A Case Study Maintenance Task Allocation Analysis on Marine Loading Arm Using Reliability Centered Maintenance

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Abstract. Marine Loading Arm (MLA) supports all liquid bulk loading and unloading activities, especially imports of chemical raw materials such as NH₃, H₂SO₄, and H₃PO₄. Therefore, to minimize the occurrence of failure it is necessary to have a treatment method. Reliability Centered Maintenance (RCM) is a maintenance method that focuses on increasing the reliability of components in the system. The RCM uses the principle of risk management to determine tasks and maintenance schedules appropriately. The RCM process is implemented using American Bureau Shipping (ABS) Guidelines. According to the results of this research, there are three types of maintenance tasks for MLA, in which category A has 14 maintenance tasks, category B has 21 maintenance tasks, and there are no maintenance tasks in category C. In all maintenance categories for Preventive Maintenance by 54% with 19 tasks, for Condition Monitoring of 37% with 13 tasks, while for Run-To-Failure of 9% with 3 tasks.

Keywords: Failure, maintenance task, marine loading arm, reliability, RCM

1. Introduction
PT. XYZ has its terminal equipped with tools for unloading bulk cargo. One of the equipments used for liquid bulk loading-unloading activity is Marine Loading Arm (MLA). MLA is one of the most used liquid bulk disassembly tools compared to the loading arm. MLA is more often used due to being simpler in its operation and is assessed safer during the loading process [1]. Some types of chemical fluids dismantled include ammonia (NH₃), sulfuric acid (H₂SO₄), and phosphoric acid (H₃PO₄). Over time the MLA system suffered various failures. Failure to a component can affect the performance of a system. The state when the tool cannot be used because one or more components are damaged is called the breakdown term [2]. If a tool is damaged, it must be repaired immediately. While the time used to repair the tool is called downtime [3-4]. This downtime causes loading and unloading activities to be delayed from the expected schedule, and this has an impact on the company’s losses. The role of MLA is very important in the chemical liquid loading process, considering that MLA is the only liquid unloading tool currently owned by the company.

Reliability Centered Maintenance (RCM) is a method of maintenance analysis that systematically establishes the appropriate maintenance tasks for assets at optimal frequencies to maintain the appropriate functions required during certain periods [5-7]. RCM regulates maintenance policies at the plant or equipment type level. RCM is a more structured way of using the best methods...
and disciplines [8]. The power of RCM is to produce a planned and effective maintenance program. RCM has been proven to increase the availability of the system by achieving its reliability and security properties while reducing maintenance costs [9-10]. The success stories of implementing RCM have been carried out by many researchers and applied in the industry. In the marine industry, there have been many applications of RCM, such as Zaman et al (2020) conducting research to determine maintenance strategies on the tugboat cooling system to prevent overheating [11]. Priyanta et al (2020) conducted RCM research on the main engine to determine proper maintenance activities and scheduling plans [12]. The latest is the RCM approach for assessing reliability challenges and maintenance needs of unmanned cargo ships [13]. In other fields, such as oil and gas, the application of RCM is also carried out by Shaneza (2019) who reviewed RCM on the cooling water pump of LNG production [14]. Zakikhani et al (2020) conducted research on Availability-based reliability-centered maintenance planning for gas transmission using Monte Carlo simulation [15]. The other critical success factors of the RCM in oil and gas were conducted by Zeinalnezhad [10].

In this research, RCM was applied to determine the appropriate type of maintenance for the Marine Loading Arm (MLA) system. The RCM method approach used is the American Bureau of Shipping (ABS) Classification [16-17]. ABS provides an RCM approach by adding a criticality assessment to its stages. Failure mode, effect, and criticality analysis (FMECA) is a method used to assess the level of equipment risk so that the maintenance strategy can be prioritized [17-18]. FMECA has undergone many developments by researchers with several approaches, such as fuzzy logic [19][20], analytical network process (ANP) [21], and grey theory method [22-23].

2. Methods

2.1. Data Collection

Data collection is used as object research. The data collected is obtained from the Department of Port maintenance PT. XYZ. The data required in this research are as follows: Data on the loading/unloading equipment in the port of PT. XYZ, (2) Historical Data on the loading/unloading machine in the port, (3) Data downtime and repair time of each loading/unloading machine in the port, (4) Cause of failure that occurs in the loading/unloading machine in the port, (5) How repairs are made to the damage of the machine.

2.2. Defining the System Limitation

In this research, the object research is Marine Loading Arm (MLA) system. Based on the working system of the dismantling of liquid ammonia, MLA acts as the connector between the pipe vessel with a pipeline on land driven using a hydraulic motor. Some of the sub-systems are integrated and when the failure occurs at one sub-system, it will affect the process of unloading the ammonia.

2.3. Identifying Mode and Operation Context

Mode operation is used to determine the operating context of each item to be identified. The operation mode identification is divided into three categories:

1. Environmental parameters based on functional assets operate.
2. Usage-based on operational function.
3. The performance capabilities are defined by the functional group.

The development of operational context is agreed to consider performance or quality, system setting, safety, environmental standards, and operation. The operation context is developed on each level hierarchy. Functional linkages of the system in functional groups will be explained through a diagram block or fault-tree diagram in the form of narration to allow the effect of the failure to be comprehensively understood.

2.4. Specifying System Definitions

On the system to be analyzed RCM must be defined by functional groups into the system, subsystem, equipment/item, and components. Further development of narrative descriptions in any functional
groups, systems, items, and components. The narrative description at each level of the hierarchy and the functional requirements will be developed and provide the following information:

1. A general overview of operations and structures.
2. The functional relationship of any item or component of the equipment.
3. Consideration of each mode of operation on the limit of acceptable functional performance of the item or component.
4. Obstacles encountered in operation.

2.5. **Identifying System Block Diagrams and Functions**

All functions must be identified including functions on functional groups, systems, items, and components. When identifying functions, the operation mode and operation context must be well recorded. Block Diagram is used for development that shows the sequence of functional flow, both technical about the function and operation of the system. The block Diagram must contain (1) functional groups are divided into systems, items, and components, (2) All inputs and outputs are labelled according to the identification number, (3) All redundancy, alternate signal paths, and other technique features show the "Fail-safe" action size.

Performance standard system function is the minimum acceptable requirement for the context of operation compared with system design capabilities. Performance standards must be identified as they are used to determine failures. Functions should be categorized as follows: (1) Primary functions, i.e., the underlying functions that are the reason why there are functional groups or items or components, (2) Secondary functions, in addition to the main functions of the system.

2.6. **Criticality Analysis using FMECA methods**

After the failure mode is specified on the subsystem, the next stage determines the effect of each – each failure that occurs or is commonly referred to as Failure Modes, Effect and Critically Analysis (FMECA). Once the specified failure mode then gets the data failure effect. This Failure effect determines what kind of maintenance task to do. FMECA results in a level of the critical asset. To obtain the value of criticism on the components, it can be done by converting the value of the probability rating against the value of consequence rating that has been determined using the risk matrix of ABS classification. The risk level is represented in a 4x5 matrix as shown in figure 1. Meanwhile, the criteria for likelihood and severity levels are shown in tables 1-2.

| Severity Level | Improbable | Remote | Occasional | Probable | Frequent |
|----------------|------------|--------|------------|----------|---------|
| 4              | Medium     | Medium | High       | High     | High    |
| 3              | Low        | Medium | Medium     | High     | High    |
| 2              | Low        | Low    | Medium     | Medium   | High    |
| 1              | Low        | Low    | Low        | Medium   | Medium  |

**Figure 1.** Risk matrix of ABS classification [17]

2.7. **Determining the Maintenance Task**

The Maintenance Task series is a work package describing the maintenance strategy based on RCM. Work package creation in the form of a spreadsheet as recommendations related to maintenance on the Marine Loading Arm.
Table 1. Severity level [17]

| Severity Level | Descriptions for Severity Level | Definition for Severity Level |
|----------------|---------------------------------|------------------------------|
| 1              | Minor, Negligible,              | Function is not affected, no significant operational delays. Nuisance. |
| 2              | Major, Marginal, Moderate       | Function is not affected, however failure detection/corrective measures not functional. OR Function is reduced resulting in operational delays. |
| 3              | Critical, Hazardous, Significant| Function is reduced, or damaged machinery, significant operational delays |
| 4              | Catastrophic, Critical          | Complete loss of function |

Table 2. Likelihood level [17]

| Likelihood level | Likelihood Descriptor | Description |
|------------------|-----------------------|-------------|
| 1                | Improbable            | Fewer than 0.001 events/year |
| 2                | Remote                | 0.001 to 0.01 events/year |
| 3                | Occasional            | 0.01 to 0.1 events/year |
| 4                | Probable              | 0.1 to 1 events/year |
| 5                | Frequent              | 1 or more events/year |

3. Result and Discussion

3.1. Object Research
Data from PT. XYZ is obtained in three ways: field observations, interviews with employees, and data retrieval information in the form of technical data, and other documentation relating to the system. Table 3 shows the technical specification of the Marine Loading Arm. Marine Loading Arm has several sub-systems with many components inside. All parts of the Marine Loading Arm have been noted to facilitate the handling of its maintenance. Table 4 shows the list of asset registers of the Marine Loading Arm system. While figure 2 shows the Marine Loading Arm on PT. XYZ.

Figure 2. The Marine loading arm on PT. XYZ
Table 3. Technical specification of marine loading arm

| Marine Loading Arm Specification |          |
|----------------------------------|----------|
| **Year made**                    | 2010     |
| **Maker**                        | Emco Wheaton |
| **Type**                         | B0030    |
| **Design Pressure**              | 10 Bar   |
| **Design Temperature**           | -40 - 40°C |
| **Weight**                       | 13.5 ton |

| Electric Motor Specification     |          |
|----------------------------------|----------|
| **Maker**                        | SIEMENS |
| **Type**                         | Motor 3 phase |
| **Frequency**                    | 50Hz     |
| **Power**                        | 5.0 kW   |
| **RPM**                          | 1445     |

| Pump Specification |          |
|--------------------|----------|
| **Type**           | External Gear Pump |

Table 4. List of asset register of marine loading arm system

| EQUIPMENT TAG | EQUIPMENT TYPE       | DESCRIPTION                                      |
|---------------|----------------------|--------------------------------------------------|
| B25M801-ERS   | Emergency Release System MLA | Stray Current Protectors                          |
| B25M801-ERS-SCP |                      |                                                  |
| B25M801-ERS-TSA|                      | Triple Swivel Assembly                           |
| B25M801-ERS-TSJ |                      | Triple Support Jack                              |
| B25M801-ERS-DS |                      | Drainage System                                  |
| B25M801-ERS-CC |                      | Camlock Coupling                                 |
| B25M801-SA    | Secondary Arm MLA    |                                                  |
| B25M801-SA-ASJ1 |                    | Apex Swivel Joint 1                              |
| B25M801-SA-ASJ2 |                    | Apex Swivel Joint 2                              |
| B25M801-SA-ASJ3 |                    | Apex Swivel Joint 3                              |
| B25M801-PA    | Primary Arm MLA      |                                                  |
| B25M801-PA-FSJ1 |                    | Fulcrum Swivel Joint 1                           |
| B25M801-PA-FSJ2 |                    | Fulcrum Swivel Joint 2                           |
| B25M801-PA-PCW |                     | Primary Counter Weight                           |
| B25M801-SP    | Stand Post MLA       |                                                  |
| B25M801-SP-ELB |                     | Earth Lug Baseplate                              |
| B25M801-SP-OF  |                     | Outlet Flange                                    |
| B25M801-SP-LD  |                     | Ladder                                           |
| B25M801-SP-SL  |                     | Slew Lock                                        |
| B25M801-SP-BSJ |                     | Base Swivel Joint                                |
| B25M801-SP-DV  |                     | Drain Valve                                      |
| B25M801-SP-PI  |                     | Pressure Indicator                               |
| B25M801-HS    | Hydraulic System MLA |                                                  |
| B25M801-HS-HPU |                     | Hydraulic Power Unit                             |
| B25M801-HS-EHP |                     | Emergency Hand Pump                              |
| B25M801-HS-HT  |                     | Hydraulic Tank                                   |
| B25M801-HS-HSV |                     | Hydraulic Solenoids Valves                       |
| B25M801-HS-HC  |                     | Hydraulic Controls                               |
| B25M801-HS-HA  |                     | Hydraulic Accumulator                            |
| B25M801-HS-ECP |                     | Eex-ed Electrical Control Panel                  |
| B25M801-HS-EH  |                     | Ex-D Housing                                     |
| B25M801-HS-HP  |                     | Hydraulic Piping                                 |
| B25M801-PL    | Purge Line MLA       |                                                  |
| B25M801-PL-FH  |                     | Flexible Hose                                    |
| B25M801-PL-BV  |                     | Block Valve                                      |
3.2. Operating Modes and Context
To determine the characteristics of operation, various modes of operation must be identified. The interconnectedness between functions of the selected system in a functional group should be explained through the use of block diagrams in a narrative format to make it easier to understand. The list of failure modes for each system to be analyzed will be developed taking into consideration the system settings, performance or quality standards, environmental standards, safety standards, and operation modes. The operation mode used for the determination of the operating context can be shown in table 5.

| General Characteristic | Operating Modes |
|------------------------|------------------|
|                        | At sea | Manoeuvring Alongside | Cargo Handling |
| Environmental Parameters | Not Used | Not Used | Pressure 1 ATM in reservoir tank hydraulic oil temperature <70°C |
| Manner of Use           | Not Used | Not Used | Generating the MLA’s arm with 180bar pressure using 5,0kW hydraulic pump |
| Performance Capability  | Not Used | Not Used | Generates 5,0kW at 1445 RPM to supply 180bar hydraulic pressure |

3.3. System and Function Block Diagram
The block diagram shows the sequence of the functional group flow, technical understanding of the functions, and system operation and for further analysis. The system block diagram also shows the effects and sequence of events that will and may occur due to component failure. So if a failure occurs, the system or other components that are affected by the failure can be seen from the system block diagram. All components in this system work in series. With this condition, it can be concluded that if there is one component in the system that fails, the whole system is declared a failure. Figure 3 shows the functional block diagram of the MLA hydraulic system.
Figure 3. The functional block diagram of the MLA hydraulic system

3.4. Result of Criticality Assessment using FMECA Methods

For each failure mode, FMECA must show all functional losses, severity, probability of failure, and resulting risk. The consequence category must be considered in FMECA when the failure mode directly initiates consequences. Each failure mode can impact performance, safety, reliability, and potentially cause a fatal failure. The failure characteristics in each failure mode must be identified into three, such as wear-in failure, random failure, and wear-out failure. In this study, failure modes were obtained from various sources, repair history, OREDA, and manufacturer's recommendations.

The effect of failure in each failure mode should be listed as a local effect, functional failure, and end effect. The local effect describes the initial changes in components or equipment when failure mode occurs. The local effect will continue to the end effect, which is a description of the overall effect that will occur. Table 6-7 shows the example of the FMECA worksheet. The recapitulation of the FMECA risk level analysis in the MLA hydraulic system is shown in figure 4. There are 30% low risk, 49% moderate risk, and 21% high risk.

Table 6. FMECA Worksheet (1/2)

| No. | Item | Functional Failure | Failure Mode | Causes | Failure Characteristic | Local effects | Functional Failure |
|-----|------|--------------------|--------------|--------|-----------------------|---------------|-------------------|
| 1   |      | The resulting pressure is less than 180 bar | Leak in solenoid valve seal (Evident) | Prolonged use and excessive pressure can damage the seal on the solenoid valve | Random Failure, Wear out | Hydraulic oil will seep out of the system | The resulting pressure is less than 180bar |
### Table 7. FMECA Worksheet (2/2)

| No. Item | End Effect                                                                 | Matrix              | Severity | Current Likelihood | Current Risk | Failure Detection          |
|----------|----------------------------------------------------------------------------|---------------------|----------|-------------------|--------------|-----------------------------|
| 1        | The pressure in the solenoid valve will decrease thereby inhibiting the movement of the actuator | Loss of Containment | Major    | Occasional        | Medium       | Failure can be detected visually by checking regularly |

#### Risk Level in the MLA Hydraulic System

![Risk Level Chart]

Legend:
- Low Risk
- Medium Risk
- High Risk

- 21% Low Risk
- 30% Medium Risk
- 49% High Risk

**Figure 4.** The recapitulation of the FMECA analysis

### 3.5. Determining Maintenance Task

Each action proposed to deal with the failure modes that occur in the FMECA analysis, will be divided into several categories. Maintenance tasks can be categorized into 3 categories following:

- **Category A** - Can be performed by on-site mechanical personnel.
- **Category B** - Must be undertaken alongside by equipment vendors or with use of dockside facilities.
- **Category C** - Must be undertaken in the dry dock/workshop.

There are several types of maintenance recommendations to do maintenance categories A, B, or C, including Preventive Maintenance (PM), Condition Monitoring (CM), Failure Finding (FF), and One-Time Change (OTC). The steps for determining the type of maintenance are based on logic tree analysis (LTA). Then the logic tree analysis results will determine recommendations for maintenance actions. Table 8 shows an example of logic tree analysis to determine maintenance tasks. Based on the results of the LTA, there are 37% maintenance category A (14 tasks), 63% maintenance category B (21 tasks) and no maintenance category C. Figure 5 shows the maintenance category chart.

### Table 8. Logic tree analysis worksheet

| No. Item | Failure Mode                                                                 | RCM LTA Task Selection | Result                                      |
|----------|------------------------------------------------------------------------------|------------------------|---------------------------------------------|
| 1        | Leak in solenoid valve seal (Evident)                                        | A1 A2 B1 B2 B3 B4 B5 B6 B7 C1 C2 C3                        | One-time change may be necessary to achieve a tolerable risk |
|          |                                                                              | N - N Y - N N - N - - - |                                             |
Figure 5. The recapitulation of maintenance category

Figure 6. The recapitulation of maintenance task

Meanwhile, figure 6 shows the results of the recapitulation of the types of maintenance task recommendations from all categories. There are 54% Preventive Maintenance types, 37% Condition Monitoring types, and 9% Run-To-Failure types.

4. Conclusion
In this research, the Reliability Centered Maintenance (RCM) method is used to determine the priority of the Marine Loading Arm maintenance on PT. XYZ. From the stage of FMECA analysis, criticality equipment is 30% low risk, 49% moderate risk, and 21% high risk. Therefore, based on logic tree analysis, the recommended maintenance category is 37% category A (14 tasks), 63% category B (21 tasks). Meanwhile, the recapitulation of the types of maintenance task recommendation from all categories is 54% Preventive Maintenance (19 tasks), 37% Condition Monitoring (13 tasks), and 9% Run-To-Failure (3 tasks). Finally, a further recommendation from this research is to add other methods such as fuzzy logic and analytical network process to develop a more comprehensive criticality assessment in the stage of RCM analysis.

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