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Optimization of Crude Oil Evacuation in Flow Stations in the Niger Delta Region of Nigeria

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ABSTRACT: In this study, a linear programming model was used with the intent of choosing the most optimal solution for the evacuation of crude oil. Elements considered by the model include the cost of evacuation, pipeline capacity, pipeline vandalism and profit margin of the evacuation. Based on a factor of consideration of the number and flexibility of evacuation routes and tactics, this study was able to deduce and determine the best evacuation strategy that could give maximum revenue with minimal cost and risk. The outcomes of the study provide an intervention solution for the oil companies that the company can adopt in another attempt to enhance their operational efficiency. The optimized system also offers quick evacuation whenever they are deemed necessary, cuts interruptions from pipeline failure and other operations slowdowns and increases the efficiency and profit in the extraction and shipment of oil. Hence in the optimized system, timely evacuation is ensured, disruption due to pipeline breaches and operational delay is decreased and the probabilities of increasing the profitability of oil extraction and export are enhanced. During the discussion, the general application of these findings was considered further with the primary objective to minimize operation interruption and ecological threats and enhance the business viability in the oil companies within the Niger Delta Region of Nigeria.

KEY WORDS: Optimization, crude oil evacuation strategy, Niger Delta, Linear Programming, Alternative Crude Evacuation (ACE).

I. INTRODUCTION

Crude oil also commonly called ‘oil’, crude or ‘black gold’ is a natural, untreated and complex blend of actual and other substances of organic nature which are composed of hydrocarbons. As described by Rudzinski & Aminabhavi [1], it is an essential unprocessed input in the world’s energy and petrochemical sectors as they depend largely on crude oil to manufacture fuels, oils, and an assortment of chemical goods. Crude oil production entails the extraction of crude oil from subterranean reservoirs; a process that is usually done at the flow stations near the wells. After extraction, the crude oil passes through some preliminary treatment in the so-called flow stations before it is sent to the refining plants. The treated crude is then conveyed, often through pipes or vessels, to other refineries for other processing and formation of finished products or to export stations for marketing in the global market.

Nigeria, one of the oil giants in the world, depends on crude oil as one of its main sources of income, and the commodity forms a large part of its exports. The Niger Delta region, based on the geographical location of the area as described by Ite et al., [2] is the southern part of Nigeria and serves as the hub of Nigeria’s petroleum sector. These geographical characteristics make the Niger Delta area of immense production importance for the Nigerian oil industry, while at the same time, constituting major production difficulties for the country in the evacuation of crude. As stated by Onwuka et al., [3], crude oil evacuation, which is one of the processes of the oil and gas industry is the physical movement of crude oil from the production area to the refinery or export centre either through pipeline transport, by using tanker ships for water transport or rail and road transport. Each of these methods has its own challenges, for example, pipeline transport is cheap and the best for large volumes over long distances but exposes commodities to vandalism and entails the establishment of costly pipelines. Ezirim [4] identified pipeline vandalism as one of series of challenges affecting the crude oil evacuation process in Niger Delta Region of Nigeria. Another major challenge is the lack of systematic manners of addressing the problem of crude oil distribution concerning the available evacuation options [3]. This is the case with the oil companies in the Niger Delta Region of Nigeria that has adopted conventional methods such as the: Alternative Crude Evacuation (ACE), pipelines and [modular] refineries, (Ukhurebor *et al*., [5]. Odogun [6] similarly states and agrees to the fact that the process of evacuating crude oil is challenging due to other factors such as logistics and infrastructure. While the ACE route also breaks the pipeline dominance, it implies higher and additional transport costs, and additional complications, which include the multi-modal transported and handling facilities [7].

This route is also faced with downtime and distortion which impacts on the timely delivery of crude oil to its intended destinations. There are capacity and operational issues in the Refinery business that make it difficult for the modular refineries in the region to process the crude oil adequately thus enhancing the evacuation problem [8]. The importance of enhancing the efficiency of crude oil evacuation in Niger Delta Region of Nigeria is paramount [9]. As a result, the region's oil and gas companies need to optimize the efficiency of evacuations to increase effectiveness and the viability of the operations. An optimized evacuation system can help to address the concerns most times associated with pipeline vandalism and theft minimizing transportation and logistical expenses as well as enhancing the efficiency of the crude oil transportation to the refineries and export terminals [10]. According to Alrabghi & Tiwari [11], design and optimization are some of the vital concepts when considering growth, profitability and sustainability in the system. Optimization is a mathematical and computational approach that seeks to enhance operations with a view of making them as effective and efficient as possible [12].

Optimization is vital in the field of oil and gas operations across exploration, production, transportation, and refining. The industry is highly compounded by process sequences and hefty capital investment, which makes the application of optimization imperative to increase efficiency and profitability [13]. In addition, the monetary gains from efficient Crude Oil evacuation may be re-directed to the costs of environmental conservation. For instance, the additional revenue can be used to reclaim and rehabilitate spoiled environments, create and improve environmental-friendly methods and also support stronger environmental policies. As a result, the optimization of crude oil evacuation improves the profitability of the oil production and the development sustainability of the Niger Delta region.

II. MATERIALS AND METHODS

Research Design : The research design serves as a framework for methodically tackling the research topic and accomplishing the goals of the study. Research design incorporates data collection, measurement, and analysis in a rational and cohesive way, as stated by Nwabuko [14]. The optimization of crude oil evacuation procedures is the aim of this study, which uses a quantitative research design with components of operations research and case study analysis. According to Zhang et al. [15], this method is supported by the necessity of precise mathematical modelling and the assessment of actual data. Analyzing numerical data and testing optimization models are suitable tasks for quantitative approaches, and the case study component offers a contextualized comprehension of operational dynamics in the Niger Delta.

Methods of Data Collection/Instrumentation : Data collection for this study was conducted using primary and secondary data collection.

Primary Data Collection : An anonymous oil company's operations records provided the data for this investigation. These statistics comprised the amount of crude oil that was evacuated via modular refineries, the Trans-Niger Pipeline, and the Alternative Crude Export system. They also included evacuation route costs and operational limitations, including capacity limitations, delays in transit, and sabotage and vandalism hazards. In order to guarantee data fidelity, instrumentation equipment were used. Transportation operations were recorded in real time, flow rates were measured, and pipeline outages were tracked using automated data recorders and monitoring devices. Furthermore, qualitative data about the decision-making procedures involved in the evacuation of crude oil was obtained through interviews with important executives.

Secondary Data Collection : For this study, academic journals, government publications, and industry reports served as secondary data sources. These sources provided insightful background data on market demands, infrastructure developments, and crude oil pricing. They also provided standards for assessing optimization models.

Route Selection Criteria and Constraints
To identify optimal evacuation routes, the study analyzed the following criteria:

Operational Capacity Constraints : Each evacuation route has specific minimum and maximum operational capacities. These constraints were quantified and are summarized in Tables 1, 2 and 3.

Table1: Trans-Niger Pipeline (TNP)

Parameter	TNP Value
Daily Minimum Requirement	6,000 bbl/day
Pipeline Reserved Capacity	6,000 bbl/day
Terminal Reserved Capacity	6,000 bbl/day

Table 2: Refinery Capacity

Train	Capacity (bbl/day)
Train 1	**4,500**
Train 2	**4,500**
Total	**9,000**

Table 3: Alternative Crude Export (ACE) Terminal

ACE Agreement	Minimum Volume (bbl)	Maximum Volume (bbl)
Throughput Agreement (TPA)	180,000	216,000
Marine Service Agreement (MSA)	220,000	300,000
Daily Reserved Volume	6,000 bbl/day	-

Economic Constraints : Economic constraints included transportation and terminal costs for each route. These costs, summarized in Tables 4, 5, and 6, were key inputs for optimization.

Table 4: ACE Terminal Costs

ACE Terminal Cost Type	Rate ($/bbl)	Volume Bracket (bbl)
TPA (within reserved)	$2.80	Reserved capacity (+10%)
TPA (exceeding reserved)	$3.00	Beyond reserved capacity
MSA (initial 220,000 bbl)	$12.53	0 - 220,000
MSA (next 40,000 bbl)	$9.00	220,001 - 260,000
MSA (subsequent increments)	$5.20	Beyond 260,000

Table 5: TNP Pipeline Costs

TNP Pipeline Cost Type	Rate ($/bbl)
Reserved Capacity	0.79
Production	1.54

Table 6: Terminal Cost Type

Terminal Cost Type	ACE Rate ($/bbl)	TNP Rate ($/bbl)
Reserved Capacity	2.49	2.64
Production	0.98	1.08

Existing Approach : Tables 7 shows the summary table for cost, revenue and profit made by the anonymous company through each route for the period of study (February to October 2024). By allocating 784,726.60 bbl to TNP, 1,036,861.64 to Refinery and 1,822,031.73 to ACE, the company made revenue of $294.3m of which its profit was $236m. This profit margin can be further improved by optimizing the crude oil allocation strategy to the three evacuation routes.

Table 7: Summary of results of the existing method ("AS IS")

Route	Allocation (bbl)	Cost ($)	Revenue ($)	Profit ($)
TNP	784,726.60	13,327,468.19	61,753,578.05	**48,436,109.85**
Refinery	1,036,861.64	7,378,107.87	84,191,978.04	**76,813,870.17**
ACE	1,822,031.73	37,506,086.35	148,305,263.99	**110,799,177.64**
Total	**3,643,619.97**	**58.211,662.41**	**294,260,820.08**	**236,049,157.67**

Optimization Parameters : Optimization for this study was guided by two primary parameters. These parameters are cost minimization and revenue maximization.

Cost Minimization : This prioritized the selection of routes with lower transportation and terminal costs per barrel. This involved leveraging economic constraints to identify pathways that minimize overall operational expenses. A possible equation for cost minimization could be:

$$Cost_{\min =} \sum_i (C_{t,i} + C_{tr,i}) \quad (1)$$

where $C_{tr,i}$represents terminal costs for route iii, and $C_{tr,i}$ represents transportation costs for route i.

Revenue Maximization : This concentrated on routes with higher revenue potential by considering market prices and allocation scalability. The aim was to optimize income through efficient allocation across ACE, TNP, and refinery routes. The revenue maximization could be expressed as:

$$Revenue_{max} = \sum_i (P_i \times V_i) \quad (2)$$

Where P_i is the market price per barrel for route i, and V_i is the volume allocated to route i.

Optimization Approach and Sharing Philosophies : The Linear Programming (LP) model is formulated to allocate crude to the routes that yield maximum revenue results based on predefined constraints, costs, and capacities.

The Objective function is given by the Equation (3)

$$Maximize\ Total\ Revenue = R_{ACE} + R_{TNP} + R_{Refinery} \quad (3)$$

Where R_{ACE}, R_{TNP}, and $R_{Refinery}$ are the total revenue of each route. Each of the revenue formular breakdowns (ACE, TNP, and Modular refinery) are shown in Appendix A, B and C respectively.

Development of Sharing Philosophies : To develop an optimized allocation strategy, it's important to understand the current allocation Philosophy, and as well estimate how much revenue is made for the set period.

Sharing Philosophies : Understanding that, in addition to the marginal cost of evacuating that excess crude through other channels, neglecting to provide ACE with up to 220,000 barrels would result in incurring a huge regret cost. To disperse oil along the routes, four different sharing philosophies, or allocation techniques, were developed. Because of these theories' unique features, ACE has at least 220,000 barrels of oil; this optimizes the cost of evacuation:

Philosophy 1: In Philosophy 1, ACE receives up to its minimum capacity first, then the remaining crude is shared with TNP and the refinery. The formula for allocating crude volume to ACE, TNP & Refinery based on Philosophy 1 are given in the Equations (4) (5) and (6) respectively.

i. ACE Crude Allocation:

$$\mathrm{T}ACE = \min\left(P \times \frac{WACE}{WACE+WTNP+WRef}, CACE\right) \quad (4)$$

ii. TNP Crude Allocation:

$$\mathrm{T}\ TNP = \min\left(P \times \frac{WTNP}{WACE+WTNP+WRef}, CTNP\right) + \left(\frac{CTNP - \min\left(P \times \frac{WTNP}{WACE+WTNP+WRef}, CTNP\right)}{\left(CTNP - \min\left(P \times \frac{WTNP}{WACE+WTNP+WRef}, CTNP\right)\right) + \left(CRef - \min\left(P \times \frac{WRef}{WACE+WTNP+WRef}, CRef\right)\right)}\right) \times$$

$$\left(P - \left(min\left(P \times \frac{WACE}{WACE+WTNP+WRef}, CACE\right)\right) + \left(min\left(P \times \frac{WTNP}{WACE+WTNP+WRef}, CTNP\right)\right) + \left(min\left(P \times \frac{WRef}{WACE+WTNP+WRef}, CRef\right)\right)\right) \quad (5)$$

iii. Refinery Crude Allocation:

$$\mathrm{T}Ref = \min\left(P \times \frac{WRef}{WACE+WTNP+WRef}, CRef\right) + \left(\frac{CRef - min\left(P \times \frac{WRef}{WACE+WTNP+WRef}, CRef\right)}{\left(CTNP - min\left(P \times \frac{WTNP}{WACE+W7NP+WRef}, CTNP\right)\right) + \left(CRef - min\left(P \times \frac{WRef}{WACE+WTNP+WRef}, CRef\right)\right)}\right) \times \left(P - \left(min\left(P \times \frac{WACE}{WACE+WTNP+WRef}, CACE\right)\right) + \left(min\left(P \times \frac{WTNP}{WACE+WTNP+WRef}, CTNP\right)\right) + \left(min\left(P \times \frac{WRef}{WACE+WTNP+WRef}, CRef\right)\right)\right) \quad (6)$$

Where:
P = Total Crude Production,
$WACE$, $WACE$, $WACE$ = Weights for ACE, TNP & Refinery, respectively.
$CACE$, $CTNP$, $CRef$ = Volume Constraints for ACE, TNP & Refinery, respectively.
$TACE$, $TTNP$, $TRef$ = Final allocations for ACE, TNP & Refinery, respectively.

Philosophy 2: In Philosophy 2, ACE gets as much as it requests, and TNP and the refinery split the remaining portion according to their limitations. The formula for allocating crude volume to ACE, TNP & Refinery based on philosophy 2 are given in the Equations (7), (8) and (9) respectively.

i. ACE Crude Allocation:

$$\mathrm{T}ACE = \left(P \times \frac{WACE}{WACE+WTNP+WRef}\right) + max\left(0, P - \left(min\left(P \times \frac{WTNP}{WACE+WTNP+WRef}, CTNP\right) + min\left(P \times \frac{WRef}{WACE+WTNP+WRef}, CRef\right) + min\left(P \times \frac{WACE}{WACE+WTNP+WRef}, CACE\right)\right)\right) \quad (7)$$

ii. TNP Crude Allocation:

$$\mathrm{T}TNP = \min\left(P \times \frac{WTNP}{WACE+WTNP+WRef}, CTNP\right) \quad (8)$$

iii. Refinery Crude Allocation:

$$\mathrm{T}Ref = \min\left(P \times \frac{WRef}{WACE+WTNP+WRef}, CRef\right) \quad (9)$$

2.7.1.3 Philosophy 3:

In Philosophy 3, ACE is capped, and priority is given to maximize refinery allocation to increase refined product output. The formula for allocating crude volume to ACE, TNP & Refinery based on philosophy 3 are given in the Equations (10) (11) and (12) respectively.

i. ACE Crude Allocation:

$$\mathrm{T}ACE = \min\left(P \times \frac{WACE}{WACE+WTNP+WRef}, CACE\right) \quad (10)$$

ii. TNP Crude Allocation:

$$T$$

$$TNP = min\left(P \times \frac{WTNP}{WACE+WTNP+WRef}, CTNP\right) \left(\left(P - \left(min\left(P \times \frac{WACE}{WACE+WTNP+WRef}, CACE\right)\right) + \left(min\left(P \times \frac{WTNP}{WACE+WTNP+WRef}, CTNP\right)\right) + \left(min\left(P \times \frac{WRef}{WACE+WTNP+WRef}, CRef\right)\right)\right)\right) \quad (11)$$

iii.Refinery Crude Allocation:

$$TRef = min\left(min\left(P \times \frac{WRef}{WACE+WTNP+WRef}, CRef\right) + \left(P - \left(TACE + min\left(P \times \frac{WTNP}{WACE+WTNP+WRef}, CTNP\right)\right) + \left(min\left(P \times \frac{WRef}{WACE+WTNP+WRef}, CRef\right)\right)\right), CRef\right) \quad (12)$$

2.7.1.4 Philosophy 4:
In Philosophy 4, ACE receives maximum allocation, with the priority given to TNP for increased pipeline utilization. The formula for allocating crude volume to ACE, TNP & Refinery based on philosophy 4 are given in the Equations (13), (14) and (15) respectively.

ACE Crude Allocation:

i. $TACE = \min\left(P \times \frac{WACE}{WACE + WTNP + WRef}, CACE\right)$ (13)

ii. TNP Crude Allocation:

$$TTNP = min\left(min\left(P \times \frac{WTNP}{WACE + WTNP + WRef}, CTNP\right) + \left(P - \left(TACE + min\left(P \times \frac{WTNP}{WACE + WTNP + WRef}, CTNP\right)\right) + \left(min\left(P \times \frac{WRef}{WACE + WTNP + WRef}, CRef\right)\right)\right), CTNP\right) \quad (14)$$

iii. Refinery Crude Allocation:

$$TREF = min\left(min\left(P \times \frac{WRef}{WACE + WTNP + WRef}, CRef\right) + \left(P - \left(TACE + min\left(P \times \frac{WTNP}{WACE+WTNP+WRef}, CTNP\right)\right) + \left(min\left(P \times \frac{WRef}{WACE+WTNP+WRef}, CRef\right)\right)\right), CRef\right) \quad (15)$$

Each sharing philosophy allows for adjustments in allocation based on operational needs, market demands, and capacity constraints, optimizing the revenue objective.

III. RESULTS AND DISCUSSION

These formulas developed for Philosophies 1 to 4 were used to allocate the total crude produced between February 2024 to October 2024 (the set period) to the three evacuation routes. Below are the results obtained from approaches 1 to 4.

Results of Philosophy one : Tables 8, 9 and 10 reveal the amount of crude oil allocated to ACE, Refinery and TNP by Philosophy one strategy as well as the cost, revenue and profit made. The summary of these results obtained from each of the three routes for the set period can be seen in Table 11.

Table 8: Results from allocating crude to ACE using philosophy one.

Month (ACE)	Allocation (bbl)	Cost ($)	Revenue ($)	Profit ($)
February	220,000.00	4,148,065.28	18,365,600.00	14,217,534.72
March	207,368.21	4,066,337.60	17,711,318.88	13,644,981.28
April	216,394.83	4,124,739.82	19,479,862.52	15,355,122.70
May	220,000.00	4,148,065.28	17,984,120.00	13,836,054.72
June	213,971.40	4,109,060.21	17,598,291.42	13,489,231.21
July	126,698.59	3,706,325.95	10,785,851.10	7,079,525.15
August	220,000.00	4,148,065.28	17,678,100.00	13,530,034.72
September	220,000.00	4,148,065.28	16,282,200.00	12,134,134.72
October	220,000.00	4,148,065.28	16,638,600.00	12,490,534.72
TOTAL	**1,864,433.03**	**36,746,789.97**	**152,523,943.92**	**115,777,153.95**

Table 9: Results from allocating crude to TNP using philosophy one

Month (TNP)	Allocation (bbl)	Cost ($)	Revenue ($)	Profit ($)
February	90,823.89	1,569,180.55	6,823,780.41	5,254,599.85
March	84,867.72	1,562,953.28	6,523,696.73	4,960,743.46
April	88,561.96	1,623,463.89	7,175,113.07	5,551,649.17
May	110,972.54	1,806,809.36	8,164,405.03	6,357,595.67
June	87,570.15	1,544,119.82	6,482,064.78	4,937,944.95
July	51,852.79	1,201,671.69	3,972,805.30	2,771,133.61
August	117,818.10	1,862,522.43	8,520,546.16	6,658,023.72
September	136,894.61	1,953,354.53	9,118,413.26	7,165,058.74
October	112,787.90	1,756,948.77	7,677,134.10	5,920,185.33
TOTAL	**882,149.66**	**14,881,024.33**	**64,457,958.83**	**49,576,934.50**

Table 10: Results from allocating crude to Refinery using philosophy One

Month (Refinery)	Allocation (bbl)	Cost ($)	Revenue ($)	Profit ($)
February	92,674.31	837,247.48	9,291,446.30	8,454,198.82
March	86,613.57	784,263.52	8,846,141.04	8,061,877.53
April	90,383.81	822,402.30	9,635,851.78	8,813,449.47
May	112,723.52	1,016,027.99	11,111,741.68	10,095,713.69
June	89,371.59	806,399.14	8,853,216.71	8,046,817.57
July	52,919.48	479,804.89	5,390,457.98	4,910,653.09
August	119,507.90	1,075,427.59	11,619,075.39	10,543,647.80
September	138,318.93	1,235,780.33	12,595,661.94	11,359,881.61
October	114,524.18	1,025,355.33	10,609,027.92	9,583,672.59
TOTAL	**897,037.28**	**8,082,708.56**	**87,952,620.74**	**79,869,912.18**

Table 11: Summary of the results for Philosophy one

Route	Allocation (bbl)	Cost ($)	Revenue ($)	Profit ($)
ACE	1,864,433.03	36,746,789.97	152,523,943.92	**115,777,153.95**
Refinery	897,037.28	8,082,708.56	87,952,620.74	**79,869,912.18**
TNP	882,149.66	14,881,024.33	64,457,958.83	**49,576,934.50**
Total	3,643,619.97	59,710,552.86	304,934,523.49	**245,224,000.63**

To maximize expenses and earnings, this method distributes remaining crude between TNP and the refinery once ACE obtains the maximum capacity first. In the optimal situation (Approach 1), 1,864,433.03 barrels of ACE are allotted, while TNP and the refinery receive the remaining 1,779,186.94 barrels. ACE's expenses came to $36,746,789.97, whilst TNP and the refinery spent $14,881,024.33 and $8,082,708.56, respectively. With TNP and the refinery earning $64.46 million and $87.95 million, respectively, $152.52 million is made on the shipment of 1,864,433.03 barrels of oil through ACE. TNP and the refinery contributed $49.5 million and $79.8 million, respectively, to ACE's $116 million profit, respectively as shown in Table 11.

Results of Philosophy Two : Tables 12, 13 and 14 reveal the amount of crude oil allocated to ACE, Refinery and TNP by Philosophy two strategy as well as the cost, revenue and profit made. The summary of these results obtained from each of the three routes for the set period can be seen in Table 15.

Table 12: Results from allocating crude to ACE using philosophy two.

Month (ACE)	Allocation (bbl)	Cost ($)	Revenue ($)	Profit ($)
February	220,860.00	4,161,369.44	18,437,392.62	14,276,023.18
March	207,368.21	4,066,337.60	17,711,318.88	13,644,981.28
April	216,394.83	4,124,739.82	19,479,862.52	15,355,122.70
May	242,862.82	4,501,753.11	19,853,064.11	15,351,311.00
June	213,971.40	4,109,060.21	17,598,291.42	13,489,231.21
July	126,698.59	3,706,325.95	10,785,851.10	7,079,525.15
August	250,323.35	4,617,167.43	20,114,732.44	15,497,565.00
September	271,061.58	4,895,953.97	20,061,267.86	15,165,313.89
October	244,842.10	4,532,372.50	18,517,407.72	13,985,035.22
TOTAL	**1,994,382.87**	**38,715,080.04**	**162,559,188.67**	**123,844,108.63**

Table 13: Results from allocating crude to Refinery using philosophy two

Month (Refinery)	Allocation (bbl)	Cost ($)	Revenue ($)	Profit ($)
February	92,248.82	833,412.65	8,415,374.30	7,581,961.65
March	86,613.57	784,263.52	8,061,877.53	7,277,614.01
April	90,383.81	822,402.30	8,813,449.47	7,991,047.17
May	101,438.96	914,515.37	9,084,848.71	8,170,333.35
June	89,371.59	806,399.14	8,046,817.57	7,240,418.43
July	52,919.48	479,804.89	4,910,653.09	4,430,848.21
August	104,555.07	941,120.36	9,224,176.62	8,283,056.26
September	113,217.02	1,011,875.79	9,297,944.96	8,286,069.17
October	102,265.66	915,816.75	8,557,635.14	7,641,818.39
TOTAL	**833,013.99**	**7,509,610.77**	**74,412,777.39**	**66,903,166.63**

Table 14: Results from allocating crude to TNP using philosophy two

Month (TNP)	Allocation (bbl)	Cost ($)	Revenue ($)	Profit ($)
February	90,389.38	1,564,528.72	6,791,135.03	5,226,606.31
March	84,867.72	1,562,953.28	6,523,696.73	4,960,743.46
April	88,561.96	1,623,463.89	7,175,113.07	5,551,649.17
May	99,394.28	1,684,860.18	7,312,576.23	5,627,716.05
June	87,570.15	1,544,119.82	6,482,064.78	4,937,944.95
July	51,852.79	1,201,671.69	3,972,805.30	2,771,133.61
August	102,447.58	1,702,768.93	7,408,957.81	5,706,188.88
September	110,934.93	1,700,014.01	7,389,264.94	5,689,250.93
October	100,204.32	1,632,107.05	6,820,607.38	5,188,500.33
TOTAL	**816,223.11**	**14,216,487.57**	**59,876,221.27**	**45,659,733.70**

Table 15: Summary of the Results for Philosophy Two

Route	Allocation (bbl)	Cost ($)	Revenue ($)	Profit ($)
ACE	1,994,382.87	38,715,080.04	162,559,188.67	**123,844,108.63**
Refinery	833,013.99	7,509,610.77	74,412,777.39	**66,903,166.63**
TNP	816,223.11	14,216,487.57	59,876,221.27	**45,659,733.70**
Total	3,643,619.97	60,441,178.38	296,848,187.33	**236,407,008.95**

In the Approach 2 scenario, ACE's crude oil demand is fully satisfied, while the remaining supply is allocated to TNP and the refinery according to their constraints. The results highlight a marginal improvement in profitability when comparing the existing method to the optimized approach. Under the optimized scenario, the total profit is $236.41 million. Similarly, total cost is $60.44 million, reflecting the redistribution of resources. However, the revenue demonstrated a slight gain, increasing to $296.85 million as compared to the existing approach ($294m).

The detailed results in Table 15 reveal the allocation and financial outcomes for each route. ACE's allocation rose to 1,994,382.87 barrels, leading to a cost of $38.72 million, a revenue of $162.56 million, and a profit of $123.84 million. The refinery's allocation was adjusted to 833,013.99 barrels, resulting in a cost of $7.51 million, revenue of $74.41 million, and profit of $66.9 million. Meanwhile, TNP received 816,223.11 barrels, incurring a cost of $14.22 million, generating revenue of $59.88 million, and contributing a profit of $45.66 million.

Results of Philosophy Three : Tables 16, 17 and 18 reveal the amount of crude oil allocated to ACE, Refinery and TNP by Philosophy Three allocation strategy as well as the cost, revenue and profit made. The summary of these results obtained from each of the three routes for the set period can be seen in Table 19.

Table 16: Results from allocating crude to ACE using philosophy Three

Month (ACE)	Allocation (bbl)	Cost ($)	Revenue ($)	Profit ($)
February	220,000.00	4,148,065.28	18,365,600.00	14,217,534.72
March	207,368.21	4,066,337.60	17,711,318.88	13,644,981.28
April	216,394.83	4,124,739.82	19,479,862.52	15,355,122.70
May	220,000.00	4,148,065.28	17,984,120.00	13,836,054.72
June	213,971.40	4,109,060.21	17,598,291.42	13,489,231.21
July	126,698.59	3,706,325.95	10,785,851.10	7,079,525.15
August	220,000.00	4,148,065.28	17,678,100.00	13,530,034.72
September	220,000.00	4,148,065.28	16,282,200.00	12,134,134.72
October	220,000.00	4,148,065.28	16,638,600.00	12,490,534.72
TOTAL	**1,864,433.03**	**36,746,789.97**	**152,523,943.92**	**115,777,153.95**

Table 17: Results from allocating crude to Refinery using philosophy Three

Month (Refinery)	Allocation (bbl)	Cost ($)	Revenue ($)	Profit ($)
February	91,249.38	824,404.97	9,148,583.88	8,324,178.90
March	84,867.72	768,495.61	8,667,831.37	7,899,335.76
April	88,561.96	805,865.64	9,441,624.08	8,635,758.44
May	122,257.10	1,101,789.28	12,051,515.83	10,949,726.56
June	87,570.15	790,185.05	8,674,764.41	7,884,579.36
July	51,852.79	470,173.88	5,281,803.73	4,811,629.85
August	132,770.93	1,194,556.95	12,908,564.33	11,714,007.38
September	161,996.52	1,446,980.23	14,751,801.55	13,304,821.32
October	125,046.42	1,119,379.02	11,583,762.72	10,464,383.69
TOTAL	**946,172.96**	**8,521,830.64**	**92,510,251.91**	**83,988,421.27**

Table 18: Results from allocating crude to TNP using philosophy Three

Month (TNP)	Allocation (bbl)	Cost ($)	Revenue ($)	Profit ($)
February	92,248.82	1,584,435.87	6,930,838.38	5,346,402.51
March	86,613.57	1,581,981.30	6,657,898.49	5,075,917.20
April	90,383.81	1,644,160.06	7,322,715.39	5,678,555.33
May	101,438.96	1,706,396.00	7,463,006.37	5,756,610.37
June	89,371.59	1,563,183.77	6,615,410.11	5,052,226.34
July	52,919.48	1,213,267.64	4,054,531.59	2,841,263.95
August	104,555.07	1,724,673.16	7,561,370.65	5,836,697.50
September	113,217.02	1,722,284.93	7,541,272.67	5,818,987.75
October	102,265.66	1,652,557.66	6,960,917.02	5,308,359.36
TOTAL	**833,013.99**	**14,392,940.39**	**61,107,960.68**	**46,715,020.29**

Table 19: Summary of the results for Philosophy three

Route	Allocation (bbl)	Cost ($)	Revenue ($)	Profit ($)
ACE	1,864,433.03	36,746,789.97	152,523,943.92	**115,777,153.95**
Refinery	946,172.96	8,521,830.64	92,510,251.91	**83,988,421.27**
TNP	833,013.99	14,392,940.39	61,107,960.68	**46,715,020.29**
Total	**3,643,619.97**	**59,661,561.00**	**306,142,156.50**	**246,480,595.51**

In Philosophy Three, refinery allocation is prioritized above ACE's allocation, which is limited to reduce its crude intake. By keeping costs and revenues balanced across the network, this strategy seeks to increase the output of refined products. Prioritizing the production of refined products, the refinery allocation increased to 946,172.96 barrels under the optimized scenario (Approach 3) while ACE's allocation was capped at 1,864,433.03 barrels. TNP was given a balanced allocation of 833,013.99 barrels. ACE's cost reduced somewhat to $36,746,789.97, while TNP and the refinery had expenses of $14,392,940.39 and $8,521,830.64, respectively. All routes saw increases in revenue: TNP made $61.11 million, the refinery made $92.51 million, and ACE generated $152.52 million.

Results of Philosophy Four : Tables 20, 21 and 22 reveal the amount of crude oil allocated to ACE, Refinery and TNP by Philosophy Four allocation, as well as the cost, revenue and profit made. The summary of these results obtained from each of the three routes for the set period can be seen in Table 23

Table 20: Results from allocating crude to ACE using philosophy Four

Month (ACE)	Allocation (bbl)	Cost ($)	Revenue ($)	Profit ($)
February	220,000.00	4,148,065.28	18,365,600.00	14,217,534.72
March	207,368.21	4,066,337.60	17,711,318.88	13,644,981.28
April	216,394.83	4,124,739.82	19,479,862.52	15,355,122.70
May	220,000.00	4,148,065.28	17,984,120.00	13,836,054.72
June	213,971.40	4,109,060.21	17,598,291.42	13,489,231.21
July	126,698.59	3,706,325.95	10,785,851.10	7,079,525.15
August	220,000.00	4,148,065.28	17,678,100.00	13,530,034.72
September	220,000.00	4,148,065.28	16,282,200.00	12,134,134.72
October	220,000.00	4,148,065.28	16,638,600.00	12,490,534.72
TOTAL	**1,864,433.03**	**36,746,789.97**	**152,523,943.92**	**115,777,153.95**

Table 21: Results from allocating crude to Refinery using philosophy Four

Month (Refinery)	Allocation (bbl)	Cost ($)	Revenue ($)	Profit ($)
February	90,389.38	816,654.06	9,062,361.24	8,245,707.18
March	84,867.72	768,495.61	8,667,831.37	7,899,335.76
April	88,561.96	805,865.64	9,441,624.08	8,635,758.44
May	99,394.28	896,122.00	9,797,809.15	8,901,687.15
June	87,570.15	790,185.05	8,674,764.41	7,884,579.36
July	51,852.79	470,173.88	5,281,803.73	4,811,629.85
August	102,447.58	922,190.72	9,960,397.37	9,038,206.65
September	110,934.93	991,519.95	10,102,008.01	9,110,488.06
October	100,204.32	897,397.15	9,282,497.66	8,385,100.50
TOTAL	**816,223.11**	**7,358,604.05**	**80,271,097.02**	**72,912,492.97**

Table 22: Results from allocating crude to TNP using philosophy Four

Month (TNP)	Allocation (bbl)	Cost ($)	Revenue ($)	Profit ($)
February	93,108.82	1,593,643.01	6,995,451.73	5,401,808.73
March	86,613.57	1,581,981.30	6,657,898.49	5,075,917.20
April	90,383.81	1,644,160.06	7,322,715.39	5,678,555.33
May	124,301.78	1,947,200.94	9,145,056.07	7,197,855.13
June	89,371.59	1,563,183.77	6,615,410.11	5,052,226.34
July	52,919.48	1,213,267.64	4,054,531.59	2,841,263.95
August	134,878.42	2,039,838.85	9,754,339.85	7,714,501.00
September	164,278.61	2,220,594.93	10,942,433.75	8,721,838.82
October	127,107.76	1,899,016.10	8,651,843.97	6,752,827.87
TOTAL	**962,963.83**	**15,702,886.60**	**70,139,680.95**	**54,436,794.36**

Table 23: Summary of the Results for Philosophy Four

Route	Allocation (bbl)	Cost ($)	Revenue ($)	Profit ($)
ACE	1,864,433.03	36,746,789.97	152,523,943.92	**115,777,153.95**
TNP	962,963.83	15,702,886.60	70,139,680.95	**54,436,794.36**
Refinery	816,223.11	7,358,604.05	80,271,097.02	**72,912,492.97**
Total	**3,643,619.97**	**59,808,280.62**	**302,934,721.89**	**243,126,441.27**

IV. CONCLUSIONS

This study demonstrated that in order to allocate crude oil efficiently, cost reduction and risk mitigation must be balanced with income growth. By addressing key impacting elements including demand, logistics, theft, and oil pricing, the research was able to meet its goals. Evaluating ACE, TNP, and modular refinery routes in both their existing and upgraded states was the initial goal. The analysis outlined the advantages and disadvantages of each route by analyzing cost, revenue, and profit, laying the groundwork for optimization. The second goal was to identify and include into the optimization model important aspects such pipeline vandalism, logistical difficulties, refined product demand, and crude oil price threats. This inclusion improved the model's dependability by guaranteeing that it represented actual real-world conditions. The third objective was to develop an optimization model that would effectively distribute crude oil along routes to maximize economic value. The model showed flexibility by adjusting to situations such as theft or fluctuations in the price of oil, demonstrating its capacity to enhance resource allocation under a range of limitations. Finding revenue-generating tactics in the face of shifting oil prices was the goal. During periods of high demand, Philosophy Three proved to be the most successful, allowing refineries to add value and increase income. Combining Philosophies One and Four resulted in a flexible, varied strategy that maintained flexibility and profitability while guaranteeing resistance to theft and changes in the market.

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