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The Supply Chain Optimization Model for Crude Oil Refineries

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Abstract- The supply chain for oil refineries begins with both onshore and offshore oil reserves. These locations are used to extract crude oil, which is then shipped to several refineries worldwide, mostly by pipelines or big vessels known as Very Large Crude Carriers (VLCCS). Crude takes a while to transport. For instance, Crude oil transported by a VLCCS from the Middle East to refineries in Asia takes four to six weeks, Nonetheless, the transportation of crude oil from the oil fields in Marib by a Very Large Crude Carrier (VLCC) only necessitates a duration of three to four days (Block 18), Masila (Block 14), and Jannah (Block 5) to go to Kerla's refineries. Crude Extraction Units (CEU) are used to treat the crudes and divide them into fractions according to their boiling points. To obtain the diverse products, these segments undergo further processing in a number of downstream refining facilities, such as blending pools, crackers, and reformers. When processing conditions are appropriately adjusted, a single crude mix can produce a variety of products and their variations. Refineries must therefore modify their processes to accommodate the various crude batches in order to satisfy the demands of their clients.

Keywords: Linear Programming, Processing Unit, CEU, Supply Chain, CEU, VLCC.

I. INTRODUCTION

Kochi Refinery Company Limited (KRCL) is a crude oil processing facility located in Kochi, a city in the Indian state of Kerala. It is recognized as the foremost public sector refinery in India. The construction of the Kochi refinery began in March 1964, and it commenced production in September 1966. In 2006, Bharat Petroleum Corporation Limited took over the refinery. The facility is situated in Ambalamugal. The KRCL Kochi Refinery operates with a capacity of 50,000 barrels per day. The refinery's daily output is also 50,000 barrels. Originally, it was established as a collaborative business venture with Philips Petroleum Corporation from the USA, and it was subsequently renamed KRCL. The refinery has been recertified. Among the products generated by this fuel-based refinery are liquefied petroleum gas, naphtha, motorized spirit, kerosene, aviation turbine fuel, high-speed diesel, and tarmacadam. Furthermore, it produces specialty items for local markets, including benzene, toluene, food-grade hexane, propylene, distinct boiling point essence, mineral turpentine oil, sulphur, pet coke, and hydrogen.

Since December 2007, the Kochi refinery has been able to receive crude oil from Very Large Crude Carriers (VLCCs) thanks to its Strategic Crude Oil receipt amenities, which include Single Point Mooring (SPM) and a corresponding coastal tank farm. This facility improves the flexibility in choosing crude oil while also drastically lowering freight costs. As a result, it is a crucial piece of infrastructure that will propel future development.

The refinery has all the amenities needed to convey goods by road, rail, and sea via pipelines to consumer canters. The region's leading industries are all connected to the refinery for product receiving. The main distribution canter for the refinery's products is the BPCL installation at "Irumpanam," which is connected to the refinery via pipes. The refinery is connected to numerous ingestion locations in Tamil Nadu, including Coimbatore and Karur, via a 300-kilometer pipeline.

While undergoing the refining process, this refinery unit uses hydrogen rising to make its products (Hydro Skinning Refinery, refines to treat high sulphur, Kuwaiti oil, and Qatar crude). Up until the mid-1990s, it refined crude from a number of Indian states, Kuwait, the Middle East, and Iraq.

II. METHODOLOGY OVERVIEW

The supply chain for oil refineries begins with both onshore and offshore oil reserves. These sites are utilized for the extraction of crude oil, which is subsequently transported to numerous refineries across the globe, primarily by pipelines or large ships known as Very Large Crude Carriers (VLCCS) [1], [2]. Transporting crude takes a long time. For example, it takes four to six weeks for a VLCCS to transport crude oil from the Middle East to refineries in Asia. However, it only takes three to four days for a Very Large Crude Carrier (VLCC) to transport crude oil from the oil fields in Marib (Block 18), Masila (Block 14), and Jannah (Block 5) to Kerla's refineries [3].

The crudes are treated and separated into fractions based on their boiling points using Crude Extraction Units (CEU). These segments go through additional processing in several downstream refining facilities, including blending pools, crackers, and reformers, to produce the various products. [4]. A single crude mix can yield a variety of products and their variations when processing conditions are suitably adjusted. To meet the needs of their customers, refineries must thus adapt their procedures to handle the different crude batches [5] and [6].

The refinery plays a vital role in the supply chain through the creation and management of its operating divisions. relationships with shippers, jetty operators, customers, oil suppliers, and third-party logistics (3PL) providers. Every stage of the refinery supply chain requires a number of decisions, including which product mix to produce, which blend to process and how to process it, which crudes to buy and in what quantities, etc. Numerous factors contribute to the different decisions.

These components and their interactions are shown in Figure (1). The units [represented as blocks in figure (1)] connect to one another via facts flows (broken arrows) in order to centralize the material flows (solid arrows). The shaded blocks that show the refinery's physical units can be further broken down into storage units like crude and product tanks and processing units like CEU, reformer, cracker, and blend tanks. The operations of these units and other supply chain activities are managed by the functional departments [7], [8], and [9].

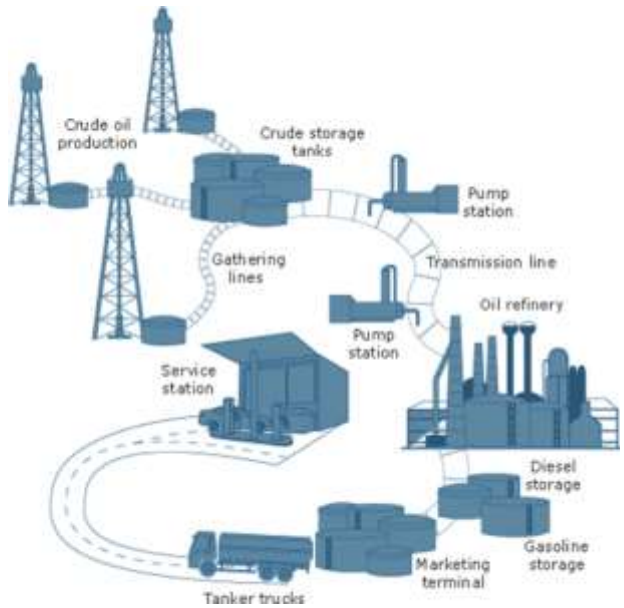

Figure 1. Diagram of the Crude Oil Refinery Supply Chain

The cumulative actions of all the enterprises, each of which follows its own policies, impact the overall performance and economics of the supply chain [10]. For example, the procurement administrative area selects the type and quantity of crude to buy, the logistics department manages the oil's transportation, and the storage department extracts it from the ship to the crude oil storage tanks. These three divisions work together to determine the amount of crude that arrives at the refinery. The complex web of fluxes between the entities creates complex dynamics, which can have cascading unintended consequences [11]. The refinery also has to deal with a variety of variables, such as pricing variations, supplier availability, production yields, and demand fluctuations [12].

Tactical (such as disruption management, policy evaluation, and production scheduling), functional (such as throughput level, scheduling, storage, and obtaining), and strategic (such as investing in capacity, expanding units, improving technology, and reorganizing the supply chain) decisions must be made in order to control the supply chain. These promote the creation of supply chain simulation models that could represent the entities' dynamic behaviour in the face of various uncertainties [13]. By allowing the user to evaluate how a particular decision would impact the supply chain's operation, analyse different supply chain policies, and use imitation to ascertain the impacts of a disruption, these models aid in supply chain management decision-making [14]. There are a number of options when choosing an appropriate modelling paradigm for supply chains. A well-informed choice must be made in order to use the best paradigm for the intended use of the simulation model. Although supply chains have traditionally been simulated using equation-based models, the agent-based model has recently attracted a lot of attention in this area [5], [15], and [16].

III. RELATED WORK

The supply chain problem for oil refineries was created as an LP problem using AMPL (A Mathematical Programming Language).

Description of the Issue of Crude Oil Refineries:
The following is an extraction of the problem statement:

As stated,
- A collection of crude oils.
- A collection of crude oil ships.
- A collection of storage tanks
- A collection of blending tanks.
- A collection of refinery network.
- A collection of product completion.
- A collection several Depots that operate.
- Details about the pipeline.
- Necessary Information.

Determine:
- Each tank's inventory levels.
- Rates at which materials move between processing units.
- A large number of finished goods that need to be produced.
- Income from every finished product.
- The price of every item that was bought.
- Total cost of all activities.

In order to:
- Maximize the overall profit realized throughout the scheduling phase.

Subject to:
- Limitations on the supply of crude.
- Refining procedure.
- Limitations on the dissemination of products.

IV. MATHEMATICAL MODELS FOR SUPPLY CHAIN MODEL

The three distinct classes into which the constraints considered in the LP model can be separated represent the three subsystems.

Assumptions:
Some presumptions are taken to consideration for the problem's simplicity:

The integrated system will only represent the material mass balance within the tanks, processing units, and the management of tank inventory.

Only linear continuous variables will be included; choices involving discrete variables, such as which processing unit allocates tasks to which processing unit, are treated as parameters because they are presumed to be predetermined. For example, every oil tanker transports A particular kind of crude oil to a designated storage tank.

- Within the planning horizon, the LP problem is deterministic.
- The elements of crude and blended oil are only fixed by a few vital components.
- A homogeneous time continuum within the specified horizon serves as the foundation for the planning model.
- During the allotted time window, a constant rate of movement of materials is anticipated.

Decision Variables:
Within this framework, the variables that determine the decisions are:
Material flow rates into and out of processing facilities.
The price of running processing units.

Matching material's volume in tanks.

Degree of crude oil refining and blending.

Parameters:

This model has the following parameters:

Raw material costs.

Materials' physical characteristics.

Processing units' capacity.

Product demand.

Tank's initial volume and minimum or maximum capacity.

V. NUMERICAL EXAMPLE

The data used in the case studies, which considered relevant information from reliable sources for the year before to the planning period, came from Kerla Refinery Company Limited [3] and [17]. For instance, the lowest and highest costs for Arabian light are 33.80 and 60.32 rupees per barrel, respectively, according to testimony provided by the U.S. Department of Energy [16].

As a result, the price of Arabian light in the example problem is generated at random between 33.80 and 60.32 ₹ bbl. Tables (1) through (6) provide a list of the data used in the case studies.

Table 1 Data on formaldehyde and crude oil

Sources	Cost range $ per bbl.	Accumulation of sulphur (in Percentage)	Particular gravity (60^0f)
Arabian light	33.80-60.32	1.77	0.764
Iranian heavy	41.51-70.92	1.20	0.687
Odoptu	37.62-64.88	0.52	0.752
Murban	44.38-71.81	0.78	0.927
Kuwait	35.31-55.49	2.52	0.700
Bonny light	44.00-71.85	0.12	0.846
Dubai	37.01-62.18	2.00	0.712
Sumatran light	41.75-70.56	0.08	0.753
Miri light	42.55-67.31	0.08	0.831
Tia Juana light	38.75-66.13	1.10	0.735
Benzene	44.85-57.96	N/A	0.876

Table 2 Data on product tanks, blending, mixing, and storage

	Storage Tank	Blending Tank	Product Tank
Inventory cost, ₹ bbl./day	0.789	1.75	0.848
Initial volume, bbl.	45,000	1.74	0.867
Maximum volume, bbl.	200,000	0.16	0.840
Minimum volume, bbl.	5,000	0.16	0.840

Table 3 Group 1/Group 2 intermediate materials' quality

Element Content	Density	Accumulation of sulphur (in Percentage)
Gas oil from C.C.	294.4/299.1	0.353/1.31
Distillate	292.0/297.6	0.526/2.83
Gas oil from CDU	295.0/303.3	0.980/5.05
Naphtha	272.0/272.0	0.283/1.48
Residuum	343.0/365.0	4.7/11.00

Table 4 Material production per unit level of process efficiency while using crude oil

Element Content	Refinery Process	Accumulation
Gasoline	Atmospheric Extraction	0.236/0.180
Naphtha	Atmospheric Extraction	0.223/0.196
Distillate	Atmospheric Extraction	0.087/0.073
Gas oil	Atmospheric Extraction	0.111/.091
Residuum	Atmospheric Extraction	0.315/0.443
Fuel Gas	Atmospheric Extraction	0.029/0.017
Amendment	Thermic Reforming	0.807/0.836

Fuel Gas	Thermic Reforming	0.129/0.099
Fuel Gas	Thermic Cracking	0.300/0.360
Creaked Gas	Thermic Cracking	0.590/0.580
Gas Oil	Thermic Cracking	0.210/0.150
Fuel Gas	Thermic Reforming	0.310/0.380
Creaked Gasoline	Thermic Reforming	0.590/0.600
Gas Oil	Thermic Reforming	0.220/0.150
Desulfurized residuum	Hydrotreater	0.970/0.970

Table 5 Capacity of processing units in the refinery

Processing Unit	Capacity (bb/day)
Crude Extraction Unit	119000
Thermic Cracker	45000
Thermic Reformer	35000
Hydrotreater	64000

Table 6 Product Proceeds range

Product (Element)	Proceeds (₹ / bbl.)
Premium Gasoline	85.26 -131.01
Regular Gasoline	47.38 - 89.60
Distillate	50.35 - 68.86
Fuel Oil	48.79-51.26
Fuel Gas	23.89-56.89

VI. RESULT & SUMMARY

The supply chain problem in oil refineries discussed in the previous section was resolved using the CPLEX solver (IBM. log. Cplex [18]), which was implemented in A Mathematical Programming Language (AMPL) [19]. The information entered into each case study is displayed in Tables (1) through (6). Certain details, such as the yield of material using that crude oil and the qualitative traits of intermediate materials derived from that crude oil, should be made explicit for each crude oil. For simplicity's sake, the crude oil is assigned one of two values derived from relevant sources.

Tables (7) and (8) provide a summary of certain case study results. The principle shown in table (7) states that when the planning horizon is doubled, the number of variables and constraints has a full-fledged stand-in, but the solution time quadruples.

Table 7 An overview of each case study's summary

Planning Model (Days)	Constraints	Variable	Number of non-zero	Maximum Profit (in ₹)	CEU Time (Hours)
2	7211	13697	48389	147713.55	0.00013
30	110027	205301	1178129	217566.34	0.71100
60	220187	410591	3409679	4232012.76	1.46110
120	440507	821171	11031779	8655432.50	5.99928

Table 8 Dimensions of the distinct and interconnected subsystems for T=2 Days

System	Constraints (Range)	Variable (Range)
Integrated subsystem	(1:7,211)/7,211	(1:13,697)/13,697
Supply subsystem	(1:1,291)/1,291	(1:1,931)/1,931
Refining subsystem	(1,292:4,919)/3,628	(1,932:11,765)/9,834
Distribution subsystem	(4,920:6,851)/1,932	(11,766:13,697)/1,932
Linking constraints	(6,852:7,211)/360	(1:13,697)/13,697

VII. CONCLUSION

The primary distribution link between upstream and downstream activities is the petroleum supply chain. When making decisions about petroleum prospecting, including the planning and design of infrastructure for oil fields, it is essential to the management of the global supply chain for the crude oil business. Petroleum may also be supplied by foreign vendors. Oil tankers deliver petroleum to oil terminals, which are connected to refineries through a network of pipes. When making judgments at this level, transportation mode and supply planning and scheduling are taken into account. Crude oil is converted into products by refineries, which can be linked to one another to take use of each refinery design within the complex. The products made at the refineries are delivered to distribution centres. Up until now, pipelines have been often employed to convey both goods and crude oil. Items can then be transported by trucks, pipelines, ships, and trains, depending on what the buyer requires.

In this paper presents a mathematical structure-based supply chain model for oil refineries. The complete horizontal integration of systems from the delivery of goods to the acquisition of crude oil sets it apart. We assume that the network of integrated refineries is already set up. Therefore, discrete or binary choice variables are avoided by generating a prior and utilizing it as an LP model parameter.

The oil refinery supply chain problem was developed in AMPL as an LP problem, and multiple test cases are solved using CPLEX.

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