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A Scheduling Model in Capturing Methane Gas from Methane Clathrates Deposits

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Abstract. The execution of any project type, especially engineering-based projects, is usually time-based, efficiency-driven, and cost-effective. These factors are the deterministic parameters that engineer successful project completion. The application of scheduling models remains the best technique for achieving these three factors to their best degrees. Therefore, this study was centered on the impact study of applying the scheduling model in harvesting methane gas from methane clathrates deposits. Various data on gas hydrate reserves in the Niger Delta region of Nigeria were collected from relevant literature, studied, and analyzed. Such data includes the pictorial representation and description of the gas hydrate site in the Niger Delta region of Africa and various shapes and sizes of gas hydrate perimeters in the studied region positions of the gas reserves. The normal faults are projected on a bathymetric map of the study area and the bathymetric map of the Pockmark (with the stippled black line indicating the sea floor projection of a prominent N-S trending fracture in 3-D seismic data). As a type of scheduling model, the critical path method (CPM) was applied to develop the project's work sequence using the activity on node (AON) architectural technique and Primavera P6 software after carefully identifying the primary operations involved in the project and their respective sub-operations or work breakdown structure (WBS). The risks associated with each operation were meticulously identified, with their consequent impact and exposure matrix determined using probabilistic measures of 1-5 according to the degree of the risk. Mitigation strategies were recommended for all the identified risks. The cost benefits of the project were X-rayed using parameters such as net present value (NPV), project payback time, internal rate of return (IRR), and net cumulative cash flow. From the results obtained, the CPM schedule showed that the project execution would last approximately ten months. All the operations involved in the project execution plan were all critical, proving that each activity should be completed within the scheduled run period. Else, the entire project would be affected. Also, risks with a high exposure matrix of 25, 12, and 4 were mitigated to 5, 3, and 0 using the recommended strategies. In addition, the project yielded an NPV of $20,736,951.04 for the run period of 22 years after the execution of the project, IRR of 14 %, and a payback time of 8 years (adding 2023- the year of project execution) provided the daily production rate is maintained within 60,000-65,000 MSCF/day. The cash flow and payback time will decrease if the daily production rate increases. Therefore, the application of CPM in extracting methane gas from gas hydrates positively affected the operation through the vivid insights provided in workflow pattern/methodology risks effects and cost benefits.

Keywords: operations research, critical path method, gas hydrate, project scheduling, risk management, cost analysis, energy efficiency.

1 Introduction

Gas hydrates are also called methane hydrates or, chemically, clathrates. As defined by [1], gas hydrates are ice-like crystalline lattices formed by combining water and methane molecules at low temperatures and high pressures. Large reserves of gas hydrates can be found under continental shelves and on land under permafrost. The percentage of organic carbon in gas hydrates is estimated to be twice that in all other fossil fuels combined. The presence of gas hydrates in oceanic sediments was first postulated based on seismic observations. According to some estimates, gas hydrates represent one of the world's largest untapped energy reservoirs and have the potential to meet global energy needs for the next 1,000 years. Gas hydrates include combustible matter and are potentially one of the most critical energy resources for the future. Gas hydrates are of considerable interest because of their potential as an energy resource and potential role in global climate change. Gas hydrates majorly contain methane gas. Methane is a thermogenic gas formed by decomposing organic matter due to geothermal heat and/or pressure [2].

Some developing countries that are seriously bedeviled by energy challenges stemming from electricity generation to heating and ventilation systems have huge reserves of gas hydrate that are untapped. For example, the Niger Delta region of Nigeria, which occupies the central part of West Africa's Gulf of Guinea, with a land area of about 75,000 km^2, forms Africa's most extensive delta system. Its continental depth holds a deposit of gas hydrate. The gas hydrate deposit in this region is primarily biogenic (formed by biological means). However, small amounts are thermogenic (heat-induced biological process) in nature. According to [3], the clathrates in this region have 99 % methane formation statistics up to the depth above 1500 m below sea level. This statistic proved that methane gas content's potential in clathrates is enormous. Exploiting methane gas from clathrates will in no small way boost the energy of Nigeria, since it is a sustainable energy source.

Applying the project scheduling technique (PST) in evaluating project cost and detailed planning for the execution of a project is a very imperative technique that should be used in the methane extraction process from gas hydrates [4]. PST also called network technique (NT) or network analysis (NA), entails a group of techniques for presenting information relating to time and resources to assist in planning, scheduling, and controlling projects. The info usually represented by a network includes the sequences, interdependencies, interrelationships, and criticality of various project activities. The three network techniques often used are the critical path method (CPM), program evaluation and review technique (PERT), and resource allocation and multi-project scheduling (RAMPS). But, CPM and PERT are considered the most convenient for application to various engineering projects.

Knowing the methane potential in Niger Delta region in Sub-Saharan Africa, it is crucial to demonstrate a workable network structure that details the cost-effectiveness of the project, risk analysis, list of activities to be performed, and their flow sequence. Therefore, this study focused on applying project scheduling in extracting methane gas from gas hydrate using the Niger Delta region in Sub-Saharan Africa as the case study. The cost-effectiveness of the extraction operation, risk analysis, and work plan modeling were carried out using CPM, risk analysis and decision criterion structure (RADCS), and Primavera 6. The data used for this research was obtained from the studies of many scholars on the existing Pockmarks described to have an approximately 600 m wide seafloor depression in deep waters situated in the Niger Delta zone offshore Nigeria. According to [5], pockmarks are subcircular or circular, or elliptical sea floor depressions known from shallow to deep-water areas worldwide. They can equally be regarded as craters (circular pits or depressions) in the seafloor caused by erupting gas or liquid. Pockmarks exit in diametric forms (tens to thousands of meters) and seafloor morphologies.

2 Literature Review

Many studies have employed project scheduling models to reveal the significant impact of PST applications in project planning and execution. Researchers [6] applied the project scheduling techniques in a real-life environment. They employed the CPM and PERT techniques in scheduling a project that aimed at expanding the production capacity of pure water at the Vlaamse Maatschappij voor watervoorziening (VMW) in Belgium. They proved that net present value (NPV) is schedule dependent. Their study showed that CPM and PERT had deficiencies in yielding their desired NPV. Hence they proposed some schedules that were combinations of the two. This led to the maximization of the NPV of the project under the restriction that each activity must have a certain amount of slack, if possible. In work [7], a study was carried out on a multi-agent system with application in project scheduling. They analyzed the implementation of a multi-agent system (MAS) considering two scheduling problems: time-constrained project scheduling problems (TCPSP) and resource-constrained project scheduling problems (RCPSP). They, therefore, developed and proposed an improved belief, desires, and intentions (BDI) based model. The model performed accurately from their findings. In addition, researchers [8] studied on aleatory uncertainty quantification of project resources and its application to project scheduling. Owing to the scanty literature on the uncertainty analysis of resource acquisition in project management, they employed the reliability theory to fill the literature gap through a take on a success-oriented view of acquiring the required resources for completing a project. They constructed the reliability block diagram (RBD) to quantify the aleatory uncertainty in resource acquisition by considering the supply of and demand for every resource and the probability that the resource is available when it is required. They also developed a new schedule sensitivity index which accounts for uncertainty in both time duration and resource acquisition of project activity. The effectiveness of the newly developed index in evaluating the relative importance of activities in stochastic project networks was also assessed. The result of their study showed that the new index yielded better performance due to its ability to capture uncertainty in both time duration and resource acquisition of project activity.

3 Research Methodology

3.1 Materials and tools

The materials and tools used in this study were essentially the gas hydrate reserve data obtained from the study site- Niger Delta region in Sub-Saharan Africa, analytical software (Microsoft Excel 2019 version), and project modeling software (Primavera 6). The extracted data from relevant literature includes the pictorial representation and description of the gas hydrate site in the Niger Delta region, various shapes and sizes of gas hydrate perimeters in the studied region, positions of the gas reserves, and the normal faults projected on a bathymetric map of the study area, the bathymetric map of the Pockmark and the methane gas constituent data.

Figure 1 depicts the photographic views of Pockmarks situated in the study site with clearly defined positions.

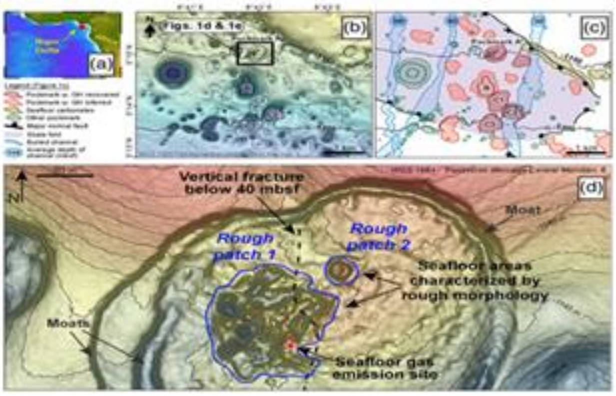


Figure 1 – Photographic views of Pockmarks: a – location of the pockmark field at the study site [5]; b – various shapes and sizes of Pockmarks; c – positions of the gas reserves and normal faults projected on a bathymetric map of the study area; d – the bathymetric map of the Pockmark [9]

Figure 1 a shows the study area where gas hydrate volume content is of the essence, and it is located at the West Africa margin continental slope off Nigeria in the transitional detachment zone of the Niger Delta. The area comprises a subcircular depression, called Pockmark, that is situated in the North-South extension of approximately 590 m and West-East of approximately 490 m, as shown in Figure 1 b-e.

The identified Pockmarks have gas hydrates widely distributed in a sediment body down to a depth of 34 mbsf at maximum [9-11]. Gas hydrates with gas-filled macro-pores in shallow sediments of the “Rough Patch 1” [9] point to their rapid formation from gaseous methane [12, 13].

In addition, Figure 2 shows the six pressure core areas of the studied site with the potential for methane gas hydrate reserves.

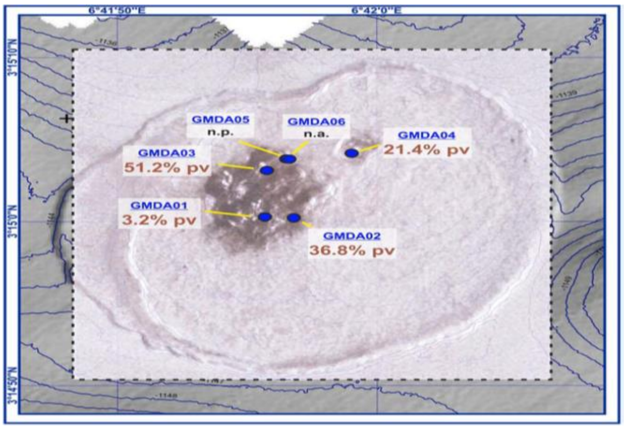


Figure 2 – The identified six pressure cores in the study site

The six pressure cores (GMDA01, GMDA02, GMDA03, GMDA04, GMDA05, and GMDA06) of methane gas hydrate are shown in their respective gas analysis results in Table 1.

Table 1 – Accumulated gas volumes, gas-sediment ratios (at ambient pressure), methane concentrations (average porosity 83 %), and calculated fractions of hydrates in sediment cores recovered by pressure coring ($GHsat_{tr}$) [5]

DAPC core code	Core recovery, m	Total vol. of gas released, L	Volumetric gas-sediment ratio, total core, L/L	Conc. CH_4 total core, mol/dm^3	Core vol. below sulfate zone, L	Hydrate saturation (sf) in pore vol. below sulphate zone $GHsat_{tr}$, %
GMDA01	1.75	52.62	5.63	0.28	7.75	3.2
GMDA02	0.73	59.15	16.52	0.83	0.91	36.8
GMDA03	1.04	282.15	54.44	2.73	3.58	51.2
GMDA04	2.36	342.90	27.19	1.36	9.94	21.4
GMDA05	2.44	4.82	0.37	0.02	6.36	N/P**
GMDA06	2.05	4.10	0.37	0.02	N/A*	N/A
					Average:	31.4

* N/A– not analyzed; ** N/P – not presented.

3.2 Project scheduling assumptions

The scheduling of methane gas extraction processes of the identified six pressure cores of the test site from clathrates and analysis (cost and risk impacts) was based on the following assumptions.

1. The chosen technology proves to be a significant success.
2. Gas production rates were estimated from data obtained from gas wells in the same region.
3. Climatic conditions remain favorable over the project’s lifetime.
4. Tax, royalty, and discount rates do not change.
5. Gas obtained from the hydrates are primarily dry gases; no liquid is produced during production.
6. Contractors and staff contracts are renewed yearly with no salary increase.
7. Stability in gas prices fixed to a particular value and applied during costing.

Royalties will be taken as a variable operating cost and remain constant for the project.

3.3 Depressurization operation

Due to the cost and technological complexities involved in exploring gas hydrates, such as water circulation and carbon(iv)oxide injection, the depressurization method was employed in this scheduling project/study. The operation includes seismic analysis, drilling, engineering constructions, and extract distribution. The seismic analysis involves a mapping study to confirm the area has a large hydrate reserve.

Preparation of the rig site, suggestion/recommendation of the possible fluid type to be used in the drilling process, etc., are involved in the drilling and engineering phase of the work. Lastly is the methane gas distribution to purification points using fluid conveyors and pump drive systems.

Methane gas extraction operations done by depressurization were modeled using the CPM tool, as shown in Figure 3.

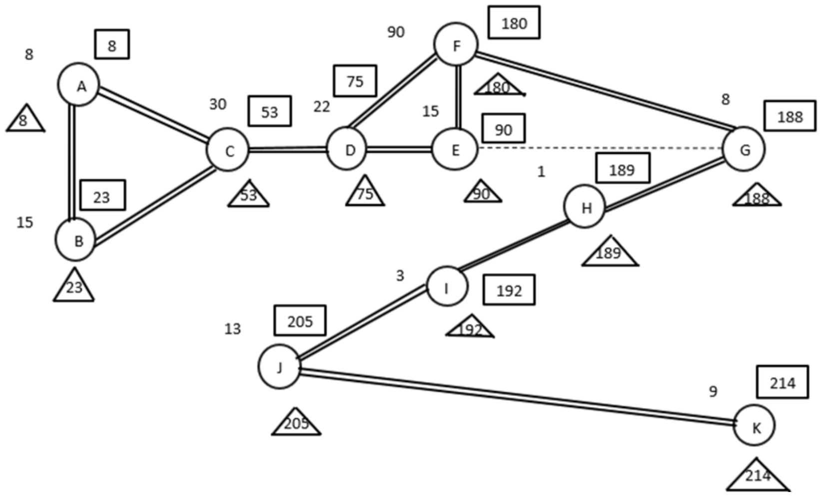


Figure 3 – Project scheduling using the CPM tool

From Figure 3, the project would last 214 working days as derived from the CPM scheduling model. The numerals without enclosures are the scheduled number of days the particular operation is expected to last, numerals with a rectangular enclosure represent the earliest finish time of the activity, and numerals with triangular enclosures are the latest finish time of the project. All the activities have double thick lines, representing the project's critical paths, while the thin broken lines show the dummy path of the project flow. At the critical path, the earliest and latest finish times are equal, implying that the slack is zero and that each of the stated activities must be completed within the scheduled time. Otherwise, the project will be delayed beyond its completion time. The activities are represented with alphabets (A, B, C, D, E, F, G, H, I, J, and K) and enclosed with circles.

Table 2 shows the project description in detail.

Table 2 – The schedule of methane gas extraction from gas hydrates (Project name: GAS HYDRATE P006)

Major Operations	**Sub-operations/work breakdown structure (WBS)**	**WBS, days**
A: Premobilization/mobilization	Premobilization of all equipment	2
	Mobilization of personnel	2
	Mobilization of materials, tools, and equipment	4
B: Site preparations	Bush clearing of the site	3
	Excavation using heavy-duty machinery	5
	Building of tent structures for workers	3
	Electrification of the site	2
	Tent equipped with essential tools and materials	2
C: Seismic study	Mapping out the identified six pressure cores	9
	Data acquisition from the site	10
	Processing of the collected data using deconvolution, stacking or migration technologies	7
	Interpretation of the processed data	4
D: Good design and analysis	CAD modeling of the well	10
	Functional specifications	4
	Design of the drilling program	5
	Completion program design	3
E: Procurement of materials	Collection of quotations from suppliers	3
	Interaction with a few suppliers	2
	Decision and awarding of the supply contract	2
	Supply and inspection of items	8
F: Drilling and installation of good fittings	Metal casing construction for the well	10
	Installation of the drill casing	2
	Drilling	50
	An influx of fluid during the drilling operation	4
	Cementing work on the well	7
	Installation of tube structure into the drilled well	6
	Removal of the drilling pipes	2
	Installation of the blow-out preventer device (BOP)	5
	Installation of the wellhead for methane gas distribution	4
G: Piping installation and RT	Installation of pipe networks to the Christmas tree	4
	Installation of the needed fittings to the pipe	3
	RT on all welded joints	1

Major Operations	Sub-operations/work breakdown structure (WBS)	WBS, days
H: Mechanical checks	Check all the piping connections, including the flanges (Torquing), pumps, etc.	1
I: Commissioning	Pressure test the piping network	3
J: Product movement	Movement of the extracted methane gas to the point of refining	13
K: Closeout/demobilization	Documentations- submissions of the reports etc.	7
	Demobilize all equipment	1

Table 3 clearly shows the duration summary of methane gas extraction from the gas hydrate project. The project was scheduled without consideration of uncertainties like public holidays, strikes, machine damages, etc. This is peculiar to the CPM technique, as it doesn't factor into consideration project uncertainties. But such uncertainties could be balanced off with the excluded days of the month (Saturdays and Sundays) to meet up with the earliest finish date of the project.

3.4 Project cost analysis

The project comprises capital cost analysis (CAPEX) and operating cost analysis (OPEX). The formulae, gas rates, and other parameters employed in the cost calculations were derived from africaoilgasreport.com, which used Nigeria as the case study.

Table 3 shows the applied factors which determine the project's cash inflow and cash outflows.

The capital cost analysis of the project is shown in Table 4.

Table 3 – Payable rates for the project execution (africaoilgasreport.com, 2021)

No.	Factors	Rate, %
1	Tax rate	30.00
2	Royalty rate	7.50
3	Discount rate	14.00
4	Inflation rate	3.45

The capital cost essentially comprises the cost of drilling one gas well (with all its accessories/components fitted) and the cost of LNG tanker for transporting extracted methane gas. Also, 30 % of the initial investment cost was used for risk contingencies. The total capital cost was derived by adding the initial investment cost to the 30 % risk contingency plan.

This cost analysis entails the fixed costs of the project execution processes. Table 5 shows the operating cost analysis of the project.

Table 4 – Capital cost analysis (CAPEX)

Operations	Specification	Unit Cost, USD	Total Cost, USD
Gas well drilling and installation of all its fittings/components	6 wells	25 million	150 million
LNG tanker (1)	29 tons (51,000 liters) capacity	70, 200	70,200
		Initial investment:	150,070,200
		Contingency for risk at 30 % of initial investment:	45,021,060
		Total CAPEX:	195,091,260

Table 5 – Operating cost analysis (OPEX)

Factors	Specification	Unit Cost, USD	Total cost, USD
Personnel salaries	15 permanent staff for 10 months	500 per month for each staff	75,000
Contractor salaries	20 contractors for 10 months	4000 per month for each staff	800,000
Maintenance cost of equipment	All machinery	2000 per month	20,000
	Total fixed OPEX:	89,500 per month	895,000

The derivation of the payback time of the project was obtained through a meticulous computation and analysis of some cost parameters like revenue, taxable income, tax paid, net cash flow (NCF), discount factor (DF), present value (PV) and net current value (NPV). The formulae used in computing these parameters for 10 months are given thus:

$$\text{Revenue} = \text{avg. daily production rate}\left(\frac{\text{MSCF}}{\text{day}}\right)\times \text{gas price}\times 365\ \text{days}; \tag{1}$$

$$\text{Taxable income} = \text{revenue} - (\text{fixed cost} + \text{variable cost}); \tag{2}$$

$$\text{Tax paid} = \text{tax rate}\times \text{taxable income}; \tag{3}$$

$$\text{Net cash flow} = \text{Taxable income} - \text{Tax paid}; \tag{4}$$

$$\text{Discount factor} = (1+\text{r})^{-\text{t}}; \tag{5}$$

$$\text{Present value} = \text{Discount factor}\times \text{net cash flow}; \tag{6}$$

$$\text{Net present value} = \text{Sum of all present values} - \text{Initial investment}, \tag{7}$$

where r – the given discount rate; t – time in years.

3.5 Risk management

It is essential to carry out effective risk management for this project. This critical process helps plan a more realistic budget, identify possible alternatives, and ensure the project delivers its set goals. Hence, the project's risk management steps were used to determine the project threats and potential mitigation strategies.

Firstly, it is essential to identify any risk that could hinder the progress or completion of the project. This could be done in a round-table meeting of the management team alongside experts from different company divisions to ensure every section was duly covered. This storming session would further help prevent the team from limiting its scope and dismissing risks prematurely. Risks were collected from different sources that could affect the project, including but not limited to organizational and management, economic, marketing, environmental, safety, and operational risks that could affect the project. All of these risks, after identification, were collected and recorded in the risk register form, as seen subsequently. As control measures were also taken, in trying to mitigate the risk, this risk register form was regularly updated.

Concerning the researched primary impact types, the impact types considered for this project include time, cost, safety, and environment. All of these have been highlighted in Table 6.

Table 6 – Impact estimate matrix

Severity	Primary Impact			
	Time	Cost, 1000 USD	Safety	Environment
Very High	> 6 months	> 2000	More than one fatality, including severe injuries	Maximum damage, including pollution to the environment
High	3-6 months	800–2000	One fatality, multiple minor and severe injuries	Serious damage, uncontrollable
Medium	3 months	200–800	No fatality, few minor and severe injuries	Minimal damage monitored and observed
Low	1-3 months	50–200	No fatality, few minor injuries	Little damage, put under control
Very Low	< 1 month	< 50	Zero fatality, zero severe injuries, zero minor injury	No damage to the environment of any sort

The risk exposure matrix was drawn up to help quantify each of the risks identified in the risk register. This will therefore help determine which risk to attend to first and the most suitable method to address such risk. Risk exposure was calculated simply by multiplication of the risk impact with the frequency of its occurrence (probability):

$$\text{Risk Exposure} = \text{impact x Probability (frequency)}. \quad (8)$$

Another essential part of the risk management process is to lay out a mitigation plan or strategy for tackling the identified risks associated with the project model. Some techniques would be peculiar to individual risks. The aim of this step is also to employ the most cost-effective mitigation strategy in reducing individual risk exposure. Strategies such as: avoid, transfer, reduce and manage were all used depending on the risk type encountered.

Furthermore, it is imperative to continually monitor the risk to evaluate the efficiency/impact of the mitigation techniques put in place. Reviews like this end up aiding decisions on whether or not to abandon a mitigation strategy. Risk review also allows for opportunity response strategies to be looked into in the order of exploit, share, enhance, and ignore. Sharing the risk has proven to be a good tool for certain operations. Still, such cannot be applied due to the uncertainty surrounding the depressurization technology employed in this project modeling.

Primavera P6 version is an enterprise project portfolio management software. It includes project management, scheduling, risk analysis, opportunity management, resource management, collaboration, and control capabilities, and integrates with other enterprise software such as ORACLE and SAP's ERP system. The software tool was used to schedule the project's primary operations and the work breakdown structures to output the durations of each activity, the start and finish dates of the project. Also, the software tool was equally employed to validate the critical nature of all the activities as given by the CPM architecture of figure 3. In addition, the sequential flow of operations is expected from the software's output through its GANTT chart for vivid comprehension of the pre and post activities of the project. This project was tagged, "Gas hydrate P006" in the software analysis. The parameters given in table 2 were used in preparing the schedule for the project.

4 Results and Discussion

4.1 Scheduling results using Primavera P6 software

The result of the project execution sequence performed with Primavera P6 software is vividly shown in Figures 4-5. The GANTT chart of the operations is also shown at the extreme right of Figures 4-5.

From Figures 4-5, the methane gas extraction operation from gas hydrates is expected to commence on January 9, 2023, and end on October 30, 2023. This implies that the project has an execution span of approximately ten months. The durations of each activity in the scheduling plan were also presented. In addition, the key activities of the project, as contained in the operation schedule, were: premobilization/mobilization, site preparations, seismic study, well design and analysis, drilling and installation of suitable fittings, piping installation, and radiographic testing (RT), mechanical checks, decommissioning, product movement, and close out/demobilization. The work breakdown structures (WBS)/sub-activities of these activities are shown equally in Figures 4-5. Radiographic testing (RT) is a non-destructive examination (NDE) technique that involves using either X-rays or gamma-rays to view the internal structure of a component.

The GANTT chart shown at the extreme right of Figures 4-5 print the sequential flow of project operations and also indicates the critical nature of all the activities involved in the project. The red-colored GANTT chart indicates that all the operations are critical and that any delay in completing one activity would consequently affect the entire project. Each operation's zero float/slack values further validated the project schedule's critical nature. Also, from the GANTT chart, the black-colored lines indicate the summary of each operation. That is, it outputs the end period of the operation. The GANTT chart showed that the drilling work took the most significant percentage of the project execution duration. This was delineated by the long red rectangular bar from May 29, 2023, till August 4, 2023.

Furthermore, by meticulously following the project schedule shown in Figures 4-5, successful execution of the project is assured. A failed project schedule results from poor adherence to the schedule plan and scope and unvivid description and comprehension of the project that necessitated the scheduling.

The identified risks associated with the project and their corresponding mitigation strategies are vividly outlined in Table 7. The probability boundary of the risk occurrence ranged from 1–5, and its impact on the project execution was also kept within 1–5. The risk exposures were computed by multiplying the probability and impact together.

From Table 7, the unmitigated risk is shown in the yellow and red colored columns. In contrast, the green colored column shows the mitigated risks – the result or the output of adopting the suggested risk mitigation strategies. A drastic drop in the risk exposure parameters could be observed from Table 7, hence endorsing a successful project completion following the planned schedule.

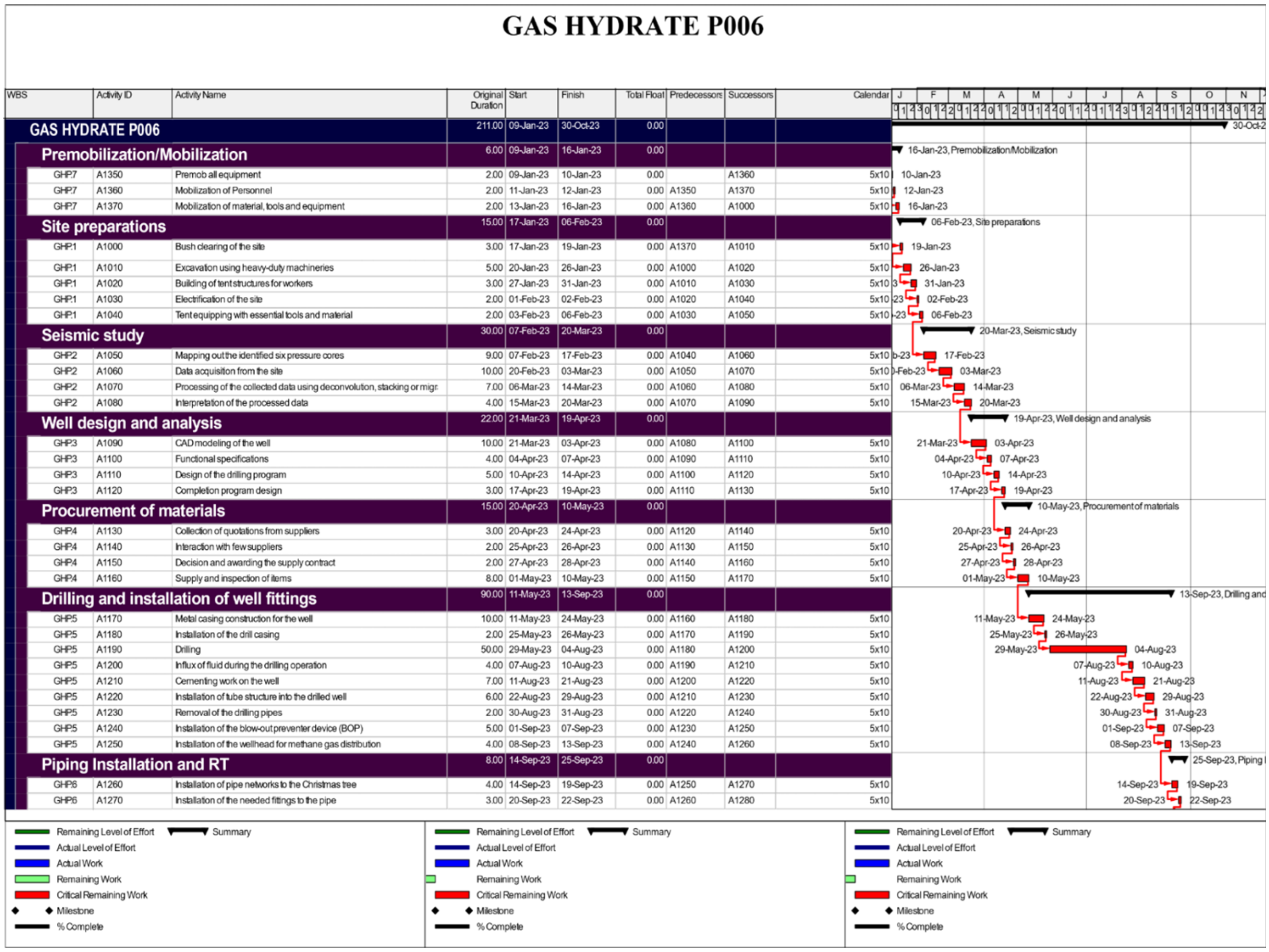
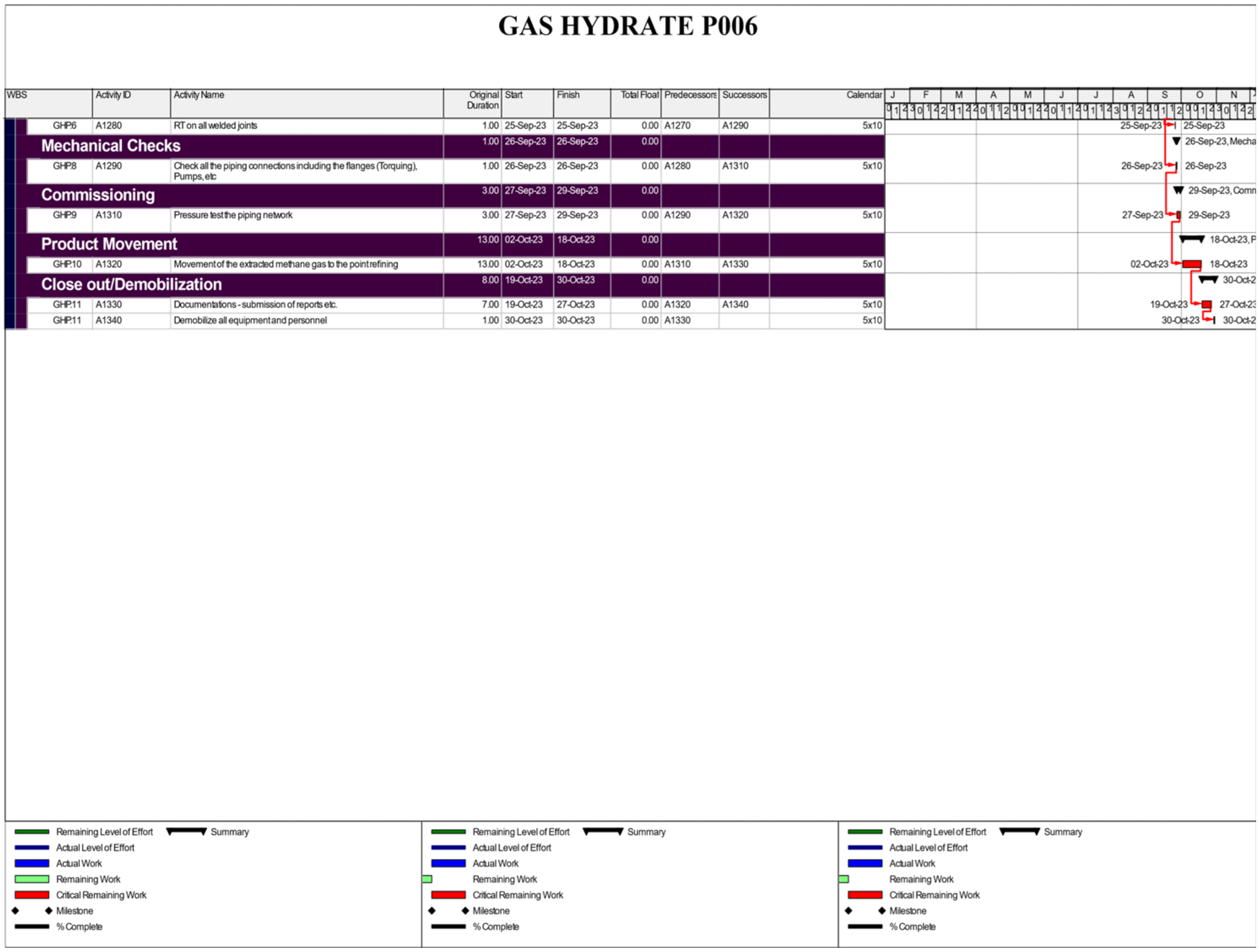


Figure 4 – Scheduling model of the project



GAS HYDRATE P006

WBS	Activity ID	Activity Name	Original Duration	Start	Finish	Total Float	Predecessors	Successors	Calendar
GHP.6	A1280	RT on all welded joints	1.00	25-Sep-23	25-Sep-23	0.00	A1270	A1290	5x10
Mechanical Checks			1.00	26-Sep-23	26-Sep-23	0.00			
GHP.8	A1290	Check all the piping connections including the flanges (Torquing), Pumps, etc	1.00	26-Sep-23	26-Sep-23	0.00	A1280	A1310	5x10
Commissioning			3.00	27-Sep-23	29-Sep-23	0.00			
GHP.9	A1310	Pressure test the piping network	3.00	27-Sep-23	29-Sep-23	0.00	A1290	A1320	5x10
Product Movement			13.00	02-Oct-23	18-Oct-23	0.00			
GHP.10	A1320	Movement of the extracted methane gas to the point refining	13.00	02-Oct-23	18-Oct-23	0.00	A1310	A1330	5x10
Close out/Demobilization			8.00	19-Oct-23	30-Oct-23	0.00			
GHP.11	A1330	Documentations - submission of reports etc.	7.00	19-Oct-23	27-Oct-23	0.00	A1320	A1340	5x10
GHP.11	A1340	Demobilize all equipment and personnel	1.00	30-Oct-23	30-Oct-23	0.00	A1330		5x10

Figure 5 – The scheduling model of the project continues

Table 7 – Risk impact analysis

No.	Risk	Prob.	Imp.	Exp.	Mitigation	Prob.	Imp.	Exp.	By/when
					Project Framing phase				
1	Misunderstanding of project objectives, resulting in the wrong framing process	1	5	5	Proper and detailed study and understanding of project aims and objectives	1	1	1	09/01/2023
2	Under or over-estimation of the project due to a lack of proper understanding of the depressurization method	3	3	9	External consultancy should be sought, and a comparison of budgets with in-house estimates	2	1	2	10/01/2023
3	Wrong selection of options during the option generation phase	3	4	12	Options should only be finalized after proper weighing of the pros and cons of each option	2	2	4	11/01/2023
4	The hiring of an incompetent and inexperienced workforce by the HR department	1	5	5	Proper screening and selection of qualified personnel with valuable experience	2	1	2	13/01/2023
5	Constant variation of project scope and inconsistency from framing team	3	4	12	The framing should be concluded only after detailed research has been done	4	1	4	15/01/2023
6	Members of the project tea continually disagree with options generated at every stage	3	3	9	Any decision that warrants disagreement should be put to the vote after extensive analysis of the pros and cons	3	1	3	17/01/2023

No.	Risk	Prob.	Imp.	Exp.	Mitigation	Prob.	Imp.	Exp.	By/when
7	The company executives refuse to grant the project due to an unconvincing proposal	2	5	10	Proposals from previous projects should be sampled to identify what the executives need to see before granting the project	1	3	3	20/01/2023
Project Appraisal phase									
8	Failure to secure license due to inability to meet Japanese government requirements	5	5	25	The appraisal team must enquire about the license requirements and take all steps to meet them	1	4	4	23/01/2023
9	Japanese government increases the tax rate and amount of royalties to be paid	2	4	8	The team should factor this into estimation and set aside a sum from revenue for such scenarios	3	1	3	25/01/2022
10	Increase in cost and time of initial drilling of a gas well due to unfamiliar formation	3	3	9	The geology team should conduct exhaustive research on the formation, and the costing team should increase drilling cost by ±5 % to cater for any uncertainty that might arise	2	1	2	27/01/2023
11	Delay in construction and delivery of FPSO vessel due to lack of raw materials and strike action by workers	3	5	15	FPSO construction should be done in a region of the world with sufficient raw materials and adequate and cooperative workers	1	3	3	30/01/2023
12	Poor scheduling by team resulted in improper management of resources and staff	5	4	20	Resource scheduling should be done as accurately as possible for effective resource management	2	2	4	02/02/2023
Project Planning stage									
13	Fluctuation of market gas price	3	4	12	The project team should draw up a sensitivity analysis using gas price changes to monitor revenue and cash flow differences.	1	1	1	04/02/2023
14	Nonavailability of clients to sell gas products to resulting in zero to low revenue and storage of excess gas products	5	3	15	Team should carry out aggressive marketing to attract enough clients to purchase gas	2	1	2	06/02/2023
15	Investors pull out of the project because of unproven technology	5	4	20	The project team should focus immensely on allaying the investors’ fears by answering their questions satisfactorily.	1	1	1	09/02/2023
16	Failure to obtain clearance from environmental agencies due to paperwork complications	2	4	8	All paperwork should be submitted in duplicates or triplicates to get rid of any misunderstanding	1	2	2	12/02/2023
17	Inability to meet the supply demands of customers when production begins	3	3	9	Proper estimation of produced gas should be made to know the amount that will be available, avoiding disappointment	3	1	3	15/02/2023
Execution and operation stages									
18	Occurrence of the earthquake in the region resulting in damage to vessels and loss of lives	5	5	25	The vessel should be constructed with adequate technology that can withstand earthquakes	2	5	10	17/02/2023
19	Loss of containment on the vessel due to leakage of valves, excessive storage, or pressure loss.	4	4	16	Up-to-date monitoring of pressure gauges and stored gases should be sold to make space for more production, and engineers should constantly check safety valves and pipes	2	2	4	20/02/2023

No.	Risk	Prob.	Imp.	Exp.	Mitigation	Prob.	Imp.	Exp.	By/when
20	Failure of Depressurization technology due to inexperienced hands and lack of understanding of the process	4	5	20	Properly trained engineers hired initially alongside experts in the technology should be brought on board during the framing stage.	1	1	1	22/02/2023
21	Political instability in the region resulted in production hiatus	5	5	25	MoU, signed with the Japanese government to exclude the vessel and its operations from any form of political instability	1	2	2	24/02/2023
22	Presence of acid gases in produced gas results in extra processing	4	2	8	Chromatography tests should be conducted during the appraisal phase to account for the presence of acid gases in the gas, allowing for it to be catered for	3	1	3	26/03/2023
23	Failure of one or multiple wells during production as a result of sand production	3	5	15	Sand screens should be installed during well completions to help combat sand production	2	2	4	28/02/2023
24	Incurring fines as a result of waste spillage and unsatisfactory water treatment before flooding into the sea	2	5	10	Waste should be properly contained and treated before disposal; likewise, water should be treated in three (3) stages before flooding back into the sea	2	1	4	04/03/2023
25	Depletion of hydrate reserves quicker than initially expected	3	4	12	Provision should be made for decommissioning program to be possibly brought forward on the scheduling plan.	1	3	3	08/03/2023
26	Fire outage on the vessel	3	5	15	All firefighting and preventing systems should be properly installed, regularly tested, and maintained through frequent fire drills	2	1	2	14/03/2023
27	Damage to any processing equipment (compressor, drill bit, etc.)	4	3	12	Regular maintenance checks should be assigned to every piece of equipment, and faulty ones should be replaced immediately	3	1	3	17/03/2023
28	Delay in the transportation of gas to customers due to logistics	2	3	6	Issues regarding transportation should be identified, and backup plans created during the planning stage	1	1	1	20/03/2023
29	Emission of greenhouse gases during methane extraction and processing	4	4	16	Adopt processes that minimize the emission of these gases to the barest minimum, which must also meet agency requirements	2	2	4	22/03/2023
30	Loss of containment of stored gases as a result of liquid present in processed gases	2	4	8	Processing equipment should be adjusted to industry settings to ensure optimum performance, thus avoiding liquid carryover	1	2	2	26/03/2023
31	Investors begin to back out from the project due to it not making enough profit in the first year	4	5	20	The economics of the project should be presented to invested, identifying that the profits would still come later in the project's life	2	2	4	28/03/2023

4.2 Result of the risk impact analysis and mitigation strategies

A vivid pictorial visualization of the unmitigated and mitigated risk matrices is shown in Figures 6 a-b.

From Figure 6a, the risk matrix further explains that risks in the top right-hand corner with the red color require urgent attention and cannot be accepted until they have been adequately dealt with to a manageable level.

Risks in the mid-region (shown in yellow) require attention only after the more urgent risks. The risks in the green zones represent tolerable risks that require minimal to zero mitigation.

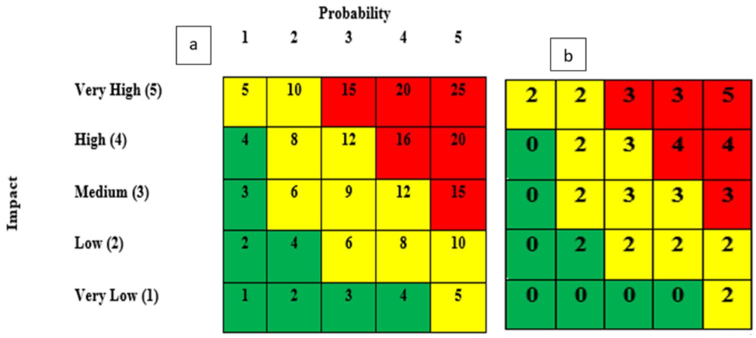


Figure 6 – Unmitigated (a) mitigated (b) risk matrices

Also, Figure 6b shows a spontaneous drop in the risk exposure matrix as a result of the application of the risk mitigation strategies. The most critical risks (red-colored cells) with a very high impact value of 25 were dropped to a minimum of 5. At the same time, the other risk matrices (yellow and green) were dropped from 12 and 4 to 3 and 0, respectively.

4.3 An impact of CPM scheduling on the project: Cost studies

The cost benefits of the application of the project scheduling (CPM) technique in the extraction of methane gas from gas hydrate reserves are determined or measured with some parameters such as net present value (NPV), the yielding time or payback time of the project and cash flow rate and internal rate of return (IRR). The results of these cost-deterministic parameters are vividly presented in Figures 7-11.

Figure 7 shows the variations in the generated revenue as the gas production rate changes. The revenues depicted in Figure 7 are only possible if the gas production rate is maintained between 60,000 to 65,000 MSCF/day. The revenues were also determined by fixing the gas price at \$2.073/MSCF.

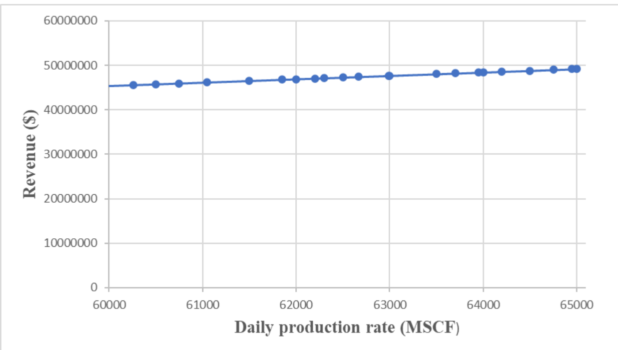


Figure 7 – Plot of revenue against daily production rate

From Figure 7, it can be observed vividly that as the daily production rate increases, the revenue also increases. This implies that there is a linear relationship between revenue and production rate.

Through a meticulous execution of the schedule plan obtained from the CPM analysis, the production is expected to start in 2024 and yield profits in 2030, hence a payback time of 8 years (adding 2023 – the year of project execution). This is shown in Figure 8.

From, Figure 8, a break-even is observed in 2030 when the operation enters profit in addition to the proportional increase in cash flow as the production year increases.

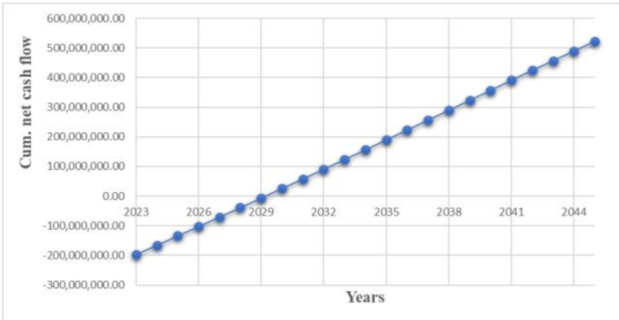


Figure 8 – Plot of cumulative net cash flow against years

This is only possible if the CPM scheduling is well applied (note that CPM assumes all operational and external variables to be efficient, giving no room for uncertainties).

The cash flows within the 22 years of production operation and the cash outflow in 2023 during the project execution phase are delineated in Figure 9.

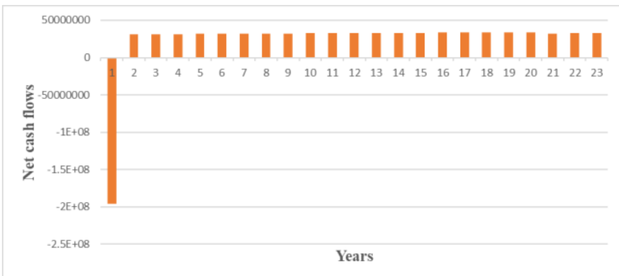


Figure 9 – Plot of net cash flows against years

Figure 9 shows that the cash inflows from year 2, 2024, to year 23 (2045) are approximately in the same range for a production rate maintained between 60,000-65,000 MSCF/day.

Figure 10 depicts the plot of cumulative cash flow for a number of years.

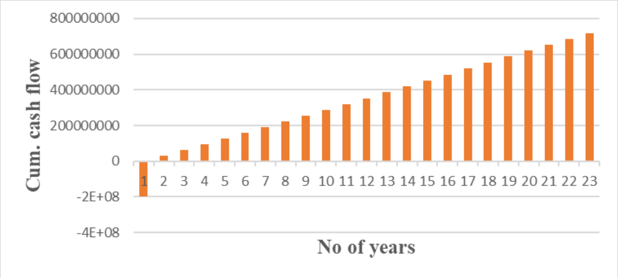


Figure 10 – Cumulative cash flow against a number of years

From Figure 10, the production operation appears to be efficient, as indicated by the excellent linear increment in the cash flows as the year increases. In addition, the net present value (NPV) obtained by subtracting the total current values (PV) from the initial investment sum of $195, 986,260.00 was derived from $20,736,951.04 for the run period of 22 years after the execution of the project. This derived sum of NPV would increase as the run period increases, keeping all other production variables and the CPM scheduling plan fixed without any variations. In addition, the safety of this project is also assured and guaranteed by the value of the internal rate of return (IRR). IRR value is derived from the plot of NPV against discount rate, and the value is gotten at the point where NPV value is 0.

Figure 11 delineates the graphical plot of NPV against the discount rate.

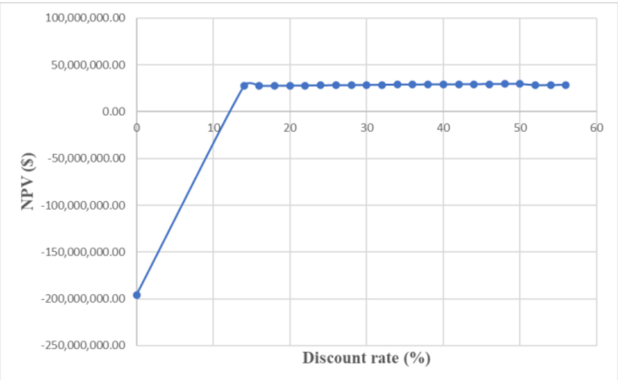


Figure 11 – Plot of NPV against discount rate

From Figure 11, the IRR value is derived from being 14 %. This is, therefore, good for the project as it implies a faster rate for the project to break even and enter profit. From a 14–58 % discount rate, an almost constant NPV is observed. This gives the value of NPV for the project, derived as $20,736,951.04 for the run period of 22 years after the execution of the project.

5 Conclusions

The impacts of the scheduling technique in extracting methane gas from gas hydrates have been demonstrated in this study. It proved efficient to be used in any other projects requiring timely completion and efficient utilization of the available project resources. The project scheduling technique is a subset of operations research where project goals are met through careful design, description, comprehension, and application of scheduling models for the efficient execution of projects. The CPM schedule expressed that the project execution would last for approximately ten (10) months, from January 9, 2023, to October 30, 2023. All the operations involved in the project execution plan were critical, proving that each activity should be completed within the scheduled run period. Else, the entire project would be affected.

Furthermore, several identified risks that would hinder or affect the project were identified and appropriately mitigated using several strategies. Risks with a high exposure matrix of 25, 12, and 4 were mitigated to 5, 3, and 0 using the recommended strategies. This, therefore, ensured an efficient and timely completion of the project. In addition, the project yielded an NPV of $20,736,951.04 for the run period of 22 years after the execution of the project, IRR of 14 %, and a payback time of 8 years (adding 2023- the year of project execution) provided the daily production rate is maintained within 60,000-65,000MSCF/day. If the daily production rate increases, the cash flow increases, and the payback time will decrease. In other words, the daily production rate determines the NPV, payback time, IRR, and cash flow rate value. The business model is safe once a linear relationship exists between the daily production rate and the deterministic cost factors – NPV, revenue, and cash flow rate. The application of CPM in extracting methane gas from gas hydrates positively affected the operation through the vivid insights provided in workflow pattern/methodology risks effects and cost benefits.

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