FREE FALL LIFEBOAT LAUNCHING *RISK ASSESSMENT* USING FAILURE MODES AND EFFECTS ANALYSIS METHOD.

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***Abstract*—Lifeboat is one of the most important life-saving equipment onboard a ship, which is used at the time of extreme emergencies for abandoning a ship. Lifeboat is a smaller rigid vessel, secured onboard into davits so that it can be launched over the side of the ship with least time and mechanical assistance possible for an early escape of the crew from the ship. In the decades since it became a requirement that lifesaving appliances are available for everyone on board a vessel, many design features of lifeboats and their launching systems have changed. These have usually been in response to the demands for larger lifeboat capacity, greater protection for those using them, ease of operation and enhanced safety. A lifeboat must carry all the equipments described under SOLAS and LSA codes, which are passed for the survival at sea. This includes rations, fresh water, first aid, compass, distress signalling equipments like rocket etc. A ship must carry one rescue boat for the rescuing purpose, along with other lifeboats. One of the lifeboats can be designated as a rescue boat, if more than two or more lifeboats are present onboard a ship. The lifeboat is a water craft used to help passengers on boats and ships in trouble. It is a small craft aboard a ship to allow for emergency escape. A lifeboat is a kind of boat that is used to escape a larger sinking structure such as a cruise ship, commercial vessel, or aircraft that has landed in the water. A lifeboat is a small, rigid or inflatable watercraft carried for emergency evacuation in the event of a disaster aboard ship. This study aims to obtain the risk which can generated from a Lifeboat during launching and recovery operation using FMEA Method and get the level of risk priority who's acceptable risk, tolerable risk or high risk. Then how to minimize the high risk category to prevent accident using LOPA. Using Failure Modes and Effects Analysis Method (FMEA) for the risk assessment.**

***Keywords*—*Free fall lifeboat launching*, risk assessment, FMEA, *risk priority, LOPA*.**

I. INTRODUCTION

Since the beginning of the 20th century, an incredible improvement in safety at sea has taken place. Much of the improvement has to do with technical and operational improvements in ship and offshore technology and equipment, with the aim to avoid dangerous situations or limit the damage when a situation has occurred. Watertight bulkheads, fireproof materials, separated engine rooms etc. have been designed and developed to do just this; to prevent escalation of a dangerous situation.

Other systems aim to resolve dangerous situations or limit the damage by use of systems on board, such as firefighting systems, bilge pumps etc. However, in severe emergencies, these systems may not be sufficient to resolve the situation.

The initial incident, such as an explosion or a ship-to-ship collision, may escalate to a situation where it is no longer safe for the crew to stay on board the ship or installation. The only option is then to abandon ship, i.e. for the crew to leave the ship or installation and find a safe refuge in a lifeboat, another ship, offshore structure or on land. When the decision to abandon ship has been made, the crew members have to rely on the lifesaving equipment, which can consist of several different components. Although the subject of this thesis is lifeboats in arctic conditions, a more general overview of commercially available evacuation equipment is presented below.

This thesis will discuss the Risk Assessment on a Free-Fall Lifeboat with the purpose of determining whether an Free-Fall Lifeboat have a risk that is acceptable or not, create awareness about the dangers and risks obtained from the Free-Fall Lifeboat. It aims to reduce the possibility of danger by adding steps - necessary control measures and precautions. The assessment also prioritize hazards and help determine whether the existing control measures are adequate. A risk assessment carried out by the "FMEA (Failure Modes and Effect Annalysis)" method

II. LITERATURE REVIEW

A. *Free fall lifeboat launching*

A lifeboat is a kind of boat that is used to escape a larger sinking structure such as a cruise ship, commercial vessel, or aircraft that has landed in the water. A lifeboat is intended only for use in case of an emergency. Lifeboats may also be used if the larger structure is not sinking but is experiencing some other sort of disaster such as a fire that has become out of control. Lifeboats are almost always intended for use solely in the event of an emergency.

Free fall lifeboats are totally enclosed lifeboats, and is similar to the enclosed lifeboats in some ways. Openings for embarkation etc. are covered by watertight hatches which must be closed before launch. Propulsion is provided by an inboard diesel engine and a conventional propeller, and steering is provided by a propeller nozzle. Navigation is performed from the conning position, which on most free fall lifeboats is positioned in the aft of the boat.

Free-fall lifeboats are stored and boarded in the davit. They are stored on sloping longitudinal skids which are approximately the same length as the craft, with locking devices which hold it in position. When the boat is released it slides longitudinally off the skids and falls freely to the water surface without any ropes or wires connecting it to the ship or installation from which it is launched. Some models have an alternative arrangement without skids, where the lifeboat is released in a direct vertical direction, and enters the water with no initial forward velocity. In both alternatives, the lifeboat hits the water with the bow first at a forward heeling angle, which causes it to move forward and away from the ship or installation. The launching process is illustrated in Figure 18, which shows a full size life boat trial performed by launching the lifeboat from a steel frame which acts as the davit. For the trial, the steel frame is suspended in a floating crane.

Figure 1 Full scale free fall lifeboat trial

Compared to conventional lifeboats, free-fall lifeboats provide a very quick escape, and the launching method involves a low risk for incidents during the launch which may occur for conventional lifeboats. Free fall lifeboats are therefore in use on many oil rigs, platforms, bulk carriers and ships which carry dangerous cargo.

B. Risk Assessment

Risk assessment is typically applied as an aid to the decision-making process. As options are evaluated, it is critical to analyze the level of risk introduced with each option. The analysis can address financial risks, health risks, safety risks, environmental risks and other types of business risks. An appropriate analysis of these risks will provide information which is critical to good decision making, and will often clarify the decision to be made. The information generated through risk assessment can often be communicated to the organization to help impacted parties understand the factors which influenced the decision.

To gain an understanding of the risk of an operation, one must answer the following three questions:

i) What can go wrong?

ii) How likely is it?

iii) What are the impacts?

To use a systematic method to determine risk levels, the Risk Assessment Process is applied. This
process consists of four basic steps:

i) *Hazard Identification*

ii) *Frequency Analysis*

iii) *Consequence Analysis, and*

iv) *Risk Evaluation*

C. *FMEA Method*

FMEA is an inductive reasoning approach that is best suited for reviews of mechanical and electrical hardware systems. This technique is not appropriate to broader marine issues such as harbor transit or overall vessel safety. The FMEA technique, considers how the failure mode of each system component can result in system performance problems and ensures that appropriate safeguards against such problems are in place. This technique is applicable to any well-defined system, but the primary use is for reviews of mechanical and electrical systems (e.g., fire suppression systems, vessel steering/propulsion systems). It also is used as the basis for defining and optimizing planned maintenance for equipment because the method systematically focuses directly and individually on equipment failure modes. FMEA generates qualitative descriptions of potential performance problems (failure modes, root causes, effects, and safeguards) and can be expanded to include quantitative failure frequency and/or consequence estimates.

FMEA method was conducted to analyze the potential for errors or failures in the system and the potential identified will be classified according to the magnitude of potential failure and its effect on the process.

III. METHODOLOGY

This thesis will discuss the Risk Assessment on a Free-Fall Lifeboat with the purpose of determining whether an Free-Fall Lifeboat have a risk that is acceptable or not, create awareness about the dangers and risks obtained from the Free-Fall Lifeboat. It aims to reduce the possibility of danger by adding steps - necessary control measures and precautions. The assessment also prioritize hazards and help determine whether the existing control measures are adequate. A risk assessment carried out by the “FMEA (Failure Modes and Effect Annalysis)” method. Here is a schematic of the research methodology to be done:

A. Background and Problem Identification

The first stage is to identify and formulate the problem. In this thesis is to analyze problems taken risks in the process of lifeboat Free-fall launching. However, the extent to which these risks will occur and of whether the consequences that would arise. Hence the need for a measurement of risk, namely the risk assessment method FMEA (Failure Modes and Effects Analysis) which is based on data that have been obtained as well as the standards used to certify whether the risk is acceptable or not and then if it can not be accepted we need some mitigation of the consequences of risk.

B. Study Literatures

The literature study was done by collecting various references to support the work and writing of this bachelor thesis. References required regarding Launching operation, Manufacture of Free-fall Lifeboat, some Journal, book, paper, internet and the data that is required in order to support the work of bachelor thesis.

C. Data Collection

Collecting data is done in order to support the thesis progress. The collection of data that are needed include informations the process of Free-fall lifeboat launching, General Arrangement, Launching Introduction and the data is that is required in order to support the work of the bachelor thesis.

D. Data Analyze Using FMEA Worksheet

Potential cause of failure describes how a process failure could occur, in terms of something that can be controlled or corrected. The goal is to describe the direct relationship that exists between the cause and resulting process failure mode. The data in order from PT. Surya Segara and based on DNV – OS – E406. Also the standard of FMEA Worksheet is based on International Electrotechnical Commission (IEC)

Indenture level:			Design by:									FMEA
Sheet no:			Item:					Prepared by:				
Operating mode:			Revision:					Approved by:				
Item ref.	Item description-function	Failure entry code	Failure mode	Possible failure causes	Symptom detected by	Local effect	Effect on unit output	Compensating provision against failure	Severity class	Failure rate F/Mhr	Data source	Recommendations and actions taken

Figure 2 IEC FMEA worksheet standard

60812 Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA).

E. Frequency Analysis and Consequence Analysis.

Analysis of the data in order to determine the levels of risk. The standards for frequency analysis, consequence analysis, and detection analysis is based on International Marine Contractors Association (IMCA M 166). Also the number of frequency are generated from Basis Event from several source such as DNV Technica 1983, ANNEX III: FSA/LSA/BC: FREE-FALL LIFEBOAT AS RCO, and UK HSE RR599 2007.

F. Risk Evaluation

Analysis of the data in order to determine the levels of danger posed using the results of risk priority. By using Table Occurance, FTA and ETA for frequency analysis and severity from IMCA for consequence analysis.

G. Mitigation

If there are any intolerable risk after the risk evaluation, then will be do a mitigation act to minimize those risk by using LOPA method.

H. Conclusion and Recommendation

Make conclusions based on the results obtained and suggestions for further research development.

IV. ANALISIS DAN PEMBAHASAN

A. *Data Analysis*

The launch of a free-fall lifeboat can be divided into four distinct phases. These are the ramp phase, the rotation phase, the free-fall phase, and the water entry phase. The ramp phase is that part of the launch when the lifeboat is sliding along the launch ramp. The ramp phase ends when the center-of-gravity (CG) passes the end of launch ramp and the lifeboat begins to rotate; this rotation marks the beginning of the rotation phase. The rotation phase ends when the lifeboat is no longer in contact with the launch ramp. This is the beginning of the free-fall phase; the lifeboat is falling freely through the air. The water entry phase begins when the lifeboat first contacts the surface of the water and continues until the lifeboat has returned to the surface and is behaving as a boat.

B. *Risk Identification*

Risk identification is understanding function of process launching which will be analyze. The result from risk identification is scenario of all failure modes. Example of failure modes list on FMEA worksheet has attached below.

For the example is the risk identification of Retrieval Arrangement (RVL) which refer to Operation Manual of free fall lifeboat.

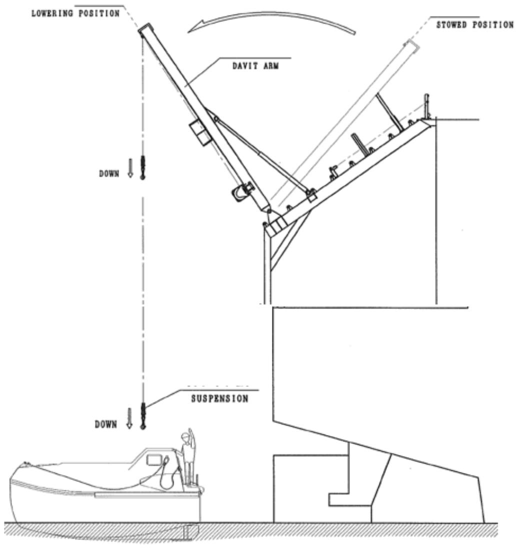


Figure 3 Lifting position

The next step is identify every single step in retrieval arrangement, what can go wrong in retrieval arrangement. After obtaining possible of failure which can be generated, the next step is investigate cause, consequence and protection. For the consequence which has possibility of failure will use IMCA standard to determine the number of consequence.

Sheet no : 01				Item : Retrieval arrangement				FMEA		
Operating mode : Launching Operation				Prepared by : PT. Surya Segara, DNV - OS - E406						
Item ref.	Description / Function	Failure Mode	Potential Effects of Failure	Possible Failure Causes	Severity Class	Failure rate F/Mhr	Recommendations and Actions Taken	Action Result		Risk Priority
								Sev	Occ	
1	Retrieve lifeboat back to platform/ship	Overload of lifting arrangement	Loss of Lifeboat	Jerk in wire because of dynamic affects (due to waves)	IMCA M 166					
	Retrieve lifeboat back to platform/ship	Man overboard	Rescue operation	Climbing on top of lifeboat while connecting lifting hook	IMCA M 166					
2	Hydraulic power pack system	Failure on electric motor	Unsuccessful Recovery operation	loss of power	IMCA M 166					
		Failure on pressure gauge	Error calibration	Error judgement	IMCA M 166					
		Failure on starter	Can't start hydraulic power pack system	Hydraulic power pack system can't work	IMCA M 166					
		Failure on control valve	Can't control and adjust hydraulic power pack	Stuck on panel	IMCA M 166					

Figure 4 Risk Identify on FMEA Worksheet

C. *Risk Analysis*

After finished on risk identification step for lifeboat free fall launching, the next step is risk analysis to determine level of Frequency and Consequence which will be used as an input data for the risk analysis result from FMEA Worksheet Retrieval Arrangement (RVL). Frequency value for each causes are decided from FTA method which had explained on sub-chapter 2.9. Failure Mode and Effect Analysis. For value of Basic Event are generated from several source such as OREDA 2002, DNV Technica 1983, ANNEX III: FSA/LSA/BC: FREE-FALL LIFEBOAT AS RCO, and UK HSE RR599 2007. After obtained the value of Failure Rates and Probability of Failure, the value will be matched to that several source, depend on Probability Description.

The FTA method will start from top event which refer to Possible Causes from FMEA worksheet. For each causes will be given a code to simplify the process. For example, failure on Hydraulic power pack system cannot work

A1 RVL 2.3.

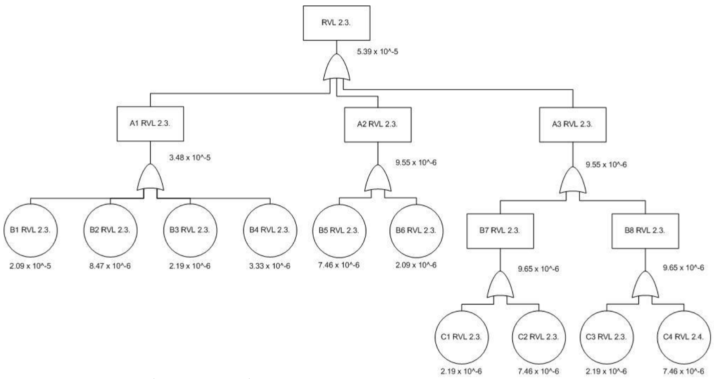
A : First level contributor (It will following alphabet for the next level)

1 : First contribution (It will following numerical order for the next causes)

RVL : System which have to identify from FMEA worksheet

2 : Failure mode's number, based on FMEA worksheet

3 : Potential cause order



A1 RVL 2.3. (RVL 2.3)

Causes of Hydraulic power pack system can't work

A1: Loss of power
A2: Internal leakage on hydraulic motor
A3 : Short circuit
B1 : Fail to start on demand
B2 : Breakdown
B3 : Overheating
B4 : Parameter deviation
B5 : Structural deficiency
B6 : Fail to start on demand
B7 : High voltage inlet
B8 : low voltage inlet
C1 : Overheating
C2 : Structural deficiency
C3 : Overheating
C4 : Structural deficiency
The value of each event are decided based on gate type. Failure Probability for Basic Event will obtained from Failure Rates value.

- C1 RVL 2.3.

$P = 1 - e^{-\lambda T}$

P : Failure Probability
λ : Failure Rate (OREDA 2002 : 0.53×10^{-6})
T : Exposure Interval (OREDA 2002 : 4.3894)

PC1 = 1-$e^{-(0.53 \times 10^{-6}) \times 4.3894}$ = 2.19×10^{-6}

- C2 RVL 2.3.

$P = 1 - e^{-\lambda T}$

P : Failure Probability
λ : Failure Rate (OREDA 2002 : 1.70×10^{-6})
T : Exposure Interval (OREDA 2002 : 4.3894)

PC2 = 1-$e^{-(1.70 \times 10^{-6}) \times 4.3894}$ = 7.46×10^{-6}

- C3 RVL 2.3.

$P = 1 - e^{-\lambda T}$

P : Failure Probability
λ : Failure Rate (OREDA 2002 : 0.53×10^{-6})
T : Exposure Interval (OREDA 2002 : 4.3894)

PC3 = 1-$e^{-(0.53 \times 10^{-6}) \times 4.3894}$ = 2.19×10^{-6}

- C4 RVL 2.3.

$P = 1 - e^{-\lambda T}$

P : Failure Probability
λ : Failure Rate (OREDA 2002 : 1.70×10^{-6})
T : Exposure Interval (OREDA 2002 : 4.3894)

PC4 = 1-$e^{-(1.70 \times 10^{-6}) \times 4.3894}$ = 7.46×10^{-6}

- B1 RVL 2.3.

$P = 1 - e^{-\lambda T}$

P : Failure Probability
λ : Failure Rate (OREDA 2002 : 4.77×10^{-6})
T : Exposure Interval (OREDA 2002 : 4.3894)

PB1 = 1-$e^{-(4.77 \times 10^{-6}) \times 4.3894}$ = 2.09×10^{-5}

- B2 RVL 2.3.

$P = 1 - e^{-\lambda T}$

P : Failure Probability
λ : Failure Rate (OREDA 2002 : 1.93×10^{-6})
T : Exposure Interval (OREDA 2002 : 4.3894)

PB2 = 1-$e^{-(1.93 \times 10^{-6}) \times 4.3894}$ = 8.47×10^{-6}

- B3 RVL 2.3.

$P = 1 - e^{-\lambda T}$

P : Failure Probability
λ : Failure Rate (OREDA 2002 : 0.53×10^{-6})
T : Exposure Interval (OREDA 2002 : 4.3894)

PB3 = 1-$e^{-(0.53 \times 10^{-6}) \times 4.3894}$ = 2.19×10^{-6}

- B4 RVL 2.3.

$P = 1 - e^{-\lambda T}$

P : Failure Probability
λ : Failure Rate (OREDA 2002 : 0.76×10^{-6})
T : Exposure Interval (OREDA 2002 : 4.3894)

$$PB4 = 1\text{-}e^{-(0.76\times10^{-6})\times4.3894} = 3.33\times10^{-6}$$

- B5 RVL 2.3.

$$P \quad 1e^{-\lambda T}$$

P : Failure Probability
λ : Failure Rate (OREDA 2002 : 0.76×10^{-6})
T : Exposure Interval (OREDA 2002 : 4.3894)

$$PB5 = 1\text{-}e^{-(1.70\times10^{-6})\times4.3894} = 7.46\times10^{-6}$$

- B6 RVL 2.3.

$$P \quad 1e^{-\lambda T}$$

P : Failure Probability
λ : Failure Rate (OREDA 2002 : 4.77×10^{-6})
T : Exposure Interval (OREDA 2002 : 4.3894)

$$PB6 = 1\text{-}e^{-(4.77\times10^{-6})\times4.3894} = 2.09\times10^{-6}$$

- B7 RVL 2.3.

$$P \quad 1e^{-\lambda T}$$

P : Failure Probability
λ : Failure Rate (OREDA 2002)
T : Exposure Interval (OREDA 2002 : 4.3894)

$$PB7 = (2.19\times10^{-6}) + (7.46\times10^{-6}) = 9.65\times10^{-6}$$

- B8 RVL 2.3.

$$P \quad 1e^{-\lambda T}$$

P : Failure Probability
λ : Failure Rate (OREDA 2002)
T : Exposure Interval (OREDA 2002 : 4.3894)

$$PB8 = (2.19\times10^{-6}) + (7.46\times10^{-6}) = 9.65\times10^{-6}$$

After finish with all basic event, then calculate the top event based on the gate.

Because there is an OR Gate then,

PA1 = PB1 + PB2 + PB3 + PB4
PA1 = 2.09 x 10^{-5} + 8.47 x 10^{-6} + 2.19 x 10^{-6} + 3.33 x 10^{-6} = **3.48 x 10^{-5}**

PA2 = PB5 + PB6
PA2 = 7.46 x 10^{-6} + 2.09 x 10^{-6} = **9.55 x 10^{-6}**

PA3 = PB7 (PC1 + PC2) + PB8 (PC3 + PC4)

PA3 = PB7 (2.19 x 10^{-6} + 7.46 x 10^{-6}) + PB8 (2.19 x 10^{-6} + 7.46 x 10^{-6})
PA3 = 9.65 x 10^{-6} + 9.65 x 10^{-6} = **9.55 x 10^{-6}**

RVL 2.3. = PA1 + PA2 + PA3
RVL 2.3. = 3.48 x 10^{-5} + 9.55 x 10^{-6} + 9.55 x 10^{-6} = **5.39 x 10^{-5}**

After obtaining all the value of frequency, the next step is determine the level of consequence, to determine the level of consequence will be use table of Severity Description

D. *Risk Evaluation*

Risk evaluation will be the next step after risk analysis, for example from failure mode Failure on Control valve which stuck on panel. Based on table severity and table of probability these failure has a level of severity on 3 and level of probability on 1. Both result will be plotted on risk matrix from International Marine Contractors Association (IMCA) M 166 2002.

Sheet no : 01			Item : Retrieval arrangen		
Operating mode : Launching Operation			Prepared by : PT. Surya S		
Item ref.	Description / Function	Failure Mode	Potential Effects of Failure	Possible Failure Causes	Severity Class
2	Hydraulic power pack system	Failure on electric motor	Unsuccessful Recovery operation	loss of power	IMCA M 166
		Failure on pressure gauge	Error calibration	Error judgement	IMCA M 166
		Failure on starter	Can't start hydraulic power pack system	Hydraulic power pack system can't work	IMCA M 166
		Failure on control valve	Can't control and adjust hydraulic power pack	Stuck on panel	IMCA M 166

Figure 5 Consequence from Failure on Control Valve

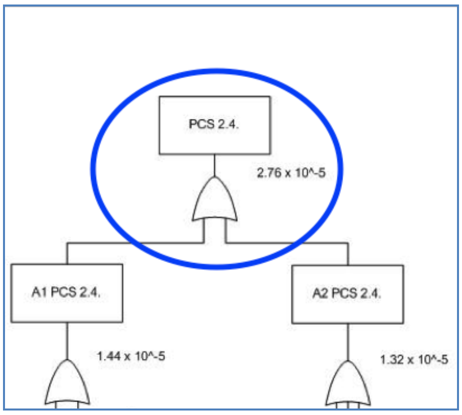


Figure 6 Frequency from Failure on Control Valve

Table 1 Severity Description from failure on Control Valve

Category	Degree	Description
I	Minor	Functional failure of part of a machine or process with no potential for injury, damage or pollution
II	Critical	Failure will probably occur without major damage to system, pollution or serious injury
III	Major	Major damage to system with a potential for serious injury to personnel and minor pollution
IV	Catastrophic	Failure causes complete system loss with a high potential for fatal injury and major pollution.

Table 2 Probability Description on Control Valve

Level	Probability	Description
A	10^{-1}	Likely to occur frequently
B	10^{-2}	Probable – may occur several times in the life of an item
C	10^{-3}	Occasional – may occur sometime in the life of an item
D	10^{-4}	Remote – unlikely to occur but possible
E	10^{-5}	Improbable – unlikely to occur at all

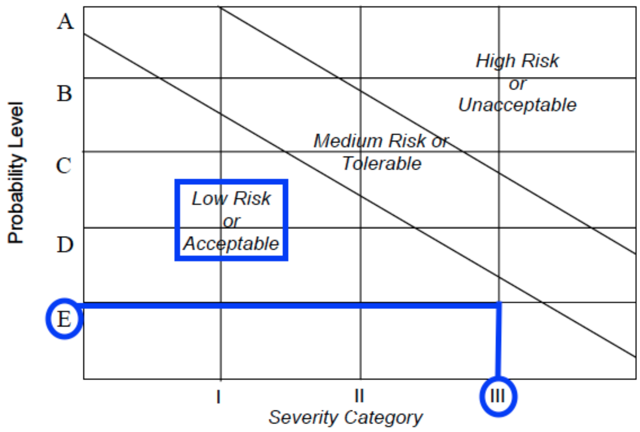


Figure 7 Risk Matrix IMCA

E. *Mitigation*

The last step will be kind of mitigation to reduce the level of risk that can happen. This mitigation is needed for high risk criteria. Whenever that high risk need to identify for protection and prevention to be adopted in order to reduce the frequency. Below is shown an example for mitigation task with LOPA method from worksheet FMEA Node No. 1 which is failure crack in hull caused by Insufficient (QA).

Scenario No. 1	Crack in hull caused by Insufficient Quality Assurance (QA) during production process		Node No. 1
Date: 28 June 2016	Description	Probability	Frequency (per year)
Consequence description/ Category	Excess buoyancy should keep the boat afloat even if hull cracks		
Risk Tolerance Criteria	Action required		$<10^{-1}$
	Tolerable		$>10^{-1}$
Initiating event			6.6×10^{-2}
Frequency of Unmitigated Consequence			6.6×10^{-2}
Independent Protection Layers	Training	5×10^{-2}	
	Survey	6×10^{-2}	
Total PFD		3×10^{-3}	
Frequency of Mitigated Consequence			1.98×10^{-4}
Risk Tolerance Criteria Met? (Yes/ No)		Yes	
Action required to meet Risk Tolerance Criteria	1. perlu dilakukan training pada production proses		
	2. A QA program must be in force during the production of the lifeboat		

Figure 8 LOPA

From LOPA worksheet above the result is frequency for failure crack in hull caused by Insufficient (QA). The number of Insufficient QA will be reduce to 1.98 x 10^{-4}, That result is generated from calculation within frequency and protection layers given. After that the result will be ploted on Risk Matrix again as shown below.

V. CONCLUSION

Depend on the result of risk assessment for free fall lifeboat launching concluded that :

1. There is so many risk can happen on the process of launching and retrieval. But that can be reduced with mitigation for decrease the frequency or give a prevention.
2. Human error proved to be a significant contributory factor in many of the reported lifeboat incidents, as it is in most accidents. Lack of supervision was not found to be a significant factor in the cause of reported human error related incidents therefore the potential for mistakes might reasonably be expected to increase during the stress of a real emergency situation.
3. The design and construction of lifeboats and in particular auxiliary equipment, such as brakes and release gear, play a significant part in contributing towards the cause of many lifeboat incidents with the most catastrophic event being the opening of a boat hook with the boat some distance from the water, Incidents of this nature can be avoided if the boat crew is able to confirm the hook is secure for lowering or lifting. Their repeated failure has, however, played a large role in reducing ship staff confidence in lifeboats.
4. SOLAS requirements for lifeboats are focused on launching. Although regular training is required, insufficient emphasis is placed on measures designed to ensure that routine operations, such as recovery and lifting of lifeboats can be conducted safely.

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