WLC for the Maintenance Options on the Oil Recovery System – A Comparative Analysis at FSØ Plant

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Abstract— The prime goal of maintenance tasks is to protect items functions. These tasks come at high costs. Evaluating and comparing different maintenance tasks is strategic in making smart decisions to select the best competitive solutions that will bring the needed economic benefits to the plant. To achieve these objectives, a WLC model is vital as it predicts how the economic life of an asset can impact maintenance performance and future cash flows. Given this, FSØ facility is an oil and gas producing plant that treats effluents to meet her environmental limits. In achieving these limits, the effluent is skimmed, and the recovered oil is fed back into the processing chain. In a recent development at the facility, the plant tripped because of gas release during the skimming operation. The outcome of the CTA revealed three mutually exclusive maintenance tasks to be selected to avoid future recurrence. However, the criteria for the alternative to be selected requires that it must be economical and has the best competitive solutions. Meeting this objective requires both financial and non-financial approach to enhance decision making. Hence, a WLC was considered, and evaluation was performed on the three competing options using different WLC models to compare which options meet the criteria. The results revealed that option A, B, and C has an NPV of $(98,366.66), $(128,353.88), and $(103,397.99), respectively. Similarly, the IRR for each of the options were 37.44%, 28.60%, and 24.26%, respectively. Also, option A has a profitability index of -1.2, while B and C have a PI of -2.9 and -22.4, respectively. The EAC for each Option A, B, and C were $(11,554.11), $(15,076.40), and $(12,145.09), respectively. Alternatively, a CEA performed for the options considered revealed that A, B, and C has an incremental BCR of 0.002104, 0.001363, and 0.001944, respectively. However, the future is unknown; hence the Sensitivity and Risk analysis conducted revealed that option C is more sensitive to variations in the cost and the probability of success is 91.05% compared to A and B whose certainty was 83.24% and 86.00%, respectively. Therefore, these results indicate that option A has greater potentials to significantly improve value in the long term if proactively implemented, hence should be prioritised.

Index Terms— Whole Life Cost, Financial Analysis, Comparative Analysis, Optimization, Profitability, Decision making, Sensitivity Analysis, NPV, .

1 Introduction

2.1 Review Stage

The prime goal of maintenance tasks is to protect items functions. However, the cost of implementing these activities have continually increased between 15-40 per cent as the asset life declines (Arashin, 2014; Upkeep Maintenance Management 2020). Consequently, comparing internal and external maintenance projects or tasks becomes vital in maximising future cash flows and ensuring a sustainable strategic maintenance decision is achieved (Mybusiness, 2020). Additionally, Plant Engineering in (2011) reported that improved cost strategies are one of the profound ways' top performers drive performance in the modern global business environment. Hence, WLC provides one of the analytical means of evaluating and comparing initial investment and future costs implications on several alternatives over the predicted life of the asset before making business decisions (Nicholas 2010; John, Andrew, and Joel 2011; Mohammed and Horner, 2020). Figure 1.0 shows a capital project development process requiring WLC before decision making.

Similarly, Diego, Peter, and Kumar (2017) and United State Energy Office of Industrial Technology (2020) pointed out that WLC techniques provide adequate management of economic life of the assets through evaluation of different alternatives and can help organisations reduce cost and optimise maintenance tasks. Also, this method is useful in resource allocations and to optimise costs generated from operation and maintenance activities for future cash flows. These economic objectives are required to align with the organisation's success drivers or KPIs and must be clearly defined and visible to create the needed financial values (Mark and Guy 2012).

Furthermore, to create the required value, each maintenance task must be assessed using a suitable risk-based approach to understand how future risks and uncertainties can impact asset lifecycle (Halim and Richard, 2004; Mohammed and Horner, 2020). These strategies are beneficial to improve asset reliability, enhance productivity, and maintain plant integrity while saving cost for the maintenance organisation (Andreas, Burkhard, and Luca 2017). Therefore, this coursework focuses on the considerable benefits of WLC technique as it compares three maintenance options on the Crude oil recovery system at FSØ facility, as shown in Figure 2.0. It demonstrates how the NPV of the three options were obtained using the available operation and maintenance cost data. Also, it shows via the sensitivity analysis how incremental improvement or deterio-

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ration can impact future cash flows. Lastly, it reveals how risk assessments can influence decisions and constraints in accessing data used for performing a reliable and consistent WLC for any given maintenance task.

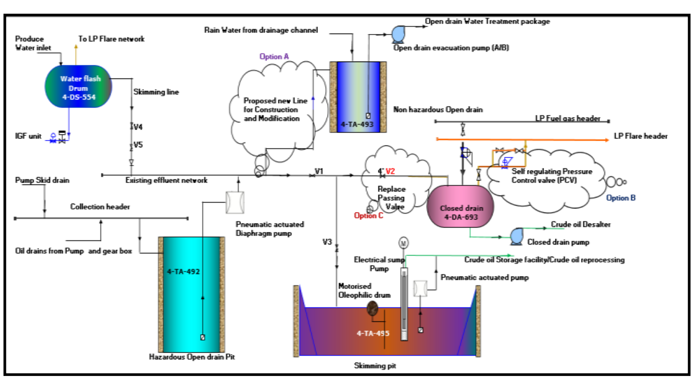
2 METHODOLGY

This course work was to evaluate and compare maintenance alternatives using WLC techniques at the FSØ facility. Obtaining data for this process is complicated (NAP, 2020). However, Table 1.0 outlines the ways used to implement the WLC for the selected alternatives.

1. Define the background of the scenario;
2. Identify all the maintenance activities that will create cost in the asset lifecycle management. This process includes the purchase of new items, repairs, operationg costs, maintenance cost and labor;
3. Develop maintenance data for each alternative;
4. Identify contstraints and assumptions for the WLC to ensure the information is consistent and data reliable;
5. Perform risk assessment and establish a risk graph for each option selected to determine future risks and uncertainities that may impact the installations such as the discount rate and Predicted life of the asset using SA, MCS, and CI models;
6. Compare the alternatives selected using non-financial measures such as Benefit Cost Ratio (BCR) to evaluate which option is most cost-effective;
7. Describe the strength and weakness of WLC using SWOT Analysis;
8. Report and recommend all the observations, outcomes, and limitations of the WLC analysis performed.

3 RESULTS/FINDINGS

Crude oil skimming is a periodic activity performed at FSØ oil and gas production facility. The prime aim is to recover crude oil from produce water treatment package and send it back into the oil processing chain. This activity helps the plant to meet her environmental limits for water discharged to the environment (see fig. 9.0, pp. 27). During the operation, the water flash drum feeds the skimming pit or the closed drain vessel with the oily water. The skimming pit is preferred since it has a higher retention capacity and better efficiency than the closed drain vessel.



In a recent development at the facility, hydrocarbon gas was released around the skimming pit during LP compressor depressurisation while the periodic skimming of water flash drum was ongoing. This situation resulted in Plant shutdown and significant production and financial losses, respectively. The preliminary incident investigation revealed the following (FSØ Energi group 2019).

1. A slight increase in pressure inside the closed drain vessel
2. Closed drain vessel was blanketed with LP fuel gas
3. Manual valve V2 (see fig. 3.0) was passing after an integrity leak test. Leak rate ≥ 30.0 Sm3/h for hydrocarbon gas
4. The LP flare header was slightly pressurised

Consequently, to prevent future recurrence arising from such event, three maintenance options were considered in the incident report to close out the identified anomalies (see fig. 3.0, pp. 11). However, the alternatives that added the most economical value and competitive solutions was a useful criterion for deciding which option to choose.

1. Option A involves modification of the existing 4" line and construction of 2" diameter pipe 200m lengthy tie-in from the existing effluent network to a non-hazardous open drain. The products in the non-hazardous open drain can be recovered with a vacuum truck and transferred back into the skimming pit.
2. Option B involves the installation and modification of 2" diameter 2m long spool pipe with self-regulating pressure control valve and its bypass valves. The goal was to regulate the pressure inside the closed drain vessel and relieve excess pressure to the flare line to prevent backflow from flare header.
3. Option C involves the replacement of the 4" passing valve, V2 on the existing effluent network. The goal was to restore the integrity and reliability of the valve.

Each of these three maintenance options considered was mutually exclusive and meant to be implemented without shutting down production nor the produce water treatment system. Hence, a WLC analysis was considered beneficial for the selected alternatives to evaluate which option presents the most competitive solutions to make an informed business decision. Table 1.0a/b summarises the advantages and disadvantages of each option selected with cost implications.

3.1.1 WLC for the Maintenance Program (Assumptions & Constraints)

If you are using Word, use either the Microsoft Equation Editor or the MathType add-on (http://www.mathtype.com) for equations in your paper (Insert | Object | Create New | Microsoft Equation or MathType Equation). “Float over text” should not be selected. Implementing a WLC for the selected maintenance options requires cost data. On the contrary, obtaining data for the analysis was complicated (NAP,2020). For example, the historical maintenance data for the facility was not available. Also, the accuracy of the data obtained from online sources cannot be verified. Lastly, the assumptions considered with regards to the life of the items and discount rates

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may not reflect the actual conditions. Table 2.0a and 2.0b summarise the assumptions and constraints considered during the process.

	Assumptions for the WLC Analysis
Cost included	Purchase cost, annual operating and maintenance cost, non-annual repair/replacement cost, and installation costs
Cost Excluded	Value-added Tax (VAT), depreciation, and inflation
Analysis period	20 years
WLC models	NPV, IRR, DPP, BCR, Sensitivity Analysis, Monte Carlo Simulation, Quantitative risk assessment, Confidence Index (CI), SWOT analysis
Discount rate	10% (Standard for oil and gas valuation methods) from Breakingintowallstreet.com Oil and gas valuation Quick reference
Sensitivity Analysis (SA) model	7 rates (5%, 10%, 15%, 20%, 25%, 30%, 35%) were used to check the sensitivity of the NPV to variations between IC and AC to discount rates, respectively. Also, SA was used to verify the NPV when Life varies from 20-30 years on a step of 2 with AC.
	The SA model did not consider the non-annual repair/replacement costs and salvage values, respectively.
Confidence index (CI)	A 10% discount and the predicted life of 20 years, was used to assess the uncertainties in the Options. Also, the Low and Best were taken at random. Where the low was set as 5% and the best 10% while high was assumed to be 15%. Lastly, the CI analysis did not consider the non-annual repair/replacement cost and salvage value
Internal rate of return (IRR)	discount rates 0% to 10% were used for the iteration process, while the NPV values @ 9% and 10% were used to estimate the IRR for the low and high discount rates, respectively.
Hourly rate	Data for hourly rate analysis of Labour was obtained from PayScale.com
Costs	Sources of cost data used for analysis was obtained for 4" OVC valve from Ohiovalve.com price lists; 2" Watson self-regulating PCV valve from Ebay.com; Denso tape was from densotape.co.uk (Lynvale adhesive tape); 2" pipes from jiji.com
Resale value	5% initial costs of all items purchased were set for the salvage value at any time for the options considered
Non-annual replacement frequency	It was assumed that the purchased items deteriorate over time due to wear and tear, environmental constraints, and operational constraints. Hence, frequency interval of 4, 5, 7, and 8 years were set for the 4" OVC, 2" new piping line, 2" Watson PCV, and 2" CS150GT and 2"CS150GL respectively based on guidelines set by UKOPA and DPR (Source: https://www.ukopa.co.uk/wp-content/uploads/2013/03/UKOPA-13-028.pdf; https://dpr.gov.ng/wp-content/uploads/2014/03/REQUIREMENTS-FOR-THE-MAINTENANCE-AND-INSPECTION-OF-FLEXIBLE-PIPES-SCR-AND-MOORING-CHAIN-SYSTEMS.pdf
Non-annual replacement/ repair cost	These costs were assumed to be the sum of the purchase cost and installation cost by the designated maintenance Technician
Technical Availability	The cost associated with production loss, downtime, productivity was excluded
Task duration	Each maintenance task selected can be performed after PTW approval within the 14 days duration for which the PTW is valid
Maintenance Record	Historic maintenance records of the facility were assumed not available
EHS	The costs associated with Environment, Health, and Safety factors were excluded from the analysis
FOREX	The foreign exchange Conversion rate used for 2" pipe purchase cost was 1 USD = 460 NGR NAIRA (Abokifx.com) as of 26 June 2016
Annualised costs	Valve integrity tests, Periodic FLM, and Integrity inspection were considered as annual costs
Alternative decisions for components	The alternative decisions for the components or items (pipe and valve) modification/replacement is assumed to be like-for-like

Consequently, to overcome some of these obstacles for future benefits, the following measures can be considered.

1. Establish a Standard for data required for WLC of the maintenance organisation.
2. Develop institutional reforms on policies and procedures required for implementing WLC estimates for maintenance organisation.
3. Management commitment at all levels to align maintenance strategies to asset lifecycle management goals.
4. Encourage the robust use of Sensitivity analysis as a tool to verify how inputs, variables, and assumptions used during WLC analysis changes with the future uncertainties and risks to make informed decisions.

3.1.2 Figures and Tables

Table 3.0 shows the data required for implementing WLC for the alternatives. Table 8.0a, and 8.0b, pp. 29-30 in the appendices show the maintenance cost data worksheet.

Maintenance Options	costs
Option A	
Purchase cost for 2" pipes	$ 10,000.00
Annual Cost	$ 4,773.60
Resale value	$ 2,238.83
Installation cost	$ 34,776.62
Repair cost at year 5	$ 9,524.90
Option B	
Purchase costs for #150 rated OVC v/v & 2" pipe of 2m long	$ 2,449.95
Annual Cost	$ 9,286.68
Resale value	$ 1,624.75
Installation cost	$ 30,045.14
Repair cost at year 5	$ 9,524.90
Repair cost at year 7	$ 1,643.67
Repair cost at year 8	$ 3,623.24
Option C	
Purchase cost for #150 OVC 4" rated valve	$ 3,084.00
Annual Cost	$ 10,679.68
Resale value	$ 220.66
Installation cost	$ 1,329.12
Non-annual replacement/Repair cost @ 4yrs	$ 4,413.12

3.2 Whole Life Cost Analysis

Computing for the WLC of the options requires both economic and non-economic approach. In achieving these strategies, the financial measures were appraised using NPV (DCF) method, IRR, PI, EAC, and DPP models. However, unlike other models, the NPV using DCF approach was beneficial as it considered the life of the asset, cash flows through-out the physical life of the items, and weight value of money even at a high and low discount rate, respectively (Sanjay 2019). Also, it ranked the options correctly in order of economic benefit using a criterion that the NPV must be positive or higher for the selected alternative to create value (Mark and Guy 2012; Jonathan 2020).

3.2.1 NPV calculation for the options

In evaluating the real economic value of the maintenance alternatives considered, there NPV needs to be estimated. The

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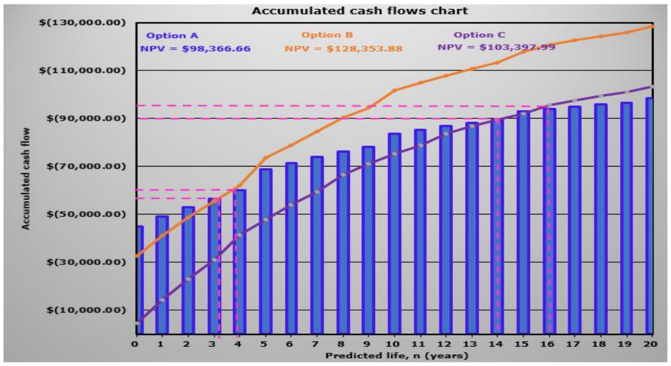
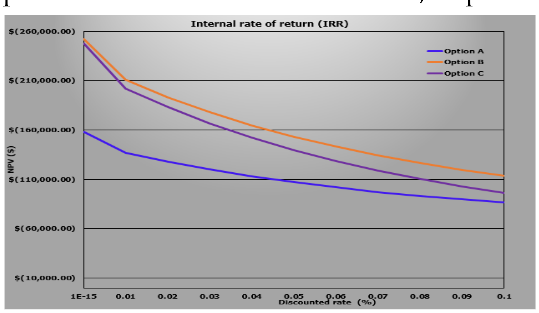
Maintenance alternatives	NPV	Ranking
Option A	$(98,366.66)	1
Option B	$(128,353.88)	3
Option C	$(103,397.99)	2



NPV was achieved using the DCF formula (ref. to Table 10.0 pp.32, fig. 10.0 pp. 33 for the NPV calculation sheet and cash flow diagram and DCF formula on pp. 41 in the appendices). Table 4.0 and figure 4.0 shows the NPV ranking and accumulative cash flow chart for the options, respectively.

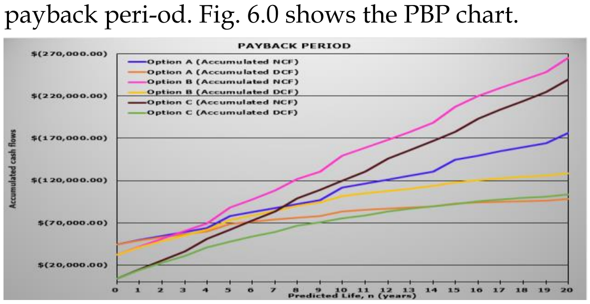
3.2.2 The Internal rate of return (IRR)

For maintenance tasks selected to be worthwhile, the expected RoR needs to be higher than the target RoR (Adam 2020). The alternative with the highest value is expected to create more value. In estimating the IRR, the trial and error interpolation was used in the excel computation for discount rates 0% - 10%. Figure 5.0 shows the IRR chart, and Table 9.0, pp.29 in the appendices shows the estimations sheet, respectively.



3.2.3 Discounted payback period (DPP)

In verifying, which of the selected maintenance alternative create the needed value, the profitability and feasibility need to be defined (Will 2019). From Table 10.0, pp.32 in the appen-dices, the three alternatives have no discounted payback peri-od. Fig. 6.0 shows the PBP chart.



3.2.4 Profitability Index (PI)

The maintenance options are mutually exclusive. Hence, the option to be considered must be attractive with competitive solutions to create the right economic benefits in the plant. Table 5.0 shows the PI ranking, and fig. 15.0, pp.40 in the appendices show the comparison charts for all the options considered.

Maintenance options	Initial costs	Annual costs	NPV	EAC	PI	Ranking
Option A	$ (44776.62)	$ (4773.60)	$ (98,366.66)	$ (11,554.11)	-1.1968	1
Option B	$ (32495.09)	$ (9286.68)	$ (128,353.88)	$ (15,076.40	-2.6499	2
Option C	$ (4413.12)	$ (10679.68)	$ (103,397.99)	$ (12,145.09)	-22.4297	3

3.2.5 Equivalent Annual Cost (EAC)

To ensure maintenance decision create the real value, we need to evaluate how the weight of the maintenance cost affects the asset. This approach is strategic as it compares the extent to which the alternatives are cost-effective (Will 2019). Table 5.0 shows the EAC for each of the options. Pp. 41 in the appendices describes the formula used to estimate the EAC.

3.3 Risk Analysis for WLC of the selected Alternatives

The likelihood of an error occurring in data used for WLC analysis and its impact on the decision in selecting suitable competitive solutions is not remote (Halim and Richard 2004). Thus, identifying, assessing, and evaluating the selected options using proper risk estimation techniques is beneficial to ensure consistency, uniformity, and reliability of the WLC results. Contrarily, the outcome of the WLC cannot be predicted with certainty. Hence, a level of confidence is required in the WLC data evaluated to ensure these risks and uncertainties are controlled and managed. Table 6.0 shows a risk summary sheet. Figure 11.0a and fig 11.0b, pp.33-34 in the appendices show the MCS risk outcomes. Table 11.0, pp. 36 indicates the calculation sheet for the CI. Table 12.0a and Table 12.0b, pp. 37-38 and fig 13.0-15.0, pp. 39-40 in the appendices shows SA matrices and charts used for evaluating the uncertainties and risks (Udeh 2020).

FSØ facility — Job Risk Analysis — Date: 6-Jul-20

S/N	Maintenance Options	Initial risk: Likelihood	Initial risk: Consequence	Initial risk: Exposure	NPV	Risk to Cost Ratio (Riskiness) (RCR)	Mitigation measures	Final risk: Likelihood	Final risk: Consequence	Final risk: Exposure	NPV	Risk to Cost Ratio (Riskiness) (RCR)
	Option A											
1	Pinch point/Trapped finger	4	4	16	$ (98,388.66)	-0.000833	Improved Training and use of adequate PPE	4	1	4	$ (98,388.66)	-0.000213
2	Electrical shock	5	4	20			Use of procedure and PPE	3	1	3		
3	Fire and explosion	6	5	30			Ensure FIFI facilties are adequate and available	3	3	9		
4	Toxic / Explosive atmosphere	4	4	16			Ensure Sufficient gas monitoring devices available	5	1	5		
			Total Risk score	82					Total Risk score	21		
	Option B											
1	Pinch point/Trapped finger	4	4	16	$(128,353.88)	-0.000592	Improved Training and use of adequate PPE	4	1	4	$(128,353.88)	-0.000164
2	Dropped object	5	3	15			Use of adequate manual handling procedure	3	1	3		
3	Fire and explosion	6	5	30			Ensure FIFI facilties are adequate and available	3	3	9		
4	Toxic / Explosive atmosphere	5	3	15			Ensure Sufficient gas monitoring devices available	5	1	5		
			Total Risk score	76					Total Risk score	21		
	Option C											
1	Pinch point/Trapped finger	4	4	16	$(103,397.99)	-0.000445	Improved Training and use of adequate PPE	4	1	4	$(103,397.99)	-0.000116
2	Dropped object	5	3	15			Use of adequate manual handling procedure	3	1	3		
3	Poor communication	5	3	15			Improved Communication during HSE induction and tool box talk	5	1	5		
			Total Risk score	46					Total Risk score	12		

	Option A	Option B	Option C
NPV	$(98,388.66)	$ (128,353.88)	$(103,397.99)
RCR (Before)	-0.000833	-0.000592	-0.000445
RCR (After)	-0.000213	-0.000164	-0.000116

Risk Analysis (Before)

LIKELIHOOD		Consequences: Minor 1	Moderate 2	Serious 3	Very serious 4	Catastrophic 5	Disastrous 6
Very Likely	6				24	30	
Likely	5			15	20		
Unlikely	4				16		
Very unlikely	3					15	
Extremely unlikely	2						
Remote	1						

Risk Analysis (After)

LIKELIHOOD		Consequences: Minor 1	Moderate 2	Serious 3	Very serious 4	Catastrophic 5	Disastrous 6
Very Likely	6						
Likely	5	5					
Unlikely	4	4	8				
Very unlikely	3	3	6	9			
Extremely unlikely	2		4	6			
Remote	1						

Legends

Level 1 High — Task not recommended
Level 2 Medium — Risk to be reduced further
Level 3 Low — Task to be done with care

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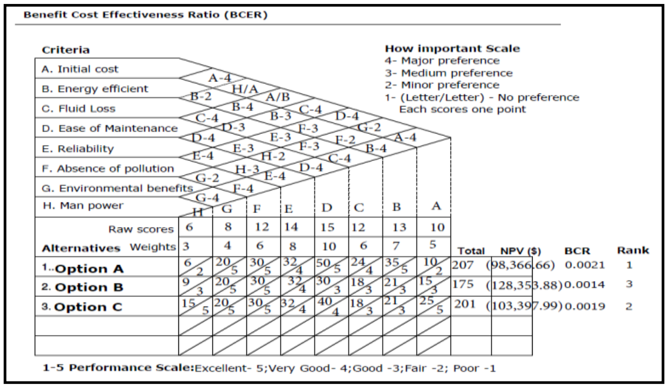
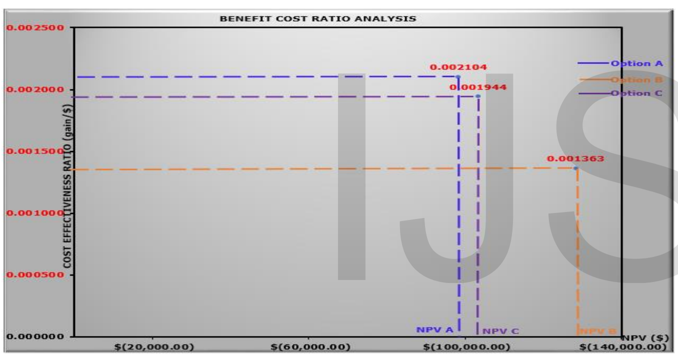
3.4 Lists

In order to make informed maintenance decision on which alternatives will bring competitive solutions, a non-financial measure is required to appraise the incremental benefits or values from each of the options selected using suitable baseline criteria (Smith, Morrow and Ross 2015; Jonathan 2020). Figure 7.0 and figure 8.0 shows the weighted evaluation criteria and BCR chart, respectively.





3.5 SWOT Analysis for WLC Alternatives Estimates

Understanding the internal and external constraints within the WLC evaluation processes is vital to reposition it for the future strategically

Strength	**Weakness**
• Easy to rank the selected alternatives based on the economic value • It gives useful insight into how different factors such as discount rate can affect the economic value of an asset in short and long term • It uses both financial and non-financial measures on an equal basis to ascertain which alternatives have the best competitive solutions • Useful in predictive analytics to make informed maintenance decisions	• The sources of cost data can introduce error which may affect the WLC outcomes • The validity of the WLC outcome depends on the degree of certainties • Requires robust risk assessment to ensure consistency, uniformity, and accuracy of the WLC result • Future costs are subject to uncertainties. Hence, it may not depict reality
Opportunity	**Threat**
• Methodologies need to be harmonised and standardised • Other WLC models should be used to verify the outcome of results • Planning and efficient efficient allocation of maintenance resources • Risk assessment approach can be re-evaluated with other risk methods • Centralise maintenance history and cost data	• EHS related factors can impact cash flows via withdrawal of license to operate • Future risks and uncertainties such as a change in government policies, inflation, depreciation can destroy value • Institutional reforms and changes • Training and Competency gap

4 Conclusion and Recommendations

Based on the assumptions and outcomes of the WLC analysis for the maintenance alternatives at FSØ facility, it is believed that option A will significantly improve value in the long term if proactively implemented. Hence, it should be assigned "high" priority or ranked 1, followed by option C whose NPV and BCR is relatively higher than B. Although, the IRR and PI are quite low, but the weighted cash flows indicate that it has more economic benefits than option B.

Conversely, the outcome of the WLC process depends mostly on the discount rates and the predicted life. Consequently, from the Sensitivity analysis, all the options are less sensitive to life. However, option C is more sensitive to cost compared to option A and B, as indicated in the SA and MCS sensitivity forecast, respectively.

Finally, the future is unknown; hence the alternatives need to be risk assessed to ensure that the competing solutions do not destroy value in the future. The risk forecast revealed the probability of success or certainty for option A, B, and C are 83.24%, 86.00%, and 91.05%, respectively. This result indicates that option C has low risk as such can enhance the economic benefits of the facility in the future, unlike option A and B, respectively. However, based on these evaluations, it is recommended that:

1. Option A is selected or implemented as it adds the best competing solutions to the plant compared to other alternatives.
2. Adequate process risk studies can be conducted to evaluate the impacts of EHS on all the alternatives considered in the WLC analysis.
3. In-depth CTA studies can be performed to ascertain the underlying causes of the gas release that triggered the plant shutdown.
4. FMAE studies can be performed for the selected options to know their modes of failure and consequences, including financial impacts.
5. Further evaluation studies can be performed on other subjects not included in this reported work.

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