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RAM ANALYSIS OF CRUDE OIL TRANSFER PUMPS USING DOMINANT FAILURE MODE

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ABSTRACT

A good maintenance strategy requires a good reliability, availability and maintainability (RAM) analysis in order to cater the real problem to specific equipment or a system. Resolving the real problem will improve the equipment/system reliability to ensure higher availability of the system to operate. In this paper, two crude oil transfer pumps were selected for RAM analysis. The analysis was done based on individual dominant failure mode that contributed to failures of the pumps. Firstly, reliability and maintainability analysis were carried out to obtain the required parameters. Then, reliability block diagram (RBD) was constructed and simulated to obtain the availability of the crude oil transfer pump system. This analysis can help to identify critical failure modes that affect the system reliability which directly affect the operational availability of the pump system.

Keywords: reliability, availability and maintainability analysis, crude oil transfer pump.

INTRODUCTION

In today's challenging world, every company is striving to optimize the operation in order to reduce the cost incurred, hence, maximizing the profit. One of the ways to achieve this objective is through reliability, availability and maintainability (RAM) analysis. The analysis is usually required to understand the current performance of the operation and its complex systems over time and to minimize the number of system failures (i.e. to increase mean time between failures). This information is useful to the management in planning necessary actions so that the performance of the system can be maintained or improved.

RAM modelling has been adopted by various industries and field including process industries (e.g. petrochemical, power plants, oil and gas, and refineries) to assess the system performance over the plant life. RAM model simulates the system configuration, operation, failure, repair and maintenance. The model assists in making decisions for possible system changes that may reduce system failures and hence, improve system efficiency and increase profitability.

In a complex system such as in the offshore facilities, failure and its effect are becoming increasingly intolerable. Equipment failure will lead to reduction in output and even a small breakdown can lead to a big lost. In order to prevent that from happen, reliability engineering has received a lot of attention since it helps to understand the failure and to determine what and how much maintenance need to be taken to prevent the failure or reduce its effects. Having a good maintenance strategy to manage assets effectively and optimize preventive maintenance program will ensure the equipment to operate with minimum downtime throughout the process.

For the offshore facilities, the crude oil transfer system functions to transfer crude oil from a central processing platform to the central pumping platform before the crude oil is being pumped to the onshore terminal via pipeline. The crude oil transfer pump is a primary equipment in the crude oil transfer system. Based on the literature findings, it was observed that very limited RAM study has been conducted for the offshore facilities and this could be due to limited failure and maintenance data or data was vague and sometimes imprecise.

The main objective of this paper was to assess the reliability and system performance in term of its operational availability of the crude oil transfer pumps using the failure modes. Based on the historical data, the crude oil transfer pumps in one of the platforms in Malaysia experienced frequent failures which contributed to the mean time between failures (MTBF) to be less than 2 months.

LITERATURE REVIEW

Availability

RAM modelling refers to the three related elements of a system and its operational support which are reliability, availability and maintainability. RAM modelling emphasizes the use of both reliability and maintainability data of a system in order to analyse the availability of the system. System availability is a measure of how well a system performs or meets its design objectives [1]. The development of a quantitative RAM model is expected to increase the efficiency and effectiveness of preventive and corrective maintenance actions, thus increasing the plant availability and reliability with less unexpected output loses. Understanding RAM model of a system or equipment and the effect of different sub-system configurations is important and can assist in achieving the required goals in the most economical manner.

Ebeling [2] stated that availability is defined as the probability that a system is performing its required function at a given point in time or over a stated period of time when operated and maintained in a prescribed manner. He added that availability measures include inherent availability A_i, achieved availability A_A and

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operational availability A_0. This study assessed the operational availability of the system.

Operational availability A_0 considers logistics, supply and administrative downtime, and both preventive maintenance (PM) downtime and corrective maintenance (CM) downtime and can be computed by Equation. (1)

$$A_0 = \frac{MTBF}{MTBF + MDT} \quad (1)$$

where $MTBF$ is the mean time between failures and MDT is the mean downtime.

There are many methods of doing the RAM modelling. The most widely used techniques are reliability block diagrams (RBD), fault tree analysis, Monte Carlo simulation and Markov model [3]. In this study, RBD method was used to assess the operational availability of the crude oil transfer pump system. RBD is a reliability network showing the relationship of the components in a system by graphical representation. The advantage of using this approach is the ease of expressing and evaluating reliability [3]. RBD is made up of individual blocks connected either in series, parallel or the combination of these configurations. Parameters of reliability and maintainability are needed for each block before simulation of the entire RBD can be carried out. BlockSim software was used in this study to build the RBD and to evaluate the pump system performance based on pump failure modes.

Based on OREDA handbook, it is stated that there are 19 dominant failure modes for a pump. This includes abnormal instrument reading; breakdown; erratic output; external leakage-process medium; external leakage-utility medium; fail to start on demand; fail to stop on demand; high output; internal leakage; low output; minor in-service problem; noise; overheating; parameter deviation; spurious stop; structural deficiency; vibration; unknown and other. Failure modes involved in this study was identified, grouped and analysed based on ISO 14224 [4] and OREDA 2009 handbook [5].

Reliability

Reliability can be defined as the probability that a system will perform its intended function under specified working condition for a specified period of time [3]. Nelson [6] stated that most definition of reliability has five common elements which are probability, failure, function, condition and time. There are two significant tactics in improving the reliability of equipment as well as the system as listed as the followings [3]:

1. Improving individual components.
2. Providing redundancy.

Since the study was focusing on reliability analysis by failure modes, the best tactic to improve the reliability is by improving individual components in order to reduce the frequency of the failure modes to happen. When performing reliability analysis, a correct distribution must be chosen to represent the data. There are several kinds of distribution used to represent the reliability statistics. Table-1 shows the probability density function (pdf) and cumulative density function (cdf) of typical distributions in RAM analysis.

Table-1. Typical distribution in RAM analysis.

Distribution	pdf	cdf
2-parameter Weibull	$f(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} e^{-\left(\frac{t}{\eta}\right)^{\beta}}$	$F(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}}$
	where β = shape parameter (slope) η = scale parameter (characteristic life) t = time to failure	
Exponential	$f(t) = \lambda e^{-\lambda t}$	$F(t) = 1 - e^{-\lambda t}$
	where λ = constant failure rate	
Lognormal	$f(t') = \frac{1}{\sigma'\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{t'-\mu'}{\sigma'}\right)^2}$	$F(t) = \frac{1}{\sigma'\sqrt{2\pi}} \int_{-\infty}^{t} e^{-\frac{1}{2}\left(\frac{t'-\mu'}{\sigma'}\right)^2}$
	where $t' = \ln(t)$ μ' = the mean of the natural logarithms of t σ' = the standard deviation of t	

Maintainability

Maintainability is the probability of a failed system will be restored or repaired to a specified condition within a specified period of time when maintenance is performed in accordance with prescribed procedures [7]. In general, system maintainability is the measure of how long it takes to restore the system. The important term in measuring the maintainability is the mean time-to-repair or the mean downtime which defines as the expected value of the repair time. Downtime is treated as a random variable since every failure event will have different downtime duration due to different failure modes, component failure, spare parts availability and skill level of maintenance people.

According to Heizer and Render [8], the two important tactics to improve maintainability of a system are by:

- Implementing or improving preventive maintenance.
- Increasing repair capabilities and speed.

These two general tactics will be used as a basis in maintainability improvement in later parts of this study. In order to represent repair data, the lognormal distribution is the most familiar model for repair time or downtime distribution and the simplified formula is as shown in Equation. (2),

$$M(t) = \Phi \frac{\ln t - \mu'}{\sigma'} \quad (2)$$

where Φ is the standard normal distribution cumulative function, μ' is the lognormal distribution mean value and σ' is the lognormal distribution standard deviation. Weibull++ software was used in this study to assess the parameters of the reliability and maintainability distribution.

METHODOLOGY

To achieve the objective, the following methodology was adopted.

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Step 1: Data gathering

The time-to-failure (TTF) and the time-to-repair (TTR) data were gathered from the daily operation reports. The dominant failure modes were identified and grouped together to specific failure event by referring to OREDA handbook. Dominant failure modes are associated to significant components of the pump in order to relate the failure event with the failed components. It is vital to associate correct components to respective failure mode in order to cater the real culprit of certain failure events.

Step 2: Trend test

For the TTF data, two tests, graphical test and Mann test, were carried out to determine whether the TTF data has a trend or not. This is important in deciding which type of analysis will be used in the Weibull++ software. Life Data Analysis (LDA) will be carried out using Weibull++ if the data tested from the trend test is not having a trend. On the other hand, if a trend is identified from the trend test, a repairable data analysis will be carried out.

Step 3: Reliability and maintainability analysis in Weibull++ software

Based on the trend test, there were no trend detected for all the failure modes which allow the use of LDA in Weibull++ for parameter estimation for the reliability distribution. For the TTR data, the data are fitted to the appropriate distributions.

Step 4: Availability analysis in BlockSim software

RBD was constructed in BlockSim software based on the relation of failure modes which was in a series configuration. It defines that if one of the failure modes occurs, the whole system will fail. Parameters from Weibull++ analysis were used for each block in the RBD. Finally, the RBD was simulated. This procedure enables to forecast the system availability in the future. Besides, this analysis also provides the information of each failure mode in term of percentage of criticality contribution to the unavailability of the system which will help in determining the most critical failure mode.

RESULTS AND DISCUSSION

The failure data of the crude oil transfer pumps was collected from one of the platforms in Malaysia. Throughout the 68 months duration, a total of 18 and 15 failures were experienced by Pump A and Pump B, respectively, making a total of 33 failures in 68 months. Based on the failure modes defined in ISO 14224 and OREDA, the failures were categorized in five different failure modes which were external leakage–process medium (ELP), breakdown (BRD), minor in service problem (SER), vibration (VIB) and external leakage – utility medium (ELU). The Pareto chart of failure mode of individual pump is shown in Figure-1.

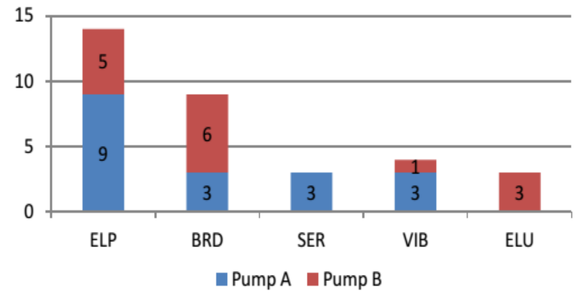

Figure-1. Pareto chart of failure mode of individual pump.

RBD of the failure modes was constructed in a series configuration, which means that any failure mode occur will contribute to the failure and unavailability to the pump. Figure-2 shows the RBD for the pump bases on the failure modes.

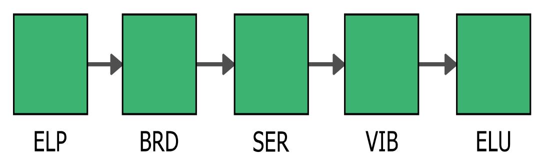

Figure-2. Reliability bock diagram for the pumps based on failure modes.

The TTF data of the five failure modes were treated individually in Weibull++ software. Based on the results as shown in Table-2, the TTF data for all of the failure modes fitted well into 2-parameter Weibull distribution, while the time to repair for all of the failure modes followed the lognormal distribution. It showed that 4 of the failure modes (i.e. ELP, BRD, SER and VIB) had decreasing failure rates and 1 failure mode (i.e. ELU) was in a constant failure rate zone. There was no failure mode with an increasing failure rate which represents aging and wear out. The following observation can be made from this result:

- External Leakage-Process Medium (ELP) failure mode has $\beta = 0.57$ where it can be implied the failure rate of the mechanical seal leak was in the infant mortality zone, based on the bathtub curve. This suggested that the mechanical seal leak might be due to defective part of the seals and maintenance error during mechanical seal installation.
- Breakdown (BRD) failure mode has a $\beta = 0.63$ indicated that the decreasing failure rate might be due to defective parts, crack, welding flaws and contamination.
- Minor In-Service (SER) failure mode has $\beta = 0.33$ suggesting that there might be poor in quality control of the pumps especially during the final acceptance test. It may cause the equipment to fail during testing after installation. Poor workmanship can also be a contributor.

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- Vibration failure (VIB) mode has $\beta = 0.44$. The low beta value suggested that there might be contamination, defective parts and poor workmanship especially during the post overhaul period.
- External Leakage-Utility Medium (ELU) failure mode has $\beta = 0.99$. This suggests that the failure event lube oil leaks was now in the constant failure rate or random failure. This might be due to weldment flaws, crack, environment or temperature variance and human error (i.e. operating and maintenance error).

Table-2. Reliability and maintainability analysis.

	Reliability Data				Maintainability Data		
Code	Failure Distribution	Parameters		Failure Characteristic	Repair Distribution	Parameters	
ELP	Weibull (2P)	β 0.57	η (year) 0.47	DFR	Lognormal	μ (hour) 7.43	σ 1.02
BRD	Weibull (2P)	β 0.63	η (year) 0.88	DFR	Lognormal	μ (hour) 7.88	σ 1.28
SER	Weibull (2P)	β 0.33	η (year) 115.1	DFR	Lognormal	μ (hour) 11.06	σ 3.16
VIB	Weibull (2P)	β 0.44	η (year) 10.72	DFR	Lognormal	μ (hour) 9.19	σ 1.90
ELU	Weibull (2P)	β 0.99	η (year) 1.75	CFR	Lognormal	μ (hour) 11.04	σ 3.12

From the simulation of the RBD as shown in Figure-3, the mean availability of the system after 1 year of operation was equal to 33.6% which was lower when compared to OREDA. OREDA is the compilation of reliability data among the best oil and gas operator worldwide. Based on OREDA, the mean availability of a centrifugal pump is 99.89% after 1-year duration. This suggested that the 2 pumps were not properly maintained and operated during its service life.

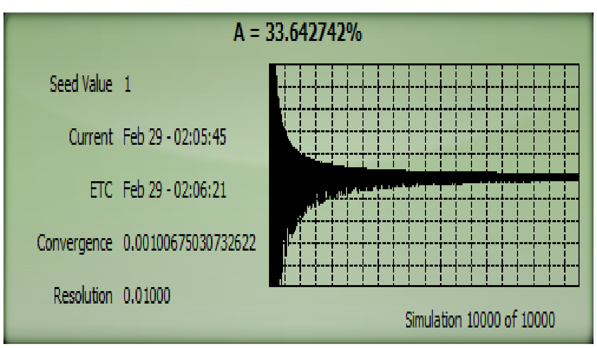

Figure-2. RBD simulation.

RS FCI also reports the percentage of times that a system failure event was caused or triggered by ELP and BRD failure modes, the two most critical failure modes and this is shown in Figure-4. It means that, the failure event mechanical seal leakage and failure due to bearings and shaft of the pumps are the 2 highest frequency of failure based on the historical records. ReliaSoft's Failure Criticality Index (RS FCI) is a relative index showing the percentage of times that the failure mode caused the system failure. This metric considers only failure events and excludes preventive maintenance and inspection events that cause an interruption in the system's operation.

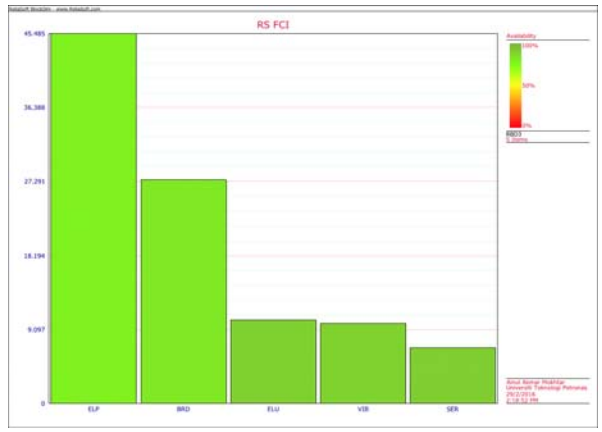

Figure-3. RS FCI reports for the crude oil transfer pumps.

CONCLUSIONS

Strategizing an action plan to remove the most critical failure mode in this analysis can make a huge improvement on both reliability as well as the availability of the crude oil transfer pump system. From the analysis, 4 out of 5 failure modes were in the infant mortality stage. It was not normal for old pumps to have failures in decreasing failure rate stage unless there was flaws in manufacturing or poor workmanship either during operation or during maintenance of the system. Thus, proper training for every technician is required to ensure they are capable of operating and maintaining the system and improving the workmanship integrity.

A decreasing failure rate also indicates that the pump may have design flaw during its manufacturing. This may be due to different undesirable environment of the operation of the pumps. Therefore, the design of the pump needs to be reviewed based on the current operating condition.

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