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Using Reliability-Centred Maintenance to Reduce Process Loss in Valves System: A Case Study

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ABSTRACT:

This study considered the application of reliability-centred maintenance methodology to reduce process loss in a butterfly Valve system. Failure mode and effects analysis were adopted for this study as the preferred reliability centred maintenance tool. This involved studying each component of an equipment to ascertain its failure mode, the root cause of each failure, and the effect of each failure mode. Mean time between Failure, Mean time to repair, and availability of sub-components were calculated. The results showed three components with the lowest percentage availability. These components are the bearing, the flange, and the stem with their percentage availability as 99.04%, 99.38%, and 99.58% respectively. This implies that these sub-components fail more often compared to others. Using the result for the mean time between failure, the risk priority number was calculated and showed components with the highest initial risk priority number, namely: seals, flange, seats, and bolts. These have risk priority numbers of 540, 450, 450, and 432 respectively. After failure mode and effect analysis were carried out, a revised risk priority number was obtained for the four components as 180, 90, 180, and 144 respectively. The reduction in risk priority number implies a reduction in component failure of the Butterfly valves.

KEYWORDS: Butterfly valve, Failure mode-and-effects analysis, Reliability centred maintenance, Risk priority number.

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1. INTRODUCTION

Over the years, safety of personnel and asset has become a growing concern for all stakeholders in any production industry. When it comes to ensuring adequate safety and prevention of process loss in the production system, valves are one of the components that are put in place to prevent or stop any immediate loss of primary containment (LOPC) that might be dangerous and difficult to control. In order to increase performance, quality and productivity at a reduced cost, valve maintenance has an important role to play in reducing the number of downtimes. A day's output lost because of an unplanned stoppage will never be recovered without additional costs being incurred (Alsyouf, 2007; Gupta & Mishra, 2018). To achieve this goal, valve life cycle management is very important, in this context the role of maintenance is redefined as an essential means for life cycle management.

Maintenance involves long-term strategic planning which integrates all the phases of a product life cycle. It includes and anticipates changes in social, environmental, economic trends, and requires benefits from innovative technologies (Gupta & Mishra, 2018).

Long term strategic maintenance planning is the term used when we are in the process of understanding every part of our equipment, understanding which component failure will pose the greatest risk to equipment and personnel, and also understand what needs attention and when, above all, how to make sure you take the machine down for maintenance on your time, rather than when the machine wants to take itself down. Unforeseen breakdown of machines poses a great risk it causes waste and is also expensive.

Shashi *et al.* (2020) in their study titled reliability centred maintenance used in metro railways concluded that, RCM plays a paramount role in railway maintenance and the RCM methodology can be used to detect fault in the railway system.
Gupta *et al.* (2016) also used RCM to achieve a practical and well-structured system to achieve a maintenance strategy for every component of a system that is generally acceptable. They conducted a study in their paper on reliability centered maintenance (RCM). The aim of their study was to achieve reduction in the overall amount of failures and the effects of these failures on the conventional lathe machine. The detection, occurrence, and severity rating integrating with failure mode and effect analysis (FMEA) are taken from several experts and then risk priority number is calculated for each of those experts. Then the criticality of the failure mode of the functionally significant items of conventional lathe machine is judged on the basis of mean RPN value as well as using the range. Identification of the criticality or rick level of every failure mode was done. Finally, an adequate maintenance plan was selected for each failure mode using the RCM logic

With the widespread use of RCM, Islam *et al.* (2019) proposed a new framework of RCM, and it was implemented in sugar production plant. The aim of this new model was to solve the problems with existing RCM models which do not propose any actions with non-critical component.
The findings of the research show a reduction in corrective maintenance downtime. It decreased from 9.7 hours/year to 4.3 hours/year, this invariably reduced cost of running and maintaining the plant. Preventive maintenance downtime also saw a reduction from 20 hours/year to 10 hours/year. The overall reliability and availability of the system were also improved.

Nader and Mohammad (2020) also used RCM to reduce cost and improve the reliability of the overhead transmission lines in Al-Madinah. Their research was focused on improving the quality of delivering power in the transmission lines. This was done by reducing the time it took to restore failed components and also minimize megawatts that goes to waste as a result of failed transmission lines. In their research, five power lines were studied, using the RCM methodology that investigates data using equipment criticality and RCM logic tree to better understand the action to be taken when there is power failure.

Afefy (2010) described in his paper, how the reliability-centered maintenance methodology is applied in developing a maintenance program for a steam-process plant. The main objective of his study in adopting the reliability-centered maintenance methodology, is to reduce the cost of plant maintenance. Components of the process-steam plant includes, feed-water pump, fire-tube boiler, process heater, steam distribution, and dryer. In the limits of this context, a maintenance program for the plant was done using this reliability-centered maintenance method.

After the reliability centered maintenance method was applied, it was observed that there was a reduction in the mean time between failures for the plant components, and also a decrease in the probability that a component will fail suddenly. The results show a decrease in labor costs from \$295,200 per year to \$220,800 per year. This is 25.8% of the total labor cost for the proposed preventive maintenance planning. Moreover, the downtime cost of the plant components is investigated. The proposed PM planning results indicate a saving of about 80% of the total downtime cost as compared with that of current maintenance.

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In addition, the proposed spare parts programs for the plant components are generated. The results reveal a savings of 22.17% of the yearly spare parts cost when proposed preventive maintenance planning other current maintenance once.

Deepak and Arumugam (2019) in their work found the difficulties in implementing RCM, and these difficulties are high skill required by people in implementation, huge resources are needed such as, software, investment documentation, manpower. They also mentioned that RCM is a complicated process that requires extensive analysis. Fore and Msipha (2001) targeted a ferrochrome processing plant. The research points out that preventive maintenance is often neglected, affecting process continuity, and thus compromising product quality due to drops and fluctuations in operating temperature.

Production targets are affected because of longer and more frequent breakdowns. Even after maintenance is carried out, start-up failures are also experienced. The maintenance department is affected by the unpredictability of the equipment's operational patterns, and faces challenges in coming up with an effective spare part inventory management regime. This leads to crisis management, thereby increasing the direct cost of maintenance. RCM was used to create a cost-effective preventive maintenance strategy to address the dominant causes of equipment failure. The result is a maintenance programme that focuses scarce economic resources on those items that would cause the most disruption if they were to fail, and thereby increases production.

2. MATERIALS AND METHODS

The valve systems studied are in unit 1200 of the Nigeria liquefied natural gas (NLNG) plant. This unit is the moisture removal unit of the plant; it is also called the dryer bed. The dryer bed unit has 3 columns called, the Alpha, Bravo, and Charlie. Each of the columns has 2 valves, one at the bottom, and one at the top of the column. These columns receive gas through the valves below the dryer bed, and the gas goes through an array of molecular sieves of different sizes which removes moisture. The valves to be studied are the six valves of unit 1200 of the NLNG plant.
The components of the butterfly valve that are to be analysed are;

i. Hand wheel
ii. Stem
iii. Body
iv. Seat
v. Disc
vi. Bearing
vii. Bolts
viii. Pins
ix. Seals
x. Flanges

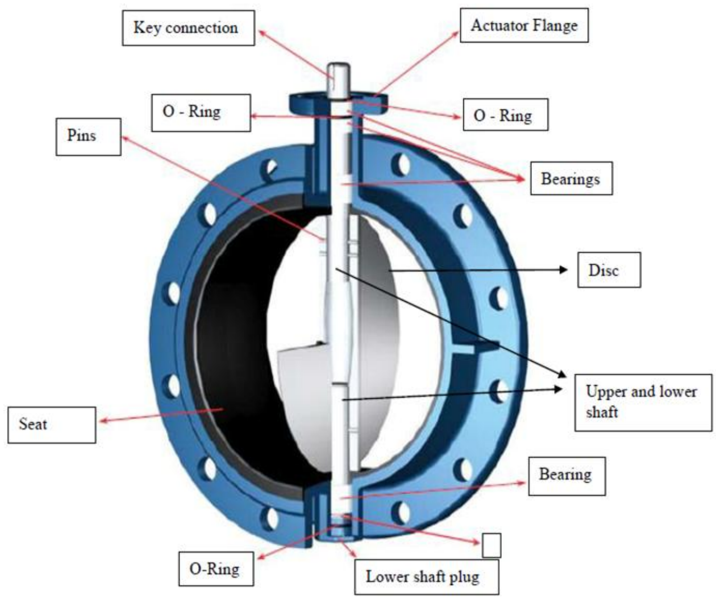

Figure 1 Detailed description of a butterfly Valve

Steps in RCM

i. The process should be reviewed.
ii. Brainstorm potential failure modes.
iii. Derive the effects of each failure.
iv. Derive Ranking in Occurrence.
v. Derive Ranking in Severity.
vi. Derive Ranking in Detection.
vii. Calculate the RPN.
viii. Create an Action Plan.
ix. Action should be taken.
x. Calculate the Resulting RPN.

The list of components to be analysed has to be determined, and this is one of the first steps to RCM. The factors that affect how critical components are selected are as follows.

i. Mean-time between failure (MTBF)

$$MTBF = \frac{\sum t_1}{n} \quad (1)$$

(Okwuobi *et al.*,2018)

where:

$\sum t_1$ = the total running time in operation of the system during an investigation period for both failed and non-failed items.

n = number of failures (breakdowns) of system or it occurring during a certain investigation period.

ii. Mean time to repair (MTTR)

$$MTTR = \frac{\sum r_1}{n} \quad (2)$$

(Okwuobi *et al.*,2018)

where:

r_1 = total accumulative time of system or its parts to repair or maintain time

n = number of repair actions in the population of system during the specified investigation period.

iii. $$Availability = \frac{MTBF}{MTBF + MTTR} \quad (3)$$

2.1. Risk Priority Number (RPN)

The RPN calculates the inherent risk from a given failure mode, by assigning numerical values to severity, occurrence and detection. As the risk increases, the RPN values of the failure mode rises. This is what is defined as the risk priority number.

RPN is a product of the severity, occurrence and detection as shown in the formula below.

$$RPN = S \times O \times D \quad (4)$$

where: S, O and D represent Severity, Occurrence and Detection respectively.

(a) Severity (S)

This shows how serious the effect of a potential failure mode is. Table 1 shows the rating details and effect of severity. The numbers with high severity rating, represents the highest seriousness or risk which could cause death.

Table 1: Severity Rating

Severity	Rating
Dangerously high	10
Extremely High	9
Very High	8
High	7
Moderate	6
Low	5
Very Low	4
Minor	3
Very Minor	2
None	1

(Ouma *et al., 2015*)

(b) Occurrence (O)

Occurrence rating is determined by the probability that a failure may occur based upon past failure and performance. Table 2 classifies occurrence into its different numerical values. This rating estimates the likelihood that a failure will occur for that reason during lifetime. It is classified using a scale from 1 to 10.

Table 2: Occurrence Rating

Failure occurrence Criteria	Rate	Rating
Failure once a week		10
Failure once a month		9
Failure once a three month		8
Failure once in six months		7
Failure once a year		6
Failure once in three years		5
Failure once in five years		4
Failure once in 7 years		3
Failure once in 10 years		2
Failure once in 20 years		1

(Ouma *et al., 2015*)

(c) Detection (D)

Detection rating estimates how easy, or difficult it is to detect a failure mode after it has occurred. This is further described in Table 3.

Table 3: Detection Rating

Rate	Rating
Absolute Uncertainty	10
Very Remote	9
Remote	8
Very Low	7
Low	6
Moderate	5
Moderate High	4
High	3
Very High	2
Almost Certain	1

(Ouma *et al., 2015*)

3. RESULTS AND DISCUSSION

The following are results of the calculations of the MTBF, MTTR and availability of components of the butterfly valve.

Calculation of MTBF from Equation (1), MTTR from Equation (2) and Availability from Equation (3) for the Hand wheel

$$MTBF = \frac{(636+421+402)}{3} = 486DAYS$$

$$MTTR = \frac{(1+1)}{2} = 1DAY$$

$$Availability = \frac{486}{(486+1)} = 0.9979 = 99.79\%$$

The results of the calculation of MTBF of the remaining components of the butterfly valve is shown in Table 4, while the result of the calculation of MTTR and availability are shown in Table 5.

From Equation (4) the Risk Priority Number of all components of the butterfly valve is determined and is shown in Table 6. The result of the risk priority number analysis of the sub-components of the butterfly valve in Table 6 shows three components with the highest RPN. These components are seals, flange, and seat. The failure modes and effects of critical components of the butterfly valve are shown in Table 7.

Maintenance actions were taken on critical components of the butterfly valve, and then a revised RPN was estimated. Table 8 shows the revised RPN.

The results show a reduction in RPN after recommended actions were taken.

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Table 4: Input Data and Result of MTBF

S/N	Sub-component	(t1)	(t2)	(t3)	(t4)	(n)	MTBF
1	Hand Wheel	636	421	402	0	3	486.3333333
2	Stem	924	533	0	0	2	728.5
3	Body	1460	0	0	0	1	1460
4	Seat	514	436	499	0	3	483
5	Disk	924	533		0	2	728.5
6	Bearing	532	472	442	0	3	482
7	Bolts	381	358	343	375	4	364.25
8	Pins	926	533	0	0	2	729.5
9	Seals	442	348	335	322	4	361.75
10	Flange	832	628	0	0	2	730

Source: NLNG maintenance Department

Table 5: Input data and Result of MTTR and Availability

S/N	Mt1	Mt2	Mt3	(N)	MTTR	Availability %
1	1	1	0	2	1	99.79
2	3	0	0	1	3	99.58
3	1	0	0	1	1	99.93
4	5	6	0	2	5.5	98.87
5	3	0	0	1	3	99.58
6	4	5	5	3	4.66	99.04
7	1	1	1	3	1	99.72
8	1	0	0	1	1	99.86
9	4	4	5	3	4.33	98.81
10	4	5	0	2	4.5	99.38

Source: NLNG maintenance department

Table 6: Risk Priority Number Analysis

Sub – Component	Severity	Occurrence	Detection	RPN	Group
Hand wheel	8	5	3	120	C
Stem	8	4	7	224	C
Body	10	1	3	30	D
Seat	9	5	10	450	A
Disc	9	5	6	270	B
Bearing	8	6	8	384	B
Bolts	8	6	9	432	B
Pins	8	5	8	320	B
Seals	10	6	9	540	A
Flanges	10	5	9	450	A

Table 7: Failure modes effects of critical components

Component	Failure Mode	Failure Effect
Seat	Leakage Tear, Permanent deformation, Swelling	Partial closure Loss of flow control
Bearing	Wear	Operation fail
Flanges	Leakage	Loss of primary containment
Seal	Leakage	Wetting the lubrication system and gearing system

Table 8: Risk Priority Number After Maintenance action was taken

Sub – Component	Severity	Occurrence	Detection	RPN
Hand wheel	8	2	3	48
Stem	8	1	7	56
Body	10	1	3	30
Seat	9	2	10	180
Disc	9	1	6	54
Bearing	8	2	8	128
Bolts	8	2	9	144
Pins	8	1	8	64
Seals	10	2	9	180
Flanges	10	1	9	90

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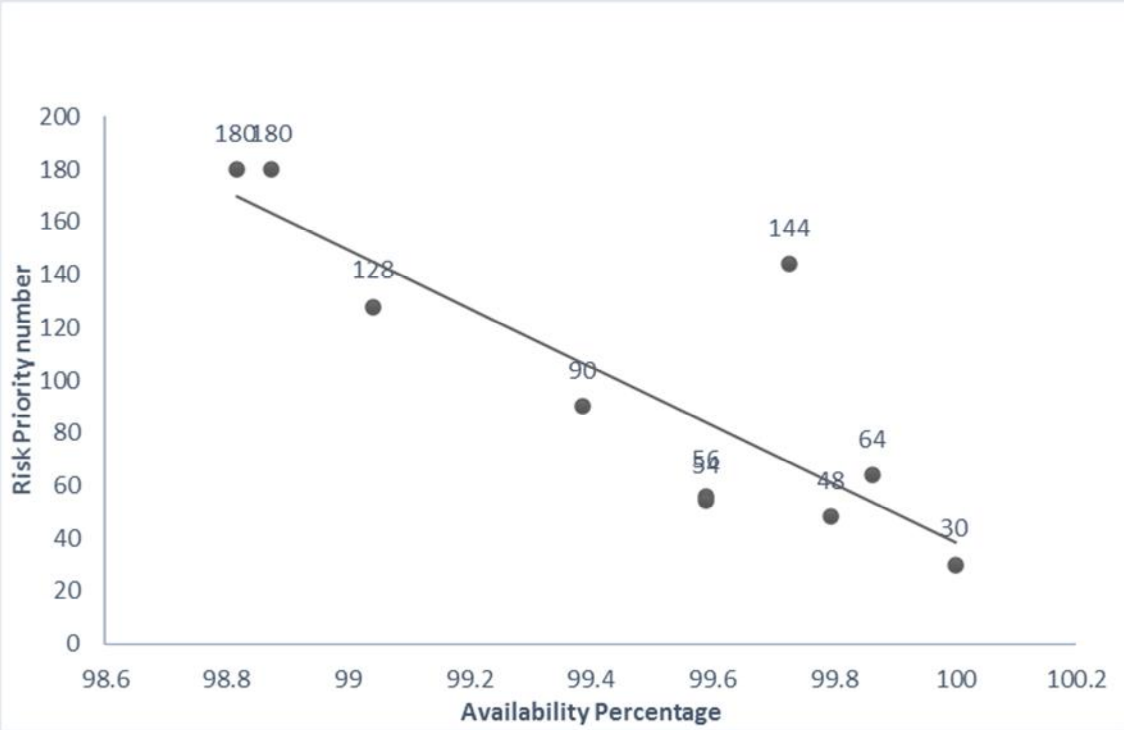

Figure 2: RPN and Availability

Figure 2 shows the relationship between the RPN and the Availability percentage of components of butterfly valve with identification number 512UZ-181A. It shows that, the lower the RPN, the higher the percentage availability of the component. The occurrence on Table 8 is the probability that a failure will occur. There was a reduction in occurrence values of Table 8 from the previous occurrence values. This is due to adequate maintenance actions carried out on valve components. These maintenance actions were what reduced the occurrence in Table 8.

Table 9 shows the percentage availability alongside the RPN of the sub components of the butterfly valve with identification number 512UZ-181C.

Table 9: Risk Priority Number and Availability

Sub - Component	Availability %	RPN
Hand wheel	100	48
Stem	99.8631	56
Body	100	30
Seat	99.2825	180
Disc	100	54
Bearing	99.178	128
Bolts	99.635	144
Pins	99.7264	64
Seals	98.9056	180
Flanges	99.3923	90

Table 10 shows the percentage availability alongside the RPN of the sub components of the butterfly valve with identification number 512UZ-182A.

Table 10: Risk Priority Number and Availability

Sub - Component	Availability %	RPN
Hand wheel	99.86311	48
Stem	99.7264	56
Body	100	30
Seat	99.07818	180
Disc	99.7264	54
Bearing	99.178	128
Bolts	99.635	144
Pins	99.863	64
Seals	98.9071	180
Flanges	99.45205	90

4. CONCLUSIONS

This paper investigated the failure of the triple offset butterfly valve at the NLNG plant in Bonny. FMEA technique was used to evaluate the ten critical parts that are prone to failure. Implementation of the recommended maintenance actions greatly reduces the RPN of all the sub-components of the butterfly valve. This directly reduces the risk of failure and also, process loss. From the initial analysis, the valve seals, seat and, flanges had the highest RPN.

The high RPN in component like the valve seal, seat and flange is due to their high severity and occurrence. The high severity is due to their effect to the system when they fail and how difficult it is to detect their failure. After the recommended action was taken on each failure mode, there was a great reduction in RPN values of some critical components like valve seals and flanges. The RPN value of the seals reduced from 540 to 180, while that of flanges reduced from 450 to 90. The relationship between the availability percentage and the RPN shows that, the lower the RPN, the higher the percentage availability of the component.

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