CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

Risk Based Inspection is used to determine what incident could occur (consequence) in the event of an equipment failure, and how likely (probability) is it that the incident could happen. Combining the probability of one or more of these events with its consequences will determine the risk to the operation. Some failure may occur relatively frequently without significant adverse safety, environmental or economic impacts. Similarly, some failures have potentially serious consequences, but if the probability of the incident is low, then the risk may not warrant immediate action. However, if the probability and consequence combination (risk) is high enough to be unacceptable, then a mitigation action to predict or prevent the event is recommended.

Risk Based Inspection produces inspection and maintenance plans for equipment that identify the actions that should be implemented to provide reliable and safe operations. The Risk Based Inspection effort can provide input into an organization's annual planning and budgeting that define the staffing and funds required to maintain equipment operation at acceptable levels of performance and risk. The process will be focusing on maintaining the mechanical integrity of pressure equipment items and minimizing the risk of loss of containment due to deterioration.

1.2 PROBLEM STATEMENT

Risk Based Inspection is an important tool that helps detecting the equipment criticality. It had been successfully conducted on several onshore plants such as Petronas Penapisan Melaka; Central Utility Facilities, Kerteh; Petronas Fertilizer, Kedah; and on more Petrochemical Plants.

Risk Based Implementation is new to the Oil & Gas production industry and now is gaining acceptance by several offshore platform operators. Study on the implementation of Risk Based Inspection on offshore facilities is required to determine the success of the program and its benefits to the operation and integrity of offshore facilities.

1.3 OBJECTIVES

a) To study on Risk Based Inspection concept and methodologies for implementations on offshore facilities

b) To conduct case studies on DUYONG Central Processing Platform and BARONIA Drilling Platform-J

c) To evaluate the success of RBI implementation on offshore facilities and determine the benefits and values generated.

1.4 SCOPE OF STUDY

a) Study on Risk Based Inspection concepts and application on offshore implementation.
b) Familiarization of Offshore Facilities and equipment installations
c) Analyze and understand RBI implementation on DUYONG Central Processing Platform and BARONIA Drilling Platform-J.
d) Conduct RBI analysis based on the API Recommended Practice
e) Evaluate the RBI analysis and implementation to determine the success of the RBI on offshore facilities.

CHAPTER 2

LITERATURE REVIEW

2.1 RISK BASED INSPECTION ON OFFSHORE FACILITIES

2.1.1 Risk Based Inspection

Risk Based Inspection (RBI) is a systematic inspection technique and data analysis of equipment condition to determine the associated risk with its operation. RBI is a multi-disciplinary approach that requires involvement mainly from operations, maintenance, inspection and engineering personnel to provide input on design, materials of construction, operating parameters, inspection data, failure history and etc. RBI involves the planning of an inspection on the basis of the information obtained from risk analysis of the equipment. Risk is the combination of the probability of some event occurring during a time period of interest and the consequences, (generally negative) associated with the event. Risk Based Inspection has capability to do the followings:

a) Evaluate current inspection plans to determine priorities for inspections
b) Evaluate future plans for decision making
c) Evaluate changes to basic operations as they affect equipment integrity
d) Identify critical contributors to risk that may otherwise be overlooked
e) Establish economic optimum levels of inspection as weighed against risk reduction
f) Incorporate “Acceptable Risk” levels [1].

2.1.2 Risk Based Inspection on Mechanical Equipment

The mechanical integrity and functional performance of equipment depends on the suitability of the equipment to operate safely and reliably under the normal and abnormal (upset) operating conditions to which the equipment is exposed. Performing the Risk Based Inspection, the susceptibility of equipment to deterioration by one or more mechanisms such as corrosion, fatigue and cracking is established. The susceptibility of each equipment item should be clearly defined for the current operating conditions including such factors as:

a) Process fluid, contaminants and aggressive components

b) Unit throughput
c) Desired unit run length between scheduled shutdowns
d) Operating conditions, including upset conditions such as pressures, temperatures, flow rates, pressure and/or temperature cycling [1].

2.1.3 Product of Risk Based Inspection

The primary product of a Risk Based Inspection program should be an inspection plan for each equipment item evaluated. The inspection plan should detail the risk related to the current operation. For risks considered unacceptable, the plan should contain the mitigation actions that are recommended to reduce the unmitigated risk to acceptable levels.

For those equipment items where inspection is a cost – effective means of risk management, the plans should describe the type, scope and timing of inspection/examination recommended. Ranking of the equipment by the unmitigated risk level allows users to assign priorities to the various inspection/examination tasks. The level of the unmitigated risk should be used to evaluate the urgency for performing the inspection.

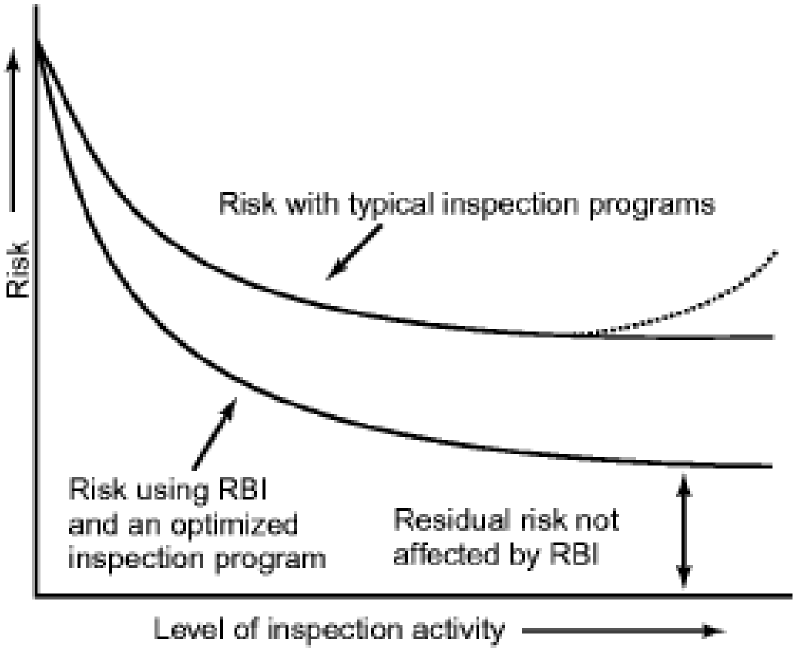


Figure 2.1: Risk Management Using RBI [1]

2.2 LEVELS OF RISK BASED INSPECTION

Various types of RBI assessment may be conducted at three levels. The choice of approach is dependent on multiple variables such as :

a) Objectives of the study
b) Number of facilities and equipment items to study
c) Available resources
d) Study time frame
e) Conplexity of facilities and processes
f) Nature and quality of available data

The RBI procedure can be applied qualitatively, quantitatively or by using aspects of both. Each approach provides a systematic way to screen for risk, identify areas of potential concern, and develops a risk ranking measure to be used for evaluating separately the probability of failure and the potential consequence of failure. These two values are then combined to estimate risk. Use of expert opinion will typically be included in most risk assessments regardless of type or level [1].

2.2.1 Level 1 : Qualitative Approach

This approach requires data inputs on descriptive information using engineering judgement and experience as the basis for the analysis of probability and consequence of failure. Inputs are often given in data ranges instead of discrete values. Results are typically given in qualitative terms such as high, medium and low, although numerical values may be associated with these categories. The value of this type of analysis is that it enables completion of a risk assessment in the absence of detailed qualitative data. The accuracy of results from a qualitative analysis are dependent on the background and expertise of the analysis.

2.2.2 Level 2 : Semi – Quantitative Approach

Semi – quantitative is a term that describes any approach that has aspects derived from both the qualitative and quantitative approaches. Typically most of the data used in a quantitative approach is needed for this approach but in less detail. The models also may not be as rigorous as those used for the quantitative approach. The results are usually given in consequence and probability categories rather than as risk numbers but numerical values may be associated with each category to permit the calculation of risk and the application f appropriate risk acceptance criteria.

2.2.3 Level 3 : Quantitative Approach

Quantitative risk analysis integrates into a uniform methodology the relevant information about facility design, operating practices, operating history, component reliability, human action, the physical progression of accidents, and potential environmental and health effects.

Quantitative risk analysis uses logic models depicting combinations of events that could results in severe accidents and physical models depicting the progression of accidents and the transport of a hazardous material to the environment. The models are evaluated probabilistically to provide both qualitative and quantitative insights about the level of risk and to identify the design, site or operational characteristics that are most important to risk : Quantitative risk analysis is distinguished from the qualitative approach by the analysis depth and integration of detailed assessments.

Quantitative risk analysis logic models generally consist of event trees and fault trees. Event trees delineate initiating events and combinations of system successes and failures, while fault trees depict ways in which the system failures represented in the probability of each accident sequence. Results using this approach are typically presented as risk numbers such as cost per year [1].

2.2.4 Continuum of Approaches

In practice, a Risk Based Inspection study typically uses aspects of qualitative, quantitative and semi – quantitative approaches. These RBI approaches are not considered as competing but rather as complementary. For example, a high level qualitative approach could be used at a unit level to find the unit within a facility that provides the highest risk. System and equipment within the unit then may be screened using a qualitative approach with a more quantitative approach used for the higher risk items. Another example could be to use a qualitative consequence analysis combined with a semi-qualitative consequence analysis combined with semi-quantitative probability analysis.

The three approaches are considered to be continuum with qualitative and quantitative approaches being the extremes of the continuum and everything in between being a semi-quantitative approach.

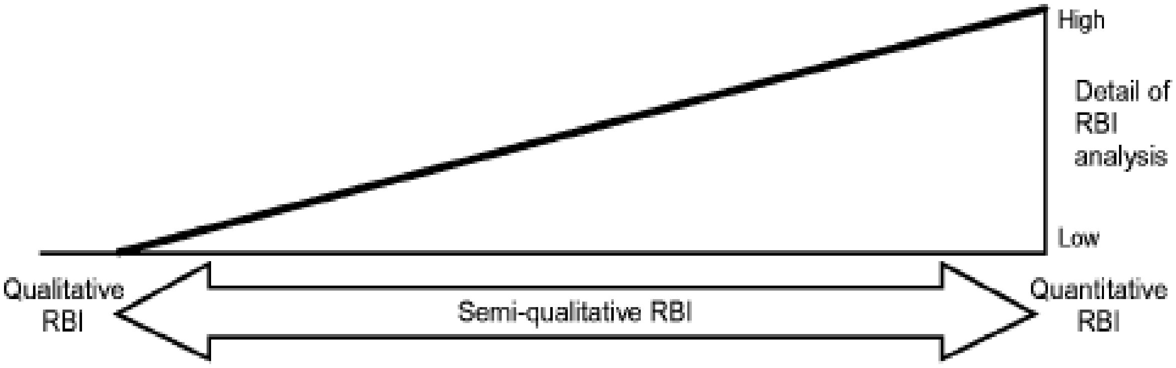


Figure 2.2 : Continuum Of Risk Based Inspection Approaches [1]

2.3 ESTABLISHING OBJECTIVES AND GOALS FOR EACH LEVEL OF RBI

Each level of RBI should be undertaken with clear objectives and goals that are fully understood by all members of the RBI team and by management [9].

2.3.1 Understand Risks

RBI assessment are conducted for better understand the risks involved in the operation of a facilities or a process unit and to understand the effects that inspection, maintenance and mitigation actions have on the risks.

From the understanding of risks, an inspection program may be designed that optimizes the use of inspection and facilities maintenance resources.

2.3.2 Define Risk Criteria

A RBI assessment will determine the risk associated with the items assessed. The RBI team and management may wish to judge whether the individual equipment item and cumulative risks are acceptable. Establishing risk criteria to judge acceptability of risk are important in the RBI assessment if such criteria do not exist already within the user's company.

2.3.3 Management of Risks

When the risks are identified, inspection actions and mitigation that have positive effect in reducing risk to an acceptable level may be undertaken. These actions may be significantly different from the inspection actions undertaken during a statutory or certification type inspection program. The results of managing and reducing risk are improved safety, avoided losses of containment, and avoided commercial losses.

2.3.4 Reduce Costs

Reducing inspection costs is usually not the primary objective of Risk Based Inspection assessment, but it is frequently a side effect of optimization of inspection activity. When the inspection program is optimized based on the understanding of risk, one or more of the following cost reduction may be realized:

a) Ineffective, unnecessary or inappropriate inspection activities may be eliminated
b) Inspection of low risk items may be eliminated or reduced.
c) On-line or non-invasive inspection methods may be substituted for invasive methods that require equipment shutdown
d) More effective infrequent inspection may be substituted for less effective frequent inspections

2.3.5 Meet Safety and Environment Management Requirements

Managing risk by using RBI assessment can be useful in implementing an effective inspection program that meets performance-based safety and environment requirements. RBI focuses efforts on area where the greatest risk exists. RBI provides a systematic method to guide a user in the selection of equipment items to be included and the frequency, scope and extent of inspection activities to be conducted to meet performance objectives.

2.3.6 Sort Mitigation Alternatives

The RBI assessment may identify risks that maybe managed by actions other than inspection. Some of these mitigation actions may include but are not limited to:

a) Modification of the process to eliminate the conditions driving the risk
b) Modifications of operating procedures to avoid situations driving the risk

c) Chemical treatment of the process to reduce deterioration rates
d) Change metallurgy of components to reduce Probability of Failure
e) Removal of unnecessary insulation to reduce probability of corrosion under insulation
f) Reduce inventories to reduce Consequences of Failures
g) Upgrade safety or detection systems
h) Change fluid to less flammable or toxic fluids.

The data within the RBI assessment can be useful in determining the optimum economic strategy to reduce risk. The strategy may be different times in a facilities life cycle. For example, it is usually more economical to modify the process or change metallurgy when a facilities is being designed than when it is operating.

2.3.7 Facilities Life Extension Studies

Facilities approaching the end of their economic or operating service life are a special case where application of RBI can be very useful. The end of life case for facilities operation is about gaining the maximum remaining economic benefit from an asset without undue personnel, environment or financial risk.

Facilities Life Extansion Studies focus the inspection efforts directly on high-risk areas where the inspections will provide a reduction of risk during the remaining life of the plant. Inspection activities that do not impact risk during the remaining life are usually eliminated or reduced.

End of life inspection RBI strategies may be developed in association with a fitness for service assessment of damaged components.

It is important to revisit the RBI assessment if the remaining facilities life is extended after the remaining life strategy has been develop and implemented [9].

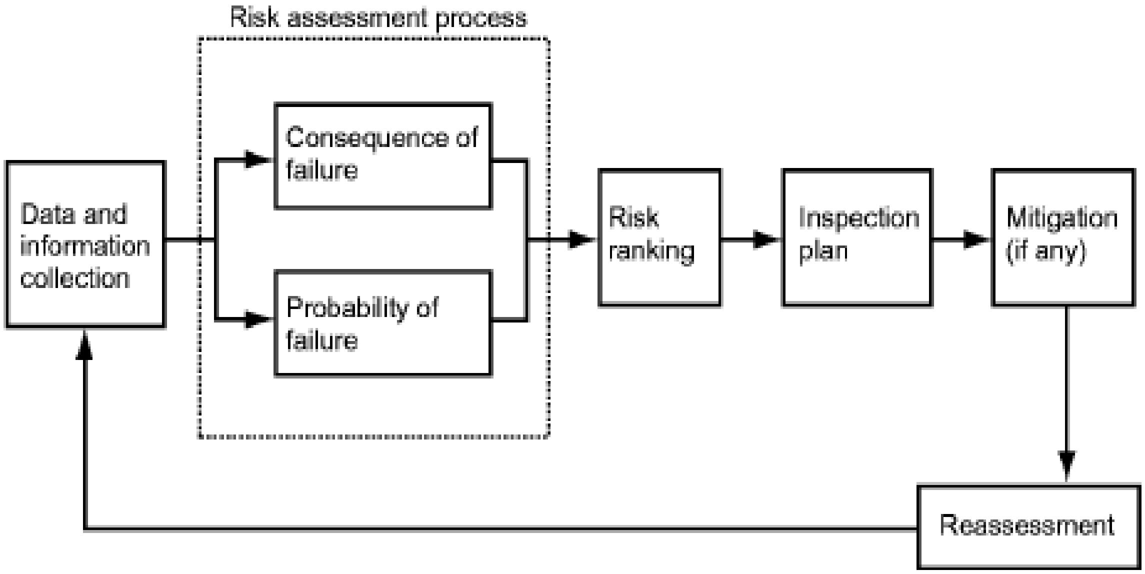


Figure 2.3 : Risk Based Inspection Planning Process [1]

2.4 PROBABILITY OF FAILURE ANALYSIS

The probability of failure analysis is conducted to estimate the probability of occurrence of a given equipment to failure. The probability of failure should address all deterioration mechanisms to which the equipment is susceptible. It also will be used to determine which degradation mechanisms are likely to be found in each component, assess the current probability of failure, and evaluate for the development of the damage.

Probability of failure is usually expressed in terms of frequency. Frequency is expressed as a number of failures occurring during a specific time frame. For analysis, the time frame is typically expressed as a fixed interval (e.g. 1 year, 2 years) and frequency is expressed as failure per specific time frame (e.g. 0.000005).

In conducting Probability of Failure analysis, regardless whether qualitative or quantitative, probability of failure is determined by two main considerations:

1. Deterioration mechanisms and rates of the equipment items resulting from its operating conditions, fluid behavior and environment (internal & external).
2. Effectiveness of the inspection program to identify and monitor the deterioration mechanisms so that the equipment can be repair or replaced prior to failure [2].

2.4.1 Determine the Deterioration Susceptibility and Rate

Combination of process conditions and materials of construction for each equipment item should be evaluated to identify active and credible deterioration mechanisms. One method of determining these mechanisms and susceptibility is to group components that have the same material of construction and are exposed to the internal and external environment. Inspection results from one item in the group can be related to the other equipment in the group.

For many deterioration mechanisms, the rate of deterioration progression is generally understood and can be estimated for offshore equipment. Deterioration rate can be expressed in terms of corrosion rate for thinning or susceptibility for mechanisms where the deterioration rate is unknown or immeasurable (such as stress corrosion cracking). Susceptibility is often designated as high, medium or low based on the environmental conditions and material of construction combination. Fabrication variables and repair history are also important.

The deterioration rate in specific offshore equipment is often not known with certainty. The ability to state the rate of deterioration precisely is affected by equipment complexity, type of deterioration mechanisms, process and metallurgical variations, inaccessibility of inspections, limitations of inspection and test methods and the inspector’s expertise.

The best information will come from operating experiences where the conditions that led to the observed deterioration rate could realistically be expected to occur in the equipment under consideration. Other sources of information could include databases of platform experience or reliance on expert opinion. The latter method is often used since platform databases, where they exist, sometimes do not contain sufficiently detailed information [2].

2.4.2 Determine Failure Mode

Probability of failure is used to evaluate the failure mode such as small hole, crack, catastrophic rupture) and the probability that each failure mode will occur. It is important to link the deterioration mechanisms to the most likely resulting failure mode. For example :

a) Pitting generally leads to small hoe-sized leaks.
b) Stress corrosion cracking can develop into small, through wall cracks or, in some cases, catastrophic rupture.
c) Metallurgical deterioration and mechanical deterioration can lead to failure modes that vary from small holes to rupture
d) General thinning from corrosion often leads to larger leaks or rupture.

Failure mode primarily affects the magnitude of the consequences. For this and other reasons, the probability and consequence analysis should work interactively.

2.4.3 Quantify Effectiveness of Past Inspection Program

Inspection programs vary in their effectiveness for locating and sizing deterioration, and thus for determining rates. After the likely deterioration mechanisms have been identified, the inspection program should be evaluated to determine the effectiveness in finding the identified mechanisms.

Limitations in the effectiveness of an inspection program could due to :

a) Lack of coverage of an area subject to deterioration
b) Inherent limitations of some inspection methods to detect quantify certain types deterioration
c) Selection of inappropriate inspection methods and tools
d) Application of methods and tools by inadequately trained inspection personnel
e) Inadequate inspection procedures

If multiple inspections have been performed, it is important to recognize that the most recent inspection may best reflect current operating conditions. If operating conditions have changed, deterioration rates based on inspection data from the previous operating conditions may not be valid.

Determination of inspection effectiveness should consider the following:

a) Equipment type

b) Active and credible deterioration mechanisms
c) Rate of deterioration or susceptibility
d) NDT methods, coverage and frequency
e) Accessibility to expected deterioration areas

The effectiveness of future inspection can be optimized by utilization of NDT methods better suited for the active/credible deterioration mechanisms, adjusting the inspection coverage, adjusting the inspection frequency or some combination [2].

2.4.4 Calculate the Probability of Failure by Deterioration Type

By combining the expected deterioration mechanisms, rate of susceptibility, inspection data and inspection effectiveness, a probability of failure can now be determined for each deterioration type and failure mode. The probability of failure may be determined for future time periods or conditions as well as current. It is important for users to validate that the methods used to calculate the Probability of Failure is in fact thorough and adequate for the users' need.

2.5 CONSEQUENCE OF FAILURE ANALYSIS

The consequence of failure analysis is conducted to determine the effect of equipments' failure to safety, environment and economic of the facilities. Different types of consequences may be described best different measures. In carrying out RBI analysis, one should consider the nature of the hazards present and select appropriate units of measure. However, the resultant consequences should be comparable for subsequent risk prioritization.

The following are measures of consequence in RBI analysis:

2.5.1 Safety

Safety consequences are often expressed as a numerical value or characterized by a consequence category associated with the severity of potential injuries that may result form an undesirable event.

For example, safety consequence could be expressed based on the severity of an injury (e.g. fatality, serious injury, medical treatment, first aid) or expressed as a category linked to the injury severity.

2.5.2 Cost

Cost is commonly used as an indicator of potential consequences. It is possible, although not always credible, to assign costs to almost any type of consequence. Typical consequences that can be expressed in ‘cost’ include:

a) Production loss due to reduction or downtime
b) Deployment of emergency response equipment and personnel
c) Lost product from a release
d) Degradation of product quality
e) Replacement or repair of damaged equipment
f) Spill/release cleanup onsite and offsite
g) Business interruption costs (lost profits)
h) Injuries or fatalities
i) Fines

The above list reasonably comprehensive, but in practice some o these costs are neither practical nor necessary to use in a RBI assessment.

Cost generally requires fairly detailed information to fully assess. Information such as product value, equipment costs, repair costs, personnel resources, and environmental damage may be difficult to derive, and the manpower required to perform a complete financial-based consequence analysis may be limited. However, cost has the advantage of permitting a direct comparison of various types of losses on a common basis [2].

2.5.3 Affected Area

Affected area represents the amount of surface area that experiences an effect (toxic dose, thermal radiation, explosion, etc) greater than pre-defined limiting value. Based on the threshold chosen, personal; equipment; environment; within the area will be affected by the consequence of the hazard.

In order to rank consequences according to affected area, it is typically assumed that equipment or personnel at risk are evenly distributed throughout the unit. A more rigorous approach would assign a population density with time or equipment value density to different areas of the unit.

The affected area approach has the characteristic of being able to compare toxic and flammable consequences by relating to the physical area impacted by a release.

2.6 CONSEQUENCE EFFECT CATEGORY

The failure of the pressure boundary and subsequent release of fluids may cause safety, health, environmental, facility and business damage.

Regardless of whether a more qualitative or quantitative analysis is used, the major factors to consider in evaluating the consequences of failure are as follows:

2.6.1 Flammable Events

Flammable events occur when both a leak and ignition occurs. The ignition could be through an ignition source or auto-ignition. Flammable events can cause damage in two ways: thermal radiation and blast overpressure. Most of the damage from thermal effects tends to occur at close range, but blast effects can cause damage over a large distance from the blast center.

The flammable events consequence is typically derived from a combination of the following elements:

a) Inherent tendency to ignite
b) Volume of fluid released
c) Ability to flash to a vapor
d) Possibility of auto-ignition
e) Effect of high pressure or temperature operations [2].

2.6.2 Toxic Release

Toxic releases are only addressed when they affect personnel. These releases can cause effects at greater distances than flammable events. Unlike flammable releases, toxic releases do not require an additional event (e.g. ignition) to cause personnel injuries. RBI typically focuses on acute toxic risks that create an immediate danger, rather than chronic risks from low-level exposures.

The toxic consequence is typically derived from the following elements:

a) Volume of fluid released and toxicity
b) Ability to disperse under typical process and environmental conditions
c) Detection and mitigation systems
d) Population in the vicinity of the release

2.6.3 Releases of Other Hazardous Fluid

Other hazardous fluid releases are of most concern in RBI analysis when they affect personnel. These materials can cause thermal or chemical burns if a person comes in contact with them. Common fluids, including steam, hot water, acids and caustics can have a safety consequence of a release. Generally, the consequence of this type of release is significantly lower than for flammable or toxic releases because the affected area is likely to be much smaller and the magnitude of the hazard is less. Key parameters in this evaluation are:

a) Volume of fluid released
b) Personnel density in the area
c) Type of fluid and nature of resulting injury
d) Safety systems

2.6.4 Production Consequence

Production consequences generally occur with any loss of containment of the process fluid such as utility fluid (e.g. water, steam, fuel gas, acid, caustic, etc). These production consequences may be in addition to or independent of flammable, toxic, and hazardous consequences. It is considered in terms of financial.

The financial consequences could include the value of the lost process fluid and business interruption. The cost of the lost fluid can be calculated fairly easy by multiplying the volume released by the value. Calculation of the business interruptions is more complex.

A simple method for estimating the business interruption consequence is to use the equation:

$$\text{Business Interruption} = \text{Process Unit Daily Value} \times \text{Downtime (days)}$$

The unit daily value could be on the profit basis. The downtime estimate would represent the time required to get back into production.

2.6.5 Repair, Maintenance and Reconstruction Impact

Repair, maintenance and reconstruction impact represents the effort required to correct the failure and to fix or replace equipment damaged in the subsequent events (e.g. fire, explosion). It should be accounted for in conducting RBI analysis. Repair, maintenance and reconstruction will generally be measured in monetary terms [2].

2.7 RISK CALCULATION/ESTIMATION

Risk equation:

$$\text{Risk} = \text{Probability} \times \text{Consequences}$$

It is now possible to calculate the risk for each specific consequence. The risk equation can now be stated as :

$$\text{Risk of a specific consequence} = (\text{Probability of a specific consequence}) \times (\text{Specific Consequence})$$

The total risk is the sum of the individual risks for each specific consequence. Often one probability/consequence pair will be dominant and the total risk can be approximated b the risk of the dominant scenario.

If probability and consequence are not expressed as numerical values, risk is usually determined by plotting the probability and consequence on a risk matrix. Probability and consequence pairs for various scenario may be plotted to determine risk of each scenario. Note that when a risk matrix is used, the probability to be plotted should be the probability of the associated consequence, not the probability of failure [1].

2.8 HOW RISK BEING PRESENTED

Once risk values are developed, they are presented in such way to communicate the results of the analysis to decision-making and inspection planning. One goal of the risk analysis is to communicate the results in a common format that a variety of people can understand. Using a risk matrix is helpful in accomplishing this goal.

2.8.1 Risk Matrix

Risk ranking methodology uses consequence and probability categories. Presenting the results in a risk matrix is a very effective way of communicating the distribution of risks throughout a plant or process unit without numerical values. As shown in Figure 2.4, the consequence and probability categories are arranged such that the highest risk ranking is toward the upper right hand corner. It is usually desirable to associate numerical values with the categories to provide guidance to the personnel performing the assessment. Different sizes of matrices may be used. Regardless of the matrix selected, the consequence and probability categories should provide sufficient discrimination between the items assessed.

Risk categories may be assigned to the boxes on the risk matrix. An example of risk categorization is shown in Figure 2.4. The risk categories are symmetrical. They may also be asymmetrical where for instance the consequence category may be given higher weighting than the probability category.

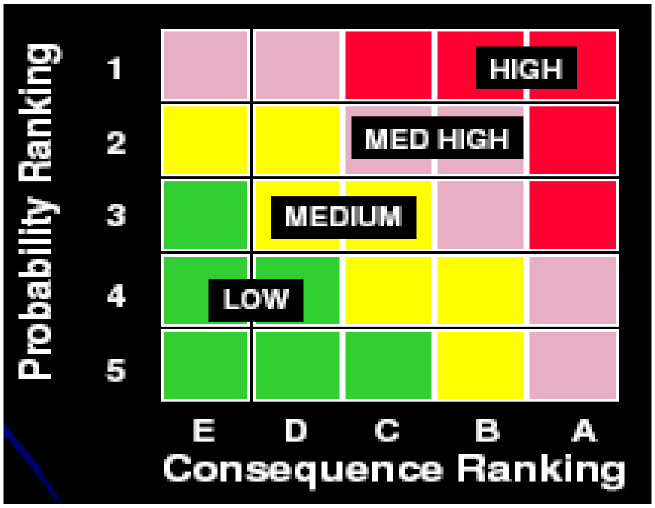


Figure 2.4: Risk Matrix [18]

2.9 CASE STUDY 1: RISK BASED INSPECTION ON DUYONG CENTRAL PROCESSING PLATFORM

2.9.1 DUYONG FACILITIES BRIEF DESCRIPTION

The Duyong gas field is located offshore, approximately 220 km (136 mi) east of peninsular Malaysia. The first gas from the field was produced in 1984. The complex comprises three wellhead platforms (DDP A, DDP-B, and DDP-C), a central processing platform (CPP), a gas-compression platform (GCP), a flare tripod (FT), and a living-quarters platform (LQP).

The platforms that make up the main complex—the LQP, CPP, GCP, and DDP-B platform—are connected by a bridge. The FT is located north of the CPP and is connected by a bridge to the CPP. DDP-A and DDP-C are remote to the CPP complex. Each wellhead platform has nine well slots. Four wells were completed on DDP-A, six wells on DDP-C, and six wells on DDP-B. The fluids from the wells are piped to the CPP. Separation of gas condensate and produced water, dehydration of the gas, and metering and disposal of the produced water take place at the CPP. Gas is then piped to shore through the peninsular Malaysia gas system.

Each wellhead platform is designed to produce 2.80 X 10-6 Sm^3/day of gas and 330 Sm^3/day of liquid. The produced fluids, comprising gas, condensate and produced water from WPA and WPC are routed to the CPP via two separate 5.6 km and 5-km 14-inch multiphase subseas pipelines respectively. The production from WPB is routed to CPP via a 10-inch production flowline alongside a 30 meter bridge connecting the two platforms.

The CPP, which forms the central hub of the Duyong Gas Field Complex, is designed to receive and treat 7.0 X 10-6 Sm^3/day of gas and 1250 Sm^3/day of condensate from the wellhead platforms. Three production trains on the CPP ensure continuous production to the OGT [10].

2.9.2 INTRODUCTION TO RBI ON DUYONG CPP

Petronas CARIGALI Sdn. Bhd. has commissioned Petronas Research and Scientific Service Sdn. Bhd. (PRSS) to perform the RBI for their Duyong Central Processing Platform (Duyong-CPP) which belongs to PM12 Asset. The scope of work for RBI study includes Risk Ranking and Initial Assessment of pressure vessels and piping on Duyong-CPP platform.

Risk Based Inspection (RBI) used to effectively manage risk in a system by focusing inspection on high-risk items in Duyong CPP. It optimizes inspection and maintenance efforts by balancing inspection costs with inspection benefits. The main objective of the project is to improve long-term production regularity, to increase personnel safety and to optimize inspection and maintenance cost.

2.9.3 RBI ASSESSMENT METHODOLOGY

The CARIGALI RBI method for topsides uses a three-stage analysis process, namely Risk Ranking, Initial Assessment and Detailed Assessment. The method facilitates the development of an inspection/monitoring plan that is designed to manage the risks associated with loss of containment of topside pressurized equipment and piping, such that CARIGALI acceptable risks limits are not exceeded.

2.9.3.1 Risk Acceptance Limits

Risk Acceptance Limits have been defined by CARIGALI for the safety risk and economic risk as stipulated in CARIGALI Manual for Offshore Mechanical and Piping and were serve in accordance with:

a) Safety Acceptance Risk Limit is given as a PLL of 10^-6 per part per year
b) Economic Acceptance Limit is given as an economic loss of RM10,000 per part per year

2.9.3.2 Risk Ranking (Level 1)

Risk Ranking was performed on a system level qualitatively to determine which system should be addressed in the Initial Assessment and Preliminary Inspection Reference Plan (PIRP). The Risk Ranking process separated the high risk systems for which inspection activities are relevant to equipment, from the low risks systems for inspection has little value. The systems that have significant risk are subject to Initial Assessment. Reducing the number of systems by screening focuses data collection, analysis and inspection effort where these will have a significant effect in the risk management for the installation. The process and results of the Risk Ranking are reported in CARIGALI Risk Ranking Report.

2.9.3.3 Initial Assessment (Level 2)

The initial assessment addresses the individual parts in the systems identified as high risk in the Risk Ranking process. Operating conditions and part geometries are used to identify degradation mechanisms that can occur on the part. A quantitative Probability of Failure (PoF) is determined for each degradation mechanism. The simplified Quantitative Risk Assessment (QRA) model built in the ORBIT Offshore is used for Consequence of Failure (CoF) analysis. The safety and economic risk are calculated for each degradation mechanism.

The output indicates a time to inspection based on calculation of the risk of failure for each tag as a function of time until that risk exceeds defined acceptance criteria limits. The software indicated the expected degradation mechanism, and can assign inspection method on the basis that the maximum risk reduction is obtained with a minimum cost of inspection. Some parts that have an immediate unacceptable risk, or are expected to become unacceptable in the shot term, shall be subjected to Detailed Assessment [10].

RISK MATRIX

Table 2.1: Risk Category

Probability of Failure			***Risk Category***				
$>10^{-2}$	Very High	**5**	>100	>1000	>10000	>100000	>1000K
$>10^{-3}$-$<10^{-2}$	High	**4**	>10	>100	>1000	>10000	>100000
$>10^{-4}$-$<10^{-3}$	Medium	**3**	>1	>10	>100	>1000	>10000
$>10\text{-}^{5}$-$<10^{-4}$	Low	**2**	>0.1	>1	>10	>100	>1000
$<10^{-5}$	Very Low	**1**	<0.1	>0.1	>1	>10	>100
Consequence of Failure			**A**	**B**	**C**	**D**	**E**
(RM)			$<10^{5}$	$>10^{5}$-$<10^{6}$	$>10^{6}$-$<10^{7}$	$>10^{7}$-$<10^{8}$	$>10^{8}$

🟫	Very High	🟥	High	🟪	Medium	🟨	Low	🟩	Very Low

2.9.4 SYSTEM & EQUIPMENT DESIGNATED FOR RBI ASSESSMENT

2.10.4.1 System Designated for RBI Assessment

Table 2.2: System Designated for Initial Assessment

System Code	Description	Service Code
04	Process Liquid System (L)	L,PL
10	Process Gas System	G,PG,DC
11	Process System (Multiphase-P)	P
13	Glycol System	GL
14	Fuel Gas System	FG
15	Diesel Fuel System	DF
18	Instrument/Utility Air System	AI,AU
23	HP/LP Flare System	F
62	Blowdown/Relief System	B,BD,R
64	Closed Drain, Pressurised Drain System	DC,DP

2.9.4.2 Equipment Designated for RBI Assessment

Table 2.3: Equipment Designated for Initial Assessment

No.	Equipment Name
1	D1670 Instrument Air Dryer
2	D1671 Instrument Air Dryer
3	D1675 Instrument Air Dryer
4	D1676 Instrument Air Dryer
5	E1170Glycol Cooler ’A’
6	E1190Glycol Cooler ’B’
7	E1210Glycol Cooler ’C’
8	E1250Glycol Reboiler
9	E1260Glycol Surge Tank & Exchanger
10	E1270Glycol Preheat Exchanger
11	E1320Glycol Reboiler
12	E1330Glycol Surge Tank & Exchanger
13	E1340Glycol Preheat Exchanger
14	E1390Glycol Reboiler
15	E1400Glycol Surge Tank & Exchanger
16	E1410Glycol Preheat Exchanger
17	E1812 Fuel Gas Heater
18	E1815 Fuel Gas Heater
19	E1912 Fuel Gas Heater
20	E1915 Fuel Gas Heater
21	E2750 Gas/Gas Exchanger (West Natuna Gas)
22	F1220 Glycol Carbon Filter
23	F1225 Glycol Carbon Filter

Table 2.3: Equipment Designated for Initial Assessment...(cont’d)

No.	Equipment Name
24	F1240 Glycol Particulate Filter
25	F1245 Glycol Particulate Filter
26	F1290 Glycol Carbon Filter
27	F1295 Glycol Carbon Filter
28	F1310 Glycol Particulate Filter
29	F1315 Glycol Particulate Filter
30	F1360 Glycol Carbon Filter
31	F1365 Glycol Carbon Filter
32	F1380 Glycol Particulate Filter
33	F1385 Glycol Particulate Filter
34	F1650 Pre Filter
35	F1660 Pre Filter
36	F1680 After Filter
37	F1685 After Filter
38	F1820 Fuel Gas Filter/Separator
39	F1825 Fuel Gas Filter/Separator
40	F1885 Glycol Filter
41	F1891 Glycol Filter
42	F1892 Glycol Filter
43	L1530 sales Gas and Condensate Launcher SCP-A
44	R-2910 Pulai Gas Receiver
45	R-2950 Natuna Gas Receiver
46	R1000 Sphere Receiver ‘A’
47	R1010 Sphere Receiver ‘C’
48	SC1250 Stripping Column for Glycol Regeneration
49	SC1320 Stripping Column for Glycol Regeneration
50	SC1390 Stripping Column for Glycol Regeneration
51	SDV1000 Air Accumulator
52	SDV1010 Air Accumulator
53	SDV1530(A) Air Accumulator
54	SDV1530(B) Air Accumulator
55	ST1250 Still Column for Glycol Regeneration
56	T1890 Glycol Storage Tank
57	V1030 Slug Catcher ‘A’
58	V1040 Low Pressure Slug Catcher
59	V1050 Slug Catcher ‘C’
60	V1060 Production Separator ‘A’
61	V1070 Production Separator ‘B’
62	V1080 Production Separator ‘C’
63	V1090 Condensate Flash Tank
64	V1100 Coalescer
65	V1110 Coalescer

Table 2.3: Equipment Designated for Initial Assessment...(cont’d)

No.	Equipment Name
66	V1130 Oil Skimmer
67	V1160 Glycol Contactor ‘A’
68	V1160 Glycol Contactor ‘B’
69	V1160 Glycol Contactor ‘C’
70	V1230 Glycol Flash Separator
71	V1265 Fuel Gas Scrubber
72	V1330 Glycol Flash Separator
73	V1335 Fuel Gas Scrubber
74	V1370 Glycol Flash Separator
75	V1405 Fuel Gas Scrubber
76	V1460 H.P. Flare Knock Out Drum
77	V1465 L.P. Flare Knock Out Drum
78	V1640 Utility Air Receiver
79	V1690 Instrument Air Receiver
80	V1910 Fuel Gas Scrubber
81	V2050A Gas Filter (Natuna)
82	V2050B Gas Filter (Natuna)

2.9.5 RBI ASSESSMENT RESULTS

The Risk Ranking was calculated using the ORBIT Offshore and had been agreed by the members of the RBI Project Team. There are a total of 82 equipment scattered in the Risk Matrix based on their level of criticality.

2.9.5.1 Risk in Current Year of Assessment (2002)

Risk Matrix for Equipment

Table 2.4: Risk Matrix for Equipment

Probability of Failure			***Risk Category***				
$>10^{-2}$	Very High	**5**	0	0	22	14	22
$>10^{-3}$-$<10^{-2}$	High	**4**	0	0	7	0	0
$>10^{-4}$-$<10^{-3}$	Medium	**3**	0	0	0	0	0
>10-^{5}-$<10^{-4}$	Low	**2**	1	0	0	0	0
$<10^{-5}$	Very Low	**1**	2	0	14	0	0
Consequence of Failure			**A**	**B**	**C**	**D**	**E**
(RM)			$<10^{5}$	$>10^{5}$-$<10^{6}$	$>10^{6}$-$<10^{7}$	$>10^{7}$-$<10^{8}$	$>10^{8}$

🟫	Very High	🟥	High	🟪	Medium	🟨	Low	🟩	Very Low

From the Risk Matrix, the total and percentage of the equipment according to their Risk Category can be concluded as:

Risk Category	**Total**	**Percentage**
Very High	22	27%
High	36	44%
Medium	7	9%
Low	14	17%
Very Low	3	4%
Total	**82**	**100%**

2.9.5.2 Risk Acceptance Limits for Equipment

The Risk Acceptance Limit is determined from the medium risk category until very high risk category.

Refer to Appendix 2A for the result of Risk Acceptance Limits for the equipment. The result shows out of a total of 82 equipment items. 65 equipment items exceed the Risk Acceptance Limit, either economically, safety or both.

2.9.5.3 Inspection Reference Plan for Equipment

The inspection time is given as a number in years starting from year 2002 (year 2002 is 0). E.g. 0.2 years means 2.4 months into year 2002. Likewise 4.0 years means the 2006.

Furthermore an inspection task and a time to inspection are suggested. Note that only continuous rate modules are subject to inspection, thus inspection tasks are suggested for rate models only. Hence where no inspection task is suggested in the systems summary, the corresponding mechanism is ‘not inspectable’, and is either above or below the CARIGALI accepted limit. In some cases, inspection methods are also suggested for susceptibility mechanisms. These are intended to detect damage but not to monitor development of damage over time, i.e. if damage is detected it should be sized, repair if necessary, and conditions causing damage shall be removed and permanent effective corrosion mitigation plan shall be implemented.

2.9.5.4 Risk Prospects

ORBIT Offshore estimates the risk per part of equipment and piping, based on the on dimensions materials and present operating conditions. This results in a summary of the Current Risk status (i.e. year 2002). In order to assess the expected development, risks are recalculated a few years hence, typically 5 years (i.e. 2007). This illustrates how risks are expected to increase if no controlling action is taken (i.e. inspection and maintenance). A good inspection plan should ensure that risks do not become unacceptable, and ORBIT offshore produces an inspection plan that aims to control this risk development. To illustrate the expected effect of the inspection plan, ORBIT Offshore recalculates the risks for a few years hence as if the inspection plan has been implemented.

Table 2.5: Risk Prospect for Year2007

Probability Of Failure	***Consequence of Failure***					
	A	**B**	**C**	**D**	**E**	**Total**
5	0	0	13	3	14	**17**
4	0	0	0	4	0	**4**
3	0	0	0	16	10	**26**
2	0	8	10	0	0	**41**
1	1	0	0	0	3	**4**
Total	**1**	**18**	**10**	**36**	**27**	**82**

Risk Category	**Total**	**Percentage**
Very High	14	18%
High	17	21%
Medium	22	26%
Low	28	34%
Very Low	1	1%
Total	**82**	**100%**

2.10 CASE STUDY 2: RISK BASED INSPECTION ON BARONIA DRILLING PLATFORM-J (BNDP-J)

2.10.1 BNDP-J FACILITIES OVERVIEW

2.10.1.1 BNDP-J Process Description

The BNDP-J platform is located some 30km offshore Miri in a water depth of 30m. The facilities were commissioned in 1990 and the platform produces and supplies crude oil and associated gas to production platform BND-B via a link bridge. It consists of 5 oil producing wells, 2 gas injection wells and 2 water injection wells.

Currently, the average daily production output from BNDP-J was 7000 bbl/day of crude and gas output is 24 MMscfd [17].

2.10.1.2 Production System

Hydrocarbon fluid (oil/gas/water) from wellhead B59 were routed through this system and branched off to three separate headers i.e. test header, HP header and LP header (carbon steel). The corrosion damage mechanisms were similar as the acid gas contents remains the same at various partial pressures. The operating pressure and temperature as 1720 kPa and 54 deg C respectively. The maximum corrosion rate anticipated is 0.13 mm/yr. General corrosion was the most common type of corrosion. The external corrosion rate was expected to be 0.01mm/yr which common for carbon steel in offshore condition.

2.10.1.3 HP Line Gaslift Line

Gaslift gas (wet gas) for the wells was distributed by the gaslift distribution header which was taken from BNP-B. The gaslift is supported by backup supply from BNG-B. The acid gas (CO_2) is the main corrosion species with damage mechanism in general corrosion forms. The operating pressure and temperature is 6210kPa and 54 deg C respectively. The expected corrosion rate is in range of 0.12 to 0.28mm/yr. The material is normal carbon steel with expected external corrosion rate of 0.01 mm/yr.

2.10.1.4 LP Line Gas Injection Line

The high pressure hydrocarbon fluid from BNG-B is supply as gas injection into wellhead BN-47/48 through gas injection header (dry gas). The acid gas content (CO_2) is low i.e. 0.23 mol%. The operating pressure and temperature is 20700 kPa and 50 deg C respectively. Therefore, a general corrosion rate of 0.12 mm/yr was used for the internal of carbon steel material used.

2.10.1.5 Fuel/Power Gas System Water Injection Line

Treated seawater from BNG-B5 was used for water injection system. There are no data available from the water quality. Generic dissolved oxygen content is assumed for the system at 10ppb. The operating pressure and temperature is 17240 kPa and 30 deg C respectively. Therefore, a general corrosion rate of 0.28mm/yr was used for the internal of carbon steel material used.

2.10.1.6 Vent System

The venting on the platform gathered gas vented from the equipment and piping through the respective relief headers. The gas was transferred to BNP-B via vent header at BNDP-J. The operating pressure and temperature is 200kPa and 30 deg C respectively. A general corrosion rate of 1.3893 mm/yr was used for the internal of carbon steel material used.

2.10.1.7 Utilities System

The instrument air for BNDP-J is supplied from the instrument air compressors located on BNG-G. The system (carbon steel) is also connected to the BNDP-B, BNP-B and BN-14 system which can be used to provide a back-up supply to active the instrument. The operating pressure ad temperature is 690 kPa and 25 deg C respectively. A general corrosion rate of 0.05 mm/yr was used utility air and 0.0372mm/yr was used for instrument air [17].

2.10.2 INTRODUCTION TO RBI ON BNDP-J

PETRONAS Research & Scientific Services Sdn. Bhd. (PRSS) was engaged by PETRONAS Carigali Sdn. Bhd., Sarawak Operations (PCSB-SKO) to provide a PETRONAS Risk Based Inspection Assessment (P-RBI) for fixed equipment and piping in BNDP-J, PCSB-SKO, Malaysia. The platform was in stalled in 1990 and a total of 2 fixed equipments and 13 piping circuits were evaluated in the study.

In general, the purpose of the study was to focus the platform inspection program toward the higher risk equipment components, reducing the overall plant risk of catastrophic failure while simultaneously providing significant reduction in cost of ongoing inspection process.

In this project, the scope of work included developing inspection plans for all static equipment and piping based on P-RBI technology. Consequently, it will optimize the existing inspection programme and eliminate unnecessary inspection tasks and locations. Upon completion of the study, PRSS will deliver to PCSB-SKO a complete system that includes RBI software and inspection database (P-RBI) for a continuous and dynamic risk monitoring of the platform.

The key objectives of the P-RBI on BNDP-J are as follows:

a) To assess and analyze the risk profile for PCSB-SKO plant through the application of API 580 & API 581 Risk Based Inspection methodology by using PETRONAS Risk Based Inspection software.
b) To prioritize and propose inspection guidance plan for the static equipment and piping.
c) To focus on the plant inspection program toward the higher risk equipment components, reducing the overall plant risk of a catastrophic failure while simultaneous providing significant reduction in cost of ongoing inspection process.
d) To provide an integrated Inspection Database to capture day-to-day inspection and corrosion monitoring
e) With P-RBI implementation, PETRONAS group will benefit in term of experience sharing, benchmarking and consistency in P-RBI implementation.

2.10.3 SCOPE OF WORK

This project scope of work covered all 2 pressure vessels and associated piping, grouped into 13 piping circuits, for BNDP-J platform, PCSB-SKO. The scope included developing inspection plans for all static equipments and piping based on P-RBI methodology. The project included recommendations for inspection plans that will optimize the existing inspection programme and eliminate unnecessary inspection tasks and locations. Upon completion of the study, PRSS would deliver to PCSB-SKO a complete system that includes RBI software and inspection database (P-RBI) for a continuous and dynamic risk monitoring of the platform.

2.10.4 PROCESS UNITS/SYSTEMS

For ease of handling and managing the equipment and piping data within the software, the piping had been grouped into various piping circuits. Piping circuits were defined as sections of continuous piping exposed to an environment of similar interval corrosivity, similar operating conditions and similar materials of construction.

2.10.5 LIST OF EQUIPMENT AND PIPING CIRCUIT

Equipment included in the study

Table 2.6: List of Equipments in BNDP-J

No.	Equipment ID	Equipment Component
1	V-800	Pressure Vessel
2	V-0001	Pressure Vessel

Piping Circuits included in the study

Table 2.7: List of Piping Circuits in BNDP-J

No	Circuit ID	Circuit Description
1	BNDP-J-01A	Wellheads to V-800
2	BNDP-J-02A	HP Header to BNP-B
3	BNDP-J-03A	LP Header to BNP-B
4	BNDP-J-04A	V-800 to LP/HP Headers
5	BNDP-J-05A	V-800 to LP/HP Headers
6	BNDP-J-06A	BNP-B/BNG-B to Wellheads
7	BNDP-J-07A	BNG-B5 to Wellheads
8	BNDP-J-08A	BNG-B to Wellheads
9	BNDP-J-09A	Vent Lines to Vent Header
10	BNDP-J-10A	Utility Air (BNG-B) to Sump Pump
11	BNDP-J-11A	Various Lines to T-700/701

Table 2.7: List of Piping Circuits in BNDP-J...(cont'd)

No	Circuit ID	Circuit Description
12	BNDP-J-11B	T-700/701 to P-701
13	BNDP-J-11C	P-701 to BNP-B

2.10.6 RBI RESULT ON BNDP-J

The overall risk ratings distribution for all analyzed equipment and piping items in BNDP-J is summarizes in Table 2.8:

Table 2.8: Risk Rating Distribution for BNDP-J

Equipment Type	Count	Equipment Components	Overall Risk Category			
			High	**M-H**	**Med**	**Low**
Pressure Vessel	2	2	0	1	1	0
Piping Circuit	13	13	1	0	6	6
Total	**15**	**15**	**1**	**1**	**7**	**6**

Out of 2 fixed equipment items and 13 piping circuits, one item in "High" and "Medium High" risk Category respectively, 7 items are in the "Medium" Risk category, and 6 items are in the "Low" Risk category.

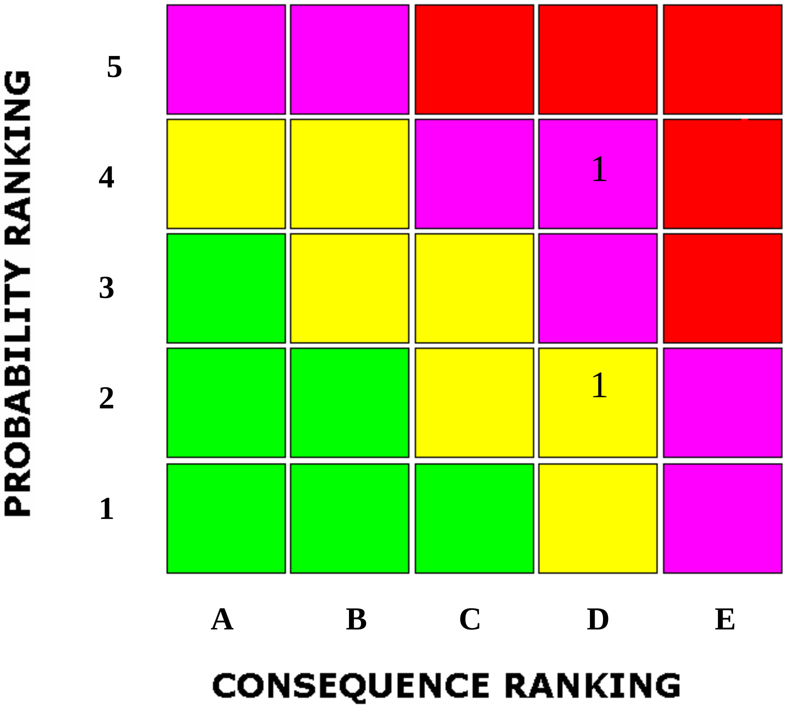
The component in "High" Risk category is th piping circuit BNDP-J-09A. This is attributed to one or more of the following reasons:

a) Piping containing flammable hydrocarbon leading to significant flammable consequence.

b) No inspection had been done on the piping throughout the 14 years service that leading to high probability of failure.

c) The internal corrosion rate used in the analysis was adopted from previous BNDP-J RBI Study, i.e. 1.3989 mm/yr.

Figure 2.5 below presents the risk matrices for equipment components

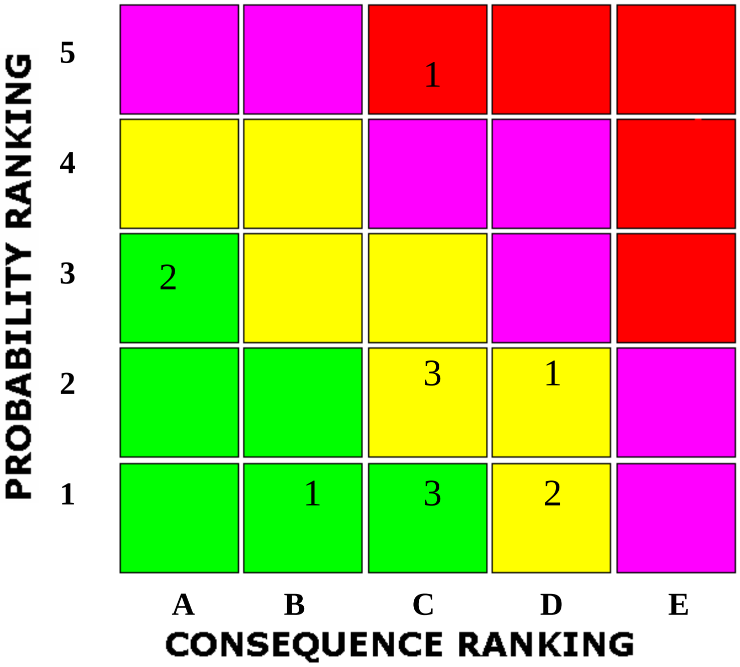


PROBABILITY RANKING	A	B	C	D	E
5	🟪	🟪	🟥	🟥	🟥
4	🟨	🟨	🟪	🟪 1	🟥
3	🟩	🟨	🟨	🟪	🟥
2	🟩	🟩	🟨	🟨 1	🟪
1	🟩	🟩	🟩	🟨	🟪

CONSEQUENCE RANKING

Figure 2.5: Risk Matrix for Equipment Components in 2005

Figure 2.6 below presents the risk category for piping circuits



PROBABILITY RANKING	A	B	C	D	E
5	🟪	🟪	🟥 1	🟥	🟥
4	🟨	🟨	🟪	🟪	🟥
3	🟩 2	🟨	🟨	🟪	🟥
2	🟩	🟩	🟨 3	🟨 1	🟪
1	🟩	🟩 1	🟩 3	🟨 2	🟪

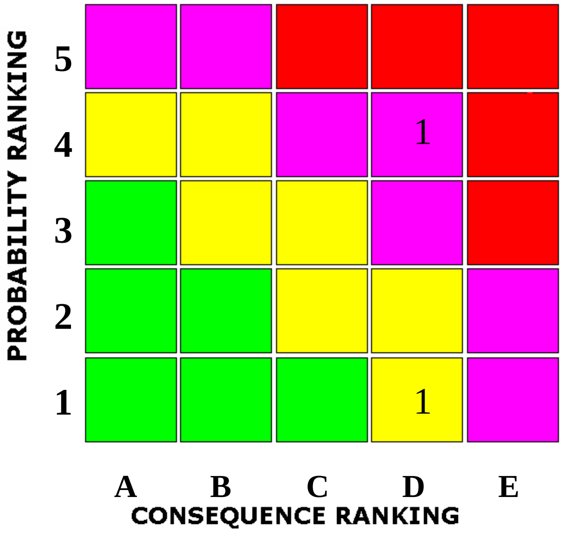
CONSEQUENCE RANKING

Figure 2.6: Risk Matrix for Piping Circuits in 2005

2.10.6.1 Risk Prospects

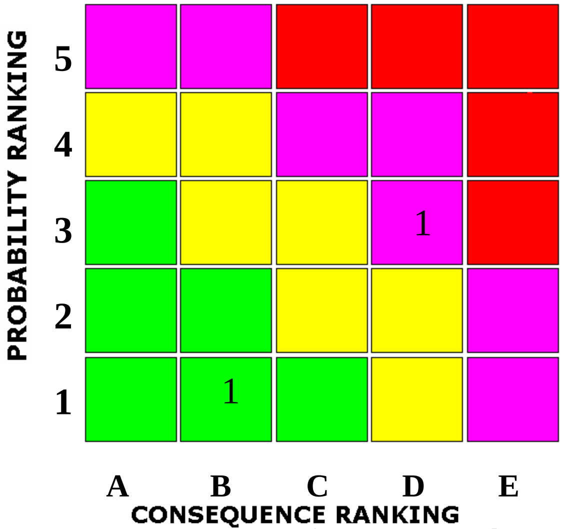
P-RBI estimates the risk of equipment components and piping circuits, based on dimensions materials and present operating conditions. This results in the summary of the Current Risk status (i.e. year 2005). In order to assess the expected development, risks are recalculated a few years hence, typically 5 years (i.e. year 2010). This illustrates how risks are expected to increase if no controlling action is taken (i.e. inspection maintenance). Figures below show the combined risk prospects for equipment and piping, respectively, for year 2005 and 2010.

Year 2005



Risk Category	*Total*	*%*
High	0	0
Med-High	1	50
Medium	1	50
Low	0	0
Total	**2**	**100**

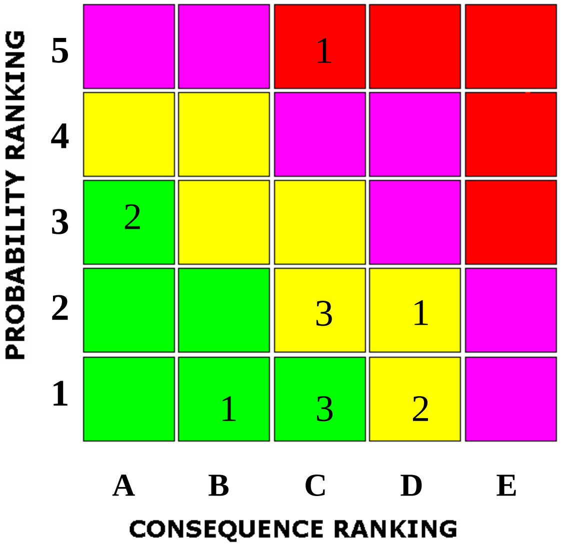
Year 2010 (Analyzed Year)



Risk Category	*Total*	*%*
High	0	0
Med-High	1	50
Medium	1	50
Low	0	0
Total	**2**	**100**

Figure 2.7: Risk Prospects for equipment component

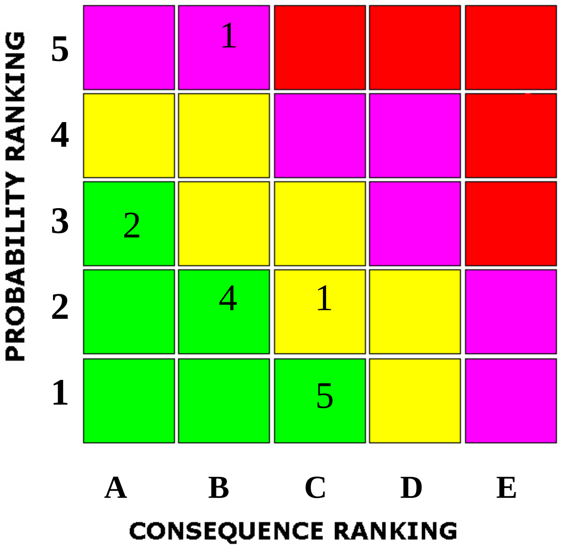
Year 2005



	A	B	C	D	E
5	🟪	🟪	🟥 1	🟥	🟥
4	🟨	🟨	🟪	🟪	🟥
3	🟩 2	🟨	🟨	🟪	🟥
2	🟩	🟩	🟨 3	🟨 1	🟪
1	🟩	🟩 1	🟩 3	🟨 2	🟪

Risk Category	*Total*	*%*
High	1	8
Med-High	0	0
Medium	6	46
Low	6	46
Total	**13**	**100**

Year 2010 (Analyzed Year)



	A	B	C	D	E
5	🟪	🟪 1	🟥	🟥	🟥
4	🟨	🟨	🟪	🟪	🟥
3	🟩 2	🟨	🟨	🟪	🟥
2	🟩	🟩 4	🟨 1	🟨	🟪
1	🟩	🟩	🟩 5	🟨	🟪

Risk Category	*Total*	*%*
High	1	8
Med-High	0	0
Medium	12	92
Low	0	0
Total	**13**	**100**

Figure 2.8: Risk Prospects for Piping Circuits

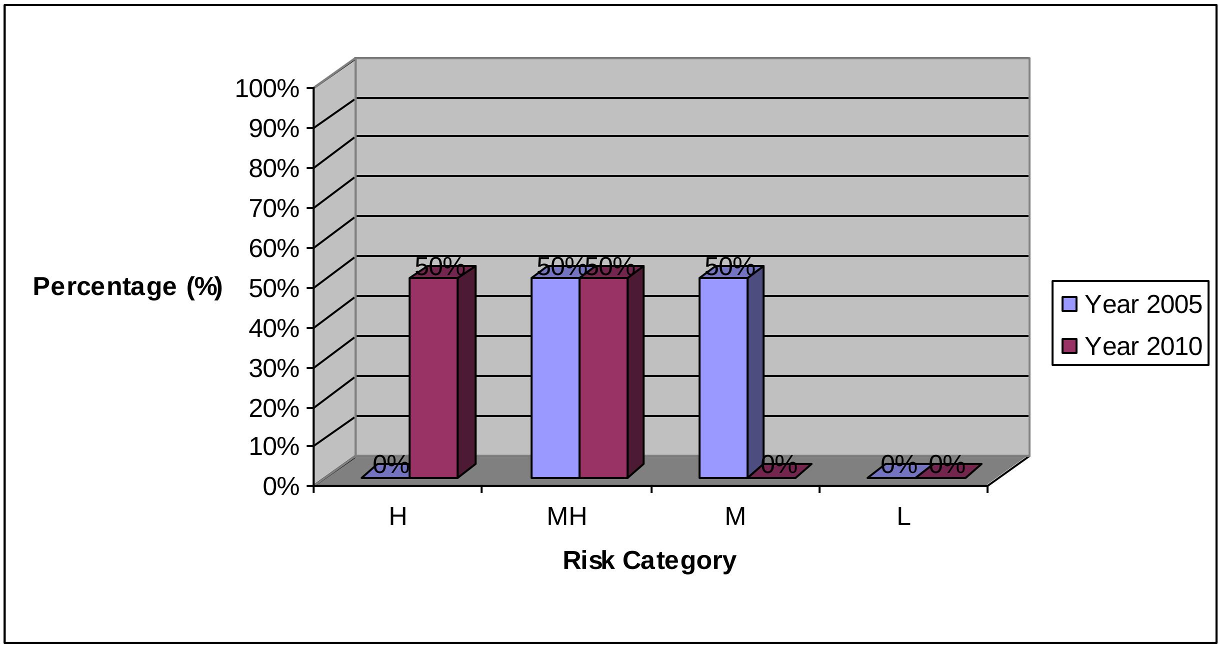


Figure 2.9: Bar Chart for Risk of Equipment Component

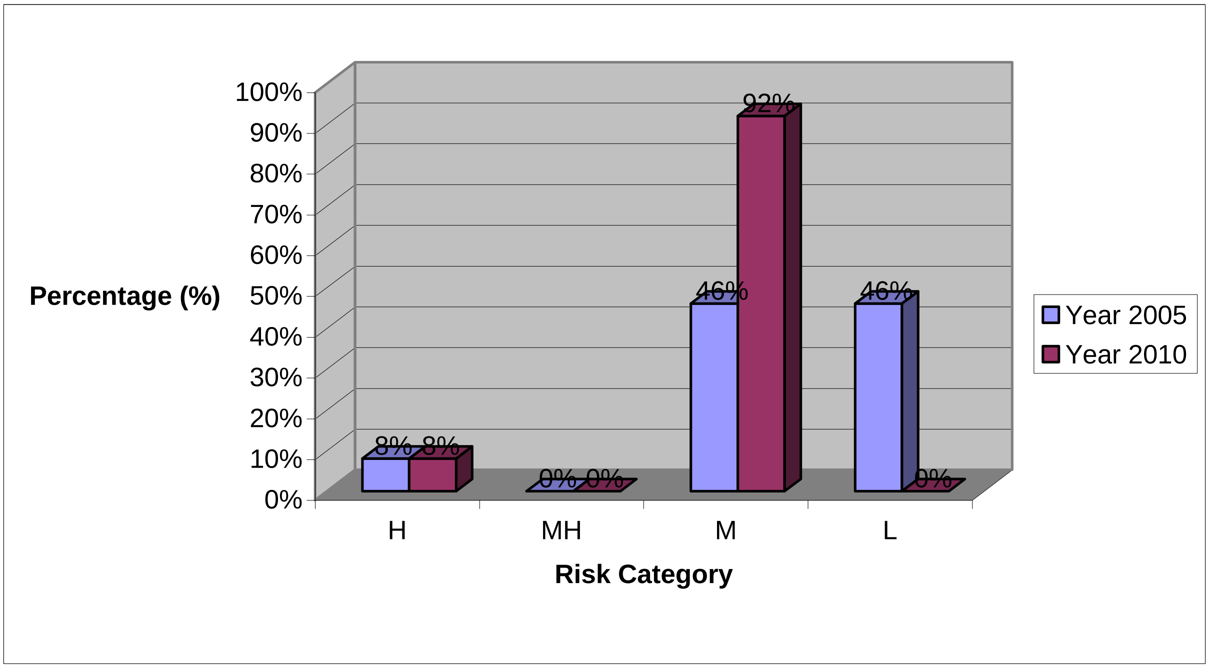


Figure 2.10: Bar Chart for Risk of Piping Circuits

2.10.6.2 Probability of Failure Analysis

All fixed equipment and piping in BNDP-J were evaluated for corrosion and external corrosion. Figure below show the distribution of equipment components and piping circuits, respectively, for internal and external corrosion probability category.

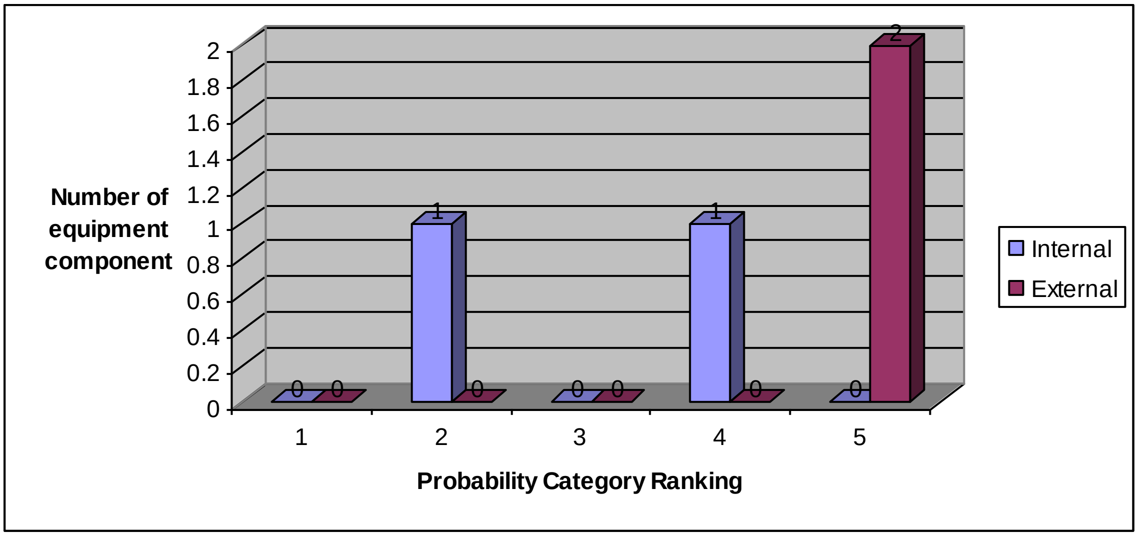


Figure 2.11: Probability Category Distribution for Equipment Components

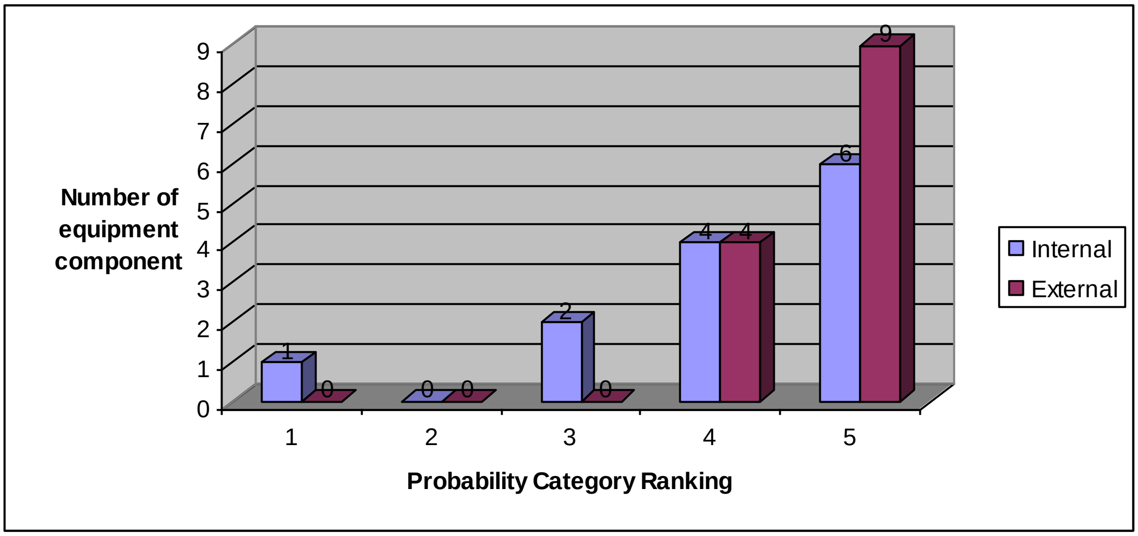


Figure 2.12: Probability Category Distribution for Piping Circuits

All equipment components were given a rating from 1 to 5 that characterize the likelihood of failure. A Probability Category of 4 indicates equipment is essentially in ‘like new’ condition. A Probability Category of 5 indicates the equipment is less likely to fail than a Probability Category 4 as a result of a higher safety factor. As a minimum, a 5 must have an estimated remaining wall of at least 1.5 times the minimum required wall thickness and a corrosion rate of less than 5 mpy (o.127 mm/y). Currently, all the equipment components fall in the 4 or 5 category.

As for the piping circuits that fall in ‘1’ and ‘3’ category, after 14 years in service these piping were found either no inspection record that can indicates no any inspection have been carried out or they have no inspection record i.e. NDT data, but having higher calculated corrosion rtes. Hence, with both conditions it leads to high probability of failure results.

The P-RBI Risk Rating includes a model for predicting corrosion under insulation (CUI) damage. It calculates a corrosion rate for CUI on carbon steel and low alloy materials over the range of 0 deg to 300 deg F (-17 deg C to 149 deg C). CUI is not expected to be a problem for BNDP-J because there are no insulated equipment or piping.

2.10.6.3 Consequence of Failure

With the exception of bundles, the consequence analysis modeled a release of fluid through the pressure-containing boundary to the atmosphere. For bundles, the safety consequence is modeled as well as the loss of product if a tube were to leak from one side of the exchanger to the other. The loss of containment consequence analysis utilized models that consider flammable or toxic consequences.

CHAPTER 3

METHODOLOGY

3.1 Literature Review

Literature review was conducted for understanding the Risk Based Inspection (RBI) concept and principal. Information was gathered by referring to documentations that are related to RBI (e.g. API Recommended Practice 580 & 581), journals, online articles and RBI training module.

3.2 Conducting Case Studies

Case studies were conducted on two offshore facilities which are DUYONG Central Processing Platform and BARONIA Drilling Platform-J.

3.2.1 Data Gathering

For both case studies, visit has been conducted to PETRONAS Research Sdn. Bhd. and PETRONAS Carigali, KLCC to gather data which are related. These data include RBI Report, Design Basis Memorandum, Material of Constructions, etc. The data were organized for further analysis.

3.2.2 Study and Analysis

This stage requires study and analysis on the RBI approach that was applied by PETRONAS for implementation on both facilities. A meeting was arranged with the project team leader, En. Zamaluddin bin Ali seeking for his kind explanations about both projects.

3.3 RBI Analysis (According to API Recommended Practice)

RBI analysis was conducted by applying basic principles of RBI based on API standards.

3.3.1 Probability Analysis

Probability of Failure analysis (PoF) was conducted by considering the equipments' condition, wall thickness, corrosion rate, years in service and inspection effectiveness. Technical Module Sub Factor was further developed that reflected the PoF of the equipments.

3.3.2 Consequence Analysis

Consequence of Failure analysis (PoF) was conducted by considering the impact of equipments failure to health, safety, environment and production losses. The effect of leaking and costs of repair were taking into account while conducting the analysis.

3.3.3 Risk Matrix Development

From the Probability and Consequence analysis, the criticality of the equipments were ranked and presented by the Risk Matrix.

3.4 Results Analysis

Results and methodology taken in conducting RBI analysis were compared to the implementation in the case studies. This was done to identify areas that could improve the implementation and to verify whether the implementation was inline with API standards.

3.5 Determination of benefits of RBI implementation

This stage determines the benefits that were generated from the RBI implementation on offshore facilities. These benefits will determine the success of the implementation.

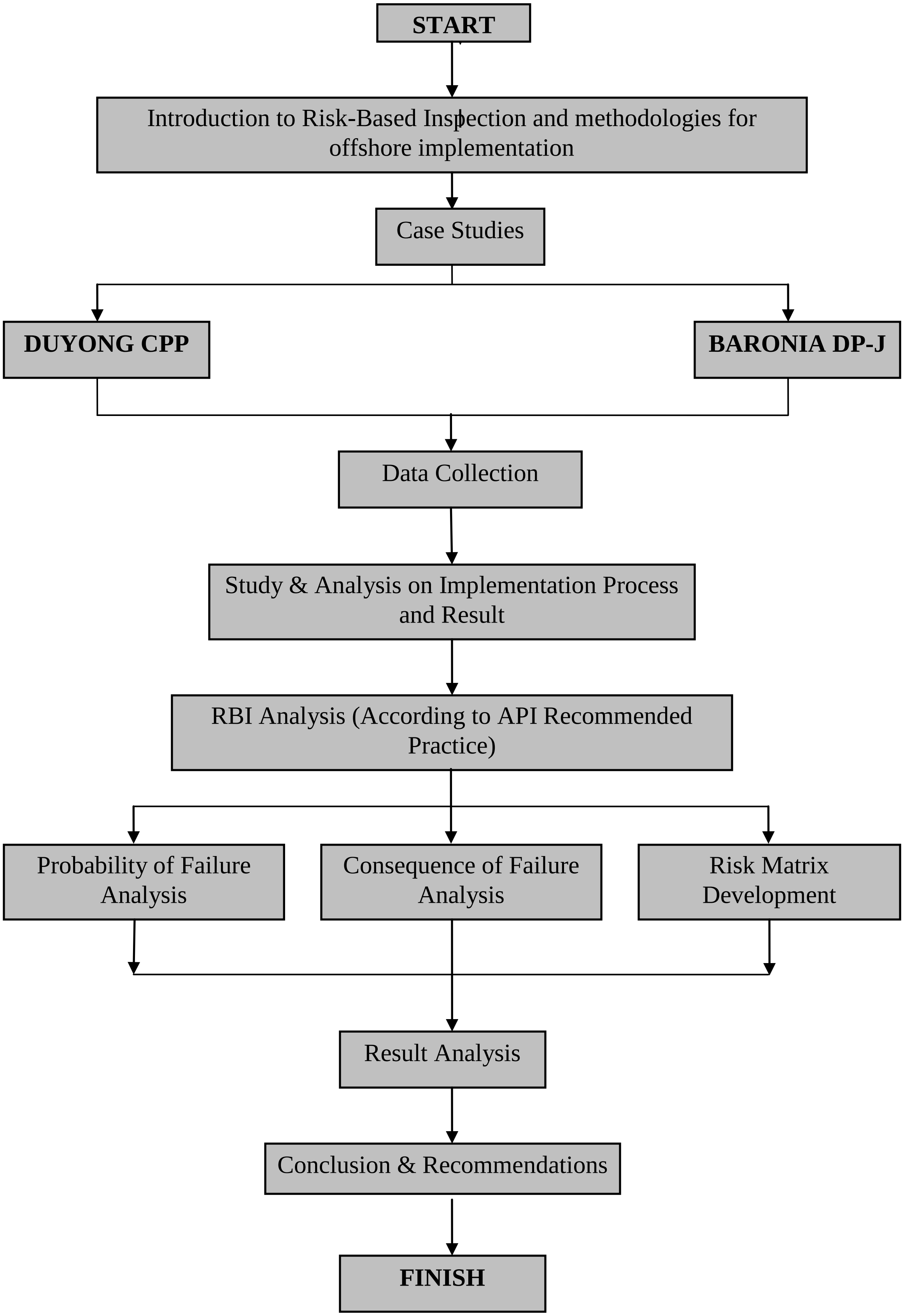


Figure 3.1: Flow Chart of Project's Methodology

CHAPTER 4

RESULTS & DISCUSSIONS

4.1 RBI ANALYSIS ON DUYONG CENTRAL PROCESSING PLATFORM (ACCORDING TO API RECOMMENDED PRACTICE)

4.1.1 PROBABILITY ANALYSIS

Step 1: Determination of Technical Module Sub Factors (TMSF)

Technical modules are the systematic methods used to asses the effect of specific failure mechanism on the likelihood of failure. They serve four functions:

a) Screen for damage mechanisms under normal and upset operating condition
b) Establish damage rate in the environment
c) Quantify the effectiveness of inspection program
d) Calculate the modification factor.

It covers the degradation mechanisms for Thinning, Stress Corrosion Cracking (SCC), High Temperature Hydrogen Attack (HTHA), Furnace Tubes, Mechanical Fatigue, Brittle Fracture, Equipment Linings and External Damage.

From inspection history of Duyong CPP, the main degradation mechanism identified was thinning. Thinning technical module established a technical module subfactor for the equipment subject to damage by thinning mechanism. To determine TMSF the following data are essential:

a) Corrosion rate
b) Equipments age
c) Current wall thickness
d) Number of highest effective inspection

I. Calculation of *ar/t*;

This number is equivalent to the fractional wall loss due to corrosion and will be used to determine Technical Module Subfactor (TMSF).

Where;

a = Age (years in service)
r = Corrosion rate (mpy)
t = Actual measured thickness (mm)

Sample calculation;

Equipment: D1670 Instrument Air Dryer
Equipment type: Vessel

$ar/t = (19)(0.08)/6 = 0.2533$

APPENDIX 4A shows the for values of *ar/t* of 82 equipments in Duyong Central Processing Platform

II. Determination the number of highest effectiveness inspections;

The effectiveness of each inspection performed within a period of time must be defined whether it is highly effective, usually effective, fairly effective, poorly effective or ineffective. Table 4.1 and Table 4.2 provide examples of inspection activities for general and localized thinning due to corrosion.

Table 4.1: Guideline for Assigning Inspection Effectiveness for General Thinning [2]

Inspection Effectiveness	**Intrusive (Internal)**	**Non intrusive (External)**
Highly Effective	50-100% examination of the surface (partial internals remove), and thickness measurements.	50-100% ultrasonic scanning coverage (automated or manual) or profile radiography.
Usually Effective	Nominally 20% examination (no internals removed), and spot external UT measurements	Nominally 20% ultrasonic scanning coverage or profile radiography, or external spot thickness (statistically validated).
Fairly Effective	Visual examination without thickness measurements.	2-3 % examination, spot external UT measurements and little or no internal visual examination.
Poorly Effective	External spot thickness readings only.	Several thickness measurements and documented inspection planning.
Ineffective	No inspection.	Several thickness measurements taken only externally and poorly documented inspection planning.

Table 4.2: Guideline for Assigning Inspection Effectiveness for Localized Thinning[2]

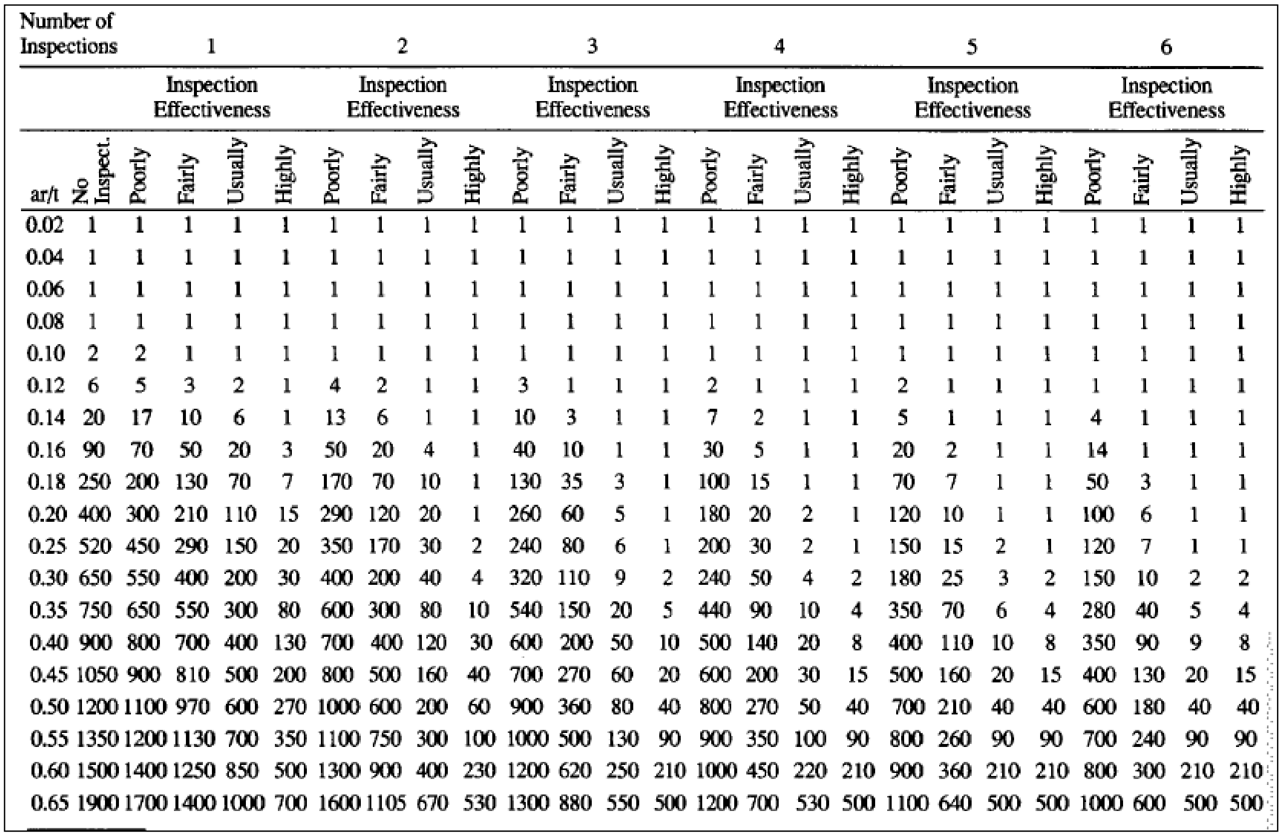
Inspection Effectiveness	**Intrusive (Internal)**	**Non intrusive (External)**
Highly Effective	100% visual examination (removal of internal packing, trays,etc.) and thickness measurements.	50-100% coverage using automated ultrasonic scanning, or profile radiography in areas specified by corrosion eng. or specialist.
Usually Effective	100% visual examination (partial removal of the internals) including manways, nozzles,etc. and thickness measurements.	20% coverage using automated ultrasonic scanning, or 50% manual ultrasonic scanning, or 50% profile radiography in areas specified by corrosion eng. or specialist.
Fairly Effective	Nominally 20% visual examination and spot UT measurements.	Nominally 20% coverage using automated or manual ultrasonic scanning, or profile radiography, and spot thickness measurements at areas specified by a corrosion eng. or specialist.
Poorly Effective	No inspection.	Spot UT measurements or profile radiography without areas being specified by a corrosion eng. or other knowledgeable specialist.
Ineffective	No inspection.	Spot UT measurements without areas being specified by a corrosion eng. or other knowledgeable specialist.

APPENDIX 4B shows the total number of highest inspection effectiveness for equipment in Duyong Central Processing Platform.

III. Determination of TMSF;

TMSF was generated based on the combination of ar/t calculated and the total number of highest inspection effectiveness. Table below shows the relationship between TMSF, calculated at/t and number of highest inspection effectiveness.

Table 4.3: Thinning Technical Module Subfactors[2]



Number of Inspections		1				2				3				4				5				6			
		Inspection Effectiveness				Inspection Effectiveness				Inspection Effectiveness				Inspection Effectiveness				Inspection Effectiveness				Inspection Effectiveness			
ar/t	No Inspect.	Poorly	Fairly	Usually	Highly	Poorly	Fairly	Usually	Highly	Poorly	Fairly	Usually	Highly	Poorly	Fairly	Usually	Highly	Poorly	Fairly	Usually	Highly	Poorly	Fairly	Usually	Highly
0.02	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.04	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.06	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.08	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.10	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.12	6	5	3	2	1	4	2	1	1	3	1	1	1	2	1	1	1	2	1	1	1	1	1	1	1
0.14	20	17	10	6	1	13	6	1	1	10	3	1	1	7	2	1	1	5	1	1	1	4	1	1	1
0.16	90	70	50	20	3	50	20	4	1	40	10	1	1	30	5	1	1	20	2	1	1	14	1	1	1
0.18	250	200	130	70	7	170	70	10	1	130	35	3	1	100	15	1	1	70	7	1	1	50	3	1	1
0.20	400	300	210	110	15	290	120	20	1	260	60	5	1	180	20	2	1	120	10	1	1	100	6	1	1
0.25	520	450	290	150	20	350	170	30	2	240	80	6	1	200	30	2	1	150	15	2	1	120	7	1	1
0.30	650	550	400	200	30	400	200	40	4	320	110	9	2	240	50	4	2	180	25	3	2	150	10	2	2
0.35	750	650	550	300	80	600	300	80	10	540	150	20	5	440	90	10	4	350	70	6	4	280	40	5	4
0.40	900	800	700	400	130	700	400	120	30	600	200	50	10	500	140	20	8	400	110	10	8	350	90	9	8
0.45	1050	900	810	500	200	800	500	160	40	700	270	60	20	600	200	30	15	500	160	20	15	400	130	20	15
0.50	1200	1100	970	600	270	1000	600	200	60	900	360	80	40	800	270	50	40	700	210	40	40	600	180	40	40
0.55	1350	1200	1130	700	350	1100	750	300	100	1000	500	130	90	900	350	100	90	800	260	90	90	700	240	90	90
0.60	1500	1400	1250	850	500	1300	900	400	230	1200	620	250	210	1000	450	220	210	900	360	210	210	800	300	210	210
0.65	1900	1700	1400	1000	700	1600	1105	670	530	1300	880	550	500	1200	700	530	500	1100	640	500	500	1000	600	500	500

APPENDIX 4C shows the TMSF of 82 equipments of Duyong Central Processing Platform

Step 2: Determination of Probability of Failure

RBI analysis according to API 581, the Technical Module Sub Factor reflects the category of Probability of Failure (PoF). Indirectly, calculation of probability of failure was influenced by the equipment age, corrosion rate, wall thickness and effective inspection.

The conversion of TMSF to PoF category is accomplished through a simple assignment of PoF categories to subfactor values based on table below:

Table 4.4: Technical Module Subfactor Conversion

PoF Category	Technical Module Subfactor (TMSF)
1	**<1**
2	**1 – 10**
3	**10 – 100**
4	**100 - 1000**
5	**> 1000**

APPENDIX 4D shows the Probability of Failure category of equipments in Duyong Central Processing Platform.

4.1.2 CONSEQUENCE ANALYSIS

Step 1: Leak Sizes & Distribution

In Duyong Central Processing Platform, the impact of hydrocarbon releases is modeled by considering the consequences of four different leak sizes.

Table 4.5: Hole sizes assumed for consequence analysis

Category	Representative Hole Size(mm)
Small	5
Medium	25
Large	50
Rupture	Modeled as least of 450

For some degradation mechanisms damage can be expected to be sudden and extensive (e.g. brittle fracture) and mostly large leaks and ruptures will occur; the leak size distribution is skewed towards large leaks. Other degradation mechanisms, like Corrosion Under Insulation (CUI) will predominantly lead to smaller leaks.

In this case the hole size distribution is such 90% of all leaks fall into the category ‘small leaks’. In general the hole size distribution depend on the damage type which occur at the time of failure.

Step 2: Repair Strategies and Repair Times

The repair data for the various repair strategies has been selected for various types of equipments. Table below shows the repair strategies for the equipments in Duyong CPP in an event of failure.

Table 4.6: Repair Strategies

Type of Part	Decision Criteria	Leak Sizes			
		Small	Medium	Large	Rupture
Nozzle, Vent, Drain		Patch Welding	Nozzle Replacement	Nozzle Replacement	Nozzle Replacement
Vessel Head, shell, launcher, receiver	Material is stainless steel	Patch Welding	Double Plate Weld	Double Plate Weld	Equipment replacement
Vessel Head, shell, launcher, receiver	Material is carbon steel	Patch Welding	Double Plate Weld	Double Plate Weld	Equipment replacement
Vessel Head, shell, launcher, receiver	Material is stainless steel and carbon steel	Patch Welding	Double Plate Weld	Double Plate Weld	Equipment replacement
Heat Exchanger Tubes		Tube Plugging	Tube Replacement	Tube Replacement	Tube Replacement

The repair strategies are meant for 82 pressure vessels included in this study. From the Table 4.6 above, the repair strategies is structured according to the part of the equipment, materials and leak sizes. Different part will need different repair and it depends on the leak size and the severity of the damage.

Table 4.7: Repair Time per Repair Method

Repair Method	Pipe Diameter (Inch)	Description Criteria	Repair Time (Hours)
Blind Grinding	No Limit	Applicable to pitting with less than CA	72
Double Plate Weld	No Limit	Leak size less than 2”	72
Equipment Replacement	No Limit	Applicable to Vessel and Heat Exchanger beyond repair	4320
HX Tube Plugging	No Limit	Leaking Tubes & Metal Loss > 50%	48
HX Tube Replacement	No Limit	Number of tube leaked > 50%	72
Nozzle Repair	No Limit	Pitting/Leak on Nozzle	72
Nozzle Replacement	No Limit	Applicable to Vessel and Heat Exchanger beyond repair	120
Patch Welding	273.05	Metal Loss>50% for 6”-10” NB	24
Patch Welding	406.4	Metal Loss>50% for 10”-16”NB	48
Patch Welding	1219.2	Metal Loss>50% for 16”-48”NB	96
Vessel Welding CRA	No Limit	Pitting exceeds API 510 criteria, part replacement	120
Vessel Welding CS	No Limit	Pitting exceeds API 510 criteria, part replacement	96

Table 4.7 above shows the repair time required for a particular repair method. From the table, the repair method is applicable to certain type of damage and time taken for each repair is varying from one to another.

Patch welding for metal loss consume the minimum repair time and equipment replacement consume the maximum repair hours. Average repair time for one part of equipment is 80 – 100 hours.

Time consumed for repair affected the production loss profile of the facilities. This is due to the costs spent for repair and maintenance and also production loss due to downtime or shutdown.

Step 3: Production Loss Profile

Consequence of failure calculated as the sum of cost of repairs to equipment and structures damages, the result of the failed component and the cost of production downtime.

When considering cost of production downtime, the individual conditions for the installation and system should be considered. Some systems have little or no effect on production, or have at least a partial redundancy in capacity.

The costs of repair to the installation and equipment onboard shall also be considered, recovering material cost, fabrication, installation and commissioning of the replacement equipment.

Table 4.8: Production Loss Profile for Hydrocarbon System

Production Loss Profile	Description
1x0%	Normal Production
1x10%	Loss of WHP-A or WHP-B
1x20%	Loss of WHP-A or WHP-B or WHP-C or Pulai
1x30%	Loss of Slug Catcher A&C
1x40%	Loss of West Natuna
1x60%	Loss of West Natuna & Pulai
1x100%	CPP Shutdown

Table 4.9: Production Loss Profile Properties

Production Loss Profile	Investigation		Ramp Up Partial Production		Repair		Ramp Up Full Production	
	Time (hour)	Production %	Time (hour)	Production %	Time (hour)	Production %	Time (hour)	Production %
1x10%	6	0	6	45	Repair Time	90	6	95
1x20%	6	0	6	40	Repair Time	80	6	90
1x30%	6	0	6	35	Repair Time	70	6	85
1x40%	6	0	6	30	Repair Time	60	6	80
1x60%	6	0	6	20	Repair Time	40	6	70
1x100%	6	0	-	-	Repair Time	-	6	50

APPENDIX 4E shows the Consequence of Failure category of equipments in Duyong Central Processing Platform.

4.1.3 RISK MATRIX FOR DUYONG CPP

Table 4.10: Summary of Risk Ranking for 82 equipments in Duyong CPP

No	Equipment	PoF Category	CoF Category	Criticality
1	D1670 Instrument Air Dryer	5	D	HIGH
2	D1671 Instrument Air Dryer	5	D	HIGH
3	D1675 Instrument Air Dryer	5	E	VERY HIGH
4	D1676 Instrument Air Dryer	5	E	VERY HIGH
5	E1170Glycol Cooler 'A'	5	D	HIGH
6	E1190Glycol Cooler 'B'	4	D	MEDIUM
7	E1210Glycol Cooler 'C'	5	D	HIGH
8	E1250Glycol Reboiler	5	A	MEDIUM
9	E1260Glycol Surge Tank & Exchanger	5	A	MEDIUM
10	E1270Glycol Preheat Exchanger	5	E	VERY HIGH
11	E1320Glycol Reboiler	5	A	MEDIUM
12	E1330Glycol Surge Tank & Exchanger	5	A	MEDIUM
13	E1340Glycol Preheat Exchanger	5	E	VERY HIGH
14	E1390Glycol Reboiler	5	A	MEDIUM
15	E1400Glycol Surge Tank & Exchanger	5	A	MEDIUM
16	E1410Glycol Preheat Exchanger	5	E	VERY HIGH
17	E1812 Fuel Gas Heater	1	D	LOW
18	E1815 Fuel Gas Heater	1	D	LOW
19	E1912 Fuel Gas Heater	1	D	LOW
20	E1915 Fuel Gas Heater	1	D	LOW
21	E2750 Gas/Gas Exchanger (West Natuna Gas)	1	C	LOW
22	F1220 Glycol Carbon Filter	5	D	HIGH
23	F1225 Glycol Carbon Filter	5	D	HIGH
24	F1240 Glycol Particulate Filter	5	E	VERY HIGH
25	F1245 Glycol Particulate Filter	5	E	VERY HIGH

Table 4.10: Summary of Risk Ranking for 82 equipments in Duyong CPP..(Cont'd)

No	Equipment	PoF Category	CoF Category	Criticality
26	F1290 Glycol Carbon Filter	5	D	HIGH
27	F1295 Glycol Carbon Filter	5	D	HIGH
28	F1310 Glycol Particulate Filter	5	E	VERY HIGH
29	F1315 Glycol Particulate Filter	5	E	VERY HIGH
30	F1360 Glycol Carbon Filter	5	D	HIGH
31	F1365 Glycol Carbon Filter	5	D	HIGH
32	F1380 Glycol Particulate Filter	5	E	VERY HIGH
33	F1385 Glycol Particulate Filter	5	E	VERY HIGH
34	F1650 Pre Filter	5	E	VERY HIGH
35	F1660 Pre Filter	5	E	VERY HIGH
36	F1680 After Filter	5	E	VERY HIGH
37	F1685 After Filter	5	E	VERY HIGH
38	F1820 Fuel Gas Filter/Separator	1	E	MEDIUM
39	F1825 Fuel Gas Filter/Separator	1	E	MEDIUM
40	F1885 Glycol Filter	5	E	VERY HIGH
41	F1891 Glycol Filter	5	E	VERY HIGH
42	F1892 Glycol Filter	5	E	VERY HIGH
43	L1530 sales Gas and Condensate Launcher SCP-A	5	E	VERY HIGH
44	R-2910 Pulai Gas Receiver	1	E	MEDIUM
45	R-2950 Natuna Gas Receiver	1	E	MEDIUM
46	R1000 Sphere Receiver 'A'	1	D	LOW
47	R1010 Sphere Receiver 'C'	1	D	LOW
48	SC1250 Stripping Column for Glycol Regeneration	5	D	HIGH
49	SC1320 Stripping Column for Glycol Regeneration	5	D	HIGH
50	SC1390 Stripping Column for Glycol Regeneration	5	D	HIGH

Table 4.10: Summary of Risk Ranking for 82 equipments in Duyong CPP..(Cont'd)

No	Equipment	PoF Category	CoF Category	Criticality
51	SDV1000 Air Accumulator	5	E	VERY HIGH
52	SDV1010 Air Accumulator	5	E	VERY HIGH
53	SDV1530(A) Air Accumulator	5	E	VERY HIGH
54	SDV1530(B) Air Accumulator	5	E	VERY HIGH
55	ST1250 Still Column for Glycol Regeneration	5	E	VERY HIGH
56	T1890 Glycol Storage Tank	1	E	MEDIUM
57	V1030 Slug Catcher 'A'	1	D	LOW
58	V1040 Low Pressure Slug Catcher	1	C	LOW
59	V1050 Slug Catcher 'C'	1	D	LOW
60	V1060 Production Separator 'A'	5	D	HIGH
61	V1070 Production Separator 'B'	1	D	LOW
62	V1080 Production Separator 'C'	1	C	LOW
63	V1090 Condensate Flash Tank	1	C	LOW
64	V1100 Coalescer	1	C	LOW
65	V1110 Coalescer	1	C	LOW
66	V1130 Oil Skimmer	4	D	MEDIUM
67	V1160 Glycol Contactor 'A'	1	C	LOW
68	V1180 Glycol Contactor 'B'	1	C	LOW
69	V1200 Glycol Contactor 'C'	1	C	LOW
70	V1230 Glycol Flash Separator	1	D	LOW
71	V1265 Fuel Gas Scrubber	4	D	MEDIUM
72	V1330 Glycol Flash Separator	4	D	MEDIUM
73	V1335 Fuel Gas Scrubber	4	D	MEDIUM
74	V1370 Glycol Flash Separator	4	D	MEDIUM
75	V1405 Fuel Gas Scrubber	4	D	MEDIUM
76	V1460 H.P. Flare Knock Out Drum	5	E	VERY HIGH
77	V1465 L.P. Flare Knock Out Drum	5	E	VERY HIGH
78	V1640 Utility Air Receiver	5	E	VERY HIGH
79	V1690 Instrument Air Receiver	5	E	VERY HIGH

Table 4.10: Summary of Risk Ranking for 82 equipments in Duyong CPP..(Cont'd)

No	Equipment	PoF Category	CoF Category	Criticality
80	V1910 Fuel Gas Scrubber	4	D	MEDIUM
81	V2050A Gas Filter (Natuna)	4	C	MEDIUM
82	V2050B Gas Filter (Natuna)	4	C	MEDIUM

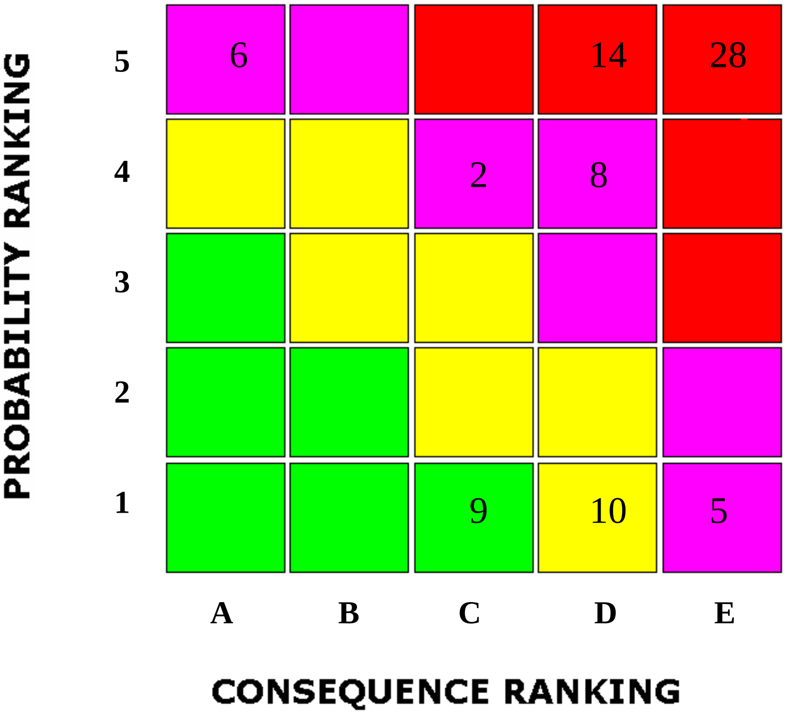


Figure 4.1: Risk Matrix for Duyong CPP (RBI Analysis)

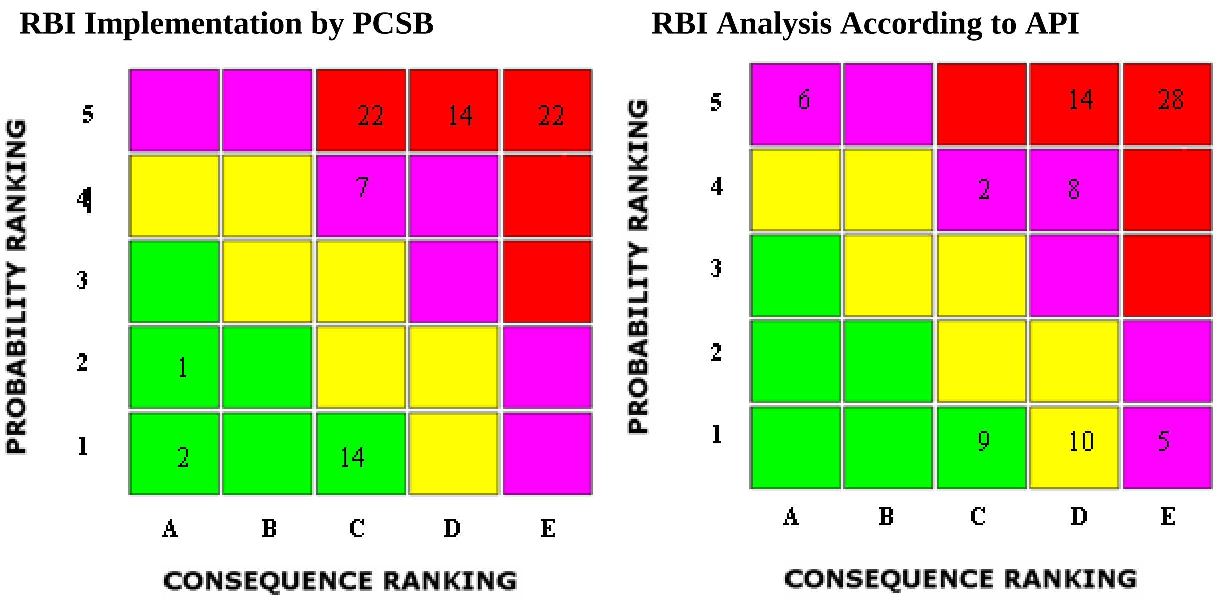
4.1.4 COMPARING RESULTS OF RBI ANALYSIS AND IMPLEMENTATION

RBI analysis was conducted on Duyong Central Processing Platform according to the guidelines recommended by the API documentations for RBI (API 580 & API 581).

Comparing the result that was obtained from the analysis to the result that was obtained by PETRONAS Carigali, there is several numbers of equipments that were put at different criticality level. As shown in the risk matrix in the analysis, number of equipments in the ‘very high’ category is higher and most of the equipments are scattered at the left hand side of the risk matrix. This means that the equipments are at high consequence category.

The difference between the result of the RBI analysis and result obtained by PETRONAS Carigali may be due to the assumptions that were made during the calculations. There are some data that were maid unavailable during the analysis and assumptions were made for the calculation to be done.

However, both result shows that most equipments are at high risk. Inspection planning were to developed to reduce the risk of the equipments.



RBI Implementation by PCSB

PROBABILITY RANKING

	A	B	C	D	E
5	🟪	🟪	🟥 22	🟥 14	🟥 22
4	🟨	🟨	🟪 7	🟪	🟥
3	🟩	🟨	🟨	🟪	🟥
2	🟩 1	🟩	🟨	🟨	🟪
1	🟩 2	🟩	🟩 14	🟨	🟪

CONSEQUENCE RANKING

RBI Analysis According to API

PROBABILITY RANKING

	A	B	C	D	E
5	🟪 6	🟪	🟥	🟥 14	🟥 28
4	🟨	🟨	🟪 2	🟪 8	🟥
3	🟩	🟨	🟨	🟪	🟥
2	🟩	🟩	🟨	🟨	🟪
1	🟩	🟩	🟩 9	🟨 10	🟪 5

CONSEQUENCE RANKING

Figure 4.2: Comparison between results of RBI implementation and analysis

4.2 RBI ANALYSIS ON BARONIA DRILLING PLATFORM-J (ACCORDING TO API RECOMMEND PRACTICE)

4.2.1 PROBABILITY ANALYSIS

Step 1: Determination of Technical Module Sub Factors (TMSF)

The approach of determining Technical Module Sub Factor (TMSF) for BARONIA-Drilling Platform J is similar that was applied in DUYONG Central Processing Platform. Each piece of equipment is a direct function of the nature and rate of the degradation mechanisms to which it is subjected.

The essential steps taken are as follows:

- Identify the damage mechanisms
- Predict the rate of degradation
- Assess inspection confidence
- Identify service age
- Determine Probability of Failure

I. Calculation of ar/t;

This number is equivalent to the fraction wall loss due to thinning and will be used to determine Technical Module Subfactor (TMSF).

Where;

a = Age (years in service)

r = Corrosion rate (mpy)

t = Actual measured thickness (mm)

Sample calculation;

Equipment: BNDP-J-01A

Equipment type: Piping Circuit

$ar/t = (14 \times 0.1299)/ 23.01 = 0.079$

APPENDIX 4F shows the values of ar/t for 2 pressure vessels and 13 piping circuits in Baronia Drilling Platform-J.

II. Determination the number of highest inspection confidence;

The confidence of each inspection performed within a period of time must be defined whether it is highly effective, usually effective, fairly effective, poorly effective or ineffective. Table 4.11 and Table 4.12 provide examples of inspection activities for general and localized thinning.

Table 4.11: Inspection Confidence for Internal Corrosion

Inspection Confidence	Corrosion Type	Extent of Inspection
Very High	General	Internal Visual with 100% Visual Coverage
High	General	Internal Visual with 50% Visual Coverage
Medium	General	4 locations per head, 4 locations per course, 50% nozzles, 2 vert. scan
Low	General	Less than 4 locations per head, 4 locations per course, 50% nozzles, 2 vert. scan
Very High	Localized	Internal Visual with 100% Visual Coverage
High	Localized	Internal Visual with 50% Visual Coverage
Medium	Localized	4 locations per head, 4 locations per course, 50% nozzles, 2 vert. scan.
Low	Localized	4 locations per head, 4 locations per course, 50% nozzles, 2 vert. scan.
High	Pitting	Internal Visual with 100% Visual Coverage
Medium	Pitting	50% visual coverage and including areas selected External UT with at least 1 strip scan per head, 25% nozzles, 50% location selected
Low	Pitting	External UT, scan 25% or < of location selected

Table 4.12: Inspection Confidence for External Corrosion

Inspection Confidence	Corrosion Type	Extent of Inspection
Very High	External Deterioration	100% External Visual
Medium	External Deterioration	100% External Visual
Very High	CUI	Strip insulation and 100% Visual Inspection
High	CUI	Strip insulation and visual inspection at location selected
Medium	CUI	Visual inspection on damaged or suspected locations
Low	CUI	Random inspection at UT spots
High	External Corrosion	Eddy Current or IRIS. 40% of the tubes with minimum 10 tubes
Medium	External Corrosion	Eddy Current or IRIS. 25% of the tubes with minimum 10 tubes
Low	External Corrosion	Eddy Current or IRIS. Less than 25% of the tubes with minimum 10 tubes

APPENDIX 4G shows a total number of inspection confidences and effectiveness for Baronia Drilling Platform-J.

III. Determination of TMSF;

TMSF was generated based on the combination of ar/t calculated and the total number of highest inspection effectiveness.

APPENDIX 4H shows Technical Module Sub Factor of equipments and piping circuits for BNDP-J

Step 2: Determination of Probability of Failure

RBI analysis according to API 581, the Technical Module Sub Factor reflects the category of Probability of Failure (PoF). Indirectly, calculation of probability of failure was influenced by the equipment age, corrosion rate, wall thickness and effective inspection.

The conversion of TMSF to PoF category is accomplished through a simple assignment of PoF categories to subfactor values based on table below:

Table 4.13: Technical Module Subfactor Conversion

PoF Category	Technical Module Subfactor (TMSF)
1	<1
2	1 – 10
3	10 – 100
4	100 - 1000
5	> 1000

APPENDIX 4 I show the Probability of Failure category of equipments and piping circuits in Baronia Drilling Platform-J.

4.2.2 CONSEQUENCE ANALYSIS

Step 1: Release Rate Calculation

I. Determine representative fluid and its properties;

Baronia Drilling Platform-J produces hydrocarbon liquid and gas from its wellhead. APPENDIX 4J shows the representative fluid of each equipment and piping circuit.

II. Inventory category for the equipment;

Inventories were estimated in an order of magnitude basis. Refer Table 8 below:

Table 4.14: Inventory Category Ranges

Category	Range	Value used in calculations
A	100 to 1000 lbs	500
B	1000 to 10 000 lbs	5000
C	10 000 to 100 000 lbs	50,000
D	100 000 to 1 000 000 lbs	500,000
E	1 000 000 to 10 000 000 lbs	5,000,000

The inventory category was chosen based on default inventory value. The inventory default value is based on initial fluid phase inside the pressure boundary. It is set to be as follows:

- Initial Gas Phase: 4,536 kg or 10,000 lb
- Initial Liquid Phase: 18,144 kg or 40,000 lb

Thus inventory category was chosen as ‘B’ for Initial Gas Phase and ‘C’ for Initial Liquid Phase.

III. Detection and Isolation rating applicable to detection and isolation systems present in the area;

Table 9 below, provides guidance for assigning a qualitative letter rating (A, B or C) to the unit’s detection and isolation systems. These letter ratings will be used later in the consequence estimation sections to determine the effect of the mitigation systems on final consequences. Detection system rating ‘A’ usually found only in specialty chemical applications.

Both detection and isolation rating applicable to the systems presented in BNDP-J were chosen as ‘B’ or in average conditions. The information in Table 4.16 will only be used when evaluating the consequences of continuous-type releases. If more than 10 000 lbs of fluid were released in 5 minutes, the process of assessing detection and isolation system is not applied.

Table 4.15: Detection and Isolation system rating guide

Type of Detection System	Classification
Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e. loss of pressure or flow) in the system.	A
Suitably located detectors to determine when the material is present outside the pressure-containing envelope.	B
Visual detection, cameras, or detectors with marginal coverage.	C
Type of Isolation System	**Classification**
Isolation or shutdown systems activated directly from process instrumentation or detectors, with no operator intervention.	A
Isolation or shutdown systems activated by operators in the control room or other suitable locations remote from the leak.	B
Isolation dependent on manually-operated valves.	C

IV. Estimate leak duration based on duration and detection systems;

The quality ratings of the detection and isolation systems have been translated into an estimation of leak duration in Table 10. Total leak duration presented in the table is the sum of the time to detect the leak, analyze the incident and decide upon corrective action, and time to complete appropriate actions.

Table 4.16: Leak Durations Based on Detection and Isolation Systems

Detection System Rating	Isolation System Rating	Leak Duration
A	A	20 minutes for ¼ inch. leaks 10 minutes for 1 inch leaks 5 minutes for 4 inch leaks
A	B	30 minutes for ¼ inch leaks 20 minutes for 1 inch leaks 10 minutes for 4 inch leaks

Table 4.16: Leak Durations Based on Detection and Isolation Systems..(Cont'd)

Detection System Rating	Isolation System Rating	Leak Duration
A	C	40 minutes for ¼ inch leaks 30 minutes for 1 inch leaks 20 minutes for 4 inch leaks
B	A or B	40 minutes for ¼ inch leaks 30 minutes for 1 inch leaks 20 minutes for 4 inch leaks
B	C	1 hour for ¼ inch leaks 30 minutes for 1 inch leaks 20 minutes for 4 inch leaks

Based on detection and isolation systems rating 'B' at BNDP-J, the leak durations for each hole size was determined to be 40 minutes for ¼ inch leaks, 30 minutes for 1 inch leaks and 20 minutes for 4 inch leaks.

V. Operating Conditions;

APPENDIX 4K shows the operating Conditions for equipments and piping circuit in BNDP-J

VI. Fluid Initial Phase

APPENDIX 4L shows the fluid initial phase in BNDP-J

VII. Liquid release rate;

Release rates depend on the physical properties of the material, initial phase, and process condition. Release rate equation was chosen based on the phase of the material when it is inside the equipment and its discharge regime as the material is released. For the liquid phase, release rate was calculated for each hole size using the equation below;

$$Q_L = C_d A \sqrt{2\rho - \rho \frac{g_c}{144}}$$

where

Q_L = liquid discharge rate (lbs/sec)

C_d = discharge coefficient

A = hole cross-sectional area (sq in)

ρ = density of liquid (lb/ft³)

g_c = conversion factor (32.2 lb_m-ft / lb_f-sec²)

The discharge coefficient for fully turbulent flow from sharp-edged orifices is 0.60 to 0.64. A value of 0.61 is recommended for the purpose of RBI calculations. Results from the calculation of liquid release rate for each hole size were shown in Table 11;

Table 4.17: Liquid release rate for equipment (vessels and piping)

Hole Size	Release Rate (lb/sec)
¼ inch.	1.34
1 inch.	5.37
4 inch.	21.48
Rupture	85.92

Step2: Determination of Release Type

Two types of release were considered in RBI analysis which include instantaneous and continuous.

a) Instantaneous release - occurs so rapidly that the fluid disperses as a single large cloud or pool.
b) Continuous release - occurs over a longer period of time, allowing the fluid to disperse in the shape of an elongated ellipse.

It is very important to properly determine the release type either instantaneous or continuous. The calculated consequences can differ greatly depending on the type chosen to represent the release. All “small” (1/4 inch) holes were considered as continuous type. If it takes less than 5 minutes to release 10 000 pounds, the release type for the given hole size is instantaneous. Calculation for the amount of release for each hole size in 5 minutes time shown below:

¼ inch. : (1.34 lb/sec) x (60 x 5) sec = 402 lbs

1 inch. : (5.37 lb/sec) x (60 x 5) sec = 1,611 lbs

4 inch. : (21.48 b/sec) x (60 x 5) sec = 6,444 lbs

Rupture : (85.92 lb/sec) x (60 x 5) sec = 25,776 lbs

From the calculated release rate, hole size of ¼ inch, 1 inch and 4 inches were considered as continuous release type while for rupture (more than 6 inches) was considered as instantaneous release type.

Step 3: Determination of phase after release

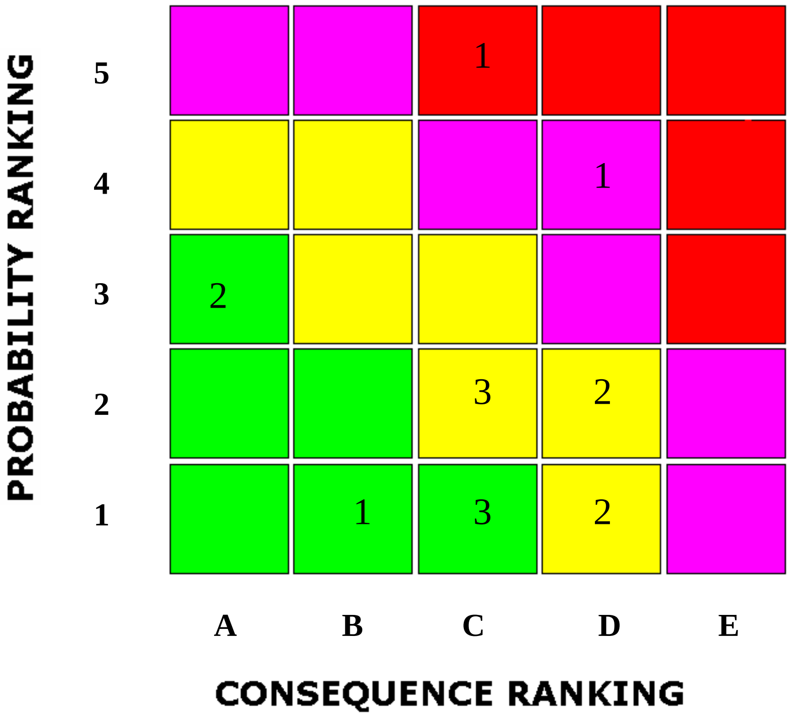
The dispersion characteristic of a fluid after release depends on the phase (gas or liquid) in the environment. If there is no change of phase for the fluid when going from steady-state operating conditions to steady-state ambient conditions, the final phase of the fluid is the same as the initial phase. If the fluid would tend to change state after release, it maybe difficult to assess the phase of the material for the purpose of consequence calculations.

APPENDIX 4M shows the Consequence of Failure category of equipments and piping circuits in Baronia Drilling Platform-J.

4.2.3 RISK MATRIX FOR BARONIA DRILLING PLATFORM-J

Table 4.18: Summary of Risk Ranking for equipments and piping circuits in BNDP-J

No	Equipment ID	Equipment Type	PoF	CoF	Criticality
1	V-800	Pressure Vessel	4	D	MEDIUM
2	V-0001	Pressure Vessel	2	D	LOW
3	BNDP-J-01A	Piping Circuit	2	C	LOW
4	BNDP-J-02A	Piping Circuit	2	C	LOW
5	BNDP-J-03A	Piping Circuit	2	C	LOW
6	BNDP-J-04A	Piping Circuit	1	D	LOW
7	BNDP-J-05A	Piping Circuit	1	C	VERY LOW
8	BNDP-J-06A	Piping Circuit	1	D	LOW
9	BNDP-J-07A	Piping Circuit	3	A	VERY LOW
10	BNDP-J-08A	Piping Circuit	2	D	LOW
11	BNDP-J-09A	Piping Circuit	5	C	HIGH
12	BNDP-J-10A	Piping Circuit	3	A	VERY LOW
13	BNDP-J-11A	Piping Circuit	1	C	VERY LOW
14	BNDP-J-11B	Piping Circuit	1	B	VERY LOW
15	BNDP-J-11C	Piping Circuit	1	C	VERY LOW



PROBABILITY RANKING	A	B	C	D	E
5			1		
4				1	
3	2				
2			3	2	
1		1	3	2	

CONSEQUENCE RANKING

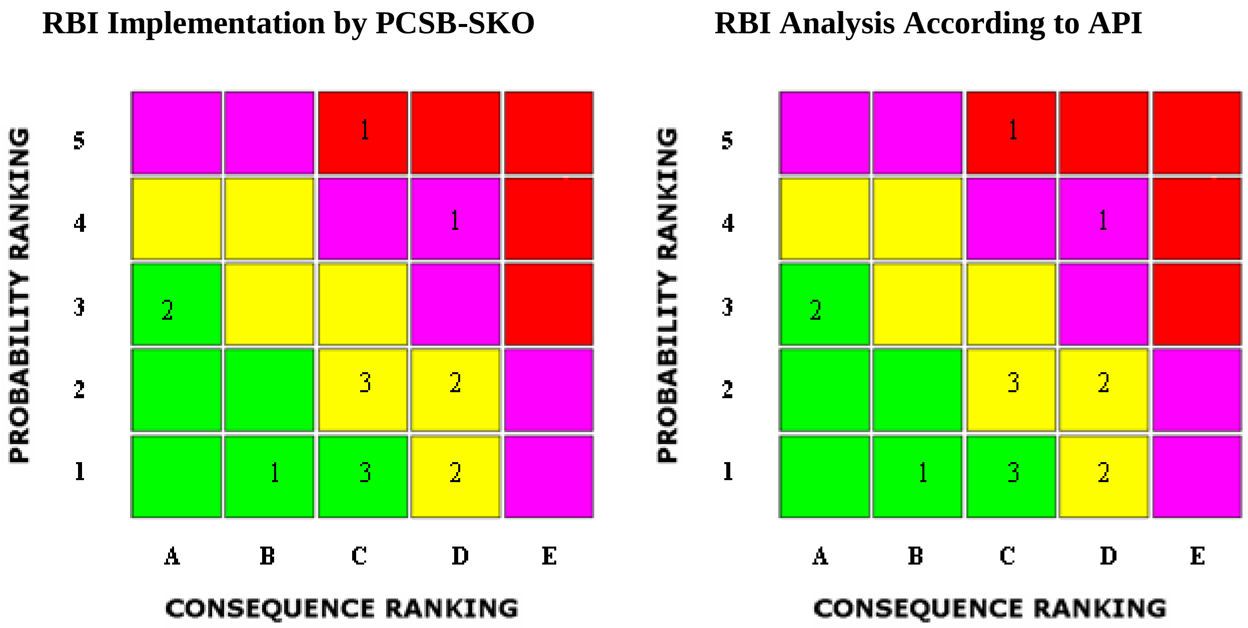
Figure 4.3: Risk Matrix for equipments and piping in BNDP-J

4.2.4 COMPARING RESULTS OF RBI ANALYSIS AND IMPLEMENTATION

RBI analysis was conducted on BARONIA Drilling Platform-J according to the recommended practice by API (API 580 & API 581).

From the analysis that had been conducted, the results obtained are similar with the results of PETRONAS Carigali. The risk ranking for all 13 piping circuits and 2 pressure vessels are the same for both results.

This shows that the approach applied by PETRONS Carigali-SKO are inline with the API Recommended Practice and they had effectively implemented RBI on BARONIA Drilling Platform-J.



RBI Implementation by PCSB-SKO

	A	B	C	D	E
5	🟪	🟪	🟥 1	🟥	🟥
4	🟨	🟨	🟪	🟪 1	🟥
3	🟩 2	🟨	🟨	🟪	🟥
2	🟩	🟩	🟨 3	🟨 2	🟪
1	🟩	🟩 1	🟩 3	🟨 2	🟪

RBI Analysis According to API

	A	B	C	D	E
5	🟪	🟪	🟥 1	🟥	🟥
4	🟨	🟨	🟪	🟪 1	🟥
3	🟩 2	🟨	🟨	🟪	🟥
2	🟩	🟩	🟨 3	🟨 2	🟪
1	🟩	🟩 1	🟩 3	🟨 2	🟪

Figure 4.4 : Comparison between results obtained by RBI implementation and analysis

4.3 BENEFITS OF RBI IMPLEMENTATION ON DUYONG CENTRAL PROCESSING PLATFORM & BARONIA DRILLING PLATFORM-J

4.3.1 COST CONTROL

4.3.1.1 Inspection Cost

Inspection costs can be more effectively managed through the utilization of RBI. Resources can be applied or shifted to those areas identified as a higher risk or targeted based on the strategy selected. Consequently, this same strategy allows consideration for reduction of inspection activities in those areas that have a lower risk or where the inspection activity has little or no affect on the associated risks. These results in inspection resources being applied where they are needed the most.

Another opportunity for managing inspection costs is by identifying items in the inspection plan that can be inspected non-intrusively on-stream. If the non-intrusive inspection provides sufficient risk management, then there is a potential for a net savings based on not having blind, open, clean, and internally inspect during downtime. If the item considered is the main driver for bringing an operational unit down, then the non-intrusive inspection may contribute to increased uptime of the unit. The user should recognize that while there is a potential for the reduction of inspection costs through the utilization of RBI, equipment integrity and inspection cost optimization should remain the focus [11].

4.3.1.2 Life-Cycle Cost

Not only can RBI be used to optimize inspection costs that directly affect life cycle costs, it can assist in lowering overall life cycle cost through various cost benefit assessments. The following examples can give user ideas on how to lower life cycle costs through RBI with cost benefit assessments.

- RBI should enhance the prediction of failures caused by deterioration mechanisms. This in turn should give the user confidence to continue to operate equipment safely, closer to the predict failure date. By doing this, the equipment cycle time should increase and life costs decrease.
- RBI can be used to assess the effects of changing to a more aggressive fluid. A subsequent plan to upgrade construction material or to replace specific items can then be developed. The construction material plan would consider the optimized run length safely attainable along with the appropriate inspection plan. This could adequate to increased profits and lower life cycle costs through maintenance, optimized inspections, and increased unit/equipment uptime.
- Turnaround and maintenance costs also have an affect on the life cycle costs of an equipment item. By using the results of the RBI inspection plan to identify more accurately where to inspect and what repairs and replacements to expect, turnaround and maintenance work can be preplanned and, in some cases, executed at a lower cost than if unplanned.

4.3.2 INSPECTION COSTS ESTIMATION FOR DUYONG CPP

4.3.2.1 Estimation of Inspection Costs

Costs of an inspection activity vary between pressure vessels and piping system. Usually, pressure vessels need to have a greater coverage of inspection compared to piping system. For a full coverage of inspection, we need to open the vessel. The operation need to be shutdown so that the vessel can be open and inspection can be conducted. Type of inspection for Pressure Vessel includes:

- Visual Internal & External Inspection
- NDE-Ultrasonic Thickness Measurement
- NDE-Radiography Technique
- Floor Scan
- Eddy Current/IRIS

4.3.2.2 Estimation of Inspection Cost without RBI

In quoting the total costs of inspection, the costs of the hiring manpower, equipments and tools, mobilizing and demobilizing of manpower, and inspection expertise need to be included. The following table shows the estimated total cost of a full coverage of inspecting a pressure vessel.

Table 4.19: Estimated total cost of a full coverage of inspecting a pressure vessel.

Item No	**Quantity**	**Description**	**Price (RM)**
1	1	• Offshore rate for Inspection Engineers (based on 12 hours) • Mob & Demob rate • Standby Rate	RM2,975.00 RM2,380.00 RM2,080.00
2	1	• Offshore rate for Qualified Inspectors (based on 12 hours) • Mob & Demob rate • Standby rate	RM1,344.00 RM962.50 RM800.00
3	LUMP SUM	Inspection Coverage: • Opening Vessel • Visual (External &Internal) • NDE-UT • Eddy Current/IRIS Equipments and Tools	RM10,140.00
TOTAL			**RM 20,681.50**

The inspection activity is quoted as a lump sum amount for the ease of calculation. The inspection methods include visual inspection internally and externally, UT, and Eddy Current inspection. There are 4 manpower involved in the inspection and they are paid according to day rate.

During a shutdown period, where every 82 pressure vessels need to be inspected, the numbers of manpower involve and total hours of manpower's service will be increase. The following table shows the total cost if every 82 pressure vessels need to be inspected.

Table 4.20: Estimated total cost if every 82 pressure vessels need to be inspected.

Item No	Quantity	Description	Price (RM)
1	9	• Offshore rate for an Inspection Engineer (based on 12 hours) • Mob & Demob rate • Standby Rate	RM 33,850.00 RM19,040.00 RM16,640.00
2	8	• Offshore rate for a Qualified Inspector (based on 12 hours) • Mob & Demob rate • Standby rate	RM21,752.00 RM7,696.00 RM7,200.00
3		Inspection Coverage: • Opening Vessel • Visual (External &Internal) • NDE-UT • Eddy Current/IRIS Equipments and Tools	RM831,480.00
TOTAL			**RM937,658.00**

The total amount of inspection cost shown above is the amount of Duyong CPP spent for a full coverage of pressure vessel inspection for an interval period 5 years. The inspection is conducted on every 82 equipments regardless the criticality of the equipment.

Conventionally, inspection activity was rather conducted based on time or condition of the equipments. In estimating cost of inspection without RBI, it is assumed that half the total number of equipments i.e. 42 equipments are inspected due to their conditions. Thus, the estimated cost of inspection for the Year 2003-2007 and Year 2008-2012 are as follows:

Table 4.21: Estimated Inspection costs without RBI for Year 2003-2007

Item No	**Quantity**	**Description**	**Price (RM)**
1	9	• Offshore rate for an Inspection Engineer (based on 12 hours) • Mob & Demob rate • Standby Rate	RM 18,850.00 RM12,040.00 RM10,640.00
2	8	• Offshore rate for a Qualified Inspector (based on 12 hours) • Mob & Demob rate • Standby rate	RM16,752.00 RM5,696.00 RM5,200.00
3		Inspection Coverage: • Opening Vessel • Visual (External &Internal) • NDE-UT • Eddy Current/IRIS Equipments and Tools	RM415,740.00
TOTAL			**RM484,918.00**

Table 4.22: Estimated Inspection costs without RBI for Year 2008-2012

Item No	Quantity	Description	Price (RM)
1	9	• Offshore rate for an Inspection Engineer (based on 12 hours) • Mob & Demob rate • Standby Rate	RM 18,850.00 RM12,040.00 RM10,640.00
2	8	• Offshore rate for a Qualified Inspector (based on 12 hours) • Mob & Demob rate • Standby rate	RM16,752.00 RM5,696.00 RM5,200.00
3		Inspection Coverage: • Opening Vessel • Visual (External &Internal) • NDE-UT • Eddy Current/IRIS Equipments and Tools	RM505,740.00
TOTAL			**RM574,918.00**

4.3.2.3 Estimation of Inspection Cost with RBI

Inspection costs can be more effectively managed through the utilization of Risk Based Inspection on Duyong CPP. Resources can be applied or shifted to those areas identified as a higher risk or targeted based on the strategy selected. Consequently, this same strategy allows consideration for reduction of inspection activities in those areas that have a lower risk or where the inspection activity has little or no affect on the associated risks. These results in inspection resources being applied where they are needed the most.

According to the inspection planning that was developed, from the 82 equipments there are equipments that don't need full surveillance and they only need certain coverage and method of inspection. This is depending on the criticality of the equipment and risk associated with the equipment.

During the year 2002, there are 61 equipments that need to undergo Internal Inspection, 7 equipments for Extensive Inspection (both Internal & External Inspection), 6 for Preventive Maintenance and 8 no need for inspection.

The estimated inspection cost for the year 2002 is as follows:

Table 4.23: Estimated inspection cost for the year 2002 for Duyong CPP

Item No.	Quantity	Description	Price (RM)
1	6	• Offshore rate for an Inspection Engineer (based on 12 hours) • Mob & Demob rate • Standby Rate	RM28,670.00 RM19,040.00 RM16,640.00
2	6	• Offshore rate for a Qualified Inspector (based on 12 hours) • Mob & Demob rate • Standby rate	RM18,430.00 RM7,696.00 RM7,200.00
3	LUMP SUM	Inspection: • Opening Vessel • Visual Inspection (Internal & External) • NDE-Ultrasound Thickness Measurement Equipment & Tools	RM754,800.00
TOTAL			**RM852,476.00**

After the inspection and rectification to the equipment, the next inspection programme is planned for next 5 years interval (2003-2007). There are 17 equipments that are subjected for Internal Inspection. The inspection is covered for Visual and NDE-UT.

The estimated costs for the inspection for Year 2003-Year 2007 is summarizes as below:

Table 4.24: Estimated costs for the inspection for Year 2003-Year 2007 for Duyong CPP

Item No.	**Quantity**	**Description**	**Price (RM)**
1	2	• Offshore rate for an Inspection Engineer (based on 12 hours) • Mob & Demob rate • Standby Rate	RM10,020.00 RM8,380.00 RM7,080.00
2	2	• Offshore rate for a Qualified Inspector (based on 12 hours) • Mob & Demob rate • Standby rate	RM6,240.00 RM3562.50 RM2900.00
3	LUMP SUM	Inspection: • Opening Vessel • Visual Inspection (Internal) • NDE-Ultrasound Thickness Measurement Equipment & Tools	RM110,850
TOTAL			**RM149,032.50**

After the inspection and rectification of the equipment, the next inspection planning is between the Year 2008 – Year 2012. According to the Inspection Planning, there are 20 equipments need to be inspected. 19 equipments are subjected for external inspection only and 1 equipment subjected for Extensive (Internal & External Inspection).

The estimated costs for the inspection of the Year 2008 – 2012 is estimated as below:

Table 4.25: Estimated costs for the inspection of the Year 2008 – 2012 for Duyong CPP

Item No.	**Quantity**	**Description**	**Price (RM)**
1	2	• Offshore rate for an Inspection Engineer (based on 12 hours) • Mob & Demob rate • Standby Rate	RM15,220.00 RM6,380.00 RM6,080.00
2	2	• Offshore rate for a Qualified Inspector (based on 12 hours) • Mob & Demob rate • Standby rate	RM8,200.00 RM2562.50 RM2400.00
3	LUMP SUM	Inspection: • Opening Vessel • Visual Inspection (External & Internal) • NDE-Ultrasound Thickness Measurement Equipment & Tools	RM57,890.00
TOTAL			**RM98,732.50**

From the analysis of estimation of inspection costs with and without RBI for DUYONG CPP, the trend were observed and represented in Figure 4.5. The total inspection costs are cumulative amount of five years.

From the figure, it is clearly shown that the total costs of inspection are reduced after the implementation of RBI.

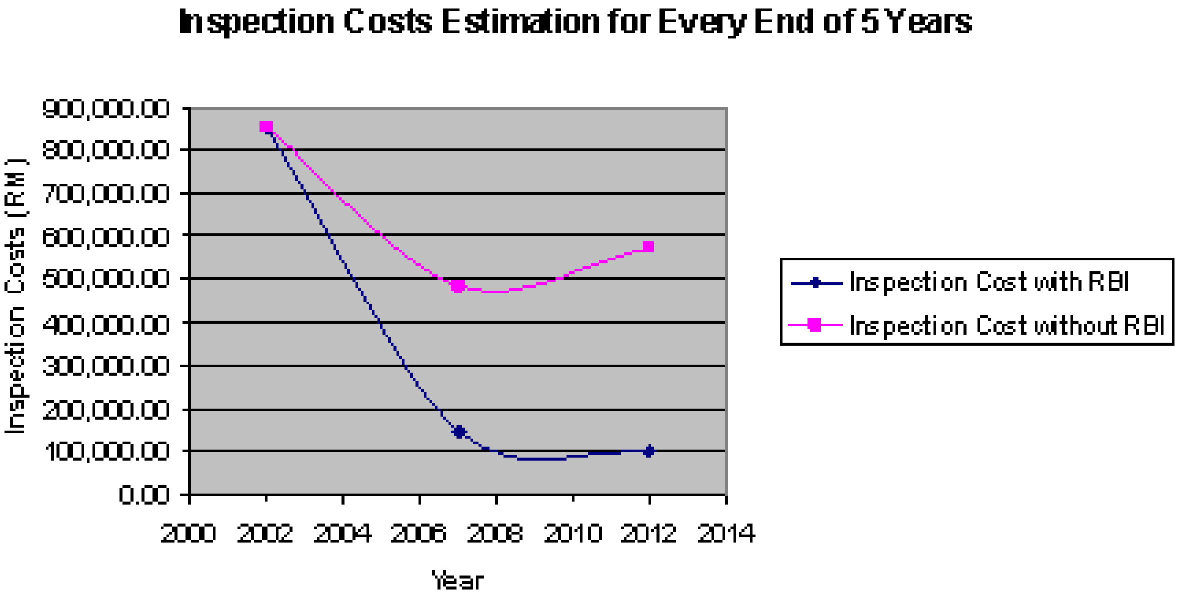


Figure 4.5: Inspection Costs Estimation for DUYONG CPP

4.3.3 INSPECTION COSTS ESTIMATION FOR BARONIA DP-J

4.3.3.1 Pressure Vessel

In BNDP-J facilities, there are only 2 pressure vessels installed which are V-0001 and V-008. Compared to Duyong CPP, costs of inspecting Pressure Vessel in BNDP-J is smaller due to the number of the installed pressure vessels. In quoting the costs of full coverage inspection of both pressure vessels regardless its criticality, a lot of aspects need to be taken care of like mobilization and demobilization of manpower, tools and equipments used for inspection, offshore rate for the manpower, etc. In fact, it is the same as analyzed in estimating inspection costs for Duyong CPP Inspection activity.

Costs of mobilizing and demobilizing manpower for inspection in BNDP-J can be higher compared to Duyong CPP due its location. BNDP-J located 30km offshore of Miri, Sarawak while Duyong CPP is located at the offshore of Peninsular Malaysia. Sometimes, they may require engineer and inspector from Peninsular Malaysia and by doing that may affect the costs of mobilizing and mobilizing them. However, in this analysis and cost estimation, we consider the cost of mobilizing manpower is consistent. Assume that the manpower is mobilized and demobilized within the platform and Sarawak.

4.3.3.1.1 Estimation of Inspection costs without RBI

The following table shows the estimated inspection costs for one pressure vessels:

Table 4.26: Estimated inspection costs for one pressure vessels in BNDP-J

Item No	Quantity	Description	Price (RM)
1	1	• Offshore rate for Inspection Engineers (based on 12 hours) • Mob & Demob rate • Standby Rate	RM2,800.00 RM2,350.00 RM2,080.00
2	1	• Offshore rate for Qualified Inspectors (based on 12 hours) • Mob & Demob rate • Standby rate	RM1260.00 RM962.50 RM800.00

Table 4.26: Estimated inspection costs for one pressure vessels in BNDP-J

3	LUMP SUM	Inspection Coverage: • Opening Vessel • Visual (External &Internal) • NDE-UT • Eddy Current/IRIS Equipments and Tools	RM10,140.00
TOTAL			**RM 20,392.50**

If both the pressure vessels is inspected at the same time, we can calculate the by multiply the total cost by two. But we can consider mobilizing and demobilizing the manpower to be once and the offshore rate and standby rate for both engineers and inspector is maintained.

Cost of inspecting both V-800 & V-1000 =

RM20,392.50 x 2 – (RM2,350.00 + RM962.50) = RM37,472.50

Above calculation reflect the total amount of inspection costs for both pressure vessels regardless is criticality for an interval of 5 years.

4.3.3.1.2 Estimation of Inspection Cost with RBI

Introducing RBI to the inspection of the pressure vessels has affected the overall inspection costs. Referring to the inspection plan developed. During the RBI is in progress in year 2005, only V-0001 need to have a full coverage of inspection and V-800 is schedule to be inspected in Year 2009 and 2014. Which means the inspection cost is estimated as one pressure vessel is inspected.

The cost estimation for the following year is divided into two time interval which are Period 1 (Year 2006 – 2010) and Period 2 (Year 2011 – 2015).

During period 1, there is only one Internal Inspection for V-800 which only covers Partial Visual Inspection in 2009. The inspection require shutdown to open the vessel. The cost estimation for V-800 inspection is as follows:

Table 4.27: Cost estimation for V-800 inspection

Item No	**Quantity**	**Description**	**Price (RM)**
1	1	• Offshore rate for Inspection Engineers (based on 12 hours) • Mob & Demob rate • Standby Rate	RM2,800.00 RM2,350.00 RM1,100.00
2	LUMP SUM	Inspection Coverage: • Opening Vessel • Visual (Internal) Equipments and Tools	RM2,140.00
TOTAL			**RM 8,390.00**

During the Period 2, there are two inspection need to be conducted onto V-800 in Year 2014. The costs estimation for the inspection are as follows:

Table 4.28: Estimation costs of inspection for two pressure vessels in BNDP-J

Item No	**Quantity**	**Description**	**Price (RM)**
1	1	• Offshore rate for Inspection Engineers (based on 12 hours) • Mob & Demob rate • Standby Rate	RM2,800.00 RM2,050.00 RM1,180.00
2	LUMP SUM	Inspection Coverage: • Visual (External) • NDE-UT Equipments and Tools	RM3,140.00
TOTAL			**RM 9,082.50**

4.3.3.2 Piping

In BNDP-J there are total of 13 piping circuits. These piping circuits transporting crude oil from the wellhead to be processed in the Processing Platform. Inspection of piping can be conducted together with inspection of pressure vessel. However, in this section, we will discuss the cost estimation of inspecting piping systems only.

Piping usually being inspected according to its system. As for BNDP- J, there are 13 piping system in the facilities. Methods that are usually applied for piping inspection are Visual Inspection and Ultrasound Thickness Measurement.

4.3.3.2.1 Estimation of Inspection Cost without RBI

Following illustrates the costs estimation for inspection of one piping system.

Table 4.29: Estimation for inspection of one piping system in BNDP-J

Item No	**Quantity**	**Description**	**Price (RM)**
1	1	• Offshore rate for Inspection Engineers (based on 12 hours) • Mob & Demob rate • Standby Rate	RM2,800.00 RM2,350.00 RM2,080.00
2	1	• Offshore rate for Qualified Inspectors (based on 12 hours) • Mob & Demob rate • Standby rate	RM1260.00 RM962.50 RM800.00
3	LUMP SUM	Piping Inspection: • NDE-UT Thickness Measurement • Visual Inspection (External) Equipments & Tools	RM4,200.00
TOTAL			**RM 14,425.50**

If all 13 piping system is inspected at the same time, we can calculate the by multiply the total cost by 13. But we can consider mobilizing and demobilizing the manpower to be once and the offshore rate and standby rate for both engineers and inspector is maintained.

Table 4.30: Estimation of Inspection costs for all piping circuits in BNDP-J

Item No	**Quantity**	**Description**	**Price (RM)**
1	6	• Offshore rate for Inspection Engineers (based on 12 hours) • Mob & Demob rate • Standby Rate	RM16,800.00 RM14,100.00 RM8,320.00
2	6	• Offshore rate for Qualified Inspectors (based on 12 hours) • Mob & Demob rate • Standby rate	RM7,560.00 RM5773.00 RM3200.00
3	LUMP SUM	Piping Inspection: • NDE-UT Thickness Measurement • Visual Inspection (External) Equipments & Tools	RM54,600.00
TOTAL			**RM 110,353.00**

Conventionally, inspection activity for piping is conducted based on time or condition of the piping. For the purpose of estimation of cost of inspection, it is assumed that for a period 5 years, about 7 piping circuits need to be inspected due to their conditions. The followings are the estimated costs for inspection without RBI Year 2006-2010 and Year 2011-2015

Table 4.31: Estimated Inspection Costs without RBI for Year 2006-2010

Item No	**Quantity**	**Description**	**Price (RM)**
1	6	• Offshore rate for Inspection Engineers (based on 12 hours) • Mob & Demob rate • Standby Rate	RM10,800.00 RM8,100.00 RM5,320.00
2	6	• Offshore rate for Qualified Inspectors (based on 12 hours) • Mob & Demob rate • Standby rate	RM4,560.00 RM2773.00 RM2200.00
3	LUMP SUM	Piping Inspection: • NDE-UT Thickness Measurement • Visual Inspection (External) Equipments & Tools	RM22,600.00
TOTAL			**RM 56,353.00**

Table 4.32: Estimated Inspection Costs without RBI for Year 2011-2015

Item No	**Quantity**	**Description**	**Price (RM)**
1	6	• Offshore rate for Inspection Engineers (based on 12 hours) • Mob & Demob rate • Standby Rate	RM10,800.00 RM9,100.00 RM3,320.00
2	6	• Offshore rate for Qualified Inspectors (based on 12 hours) • Mob & Demob rate • Standby rate	RM4,560.00 RM2773.00 RM2200.00
3	LUMP SUM	Piping Inspection: • NDE-UT Thickness Measurement • Visual Inspection (External)	RM20,600.00
TOTAL			**RM 53,353.00**

4.3.3.2.2 Estimation of Inspection Cost with RBI

Implementing RBI on the piping circuit of BNDP-J has affected the overall inspection costs. During the RBI is in progress (Year 2005) there are 11 piping circuits subjected for NDE-UT and 5 subjected for External Visual Inspection. The total cost of inspection for that year for piping circuits is estimated as follows:

Table 4.33: Estimated total cost of inspection for that year for piping

Item No	**Quantity**	**Description**	**Price (RM)**
1	4	• Offshore rate for Inspection Engineers (based on 12 hours) • Mob & Demob rate • Standby Rate	RM11,200.00 RM9,400.00 RM2,773.00
2	2	• Offshore rate for Qualified Inspectors (based on 12 hours) • Mob & Demob rate • Standby rate	RM2,520.00 RM1924.00 RM1600.00
3	LUMP SUM	Piping Inspection: • NDE-UT Thickness Measurement • Visual Inspection (External) Equipments & Tools	RM28,600.00
TOTAL			**RM 58,017.00**

For the Period 1 (Year 2006 – 2010) there are 5 piping circuits subjected for External Visual Inspection in Year 2009. The estimated cost for the inspection is estimated as follows:

Table 4.34: estimated cost for the inspection for Year 2006-2010 of BNDP-J

Item No	Quantity	Description	Price (RM)
1	1	• Offshore rate for Inspection Engineers (based on 12 hours) • Mob & Demob rate • Standby Rate	RM2,800.00 RM2,350.00 RM2,080.00
2	1	• Offshore rate for Qualified Inspectors (based on 12 hours) • Mob & Demob rate • Standby rate	RM1260.00 RM962.50 RM800.00
3	LUMP SUM	Piping Inspection: • Visual Inspection (External)	RM8,300.00
TOTAL			**RM 18,552.50**

For the Period 2 (Year 2010 – 2015), 2 piping circuits subjected for External Visual Inspection and 3 piping circuits subjected for NDE-UT. The estimated cost is as follows:

Table 4.35: Estimated inspection costs for Year 2010-2015 in BNDP-J

Item No	**Quantity**	**Description**	**Price (RM)**
1	1	• Offshore rate for Inspection Engineers (based on 12 hours) • Mob & Demob rate • Standby Rate	RM2,800.00 RM2,350.00 RM2,080.00
2	1	• Offshore rate for Qualified Inspectors (based on 12 hours) • Mob & Demob rate • Standby rate	RM1260.00 RM962.50 RM800.00
3	LUMP SUM	Piping Inspection: • Visual Inspection (External) • NDE-UT Thickness Measurement	RM10,800.00
TOTAL			**RM 21,425.50**

4.3.3.3 Overall Inspection Cost with RBI for Piping & Pressure Vessel

Year 2005:

RM 58,017.00 + RM 20,392.50 = RM78,409.00

Year 2006 – 2010:

RM 18,552.50 + RM 8,390.00 = RM 26,942.50

Year 2011 – 2015:

RM 9,082.50 + RM 21,425.50 = RM 30,508.00

From the analysis of estimation of inspection costs with and without RBI for BNDP-J, the trend were observed and represented in Figure 4.6. The total inspection costs are cumulative amount of five years.

From the figure, it is clearly shown that the total inspection costs are reduced with the implementation of RBI.

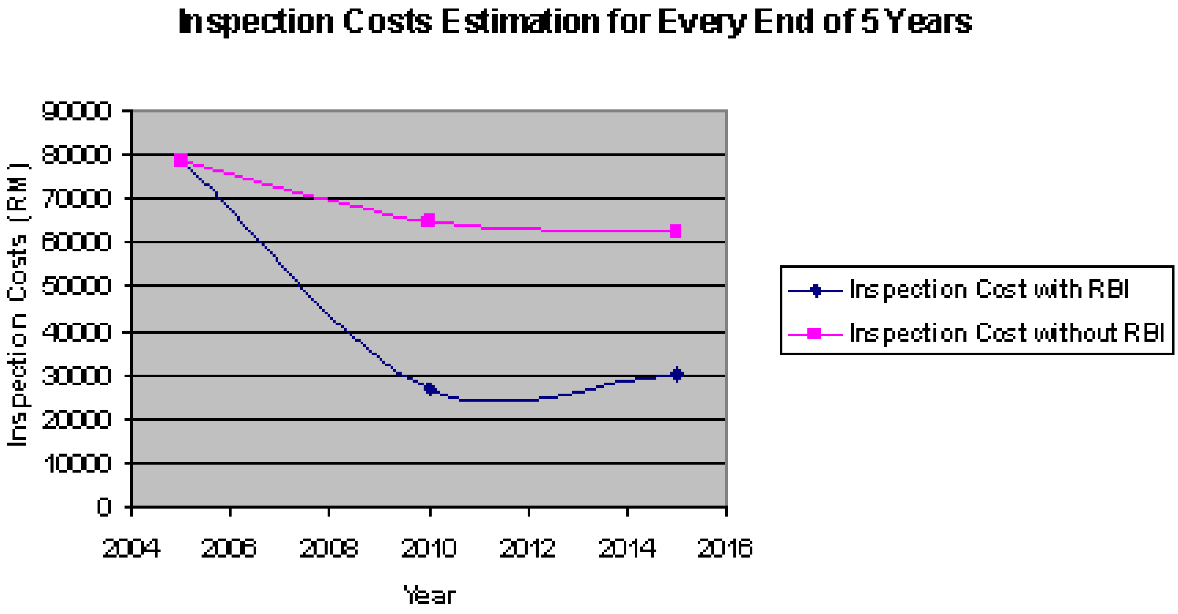


Figure 4.6: Inspection Costs Estimation for BNDP-J

4.3.3.4 Production Loss

RBI should predict when the equipment is going to fail due to certain degradation mechanisms. From that prediction, the user can develop the inspection plan to rectify the problem and lower the risk so that the equipment can operate safely. Shutdown due to equipment failure can affect the production of the facilities. As for BNDP-J, the production loss per hour due to failure of any equipment and piping are assumed as follows:

a) Total Production for BNDP-J Oil Output = USD18/barrel x 7094 barrels/day
= **USD 127,692 /day**
= **USD 5320.50 / hour**

b) Gas Output = USD 921/MMSCFx 24.087 MMscfd
= **USD 22,184 /day**
= **USD 924/hour**

c) Therefore, total production loss due to equipment failure is estimated as
= **USD 6,245/ hour**

4.3.2 OPTIMIZING INSPECTION ACTIVITY

The case studies show that implementing Risk-Based Inspection, inspection activity can be optimized by:

I. Increasing activity level or frequency if insufficient reduction in risk occurs, or
II. Decreasing activity level or frequency if no gain in risk reduction results from the higher level of inspections.

The followings are general guidelines that were obtained from the case studies that may be used for inspection optimization.

a) Damage factors can usually be kept close to one by inspection activities of a moderate extent. Values exceeding ten can usually be avoided.
b) Damage factors significantly greater than ten may be calculated when an inspection program that has not previously been on risk is first evaluated. Equipment items showing these higher values should receive first priority for inspection optimization. Within this sets of equipment items. Those with the highest risk should be evaluated first.
c) Some equipment that had been inspected multiple times and has confirmed low damage rates may be over-inspected. Alternate plan to reduce inspection activities or frequency can be evaluated through the technical modules to determine the effect of risk. Within this sets of equipment items, those with the lowest risk should be evaluated first.
d) Equipment that is subjected to a large uncertainty in the damage rate (as expressed in the (Technical Module) will require frequent or thorough inspections to keep risks levels low, at least until sufficient history on performance has been established.
e) Equipment that is approaching the end of its life due to corrosion or other deterioration requires increased inspection activities to be sure that the limits of deterioration (e.g. corrosion allowance) are not exceeded. Increased inspection will not reduce the damage factor once the remaining life has been consumed.

f) Inspection program option should be projected over a significant portion, at least half, of the equipment’s intended remaining life. Damage factors may tend to increase later in the equipment life if insufficient inspections are performed.

These guidelines are summarizes in table below:

Table 4.36: Damage Factors for Four Inspection Plans

Year (ar/t)	**Damage Factor, Before/after Inspection**				**Damage Factor Comments**
	Plan 1	**Plan 2**	**Plan 3**	**Plan 4**	
6 (0.08)	1	1	1	1	All four plans start out the same time
9 0.12)	1/1			1/1	1/1 indicated the damage factor was the same before and after inspection. No inspection are done for Plan 2 and Plan 3
15 (0.20)	2/1	10/2	2/1	10/5	Plan 4 has not performed enough inspections. Confidence in the corrosion rate does not outweigh the possibility that a higher rate exists.
18 (0.24)	1/1	15/3	1/1	15/8	Plan 2 has not performed enough inspections. Confidence in the corrosion rate does not outweigh the possibility that a higher rate exists.

Table 4.37: Inspection activity evaluation for risk reduction inspection optimization

Steps	**Purpose**	**Evaluation**
Step 1	Baseline Risk Ranking	Perform risk ranking of current system
Step 2	Risk Reduction	From the set of highest risk items, select those that also have a high probability of failure due to a high damage subfactors. Evaluate optional inspection plans to reduce the risk and implement the plan selected.
Step 3	Inspection Optimization	From the set of lowest risk items, select those that have a low probability of failure due to a low damage factor. Evaluate optional inspection plans to find the optional amount of inspection effort required to maintain low risk.

4.3.2.1 Inspection Work Plan for Duyong Central Processing Platform

The purpose of the Inspection Work Plan is to optimize the inspection activity by putting the necessary inspection for a certain type of Degradation Mechanisms.

There are only continuous rate models are subjected to inspection, thus inspection tasks are suggested for rate models only. In some cases, inspection methods are suggested for susceptibility mechanisms. These are intended to detect damage, but not to monitor development of damage over time, i.e. damage is detected it should be sized, repair if necessary, and conditions causing shall be removed and permanent effective corrosion mitigation shall be implemented.

APPENDIX 4N shows the full Inspection Work Plan of Duyong Central Processing Platform

4.3.2.2 Inspection Work Plan for Baronia Drilling Platform-J

The purpose of the Inspection Work Plan is to optimize the Inspection activity in BNDP-J so that it can be cost effective and help reducing the risk of the equipment by suggesting appropriate rectification. Table in the appendix shows the Inspection Work Plan that was developed by the RBI team members of BNDP-J. From the plan, we can see that Inspection method is different depending on the damage mechanisms. For example, NDE-UT is conducted for internal corrosion and visual inspection is conducted for external corrosion.

The Inspection Work Plan also suggests the coverage of the inspection. Coverage for each of the inspection to be conducted is depending on the extent of the damage mechanisms. An equipment doesn’t need a 100% coverage of inspection if there is only certain area are damage or corroded. For example, as in the table, only 10% of the potential location will be inspected if there is corrosion occurs and for pressure vessel, there are certain parts that need more attention such as nozzles, shells, etc.

APPENDIX 4P shows the full Inspection Work Plan of Baronia Drilling Platform-J

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

- The project concluded that Risk-Based Inspection was properly implemented on offshore facilities. From the case studies that has been conducted shows that the methodology and process applied by the offshore operators are inline with the API Recommended Practice (API 580 & API 581). Both methodologies (API Recommended Practice and PETRONAS-RBI) derived similar results which are shown by the analysis and Risk Matrix (Figure 4.2 and Figure 4.4).

  Thus, the objective of implementing RBI on offshore facilities to maximize facilities and equipments availability and optimize the inspection activity can be achieved.

- In conducting RBI analysis, sufficient data is essential. As more data were made available, more assumptions can be eliminated and more accurate result can be obtained.

- Implementation of RBI in offshore facilities generates benefits for the facilities:
  1. RBI optimizes the inspection activity. Inspection Planning developed allows consideration for reduction of inspection activities in those areas that have a lower risk or where the inspection activity has little or no affect on the associated risks. Thus the number of inspection activity and frequency can be optimized by inspecting only the necessary equipments.
  2. Inspection costs can be more effectively managed. Resources can be applied or shifted to those areas identified as a higher risk or targeted based on the strategy selected. These results in inspection resources being applied where they are needed the most.

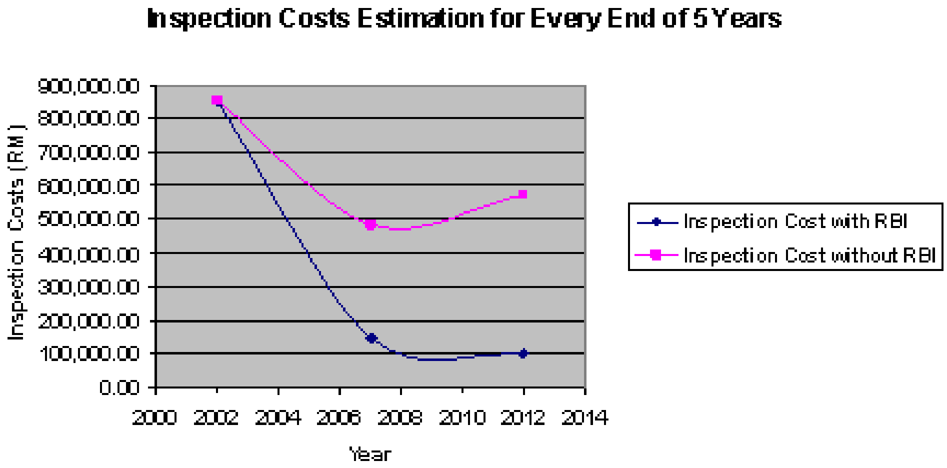


Figure 5.1 a: Estimated Inspection Costs for Duyong CPP

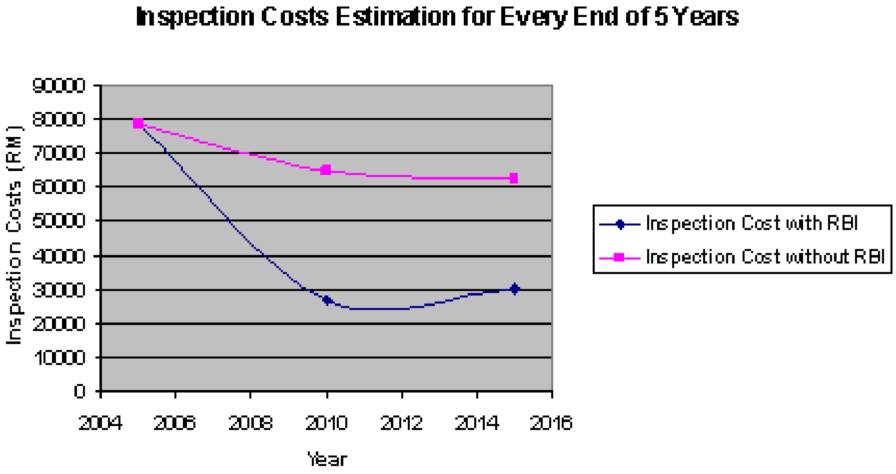


Figure 5.1 b: Estimatred Inspection Costs for BNDP-J

Figure 5.1: Estimated Inspection Costs with and without RBI on DUYONG CPP & BNDP-J

5.2 Recommendations

5.2.1 Duyong CPP

The implementation of RBI in Duyong CPP only started in the year 2002. To implement RBI on Duyong CPP they need base line data for every equipment and piping circuits so that less assumption can be made and the results are more accurate. They found that it is so difficult to locate and find the data since that there thousands of equipments in the facilities and sometimes the documents are no longer relevant for current review.

It is recommended for the RBI team of Duyong CPP to reevaluate their implementation of RBI. An effort to locate the necessary data and documents need to be more aggressive. This is important so that the assumptions that were made during the first RBI practice can be eliminated. Thus, will result more accurate calculations and risk ranking of the equipments.

5.2.1 Baronia DP-J

The intent of RBI implementation on BNDP-J is to manage the probability of failure associated with the components while establishing and optimized inspection program. As more data is gathered from upcoming inspections and damage mechanism continues to be defined, the final result should be updated to provide guidance for further inspections.

By managing the inspection activities, it will improve the equipment condition confidence and consequently, the risk associated with the equipment and piping can be managed to an acceptable level with the lowest inspection costs.

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