Engineering and Technology Journal e-ISSN: 2456-3358

Volume 11 Issue 02 February-2026, Page No.-9112-9120

DOI: 10.47191/etj/v11i02.39, I.F. – 8.482

Application of Turnaround Maintenance Models in Offshore Crude Oil Production Platform

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ABSTRACT: Turn-round maintenance in the oil and gas industry involves a four yearly total facility shut-down for equipment maintenance and overhaul. However, not all equipment qualifies for turnaround maintenance (TAM). Some maintenance can be carried out on the fly, while others can be carefully scheduled to fit into a specific maintenance cycle such as TAM. Weibull analysis was adopted and applied on live data from two Oil and Gas production platform DP-A to determine that equipment by evaluating their Availability, Unavailability, Reliability and Unreliability with beta β factor being the determinant factor for maintenance modelling. "$\beta < 1$" implies that reliability growth is occurring (decreasing failure rate- infant mortality); and "$\beta = 0$" implies no growth (constant failure rate-random failures). "$\beta > 1$" implies that deterioration is occurring (increasing failure rate-wear out) .Results show Beta factor for platform DP-A equipment as follows; Wing Valve positioner 0.95, Wellhead control panel 0.72, FRAMO pump 0.44, HVAC chiller 0.33, Water injection pump 0.95, HPU Compressor 0.74, Choke actuator 0.80, Heater blower fan 0.37. The model present can be used to predict and schedule maintenance on oil and gas production platforms. It is recommended that oil and gas companies should employ this model in their maintenance schedules for offshore production facilities.

KEYWORDS: Offshore, production platform, maintenance, crude oil, models, turnaround.

1.0 Introduction

Offshore oil and gas facilities play a crucial role in meeting the global energy demand, with a significant portion of the world's hydrocarbon reserves located offshore [1]. These facilities are complex structures that operate in offshore environments, typically located in coastal waters or deep-sea regions. They are designed to extract, process, and transport oil and gas resources from beneath the seabed [1] Offshore oil and gas facilities are composed of various components and systems that work together to facilitate the production and processing of hydrocarbons. They typically consist of fixed platforms, floating production systems, subsea installations, and pipelines [2] Fixed platforms are structures firmly anchored to the seabed, while floating production systems are mobile units that float on the surface of the water and are held in place by mooring systems [1].

These facilities are exposed to harsh and challenging operational conditions, including extreme temperatures, corrosive saltwater, high pressures, and unpredictable weather conditions [3]. The hostile offshore environment poses unique challenges to equipment integrity, system performance, and overall safety of operations [4]. To ensure the continuous and safe operation of offshore oil and gas facilities, effective maintenance strategies are essential. Maintenance activities in these facilities encompass preventive, predictive, and corrective measures to address equipment deterioration, perform inspections, conduct repairs, and optimize operational efficiency [2]. One significant maintenance strategy employed in offshore facilities is turnaround maintenance.

Turnaround maintenance in offshore oil and gas facilities involves the temporary shutdown of production units for comprehensive maintenance activities [5]. During turnarounds, equipment are inspected, repaired, and replaced when necessary to maintain the integrity, reliability, and performance of the facilities [4]. The goal of maintenance in offshore facilities is not only to ensure the reliable operation of equipment but also to maximize production output, minimize downtime, and enhance safety performance [6]. Effective maintenance practices are critical to optimize plant productivity, reduce the risk of equipment failures, and mitigate potential environmental hazards associated with offshore oil and gas operations [1]. It is therefore safe to say, offshore oil and gas facilities are complex structures that operate in challenging offshore environments. They consist of various components and systems designed to extract, process, and transport hydrocarbons. Maintenance activities, including turnaround maintenance, are crucial to ensure the continuous operation, reliability, and safety of these facilities. By implementing effective maintenance strategies, operators can enhance plant productivity, minimize downtime, and ensure the efficient and sustainable extraction of offshore oil and gas resources. Typical Drilling platforms are shown in Figures 1, 2 and 3 respectively.

Figure 1: Typical unmanned satellite drilling platform; shell EA field [7]

Figure 2: The sea eagle FPSO; shell EA field operations manual [8]

Figure 3: The risers platform RP-A; shell EA field operations manual [7]

operation of the facilities" [2]. Turnaround maintenance, characterized by the temporary shutdown of production units, is a commonly employed strategy in the industry to conduct comprehensive inspections, repairs, and equipment replacements [5]. The goal of turnaround maintenance is to enhance plant productivity, equipment reliability, and overall operational efficiency [4].

Several studies have examined the impact of turnaround maintenance on plant productivity in offshore oil and gas facilities. For instance, [2] conducted a case study on an offshore platform and found that turnaround maintenance positively influenced plant productivity by reducing equipment downtime and improving production efficiency. Similarly, [7] analyzed maintenance data from multiple offshore facilities and reported a significant improvement in production output and overall equipment effectiveness after turnaround maintenance events.

In addition to plant productivity, equipment reliability is another critical aspect affected by turnaround maintenance by [7] investigated the impact of turnaround maintenance on the reliability of critical equipment in offshore facilities. Their findings indicated that proper maintenance activities during turnarounds led to increased equipment reliability and reduced the likelihood of unexpected breakdowns, thus improving the overall operational reliability of the plants. The cost implications associated with turnaround maintenance have also been explored in the literature.[4] conducted a cost analysis of turnaround maintenance activities in offshore oil and gas facilities and found that although the initial costs of shutdowns and maintenance procedures were substantial, the long-term benefits, such as improved equipment performance and reduced emergency repairs, outweighed the costs. Additionally [5] highlighted the importance of proper planning and scheduling of turnaround maintenance to minimize downtime and associated financial losses.

Despite the existing studies, there are still gaps in the literature regarding the impact of turnaround maintenance on plants for quality productivity in offshore oil and gas facilities. Firstly, there is a need for more empirical studies that cover a broader range of offshore facilities to provide a comprehensive understanding of the impact. Additionally, the literature would benefit from investigations into the specific factors and strategies that contribute to successful turnaround maintenance outcomes, such as effective planning, resource allocation, and collaboration between maintenance teams and plant operators.

Despite the existing studies, there are still gaps in the literature regarding maintenance strategies in the oil and gas industry. Future research should focus on investigating the integration of different maintenance strategies, the optimization of maintenance scheduling algorithms, the adoption of emerging technologies (such as the Internet of Things and artificial intelligence) in maintenance practices, and the development of decision support systems for maintenance strategy selection. It is vital to understand that maintenance strategies play a vital role in the oil and gas industry, ensuring equipment reliability, safety, and optimal performance. The existing literature highlights the benefits of preventive maintenance, predictive maintenance, RCM, CBM, and TPM in improving equipment reliability, reducing downtime, and enhancing operational efficiency. However, further research is needed to address the existing gaps and explore innovative approaches to maintenance strategy development and implementation in the evolving landscape of the oil and gas industry.

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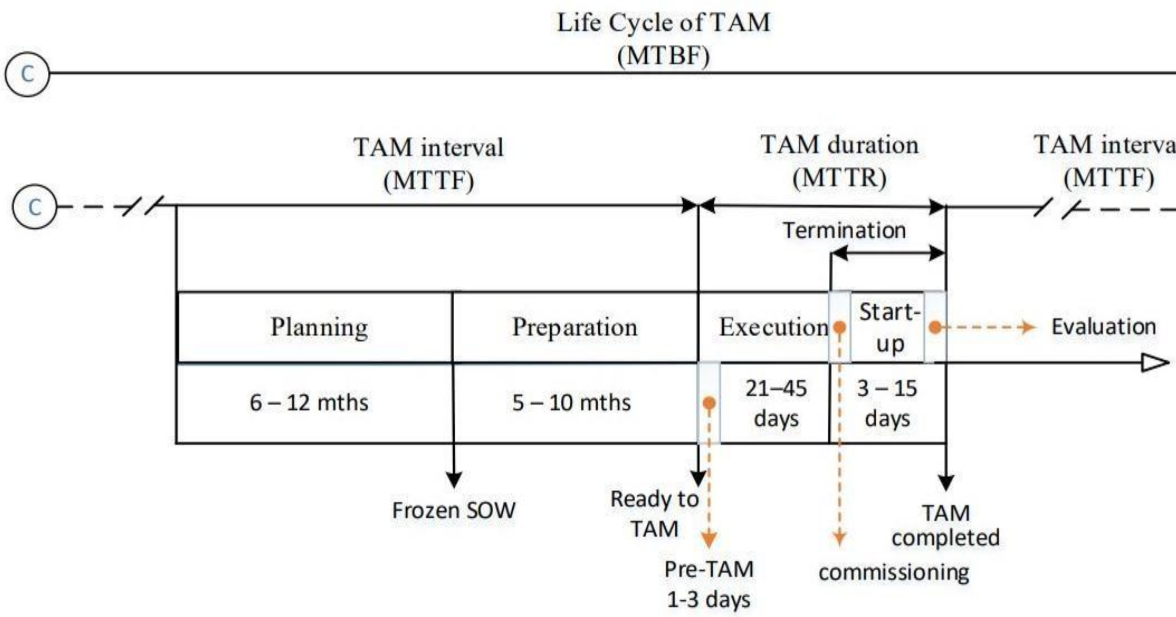

Figure 4: Flow chart showing failure mode, effect and criticality [10]

The objective of this research is to apply Weibull reliability models for TAM on crude oil production platform.

2.0 MATERIALS AND METHODS

The reliability of the system is mathematically represented by Equation 1 as:

Reliability:exp(−t/MTBF) Equation 1

where, R is reliability, t is time and MTBF mean time before failure, a reliability index for a repairable unit.

Mode Criticality = IMPo(t) Equation 2

where I is Item Unreliability, M is mode Ratio of Unreliability, Po is Probability of Loss and t is Time (life).

Risk priority number (RPN) is a function of the three parameters, the severity of the effect of failure, the probability of occurrence, and the ease of detection for each failure mode. RPN is calculated by multiplying these three numbers as per the formula given in FMECA as shown in Equation 3.3 as:

RPN = SPD Equation 3

where S is the severity of the effect of failure, P is the probability of failure, and D is the ease of detection. RPN may not play an important role in the choice of an action against failure modes but will help in indicating the threshold values for determining the areas of greatest concentration. In other words, a failure mode with a high RPN number should be given the highest priority in the analysis and corrective action. The relationship between the above-mentioned parameters of FMEA is represented in Figure 1.

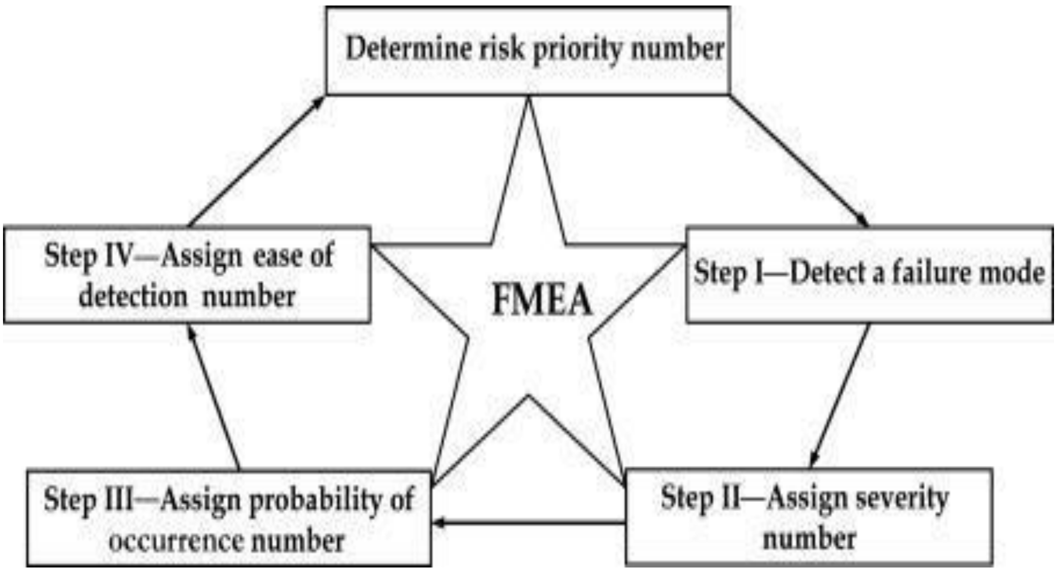

Figure 1: Flow chart showing failure mode, effect, and criticality [10]

Data Collection

The data collected in this research was obtained from an offshore production platform-The basic information gotten were:

i. TAM Documentation,
ii. Archival maintenance records,
iii. Interviews with maintenance personnel,
iv. Real time equipment performance/condition monitoring parameters,
v. Critical alarm logs and notification analysis.

The reliability characterizes components or system of components is mathematically expressed as by Equations 3 to 23 respectively.

UT = (8760- OT) Equation 3

where UT is uptime or operational hours, 8760 is numbers of hours in a year, OT is Outage time.

AFH = OT/NF Equation 4

where AFH is Average failure hour, OT is Outage time or failure hours, NF is Number of failures

OTR1 = (OT/(OT+U)) x 100% Equation 5

where OTR1 is outage hour rate, OT is Outage time and U is unavailability.

OTR2 = OT/U x 100% Equation 6

where OTR2 is outage hour ratio, OT is Outage time and U is unavailability.

CTR1 = (CT/(CT+U))100% Equation 7

where CT is corrective (maintenance) hour rate, and U is unavailability.

CTR2 = (CT/U)100% Equation 8

where CTR2 is corrective (maintenance) hour ratio, and U is unavailability.

MTTF = U/NF Equation 10

where MTTF is mean time to failure, NF is number of failures and U is unavailability.

MTTR(t) = CT/NF Equation 13

where MTTR is mean time to repair, , NF is number of failures and CT is corrective maintenance MTBF = T= (MTTF + MTTR) period, Equation 14

where MTBF is mean time before failure, MTTF is mean time to failure and MTTR is mean time to repair.

λ =1/MTBF Equation 15

where λ is failure rate and MTBF is mean time before failure,

μ = 1/MTTR Equation 16

where μ is repair rate and MTTR is mean time to repair.

A = UT / (UT+OT) Equation 17

where A is availability, UT is uptime or operational hours, and OT is Outage time.

UA = OT/ (OT + UT) Equation 18

where UA is unavailability, UT is uptime or operational hours, and OT is Outage time.

R = exp(-t/MTBF) Equation 19

where, t =8760hrs & R is reliability and MTBF means time before failure.

UR = 1 – R = exp(-t/MTBF) Equation 20

where UR is unreliability, R is reliability and MTBF means time before failure.

:

R(t) = 1 – (UR)x(UR2) Equation 21

Availability deals with the duration of uptime for operations and is a measure of how a system is alive and well.

A = Uptime/ (Uptime + downtime) = (uptime/downtime). Equation 22

Machine availability, also referred to as uptime, is the total amount of time a machine actually runs versus the time it was scheduled to run. Availability is a key figure to monitor when it comes to production planning. Production capacity, delivery dates, expected breakdowns, and costing are determined from availability data.

Machine availability is calculated in the following way as shown by Equation 23

Availability = Rt / Pt Equation 23

where Rt is run time, Pt is production time.

$R = e^{(-t/\eta)\beta}$ Equation 24

where η is the characteristic life, β is the shape factor and t, the time

The cumulative distributive function CDF is very critical and it is where Weibull reliability (R)is determined.

The EA Field is located at the Southeast corner of Oil Block OML 79, 15 kilometers off the mouth of Dodo River, offshore Bayelsa State of Nigeria. Together with an adjoining Associated Gas EJA Field, the field operated by the Shell Petroleum Development Company Nigeria Limited were DP-A is located.

This platform houses the oil-producing wells which produce reservoir fluid into a production manifold system via which two common headers, one for high-pressure wells and the other for low-pressure wells, deliver the untreated reservoir mixture of crude oil, natural gas, water, and solid impurities to the sea eagle FPSO topside equipment for separation into the various constituents.

3.0 RESULTS AND DISCUSSION

3.1 Results

The Tables 1, 2, 3 and 4 below show computation of equipment reliability and availability for drilling platform A (DP-A) for 2020, 2021, 2022 and 2022 respectively.

Table 1: DP-A equipment reliability and availability for 2020

Equipment	HPU Compressor	Wellhead Control Panel	HVAC Chiller	H2O Injection Pump	Heater Blower Fan	Choke Actuator	Wing Valve Positioner
Study Interval, t	8760	8760	8760	8760	8760	8760	8760
No. of failure	2	2	2	1	1	1	1
Outage time (per year) OT	592.5	435	198	141	187.5	244	162
AFH	296.25	217.5	99	141	187.5	244	162
MH	4	5	3	4	2	5	3
Uptime, U	8,167.5	8,328	8,562	8,619	8,572.5	8,516	8,598
FHR1%	6.76	4.964	2.260	2.129	2.1872	2.783	1.849
FHR2%	7.25	5.22	2.31	1.64	2.19	2.87	1.88
MHR%	0.04	0.06	0.03	0.04	0.02	0.05	0.3
MTTF (U)%	4083.5	4164	4281	8619	8572	8516	8598
Mean time to repair, MTTR(D)%	4	5	3	4	2	5	3
MTBF	4087	4169	4284	8623	8574	8521	8601
Λ	0.00024	0.00023	0.00023	0.00011	0.00011	0.00011	0.00011
M	0.25	0.20	0.33	0.25	0.50	0.20	0.33
A%	93.23	95.03	97.73	98.39	97.85	97.21	98.15
UA%	6.76	4.96	2.26	1.61	2.14	2.79	1.85
R%	11.72	12.23	12.94	36.21	35.99	35.77	36.11
UR%	88.28	87.77	87.06	63.79	64.01	64.23	63.88

Table 2: DP-A equipment reliability and availability for 2021

Equipment	HPU Compressor	Wellhead Control Panel	HVAC Chiller	H2O Injection Pump	Heater Blower Fan	Choke Actuator	Wing Valve Positioner	FRAMO Pump
Study Interval, t	8760	8760	8760	8760	8760	8760	8760	8760
No. of failure	2	1	2	1	1	1	2	2
Outage time (per year) OT	568.5	311.5	375.5	268.5	184	155.5	487.5	619
AFH	284.25	311.5	187.75	268.5	184	155.5	243.75	309.5
MH	6	7	3	4	3	2	5	8
Uptime, U	8191.5	8448.5	8384.5	8491.5	8576	8604.5	8272.5	8141
FHR1%	6.49	3.56	4.29	3.07	2.10	1.78	5.57	7.07
FHR2%	6.94	3.69	4.48	3.16	2.15	1.81	5.89	7.60
MHR%	0.07	0.08	0.04	0.05	0.03	0.02	0.06	0.10
MTTF (U)%	4095.75	8448.50	4192.25	8491.50	8576.00	8604.50	4136.25	4070.50
Mean time to repair,MTTR(D)%	6.00	7.00	3.00	4.00	3.00	2.00	5.00	8.00
MTBF	4101.75	8455.50	4195.25	8495.50	8579.00	8606.50	4141.25	4078.50
Λ	0.00024	0.00012	0.00024	0.00012	0.00012	0.00012	0.00024	0.00025
M	0.17	0.14	0.33	0.25	0.33	0.50	0.20	0.13
A%	93.51	96.44	95.71	96.93	97.90	98.22	94.43	92.93
UA%	6.49	3.56	4.29	3.07	2.10	1.78	5.57	7.07
R%	11.82	35.49	12.39	35.66	36.02	36.14	12.06	11.67
UR%	88.18	64.51	87.61	64.34	63.98	63.86	87.94	88.33

Table 3: DP-A equipment reliability and availability for 2022

Equipment	HPU Compressor	Wellhead Control Panel	HVAC Chiller	H2O Injection Pump	Heater Blower Fan	Choke Actuator	Wing Valve Positioner	FRAMO Pump
Study Interval, t	8760	8760	8760	8760	8760	8760	8760	8760
No. of failure	1	2	2	1	2	2	2	2
Outage time (per year) OT	178	577	438	196	389	421	565	407
AFH	178	288.5	219	196	194.5	210.5	282.5	203.5
MH	3	5	6	4	5	9	6	9
Uptime, U	8582	8183	8322	8564	8371	8339	8195	8353
FHR1%	2.03	6.59	5.00	2.24	4.44	4.81	6.45	4.65
FHR2%	2.07	7.05	5.26	2.29	4.65	5.05	6.89	4.87
MHR%	0.03	0.06	0.07	0.05	0.06	0.11	0.07	0.11
MTTF (U)%	8582.00	4091.50	4161.00	8564.00	4185.50	4169.50	4097.50	4176.50
Mean time to repair,MTTR(D)%	3	5	6	4	5	9	6	9
MTBF	8585.00	4096.50	4167.00	8568.00	4190.50	4178.50	4103.50	4185.50
Λ	0.00012	0.00024	0.00024	0.00012	0.00024	0.00024	0.00024	0.00024
Μ	0.33	0.20	0.17	0.25	0.20	0.11	0.17	0.11
A%	97.97	93.41	95.00	97.76	95.56	95.19	93.55	95.35
UA%	2.03	6.59	5.00	2.24	4.44	4.81	6.45	4.65
R%	36.05	11.78	12.22	35.97	12.36	12.29	11.83	12.33
UR%	63.95	88.22	87.78	64.03	87.64	87.71	88.17	87.67

Table 4: DP-A equipment reliability and availability for 2023

Equipment	HPU Compressor	Wellhead Control Panel	HVAC Chiller	H2O Injection Pump	Heater Blower Fan	Choke Actuator	Wing Valve Positioner	FRAMO Pump
Study Interval, t	8760	8760	8760	8760	8760	8760	8760	8760
No. of failure	2	2	1	2	2	2	2	1
Outage time (per year) OT	364	486	199	603	516	649	474	219
AFH	182	243	199	301.5	258	324.5	237	219
MH	6	8	3	6	8	4	8	4
Uptime, U	8396	8274	8561	8157	8244	8111	8286	8541
FHR1%	4.16	5.55	2.27	6.88	5.89	7.41	5.41	2.50
FHR2%	4.34	5.87	2.32	7.39	6.26	8.00	5.72	2.56
MHR%	0.07	0.10	0.04	0.07	0.10	0.05	0.10	0.05
MTTF (U)%	4198.00	4137.00	8561.00	4078.50	4122.00	4055.50	4143.00	8541.00
Mean time to repair, MTTR(D)%	6.00	8.00	3.00	6.00	8.00	4.00	8.00	4.00
MTBF	4204.00	4145.00	8564.00	4084.50	4130.00	4059.50	4151.00	8545.00
Λ	0.00024	0.00024	0.00012	0.00024	0.00024	0.00025	0.00024	0.00012
Μ	0.17	0.13	0.33	0.17	0.13	0.25	0.13	0.25
A%	95.84	94.45	97.73	93.12	94.11	92.59	94.59	97.50
UA%	4.16	5.55	2.27	6.88	5.89	7.41	5.41	2.50
R%	12.45	12.08	35.96	11.71	11.99	11.56	12.12	35.87
UR%	87.55	87.92	64.04	88.29	88.01	88.44	87.88	64.13

Table 5 shows reliability and Table 6 shows results obtained from Weibull plots for beta values.

Table 5: Platform DP-A log of time and reliability per year for weibull plot

HPU Compressor - A				Wellhead Control Panel			
Year	**Time (hrs)**	**Log Time**	**Reliability (%)**	**Year**	**Time (hrs)**	**Log Time**	**Reliability (%)**
2020	8167	3.912	11.72	2020	8328	3.921	12.23
2021	8191.5	3.913	11.82	2021	8448.5	3.927	35.49
2022	8582	3.934	36.05	2022	8183	3.913	11.78
2023	8396	3.924	12.45	2023	8274	3.918	12.08
	Average Reliability		18.01		Average Reliability		17.895

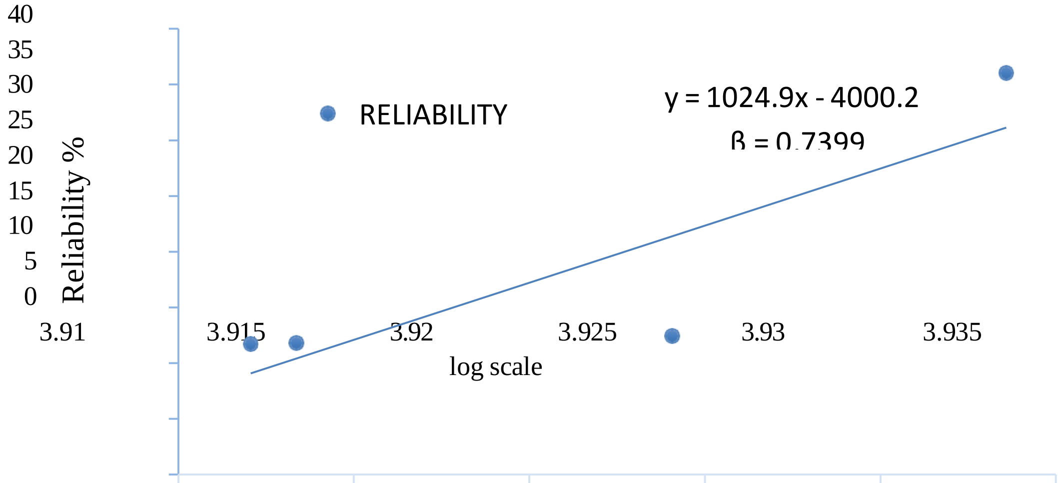

Figure 2: Reliability graph for HPU compressor (2020-2023)

Table 6: Platform – A β result

S/N	DP-A Equipment	β
1	Wing Valve positioner	0.95
2	Wellhead control panel	0.72
3	FRAMO pump	0.44
4	HVAC chiller	0.33
5	H2O injection pump	0.95
6	HPU Compressor	0.74
7	Choke actuator	0.80
8	Heater blower fan	0.37

3.2 Discussion

From the results of the platform, annual availability, unavailability, reliability, and unreliability as shown in Tables 1 to 4. All failures are not the same. The Tables also show that it is important to determine the average maintenance times for failure to make good estimate of total downtime (Lost production time). To improve on the reliability and overall equipment efficiency of the production platform DP-A the mean time between failures (MTBF) must be large when compared to the mission time as small values of MTBF will give high unreliability values.

The average availability is 95.13%, unavailability 4.86%, reliability 18.01%, and unreliability 81.99% of HPU compressor for a period of four years. This result shows that that HPU compressor has a high availability of 95.13%, but a low reliability index of 18.01%. β value of 0.74 was deduced from the graph in Figure 1 and used to model a preventive maintenance schedule and equipment selection for TAM (turn around maintenance).

For the Wellhead control panel, the average availability, unavailability, reliability and unreliability for a period of four years are: 94.83%, 5.16%, 17.89%, and 82.10% respectively. Here, the availability of Wellhead control panel is high, but lacking in reliability which is 17.89%. β value of 0.72 was obtained.

The average availability, unavailability, reliability and unreliability for a period of four years for HVAC were: 96.54%, 3.45%, 18.37%, and 81.62% respectively. The availability of HVAC chiller is high at 96.54%, but lacking in overall reliability which is 18.37%. This equipment was more reliable in the first year with a reliability index of 36.11% but declined in the years after. β value of 0.33 was obtained from and used to model maintenance schedule for offshore production platform to determine equipment selection for TAM.

Water injection pump has 96.55%, 3.6%, 29.88%, 70.11% as availability, unavailability, reliability and unreliability respectively for a period of four years. Water injection pump is seen to be the most reliable equipment amongst all the equipment on the platform DP-A with reliability index of approximately 30% and average availability of 96.55%. β value of 0.95 was obtained from the plot and used to model maintenance schedule for offshore production platform to determine equipment selection for TAM.

96.35%, 3.64%, 24.09%, 75.91% are the average availability, unavailability, reliability and unreliability respectively for a period of four years for heater blower fan. This result shows that that Heater blower fan has a high availability of 96.35%, with more reliability index of 24.09%. β value of 0.37 was deduced from plot and used to model a preventive maintenance schedule and equipment selection for TAM.

For the Choke actuator, the average availability, unavailability, reliability and unreliability for a period of four years are: 95.80%, 4.02%, 23.94%, and 76.06% respectively. Here, the availability of Choke actuator is 95.80%, but lacking in reliability which is 17.89%. β value of 0.80 was obtained from the plot and used to model maintenance schedule for offshore production platform to determine equipment selection for TAM.

For wing valve positioner**:** 95.18%, 4.82%, 18.03%, 81.93% are the average availability, unavailability, reliability, and unreliability of wing valve positioner were obtained for a period of four years. This result shows that that Wing valve positioner has a high availability of 95.18%, with low reliability index of 18.03%. β value of 0.97 was deduced from the plot and used to model a preventive maintenance schedule and equipment selection for TAM.

FRAMO Pump**:** The average availability, unavailability, reliability, and unreliability for a period of four years are: 95.26%, 4.74%, 19.95%, and 80.04% respectively. However, the availability of Framo pump is high at 95.26%, but lacking in overall reliability which is 19.95%. This equipment had the highest reliability in the last year with a reliability index of 35.87%, which shows an improvement of the period. β value of 0.44 was obtained from graph in Figure.4.8 and used to model maintenance schedule for offshore production platform to determine equipment selection for TAM.

4.0 CONCLUSION

This research results show Beta factor for platform DP-A equipment as follows; Wing Valve positioner 0.95, Wellhead control panel 0.72, FRAMO pump 0.44, HVAC chiller 0.33, Water injection pump 0.95, HPU Compressor 0.74, Choke actuator 0.80, Heater blower fan 0.37. The Weibull model is a potent tool in reliability engineering. Weibull model offers a good inside into equipment's reliability as it helps to understanding the equipment's risk and failure. The model developed for each equipment in this research has provided in better understanding of the nature of failure associated with the offshore crude oil production equipment for the facility.

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