The Development of Equipment Criticality Analysis (ECA) Protocols of Offshore Carbon Steel Static Mechanical Equipment

Dwi Priyanta[1]

[1]Department of Marine Engineering, Institut Teknologi Sepuluh Nopember (ITS)
Surabaya, Indonesia
Email: priyanta [AT] its.ac.id

ABSTRACT— ***Best practice in developing Inspection Plan for static mechanical equipment on offshore topside platform is by performing Risk-based inspection (RBI) analysis. However, there are hundreds or even thousands static mechanical equipment on offshore topside platform. Since detailed RBI analysis requires a lot of data and tedious calculation then it is necessary to do equipment criticality screening prior to perform detail RBI analysis as it is suggested in DNV-RP-G101. Equipment Criticality Analysis (ECA) protocols for carbon steel static mechanical equipment have been developed as criticality screening tools. The protocols were developed based upon DNV-RP-G101. ECA categorizes the static mechanical equipment into C1, C2, or C3 which refer to high, medium or low criticality equipment respectively. The C3 equipment will receive minimum surveillance with planned corrective maintenance while C2 and C1 equipment will require detail RBI analysis.***

Keywords— Equipment Criticality Analysis (ECA), Risk-Based Inspection (RBI), DNV-RP-G101, Risk

1. INTRODUCTION

There are hundreds even thousands static mechanical equipment installed on topside of offshore platforms. The equipment might suffer more than one degradation mechanism that leads to loss of its integrity. Inspection program will ensure the integrity of the equipment. It will check the wall thickness of the static mechanical equipment, predict the degradation rate and conclude whether the existing equipment is still fit to operate. A comprehensive and effective inspection program will describe clearly of what, when, where and how to inspect [1, 2]. These can be achieved by performing Risk-Based Inspection (RBI) Analysis. RBI is a decision making technique for inspection planning based on risk.

Risk is a measure of possible loss or injury, and is expressed as the combination of the incident probability and its consequences. RBI defines risk as loss of containment of pressurized equipment. Mathematically, risk can be expressed in equation (1).

$$Risk = Probability\ of\ Failure\ \times Consequence\ of\ Failure \tag{1}$$

To carry out the RBI analysis for each equipment, the consequences of failure (CoF) and probability of failure (PoF) are assessed separately. Both of them are then combined to obtain risk of equipment failure. This evaluation is carried out separately for safety (addressing personnel death and injury), environmental (addressing damage to the environment) and economic (addressing financial loss).

Equipment criticality analysis (ECA) will be a crucial screening tool prior to performing RBI analysis when the analysis involves hundreds or even thousands of equipment. The premise says that a large percent of the total unit risk will be concentrated in a relatively small percent of the equipment items [3].

ECA is a risk-based screening process to prioritize which equipment should be analyzed further using RBI or not. The basic equipment criticality analysis risk matrix uses a 2 x 2 risk matrix as screening tool as it is shown in Figure 1. DNV [2] recommends that the boundary between low and high probability of failure has been set to approximately 10^{-5} per year, i.e. no significant degradation is expected with PoF of 10^{-5} per year or less. The matrix classifies risk into three levels; they are low risk, medium risk and high risk. ECA denotes low risk, medium risk and high risk as C3, C2 and C1 respectively. Generally, low criticality equipment (C3) requires minimal inspection supported by maintenance. Medium

(C2) and high (C1) criticality equipment require detail evaluation. In the case of piping and pressure vessels, risk-based inspection (RBI) will be utilized to perform analysis in detail.

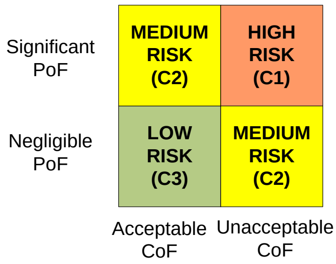

Figure 1: Basic Equipment Criticality Analysis Matrix

2. EQUIPMENT CRITICALITY ANALYSIS (ECA) PROTOCOL

Concept of risk is adopted in developing the equipment criticality analysis protocol of offshore carbon steel static mechanical equipment. In this case, risk is defined as the loss of containment of pressurized mechanical equipment. The categories of equipment belong to the ECA are mostly carbon steel pressure vessels and piping. The criticality of equipment is determined by scoring probability of event that leads to the loss of containment of pressurized equipment and the consequences of it that leads to health and safety of personnel, environmental pollution as well as business interruption. The combination of probability and consequence scoring will represent the risk or the criticality level of the equipment being analyzed.

The ECA protocols will adopt scoring system as it is suggested by Muhlbauer [4]. The ECA scoring system for offshore carbon steel mechanical equipment will be developed based on the model shown in Figure 2. The left and right side of Figure 2 shows the probability of failure and consequence of failure model respectively.

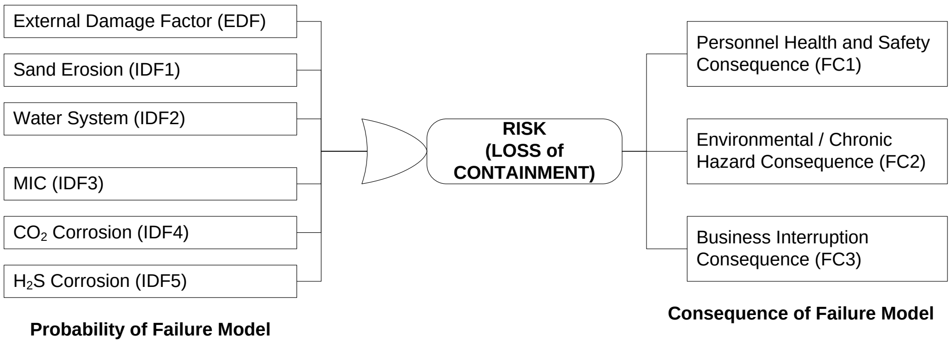

Figure 2: ECA Model for Offshore Carbon Steel Mechanical Equipment

The probability is modeled based upon external damage factor (EDF) and internal damage factor (IDF) as it is suggested in [2]. The sub category of internal damage factor consists of sand erosion (IDF1), water systems (IDF2), microbiologically induced corrosion (IDF3), CO_2 corrosion (IDF4) as well as H_2S corrosion (IDF5). Each damage factor is assessed separately since each damage factor occurs independently.

The consequence of failure is evaluated based on three types of consequences. The consequences relate to the safety of personnel (FC1), to the environment (FC2) and to the economy / business interruption (FC3).

The developed ECA protocols will be implemented in an oil gas company which has established a 5 x 6 risk matrix. The risk matrix consists of 5 probability ratings and 6 consequence ratings. For those reasons, the ECA scoring protocols will also be developed based upon a 5 x 6 risk matrix.

3. PROBABILITY OF FAILURE MODEL

Probability of failure (PoF) model of carbon steel material will be represented by external damage factor (EDF) and internal damage factor (IDF). The IDF covers sand erosion (IDF1), water system (IDF2), microbiologically induced corrosion or MIC (IDF3), CO_2 Corrosion (IDF4) and H_2S Corrosion (IDF5) as it is recommended by DNV [2].

EDF will be scored ranging from 1 to 10 while IDF1 to IDF5 will be scored ranging from 1 to 5. The minimum score 1 means that the probability model will have low probability of occurrence. The maximum score 5 or 10 means that that the probability model will have high probability of occurrence.

3.1 External Damage Factor (EDF)

Atmospheric corrosion is basically a chemical change that occurs in the material of component as a result of material interactions with the atmosphere. Generally, these interactions cause oxidation on metal. Corrosion rate of external corrosion will increase if the coating of the component is damaged or the temperature is increased.

The external damage factor is modeled based upon the atmospheric type where the equipment is operated, coating age and corrosion rate as a function of temperature. The scoring protocol of external damage factor (EDF) is given by equation (2).

$$EDF = AT + \frac{(CO+T)}{2} \qquad (2)$$

AT, CO and T represent atmospheric type, coating age and corrosion rate as a function of temperature respectively. The scoring protocol for each parameter is listed in Table 1, Table 2 and Table 3 respectively.

Table 1: Atmospheric type scoring protocol

Atmospheric Type (AT)	Score
Low humidity and low temperature	1
Chemical and low humidity	2
High humidity and high temperature	3
Marine, swamp, coastal	4
Chemical and high humidity	5
Chemical and marine	5

Table 2: Coating age scoring protocol

Coating Age (CO)	Score
< 5 years	1
≥5 to < 7.5 years	2
≥7.5 to < 10 years	3
≥10 to < 12.5 years	4
≥12.5 years	5

Table 3: Temperature scoring protocol

Temperature Range (T)	Score
T< 20 C	1
20 < T < 50 C	2
50 < T < 80 C	3
80 < T < 100 C	4
T > 100 C	5

3.2 Internal Damage Factor 1 (IDF1) – Sand Erosion

Degradation due to sand erosion gives general wall thinning where the product flow impinges on the pipe or vessel wall. The rate of wall loss by erosion increases with the quantity of sand in the product and the product flow rate.

The sand erosion is modeled based upon the solid quantity and velocity of the fluid [5]. The combination of these two parameters will form an evaluation matrix to predict the occurrence of sand erosion as it is shown in Figure 3. The matrix will show whether the probability of occurrence of sand erosion will be very high, high, medium, low or very low. These classifications are then used as a basis of sand erosion scoring protocol as it is shown in Table 4.

Velocity \ Solids	Low	Medium	High
High	Medium	High	Very High
Medium	Low	Medium	High
Low	Very Low	Low	Medium

Figure 3: Evaluation Matrix to Predict the Occurrence of Sand Erosion

Table 4: IDF1 scoring protocol – sand erosion

Possibility Erosion Occurrence	IDF1 Score
Very High	5
High	4
Medium	3
Low	2

Possibility Erosion Occurrence	IDF1 Score
Very Low	1

3.3 Internal Damage Factor 2 (IDF2) – Water Systems

Water systems use "water" of various corrosiveness, ranging from untreated seawater to potable water. Corrosion rate increases with the increase in flow rate, oxygen concentration and temperature. DNV has shown that the rate of internal corrosion of carbon steel piping depends on the flow rate of sea water and it can be described by normal distribution [2]. The flow rate of sea water varies from 0 m/s to about 5.5 m/s while the mean corrosion rate varies from 0.1 mm/year to about 0.9 mm/year. In this case, the higher the flow rate, the higher mean corrosion rate will be. The combination of sea water flow rate and estimated corrosion rate will be adopted in scoring protocol of water systems (IDF2) as it is shown in Table 5.

Table 5: IDF2 scoring protocol – water systems

Water Flow Rate	Estimated Corrosion Rate	IDF2 Score
< 1 m/s	0.1 - 0.2 mm/year	1
1 to 1.5 m/s	0.2-0.4 mm/year	2
1.5 to 2 m/s	0.4 - 0.6 mm/year	3
2 to 3.5 m/s	0.6 - 0.8 mm/year	4
3.5 to 6 m/s	0.8 - 1 mm/year	5

3.4 Internal Damage Factor 3 (IDF3) – Microbiologically Induced Corrosion (MIC)

The microbiologically induced corrosion (MIC) is generally not expected in other materials than carbon steels in anaerobic hydrocarbon systems. DNV presented the graph that shows the relation of probability of failure (per mm of wall thickness) of carbon steel static mechanical equipment due to microbiologically induced corrosion as a function of water temperature [2]. By knowing the water temperature that flows in the equipment we may estimate the probability of the failure of the equipment due to microbiologically induced corrosion. The scoring protocol of MIC is developed based upon the probability of failure value read from the graph. Table 6 shows the scoring protocol of microbiologically induced corrosion (IDF3).

Table 6: IDF3 scoring protocol – microbiologically induced corrosion

Probability of Failure (failure per year)	IDF3 Score
$<10^{-6}$	1
10^{-6} to 10^{-4}	2
10^{-4} to 10^{-2}	3
10^{-2} to 1	4
>1	5

3.5 Internal Damage Factor 4 (IDF4) – CO2 Corrosion

Carbon Dioxide is a weakly acidic gas which is corrosive when dissolved in water becoming carbonic acid (H_2CO_3). The partial pressure of CO_2 is used as a guideline to determine the corrosiveness of CO_2 as recommended by NACE [6]. In the presence of water, NACE divided the CO_2 corrosion into three categories. A partial pressure of CO_2 above 207 kPa (30 psi) is usually corrosive, between 21 kPa (3 psi) and 207 kPa (30 psi) may be corrosive and below 21 kPa (3 psi) is generally considered noncorrosive. These criteria are adopted to develop the scoring protocol of CO_2 corrosion as it is shown in Table 7.

Table 7: Scoring protocol of IDF4 – CO_2 corrosion

CO_2 Partial Pressure	IDF4 Score
> 30 psi	5
3 psi to 30 psi	3
< 3 psi	1

3.6 Internal Damage Factor 5 (IDF5) – H2S Corrosion

If equipment material made of carbon or low alloy steel and the process contains water and H_2S in any concentration, the equipment should be evaluated for susceptibility to H_2S corrosion. The H_2S scoring protocol is developed based upon the environmental severity since this will contribute to H_2S corrosion growth. API provides the H_2S environmental severity level as a function of pH of water and H_2S content in water as it is shown in Table 8 [3]. Table 9 shows the scoring protocol of H_2S corrosion that is generated based upon values listed in Table 8.

Table 8: Environmental severity as function of water pH and H_2S content

pH of Water	H_2S Content (ppm)			
	< 50	50 to 1,000	1,000 to 10,000	> 10,000
< 5.5	Low	Moderate	High	High
5.5 to 7.5	Low	Low	Low	Moderate
7.6 to 8.3	Low	Moderate	Moderate	Moderate
8.4 to 8.9	Low	Moderate	Moderate	High
> 9.0	Low	Moderate	High	High

Table 9: Scoring protocol of IDF5 – H_2S corrosion

Environmental Severity	IDF5 Score
High	5
Moderate	3
Low	1

4. CONSEQUENCE OF FAILURE MODEL

Consequence of failure (CoF) is evaluated based on three types of consequences. They are: the consequences related to the safety of personnel (FC1), to the environment (FC2) and to the economy / business interruption (FC3). Size of the leakage hole (Ch) and pressure (Cp) will contribute significantly to the severity of the consequences of failure.

4.1 Size of the Leakage Hole

Size of the leakage hole together with pressure of product service will determine the amount of product service released to the atmosphere when a static mechanical equipment is leaking. The scoring protocol of the size of the leakage hole is based on standard size of the leakage hole category model. Table 10 shows the scoring protocol of size of the leakage hole.

Table 10: Scoring protocol of size of the hole (Ch)

Leakage Hole Category	Hole Size Diameter (D)	Score
Small Holes	$D \leq 5$ mm	1
Medium Holes	$5mm < D \leq 25$ mm	2
Large Holes	$25 \text{ mm} \leq D$	3
Ruptures	Equipment Diameter < D	4

4.2 Pressure

Pressure hazard is proportional to the internal pressure inside the equipment. Maximum operating pressure (MOP) will be used as parameter to consider the contribution of pressure inside the equipment when it leaked. Table 11 shows the pressure distribution and its scoring protocol which will be used during ECA process.

Table 11: Scoring protocol of MOP (Cp)

Pressure	Score
≤ 50 psig	1
> 50 psig to ≤ 200 psig	2
> 200 psig to ≤ 400 psig	3
> 400 psig to ≤ 600 psig	4
> 600 psig to ≤ 700 psig	5
> 700 psig	6

4.3 Consequence Modeling of Health and Safety of Personnel (FC1)

The consequences of equipment failure are modeled based on the properties of the product service that is transported within the equipment. The hazard category levels caused by product service may refer to NFPA 704 [7]. Chemical compositions of the product service consist of several materials. The most dominant chemical composition will be selected to represent the consequence model.

The primary factor in determining the nature of the hazard is the product service itself. Most products will have some acute hazard characteristics and some chronic hazard characteristics. Acute means sudden onset, or demanding urgent attention, or of short duration. Hazards such as fire, explosion, or contact toxicity are considered to be acute hazards.

They are immediate threats caused by a leak. Acute hazard scoring will consider following hazard characteristics, flammability (Nf), reactivity (Nr) and toxicity (Nh). These hazard characteristics will be adopted as part of FC1 scoring protocol as it is also found in [8]. Flammability scoring protocol is shown in Table 12, reactivity scoring protocol is shown in Table 13 and toxicity scoring protocol is shown in Table 14.

Scoring Personnel Health and Safety Consequence (FC1) can be obtained by summing up all Nf, Nr, and Nh scores and then multiply them by the size of the leakage hole score (Ch) and pressure score (Cp) as it is shown in the equation (3). Based on the values listed in Table 10 to Table 14, the possible score of FC1 will vary from 0 to 288.

$$FC1 = Ch \times Cp \times (Nf + Nr + Nh) \tag{3}$$

Table 12: Scoring protocol of flammability

Flammability Criteria	Nf
Noncombustible	0
FP > 200°F	1
100°F < FP < 200°F	2
FP < 100°F and BP < 100°F	3
FP < 73°F and BP < 100°F	4

Table 13: Scoring protocol of reactivity

Reactivity Criteria	Nr
Substance is completely stable	0
Mild reactivity on heating with pressure	1
Significant reactivity	2
Detonation possible with confinement	3
Detonation possible without confinement	4

Table 14: Scoring protocol of toxicity

Toxicity Criteria	Nh
No hazard beyond that of ordinary combustibles	0
Only minor residual injury is likely	1
Prompt medical attention required to avoid temporary incapacitation	2
Materials causing serious temporary or residual injury	3
Short exposure causes death or major injury	4

4.4 Consequence Modeling of Environmental Pollution (FC2)

The environmental pollution consequence (FC2) is modeled based on the combination of leakage hole size, pressure and the amount of reportable spill quantity (RQ) of product service that spilled when a component is leaking [8]. The score of RQ varies from 0 to a maximum 10. Score 0 can be interpreted that the spill corresponds to least spill while score 10 corresponds to large spill. Environmental pollution consequence score (FC2) can be obtained by multiplying leakage hole size score (Ch), pressure score (Cp) and spill quantity score (RQ) as it is shown in equation (4). The possible score of FC2 will vary from 0 to 240.

$$FC2 = Ch \times Cp \times RQ \tag{4}$$

Auto ignition likelihood of released product will contribute to the possibility of fire or explosion if the product service released into the air due to equipment leakage. Released product that has AIT (auto ignition temperature) lower than the operating temperature or the temperature around when the product is released to the air will be more flammable. Table 15 shows the scoring protocol regarding the possibility of auto ignition occurrence when the product service leaked (FC3.1).

Table 15: Scoring protocol of released product auto ignition (FC3.1)

Likelihood of Released Product to be Auto Ignited	Score
Likely	2
Unlikely	1

The location of the equipment also contribute to the damage of other components around the equipment that is being analyzed. Equipment located on the corner will have a lower contribution of damage to other equipment compared to that is located in the center of the plant. Table 16 tabulates the scoring protocol regarding to the equipment location in a plant (FC3.2).

Table 16: Equipment location scoring protocol (FC3.2)

Equipment Layout	Score
In a plant corner	1
In a vicinity of plant side	2

Equipment Layout	Score
In a vicinity between plant side / plant corner and plant center	3
In a vicinity close to center of the plant	4
In the center of the plant	5

Recovery time of plant outage depends on how severe is the damaged plant. Outage of the plant as a consequence of damaged equipment may last from a few hours to months. Table 17 lists the scoring protocol regarding to the plant outage evaluation (FC3.3).

Secondary damage to other equipment may only occur if the damage to the equipment being analyzed severe enough to affect other equipment. Table 18 shows the secondary damage scoring protocol regarding to the secondary damage equipment caused by other damaged equipment (FC3.4).

Table 17: Plant outage scoring protocol (FC3.3)

Plant Outage	Score
Partial shutdown < 1 day	1
Production loss total shutdown for < 1 day	2
Production loss total shutdown for > 1 day up to 1 week	3
Production loss total shutdown for > 1 week up to 0.5 month	4
Production loss total shutdown for > 0.5 month	5

Table 18: Scoring protocol of secondary damage equipment (FC3.4)

Secondary Damage	Score
Equipment it self	1
Some equipment in process unit	3
More than one process units	5

Considering the scoring protocols, the possible business interruption scores will vary from 3 to 720.

5. CONVERTING DAMAGE FACTOR SCORE INTO PROBABILITY RATING

Probability of failure models cover external damage factor and other five internal damage factors. It only needs one of damage factors to occur to make carbon steel static mechanical equipment leaks. That is the reason why damage factors which represent probability model in Figure 2 are connected in OR gate. Since there will be six different scores of damage factors, then it is only the worst score that will be selected to represent the probability of failure of the equipment being analyzed. Table 19 shows the conversion of damage factor score into probability rating.

Table 19: the Conversion of Damage Factors Scores into Probability Rating

EDF Score	IDF1 Score	IDF2 Score	IDF3 Score	IDF4 Score	IDF5 Score	Probability Rating	Probability Descriptor
1 – 2	1	1	1	1	1	1	Almost Impossible
3 – 4	2	2	2			2	Unlikely
5 – 6	3	3	3	3	3	3	Possible
7 – 8	4	4	4			4	Likely
9 – 10	5	5	5	5	5	5	Almost Certain

6. CONVERTING FAILURE CONSEQUENCE SCORE INTO CONSEQUENCE RATING

As it can be seen in Figure 2, there are three models to represent the consequences of failure. Those three models are the consequences related to the safety of personnel (FC1), to the environment (FC2) and to the economy / business interruption (FC3). Scoring protocols have been developed for those consequences. The conversion of consequence scores into consequence ratings is shown in Table 20.

Table 20: the Conversion of Consequence Scores into Consequence Rating

FC1 Score	FC2 Score	FC3 Score	Consequence Rating	Consequence Descriptor
$0 \leq FC1 \leq 48$	$0 \leq FC2 \leq 40$	$0 \leq FC3 \leq 120$	A	Slight
$48 < FC1 \leq 96$	$40 < FC2 \leq 80$	$120 < FC3 \leq 240$	B	Minor
$96 < FC1 \leq 144$	$80 < FC2 \leq 120$	$240 < FC3 \leq 360$	C	Moderate
$144 < FC1 \leq 192$	$120 < FC2 \leq 160$	$360 < FC3 \leq 480$	D	Serious
$192 < FC1 \leq 240$	$160 < FC2 \leq 200$	$480 < FC3 \leq 600$	E	Major
$240 < FC1 \leq 288$	$200 < FC2 \leq 240$	$600 < FC3 \leq 720$	F	Catastrophic

Table 21: Corporate probability ratings criteria

Probability Rating	Descriptor	Occurrence per Year
1	Almost Impossible	$<10^{-6}$
2	Unlikely	10^{-6} to 10^{-4}
3	Possible	10^{-4} to 10^{-2}
4	Likely	10^{-2} to 1
5	Almost Certain	>1

7. CASE STUDY OF THE IMPLEMENTATION OF ECA PROTOCOLS

The problem in implementing ECA protocols to the corporate which has developed its own risk matrix is quite challenging. In this case study, the developed ECA protocols will be adopted by a corporate which has a 5 x 6 risk matrix. The risk matrix consists of 5 (five) probability ratings and 6 (six) consequence ratings as it is shown in Figure 4. The risk level is divided into three levels, they are high risk (H), medium risk (M) and low risk (L). Table 21 shows the probability criteria and Table 22 shows the business interruption consequence criteria which are adopted by the corporate.

Table 22: Corporate business interruption consequence ratings criteria

Consequence Rating	Descriptor	Business Interruption
A	Slight	Partial shutdown < 1 day
B	Minor	Production loss total shutdown for < 1 day
C	Moderate	Production loss total shutdown for > 1 day up to 1 week
D	Serious	Production loss total shutdown for > 1 week up to 0.5 month
E	Major	Production loss total shutdown for > 0.5 up to 1 month
F	Catastrophic	Production loss total shutdown for > 1 month

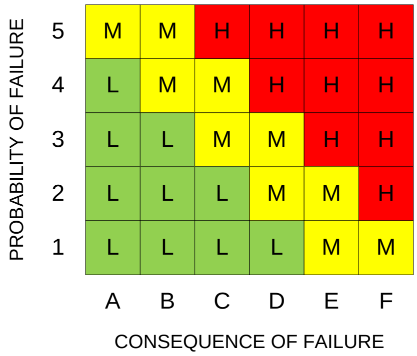

Figure 4: A 5 x 6 Corporate Risk Matrix

In order to be able to determine the criticality of the equipment, the integrated risk matrix must be converted into ECA risk matrix. To convert it, the following boundaries should be set. The boundary between negligible PoF and significant PoF has been set to approximately 10^{-4} per year. The boundary between acceptable CoF and Unacceptable CoF is set at minor consequence rating (Rating B). By adopting ECA protocols, a new ECA risk matrix based on corporate risk matrix has been developed as it is shown in Figure 5. C1, C2 and C3 in Figure 5 represent high, medium and low criticality of the equipment. The protocols and the matrix are ready to be implemented in screening the criticality of Offshore Carbon Steel Static Mechanical Equipment.

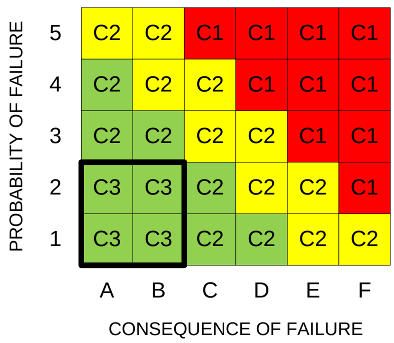

Figure 5: Adjusted Corporate Risk Matrix for ECA

8. CONCLUSION

The equipment criticality analysis (ECA) protocols of offshore carbon steel static mechanical equipment together with adjusted corporate risk matrix for ECA purpose have been developed. The case study shows that the methodology can be applied to any dimensions of risk matrix. The key point in implementing this methodology is to find the boundaries between negligible and significant probability of failure as well as between acceptable and unacceptable consequence of failure.

The ECA of offshore carbon steel static mechanical equipment will involve hundreds or even thousands piping segments and pressure vessels. Therefore, the future development will be focused in the database programming.

9. REFERENCES

[1] API RP 580 Risk-Based Inspection, Second Edition, Washington D.C, 2009.
[2] DNV-RP-G101 Risk Based Inspection of Offshore Topsides Static Mechanical Equipment, 2010.
[3] API RP 581 Risk-Based Inspection Technology, Second Edition, September 2008.
[4] Muhlbauer, W. Kent, Pipeline Risk Management Manual: Ideas, Techniques, and Resources, 3rd Edition, Gulf Professional Publishing, 2004.
[5] Bjarte Rød, Evaluation of Probability of Failure of Static Equipment in Pressurized Mud Systems on an Offshore Drilling Installation, Master Thesis, The Arctic University of Norway, pp. 47-49, 2015.
[6] NACE SP0106-2006 Item No. 21111 Standard Practice Control of Internal Corrosion in Steel Pipelines and Piping Systems, 2006.
[7] NFPA 704 Standard System for the Identification of the Hazards of Materials for Emergency Response, 2012.
[8] Muhlbauer, W. Kent, Pipeline Risk Management Manual: A Systematic Approach to Loss Prevention and Risk