INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X

Impact Factor: 6.078

(Volume 7, Issue 5 - V7I5-1199)

Available online at: https://www.ijariit.com

Application of operational research in the oil and natural gas industry

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ABSTRACT

Operations research is a science / process in which one applies mathematics to real life business problems to come up with the most highly effective and efficient solutions/ decisions. Algorithms, simulations and optimization are the key to finding any solution with the help of OR. The oil and natural gas industry were one of the early adopters of this scientific process and the use of OR helped this industry to grow and overcome several hurdles throughout. The report further provides insights into the different problems faced in the operations of business in this industry and how different models and theories of Operations Research help in making the best decisions regarding it. We have also discussed in detail how several oil corporations have used OR in their functioning.

Keywords— *Operations Research, Oil, Natural Gas, Chevron, Texaco, Trolls West, China's National Petroleum Corporation*

1. INTRODUCTION

Oil and natural gas industries have been empowering nations for over 150 years now and approximately 100 million barrels of oil were produced and consumed per day in 2019, globally. Despite the drop in consumption and production of oil in 2020 because of COVID 19 pandemic, it is expected to return to the 2019 level within a few years. The natural gas industry has also transitioned into a high growth economy especially in China because of its 12th five-year national plan where natural gas has been considered to be a great source of green energy. The usage and demand of both these fossil fuels have rapidly increased and put pressure on corporations to optimize their production in a way to maximize the potential of each reservoir and at the same time maximize their profits.

Operations Research (OR) is a scientific process that turns data into insights through analytical methods that help an individual or organization to make better and more effective decisions. The oil and natural gas industry may be divided into three areas which are as follows:

- Exploration and production- exploration encompasses the process and methods involved in locating potential sites for oil and natural gas/ reservoirs from where crude oil can be drilled and extracted.
- Transportation and storage - the extracted crude oil and natural gas are transported through underground pipelines, trains and tankers to refineries where they are further processed. The processed petroleum products are required to be further transported for consumption.
- Refining and marketing- refining is a chemical process where crude oil is processed to form more useful products like LPG, gasoline or petrol, etc. These final products are marketed under various brand names given by the companies.

Under each of these three areas, certain problems arise which can be solved using OR. The application of OR in the oil and natural gas industry has not only helped in the advancement of the industry but of OR as well.

The scope of this paper is to define these problems and suggest appropriate solutions using various tools of operation research. These problems are either generic or stated with examples of current applications in various Corporations like Texaco, Chevron, Statoil hydro, China national petroleum corporation (CNPC), etc. The efficiency achieved due to the use of OR has helped to save millions of dollars annually.

2. LITERATURE REVIEW

Orations Research techniques enable the oil and natural gas industry to utilize its resources more efficiently, meet performance targets, manage costs and find optimum solutions. To this, Standard Oil California's vice president said that they have been using OR for a very long period of time, even before it was officially given its term (Singh, refer to reference 9). Efficient functioning of this industry depends on how it allocates resources and addresses the problems faced.

The objective of this study is to enlist the various intricacies involved in the oil and natural gas industry by dividing it into the major three departments of the industry. We will cater to finding solutions from problems that arise starting with the initial setting up phase to the point where the oil reaches the end consumer.

There are substantial published researches evaluating the use of operation research to analyze and design problems in the oil and natural gas industry. Our research was solely focused on secondary research, references we have used for our study are:

Tore Wiig Jonsbråten (1998) examines on the ground of optimal development in the petroleum field. There are various frameworks presented throughout the study which analyze decisions concerning platform capacity, where and when to drill wells and production strategy for each of the wells.

Eirik Hagem and Erlend Torgnes (2009) study combines the field of petroleum industry and operations research, by evaluating different models for a petroleum production and allocation problem. This report has been written along with the master theses of Gunnerud & Langvik (2007) and Vestbø & Walberg (2008). It also presents the StatoilHydro operating in the troll west field case to explain through a real-life example. This gives a clear understanding that the objective when optimizing petroleum production allocation problems is to achieve an ideal allocation of limited resources, typically to maximize weekly oil production.

Edelman (2019) study discusses China's natural gas consumption and applies innovative operations research to develop and implement new software that helps CNPC improve the management of its gas pipeline network. Convex relaxation methods and iterative piecewise linear approximation methods are discussed as optimal solutions.

Some of the other studies were by Bismark Singh, Jayant Rajgopal, Shira Hetz and Margery H. Connor (2018). These studies presented an overview of operations research, its origins, its approach to solving problems, and some examples of successful applications. O.R. is a tool that can do a great deal to improve productivity. These list more contemporary and modern-day applications involving computer simulation models which simulate changes of a modelled system in response to input signals. Some of the most famous software are CPLEX, LINDO, OSL, MPL, SAS, SIMAN.

3. ANALYSIS AND FINDINGS

Most of the major oil and natural gas corporations around the globe applies Operational Research in both initial planning of setting up as well as in day-to-day operations in order to eliminate the uncertainties involved and to make complex decisions. There are two main types of problems in this industry: Operational and Investment problems.

Operational problems are concerned with optimization of natural gas flow rates, pressure, or other physical parameters, given a fixed network infrastructure. Operations problems usually consider the problem within three to five years which are more complex since they are mixed integer nonconvex optimization models. The nonconvexity implies that we may not be able to find a global optimal solution.The investment problems optimize the network for over 10 years. It considers the optimization of the network topology and the decisions of building new infrastructure.

Since the magnitude of such calculation is massive, these companies tend to use highly customized computer software. Through this secondary research paper, efforts have been made to review the literature on usage and awareness of operations research in the oil and natural gas industry. The approaches identified in the literature include operations research techniques to address the following problems:

- **Exploration and Production**

There are problems associated in the early phase of setting up an oil field, like uncertainties with regards to the future oil price, project costs and reservoir properties. It basically deals with devising a model for optimal design and operation of an offshore oil field under price uncertainties. This includes taking decisions regarding platform capacity, number of wells to be drilled, location of well, and production profile of each well.

For this, the starting point of analysis is the mixed-integer programming model where some of the decision variables are constrained to be integer variables. The next stage introduces the uncertainty regarding the oil prices. The problem then becomes a multistage mixed-integer stochastic programming problem. A set of pricing scenarios has been taken and assigned a certain probability. The solution procedure uses progressive hedging on the continuous variables and lets the binary variables adjust automatically. Additionally, to determine the sequence in which the wells have to be drilled, the information method is used. This method states the following:

The Bayesian Model: It updates the probability distribution over reservoir realizations when new information is acquired from drilling activities. This Bayesian approach can be modelled in terms of decision tree. Through this decision tree, an implicit enumeration algorithm is proposed for finding the optimal drilling sequence. This is a numerical problem. Thus, the results are computed by use of a mixed-integer optimization model where a reservoir simulator is included. Overall, future information discovery may influence optimal drilling decisions.

Extracting oil is a difficult process because oil is found in thin layers beneath the thick gas layers, this feature makes oil wells highly reliant on the GOR (gas/oil ratio) rate. This problem is looked upon in reference to the Trolls West field case study.

This is about an integrated oil and gas company, StatoilHydro which currently plans the production at the Troll West field. This field is regarded by many as the cornerstone of Norwegian gas production as it contains about 60% of the total gas reserves on the Norwegian Continental Shelf. Gas has to be allocated to a large set of wells where the production rates of each well strongly vary with changes in their allocated gas rate. Troll West's production framework consists of a platform and a group of wells, each well is associated to the first stage separator on the platform by two pipelines. StatoilHydro said that the objective of its production plan is currently to augment week by week oil creation.

These are some methods of production optimization by StatoilHydro:

1. Gas Oil Rate Model (GORM) is a well/reservoir simulator. It was created to simulate gas coning in a horizontal well in the Troll West oil field. Based on the pressure in the well, they contain information about the flow of water, gas and oil in the well.
2. Production Data Portal (PDP) is a web portal that stores all current and historical production data. The system logs data every four seconds The system can be used to compare planned and historical production rates.
3. General Allocation Package (GAP) is software used to optimize well routing and production of oil for a single group. It was developed as a multiphase well pattern optimizer.
4. Scheduler- Scheduler has been developed to handle time-consuming task execution. Automate the transfer of information between various programs.
5. Software integration- The current practice at StatoilHydro is a combination of the above software packages. All of the softwares are interrelated, the GORM generates information about the performance of wells, GAP optimizes each cluster of wells and scheduler finds the optimal routing. Software integration is done to optimize the production at Troll West.

- **Transportation & storage**

Problems in this department consist of optimization of the schedule of when oil should be produced over from the reservoirs kept, delivery of oil to service stations.

For this, several papers had been published at the Cowles Commission Conference in 1949 where one suggested a Linear Programming for scheduling crude oil production to maximize profits. Along with this, the operations in the petroleum industry are also based on demand and supply. OR helps in ascertaining availability of materials as per requirements. This application also helped in the advancement of CCP (chance constrained programming). Many companies have separate specialized OR groups that perform such processes for example: ExxonMobil, which was largely devoted to applications of OR in their functioning for multi facility processes. It is scheduled for unit operations in a refinery. Additionally, Shell corporation and Chevron also have an OR department for scheduling oil tankers.

Another problem is to find ways to transmit gas at a particular temperature and safely. This also includes the decisions on gas production, imports, transportation, storage, and sales. It is based on the locations of available natural gas resources, locations of demand, and prices for natural gas at different locations in the network. This is examined through China's national petroleum corporation (CNPC), where its users were facing distance issues. For this they applied operation research, where the operations problem aided them to determine the weekly natural gas flow and pressure whereas the scheduling problem focused on the hourly flow and pressure of the natural gas. These were done to get data on the optimal flow and pressure in which to transmit the gas. This would help them in taking better decisions while implementing the gas pipelines as per the plan.

Another research proposed two approaches. In the first approach the natural gas transmission problem is introduced as a mixed-integer linear programming problem (MILP). This is done by iteratively approximating all nonlinear relationships as piecewise linear. It provides results for problems on a small scale. The second approach was advanced to solve large scale problems, where a two-stage framework to separately obtain solution optimality and solution accuracy was developed. Implementation of these techniques have generated more than $530 million in additional profits for CNPC's natural gas transmission.

- **Refining and marketing**

The distillation of crude petroleum produces a number of different products at different distillation temperatures. Different grades of crude yield different concentrations of output and incur different costs. These different end-products fetch different revenues and use different amounts of refinery resources. Managing all these variables in the correct proportion necessitates making complex decisions. This is studied in reference to Texaco.

Texaco, like virtually all other major oil corporations, uses sophisticated optimization models. The system used here is called StarBlend which runs on networked microcomputers. At the heart of this was a nonlinear optimization model which supported an interactive decision support system. StarBlend can work in a multi-period planning environment where optimal decisions could be made over a longer planning horizon. In addition to blend quality constraints, the optimization model also incorporates inventory and material balance constraints for each period in the planning horizon. It can also be used to analyze various "what-if" scenarios

for future and long-term planning. The efficiency of this system alone was estimated to have saved Texaco about $30 million annually.

Operations research tools come very handily in advising the crude traders on optimal bids. Since, acquiring crude at a competitive price is very valuable for respective market conditions. Further, it is looked through Chevron's point of view, which not only produces but also purchases crude oil.

Chevron uses an in-house software tool called Petro. It is led on the foundation of distributive recursion-based linear programming in decision making for over more than 30 years. This has helped Chevron to generate approximately $10 billion in value. Petro processes 400 to 500 variables associated with crude oil characterization, along with thousands of refinery-capability variables, to arrive at the most valuable operation's parameters within a few seconds, it helps in:

1. Petro analysts advise refinery operations and product traders on the most economic mix of products to produce, buy or sell.
2. Petro scenarios results are also used in discussions with the Environmental Protection Agency and the California Air Resources Board. This aids in analyzing different fuel blends being considered for future regulation. The collaboration with external agencies is central to Chevron's goal of supporting the community and environment through scientific and technological discoveries.

4. CONCLUSION

Different literature was reviewed to define the problems of the oil and natural gas industry and tackle them with application of OR. They used different techniques and models for optimization in different areas of the industry. The major areas in the industry which are highlighted throughout our study are: Exploration and production, transportation and storage, refining and marketing.

- Under exploration and production, the study enlist methods to optimize setting of an oil field under uncertain conditions. This also suggests the sequence in which wells have to be drilled. This section also presents the case of statoilhydro and how it optimizes the production/extraction procedure using stimulators.
- The next area of study is transportation and storage problems which is explained through brief references of Exxonmobil, Shell corporation and Chevron followed by an insight of China's national petroleum corporation.
- The last area focuses on the classical blending problem at Texaco which later merged with Chevron. At Chevron OR is used for more diverse problems like acquiring crude at competitive prices.

Through this study, the purpose is to provide a comprehensive dive into various large corporations and how they have evolved their solution methods to using OR for optimizing the finite resources and maximizing their profits. This study helps new corporations to follow the lead of these large corporations, identify these problems in the earlier phase and bridge them using the operation research tools.

5. LIMITATION AND FURTHER RESEARCH

The objective of this research has been met to an extent. The world has been adopting technology at a greater pace today. This study cites references from 1998 to 2019, a period full of technological advancements. All the technological advancements couldn't be considered and evaluated in this study which limits it from reaching its objective fully. Since oil and natural gas is a huge industry there is a lot of scope of research, but for sake of simplicity we focused on only the three broad areas.

There is room for further research to this study. Marketing is one area of research which can be further explored and evaluated. This consists of a wide range of techniques and models of OR. It is also used by all companies, be it oil and natural gas industry or any other.

Further, unexplored areas of research which can also be looked upon include: market forecasting, economic evaluation and artificial intelligence to form a data-driven supply chain optimization platform for the oil and natural gas industry. Overall, these areas will add to our acquired knowledge of applications of OR in the oil and natural gas industry.

Lastly, in an era full of growing trends, it stands important to be upgraded with advancements. This can also be further studied upon, where some new modern techniques and models are used to optimize problems. There is no doubt that the future would see increasing and diversified applications of operations research techniques in the oil and natural gas industry with the dynamic changes across the globe.

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