Thodi et al., 2013). The Bayesian Theorem graph was obtained by performing 1000 iteration run in MATLAB software.

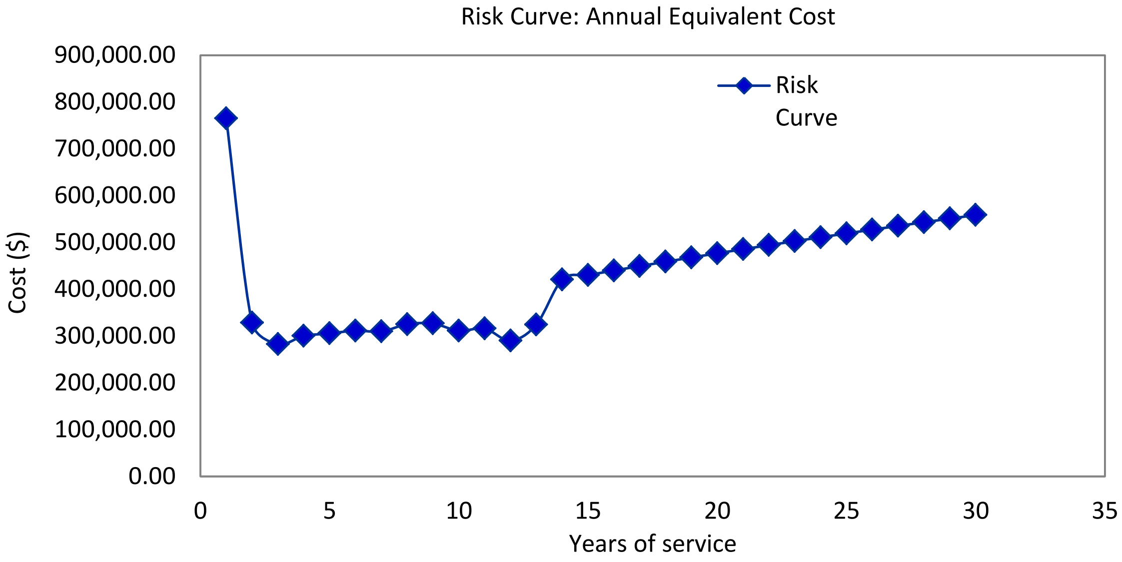


Figure 10: Total risk cost caused by corrosion for every year

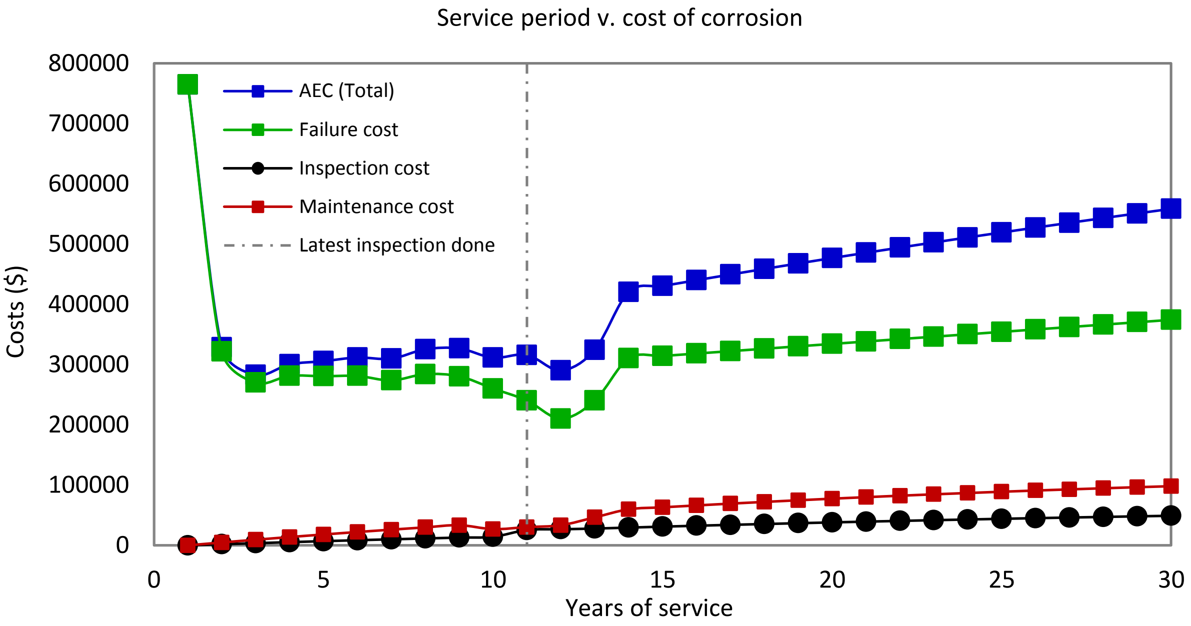


Figure 11: Service period compare to corrosion cost

Cost of risk due to corrosion was calculated and the results are shown in Figure 10 and Figure 11. Figure 10 only shows the overall risk cost for the corrosion degradation process by performing economic consequence analysis for the Annual Equivalent Cost (AEC). An opaque trend is achieved for the cost of the functioning lifecycle risk due to corrosion in the form of a partial convex curve. An irregular convex line curve is found until year 11 because the line is based on the actual data and rate acquired from few inspections done to the piping. After year 11, it shows a gradual and regular increase in the cost, this is due to the failure risk caused by corrosion to the piping.

Figure 11 shows the AEC and the estimated breakdown cost, which is divided into annual equivalent failure, maintenance, and inspection cost. Failure, inspection and maintenance cost analysis graph are obtained from the economic cost analysis that was done by assuming a fixed rate of annual interest rate of 10.47%. Figure 11 is the comparison between the failure, inspection, maintenance and the AEC analysis done. Present worth factor was used to obtain the maintenance and inspection cost estimation by assuming the same rate of interest. The AEC is observed to be reducing for the first three years, at the fourth year, it started to increase and reduce mildly, and there is a significant fall at year 12 (lowest peak), and a sudden rise in cost at year 14. The same goes with the annual equivalent of failure cost, the significant increase in the failure cost after year 13 is due to the corrosion risk. This proves the results which were obtained by (Thodi et al., 2013), the escalation in inspection and maintenance costs are due to the loss caused by the deterioration of the material strength of the flowlines. The optimal replacement interval based on Figure 11 is at year 12, which is the minimum cost observed and it is the cost efficient point of replacement interval, where there will be less expenditure compare to the other years. The calculated AEC is identified to be a distorted and partial service life convex curve function.

The ideal optimal replacement interval strategy is between year 12 to year 13. This is due to the consideration of the minimum risk and minimum cost which determines the ideal optimal replacement interval. This decision was made by comparing the results obtained in Figure 9 and Figure 11.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Risk posed by corrosion in piping is measured in terms of failure rate and cost. The failure rate predicted based on Bayesian Theorem is at year 14.8. The cost due to corrosion is increasing by time because the material is degrading and losing its strength. One of the advantage of the RBIM strategy is, the probability density distribution function for the corrosion can be updated using the same Bayesian Theorem method. This enables the failure rates easy to be modified when the actual measurements are available after the inspections are done in the upcoming years. Results obtained for this case study illustrates that this method used in this project yields a valid judgment for the replacement interval that was achieved. The optimal replacement interval is the period or meantime of which resembles to the minimum risk and minimum cost. Implementation of replacement at this interval will reduce the operation's risk level locked to the ALARP level. This study focused on a straight piping (surface flowlines) segment which was affected by the carbon dioxide corrosion degradation. Decision to replace the surface line is more effective than carrying out maintenance. Optimal replacement is to return the lines to a more integrated condition which possess less risk compare to the ones that have operated for very long period.

Risk-based Integrity Model is developed by using Bayesian Theorem to find the optimal replacement strategy of the piping by knowing the time to replace the piping before it enters the failure point. The optimal replacement interval is ideal when it corresponds to the minimum risk (safety and cost is considered). In conclusion, the replacement intervals, which is known as the method of the RBIM strategy was discussed. The ideal optimal replacement interval of this case study is at year 12, given that it is the most cost effective and safer period before it reaches the failure point. Replacement strategies are focused to cure the consequences of the deterioration of the component. It also act as a remedy on strength loss and outmodedness of the process components, in this case is piping (flowlines). The component deterioration makes the component to face reduction in the efficiency of the operation, thinning of the wall thickness and reduction in the material strength. Outmodedness take place as an outcome of new technology advancement is introduced in the industry.

The failure consequences of offshore process piping corrosion are identified in terms of Annual Equivalent Cost (AEC) (also known as overall cost). The overall cost is obtained by adding the failure, maintenance, and inspection cost together. Cost will escalate if the component degrades over time and if it fails. To avoid the failure, Risk-based Integrity Model is done by identifying the replacement interval. Initially, the corrosion cause was discussed, followed by a brief discussion on the RBIM, Bayesian Theorem model. Further discussed about the economic consequences analysis, where the AEC is calculated by combining the failure, maintenance and inspection costs. The density distribution of the piping corrosion is then combined with the economic analysis to produce the effective life expectancy risk curve (Bayesian model), which is also known as RBIM.

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APPENDIX I. Tools Used for Project Completion

Table 3: Tools used to complete this project.

Tool	Function
SAP Software	This software will be used to download all the inspection and maintenance activity records of the facility and piping's, which was recorded by the technicians in SAP.
MATLAB (matrix laboratory)	This will be used to compute the probability models and develop the stochastic degradation model to obtain an optimal replacement strategy of the piping that will be used to study in this paper.
Microsoft Excel	This software will be used to create the calculations used in the report and to create a chart to visualize the comparison or trend of any data.
Microsoft Word	This software will be used to write report, proposal and referencing.
Electronic Document Management System	This software will be used to obtain the P&ID drawing of condensate transferring process.

APPENDIX II. ASME B31.3 Calculation

Given:

Internal design gauge pressure, P = 840 psig

External diameter of pipe, OD = 24 inch

Stress value for material:

Tensile stress, St = 90 MPa

Yield stress, Sy = 50 MPa

Quality factor, E = 1

Weld joint strength reduction factor, W = 1

Coefficient, Y = 0.4

Corrosion coefficient, c = 0.5

Based on Equation (2), $\mathrm{t} = \frac{\mathrm{PD}}{2(\mathrm{SEW}+\mathrm{PY})}$

The piping's pressure design thickness, $\mathrm{t} = \frac{840\times24}{2((90)\times1\times1+(840\times0.4))} = 23.66197\mathrm{mm}$

Minimum allowable wall thickness, $\mathrm{t_{min}} = \mathrm{t} + \mathrm{c} = 23.6620 + 0.5 = 24.1620\ \mathrm{mm}$

Initial thickness, 35.61 mm at year 0

Latest thickness reading taken, 26.52 mm at year 11

Time interval between initial thickness reading to the latest thickness reading take = 11 years

Difference from initial thickness, $\Delta\mathrm{t} = 35.61 - 26.52 = 9.09\ \mathrm{mm}$

Corrosion rate, $\mathrm{Corr_t} = \frac{9.09\ \mathrm{mm}}{11\ \mathrm{years}} = 0.8263\ \mathrm{mm/year}$

No. of years needed before replacing the piping, $\mathrm{t_r} = \frac{26.52\ \mathrm{mm}-24.16\mathrm{mm}}{0.8263\,\frac{\mathrm{mm}}{\mathrm{year}}} = 3.46\ \mathrm{years}$