EVALUATING THE ECONOMIC IMPACTS OF PIPELINE USEAGE ON THE INDIAN OIL AND GAS UPSTREAM SUPPLY CHAIN

by

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I also thank my family who encouraged and prayed for me throughout the time of my research. This thesis is heartily dedicated to my grandfather who took the lead to heaven before the completion of this work.

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Abstract

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The objective of this dissertation is to find the minimum supply chain costs for the Indian oil and gas industry. The problem is solved by introducing a mixed - integer programming model which will avail in taking the obligatory decisions predicated on the cost estimates for various scenarios. In order to meet the objective, categorical objectives were put down to evaluate their impacts. This research was to evaluate the economic impact of mode of transport. This research primarily focusses on the pipeline mode of transport and how the selected pipe diameter and the flow through the selected pipe affects the supply chain costs. Conclusively this dissertation aims at the mixed – integer programming model to demonstrate the economic impacts on the supply chain.

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Chapter 1

Introduction

1.1 Indian Oil Industry

According to the statistics, India has increased its dependence on crude oil and petroleum product from other countries by more than 20 percent. “The petroleum and natural gas statistics 2014” stated that India imported nearly 75 to 80 percent of the oil in 2013. See figure (“Crude oil production and consumption” 2014). The world outlook report stated that

> “The center of gravity of energy demand is switching decisively to the emerging economies, particularly China, India, and the Middle East, which drive global energy use one - third higher. In the new policy scenario, the central scenario 2013, China dominates the picture within Asia. Before India takes over from 2020 as the primary engine of growth.”

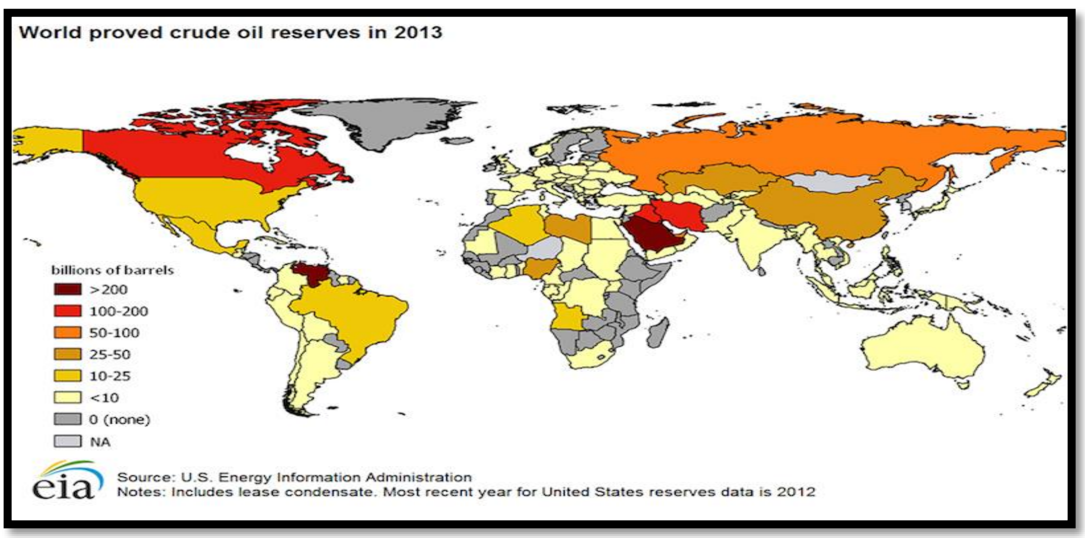


Figure 1 – World Oil Reservoir

1.1.1 Problem Statement

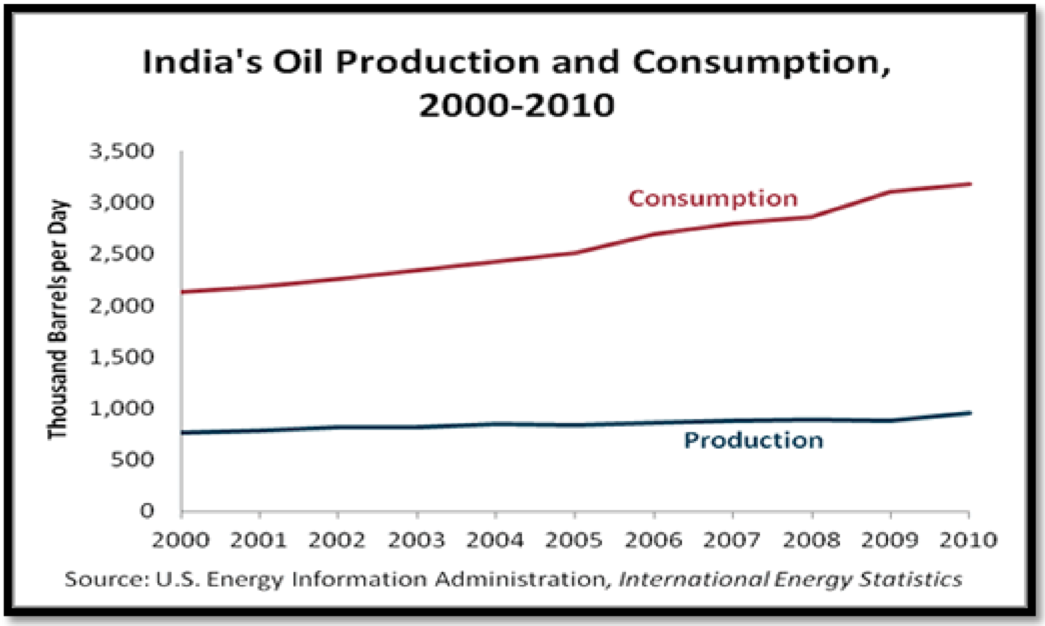


Figure 2 - India Petroleum and other liquids Production and consumption from 2000 to 2010. Preliminary data: U.S. EIA, December 2011, Web.

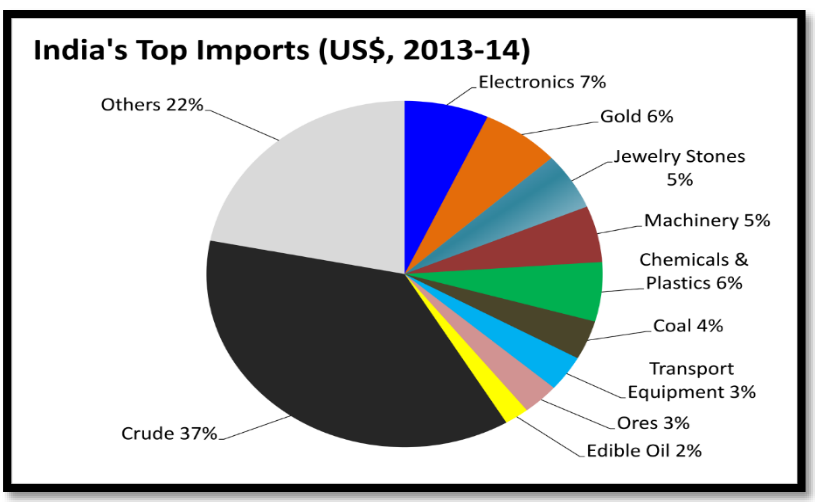


Figure 3 - Indian top imports 2013-14

The U.S. Energy Information Administration, International Energy Statistics in its report said that the western hemisphere and Africa contributed 18 percent and 17 percent respectively in the oil imports. While Saudi Arabia, Iraq, Kuwait United Arab Emirates, Iran and other Middle East countries contributed 19%, 13%, 10%, 9%, 6%, 6% respectively.

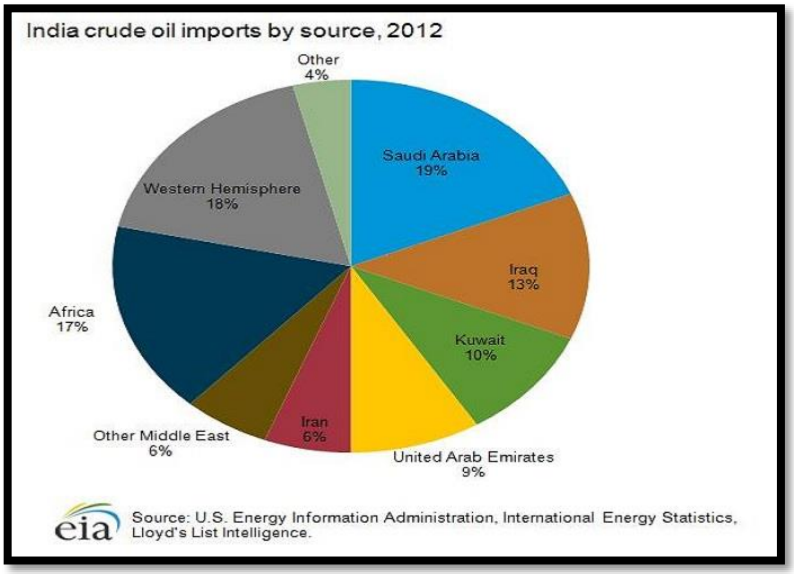


Figure 4 -India Crude oil Import from Sources in 2012. Preliminary Data: U.S. EIA, 2012, the Web.

We are decrying an increasing pace of global integration and it is thus compulsory that the supply chain of the oil industry competes in terms of its capacity. This research study fixates on the sundry supply chain and logistics issues in the upstream oil industry. The goal is to amend the quality of the logistics and minimize the cost of transportation by providing logistics solutions in the sector of the supply chain.

1.1.2 Research Significance and broader impacts

What transpires to the Indian oil and gas supply chain when the transportation mode is transmuted? Over a period of time, the Indian oil and gas supply chain has optically discerned an incrementing demand in the crude oil. According to the “Petroleum and Natural Gas Statistics” India, imports 75% of crude oil for its domestic requisites. It is optically discerned that the refining capacity is much more preponderant than the domestic crude oil production. Today, we face a question that if the present supply chain network can handle the incrementing ordinant dictation of crude oil. The paramountcy of this dissertation is to seek the impacts of the utilization of pipeline as a mode of transportation and the supply chain cost or the transportation cost. The problem here is solved by introducing a mixed – integer programming (MIP) model. The broader impacts are whether the supply chain can be optimized by identifying the possible investment for the future global supply chain of crude oil needs.

1.1.3 Research Question and Hypotheses

With most of the petroleum and gas products being imported thus the country faces the case if the current pipeline and the refinery capacity can handle the growing demand. .Is it economically beneficial to invest in the supply chain quality of crude oil for India? I hypothesize that the pipeline infrastructure will impact crude oil supply chain costs, and suggests what will give us the minimum supply chain costs.

1.2 Research Purposes

The goal of most company is to maximize the company profits or minimize the transportation cost. Researchers have put forth their theories how companies can accomplish their goal to make profit. The following activities can help to maximize company profits such as developing new product lines, considering price discounts, improve the customer service, and decrease costs thus increasing the profitability.

1.2.1. Overall Research Objective

In Indian oil industry, the government own most of the production sites and the refinery operations. The Indian Petroleum and Natural Gas industry has set the main goal to maximize its profits. The government has adopted new policies to attract the foreign investment to sustain its growing demand. By improving the efficiency in the entire supply chain can lead to improvement in the product performance, and also minimize the cost.

The research question is to evaluate the impacts of mode and flow through the selected mode on the supply chain costs. This dissertation aims to investigate a mixed – integer programming (MIP) model that supports all the decision variables and provide a best economic decision. The specific objectives are to find if the pipeline mode of transportation and the flow through the pipeline network will affect the supply chain costs or not.

1.2.2 Specific Research Objectives

The Ministry of petroleum and natural gas governs the entire functioning of the Indian oil and gas industry. India owns a national oil company named Oil and Natural gas Corporation, governed and run by the government of India.

The objective of this research dissertation will be to evaluate the mixed-integer programming model (MIP) that will demonstrate the cost estimation between the transport medium and the profits of the Indian Oil Industry. In order to meet the objective, specific objectives are investigated such as evaluating the factors that determine the pipe outside diameter and the percentage of oil that can be transported by the pipeline medium of mode. Finally we have to evaluate the economic impacts of transporting oil through pipeline.

Chapter 2

Background

2.1 Background on crude oil

Crude oil or unrefined petroleum is a naturally occurring liquid product composed of hydrocarbons, metals etc. Crude oil can be refined to produce products such as gasoline, diesel and other forms of petrochemicals.

Scientists and researchers have explained that crude oil is found in geological formations beneath the earth's surface. Petroleum is formed when large quantities of dead organisms like one – celled creatures usually algae and other animal forms are buried underneath sedimentary rock. These creatures absorbed energy from the sun and stored this energy in the form of carbon. As these animals died they sank to the bottom of the ocean and got covered under the deposits of sediments. Over the period of years they are subjected to intense heat and pressure and due to a chemical action they are converted into oil. Oil cannot be produced because the formation takes place over a period of millions of years. Thus crude oil is a nonrenewable energy source. After Oil is formed it travels from the source rock through seeps or pores in the surrounding rocks and traps beneath layers of clay or impermeable rock thus forming an oil reservoir. 70 percent of the oil deposits were formed in the Mesozoic age, 20 percent were formed in the Cenozoic age, and 10 percent were formed in the Paleozoic age (Source: The Society of Petroleum Engineers).

The history about petroleum pre dates to 4000 years ago when it was first used for the construction of oil pits in Egypt. Today with the invention of combustion engine and the rise in commercial aviation have given an importance to petroleum. The American petroleum institute explained that oil exploration and production is a complex process and it comprises of activities like geologic survey, exploration drilling, production, licensing. All these process add up and contribute to the overall oil and gas industry supply chain cost.

Oil is a fossil fuel found in many countries around the world. Oil exploration and production processes start with geologic surveys. Following the surveys, existing data, such as geological maps and aerial photography are studied to determine favorable locations where hydrocarbons may be present. Geologist are the ones responsible for finding the location of oil. The main task in hand of the geologist is to find the right conditions for an oil trap the right source rock, reservoir rock and the entrapment. Next, on site surveys are taken. These comprise of a field geological assessment, and then one of three methods such as magnetic, gravimetric, or seismic site scanning are used to determine the rock strata depths and characteristics. In seismic surveys, shock waves are created by compressed air gun, these shock waves travel beneath the earth's surface and they are reflected ones they come in contact with rock layers. The reflected waves travel at different speeds which is determined due to the density of the rock layers. These readings of speeds are used by seismologists to coordinate the exact location of oil.

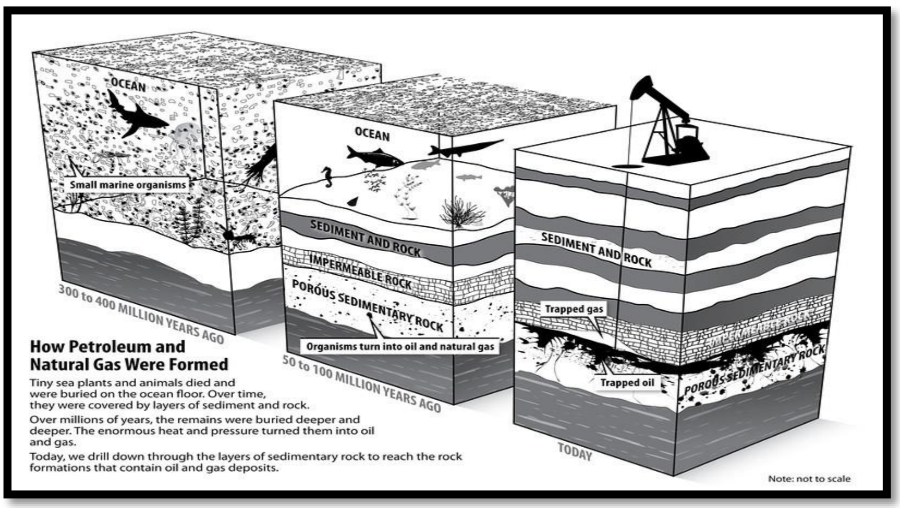


Figure 5 – Formation of Petroleum and Natural gas: Wikipedia

Once the geologist select the site, scientist survey and conduct environmental impact studies if necessary. Once the selected site has been prepped exploratory drilling is used to confirm the presence of oil. If the drilling confirms the presence of oil the next activity is to confirm the oil reservoirs nature and the size. Next in the exploration drilling is the construction of production wells. Based on the oil reservoir size and the oil field the number of production wells vary. Some of the reservoirs have production wells more than 100. Production wells are constructed with light weight tubing compared to the exploratory wells. Production consists of transporting oil either by pumping or free flowing from the well to the facility. It is here where oil, gas and water is separated. Further in the process the oil is treated with heat to stabilize the flow of the oil so it becomes easy to transport oil by any means of mode tanker truck, rail, ship or pipeline. Offshore exploration differs from onshore exploration specifically in terms of the rig drill structures. There are three primary rig types. Jackups, semisubmersibles and drillships make up the majority of the offshore rig fleet which are used worldwide. Other rig types used are platform rigs, inland barges and tender-assisted rigs they are generally used in specific geographic areas. The final step in the process is to abandon the production facility when all the oil from the reservoir has been used.

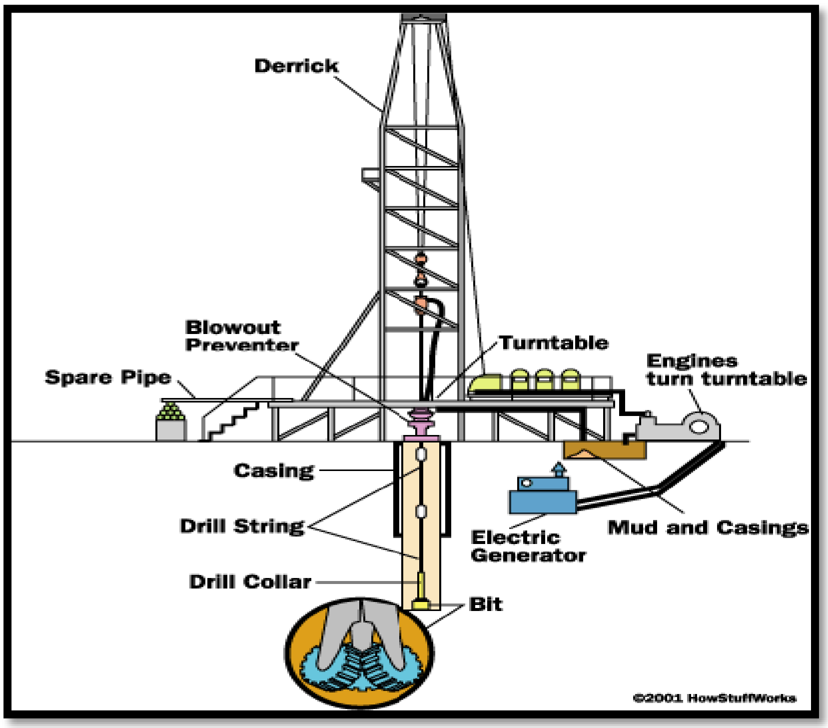


Figure 6 - Drilling Equipment

After exploration and production, crude oil is sent to a refinery, where it is transformed into petroleum products. By definition a refinery is a factory or a processing plant where crude or elementary materials are processed into more usable forms. There are many types of refineries based on the sort of products needed, from petroleum to salt. It is a complex system. Oil refinery is where crude oil is exposed to chemical and mechanical process to create gasoline, kerosene, and other petroleum products.

There are different types of crude oil they are categorized in terms of quality. The quality is measured in in terms of the density (light to heavy) and the sulfur content (sweet to sour). American Petroleum Institute (API) has defined API gravity which is the density at temperature of 15.6 degree Celsius. The higher the API gravity the lighter the crude, generally API gravity of 38*C or more is considered to be light crude. Crude with API gravity 22 degrees or less is considered to be heavy crude. Between 22 degrees and 38 degrees the crude is referred as medium crude. According to the location of its origin crude oil is classified as West Texas Intermediate (WTI), West Texas Sour (WTS), Brent Blend, Russian Export Blend, Dubai or Minas. Light and sweet crude is more expensive than heavier, sour crude. Also the light sweet crude requires less processing time and they are used to produce most of the value added products like gasoline, diesel and aviation fuel.

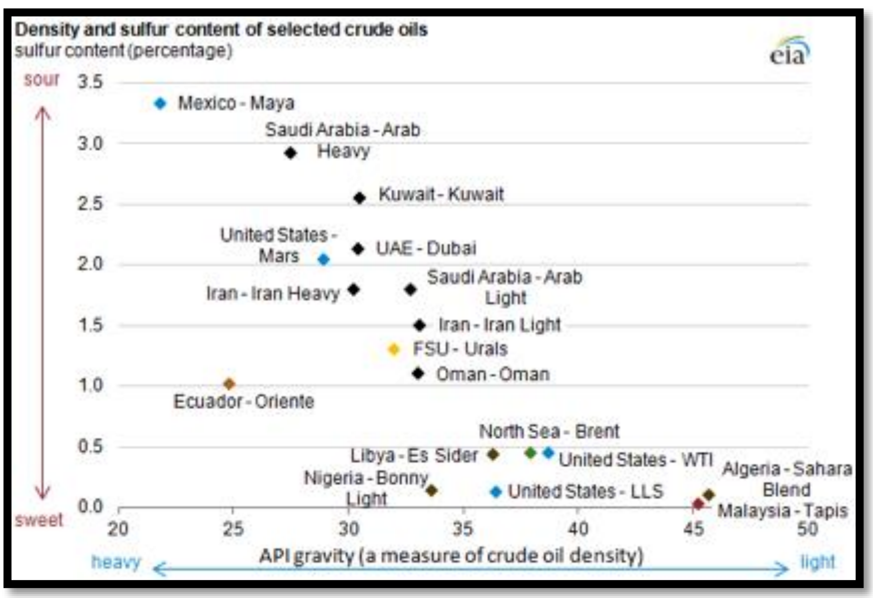


Figure 7 - Classification of conventional crude oil benchmarks; Sources: U.S. Energy Information Administration.

2.2 Todays crude oil and petroleum market

The world has seen an increase in population and in turn has seen an increase in the energy demand. According to the World Energy Report fossil fuels contribute about 25 – 35% of the energy demand. The growing significance is towards the developing countries specially the continent of Asia. Reports indicated that during the period of 2010 – 2040 the energy demand will increase by 60%.

In order to stabilize the oil market and secure an efficient, economic and regular supply of petroleum to consumers and giving a fair return on the capital for those investing in the industry an organization was established "Organization of the Petroleum Exporting Countries" (OPEC). As of 2014, OPEC comprises of 12 countries, the figure below displays the location of the OPEC countries.

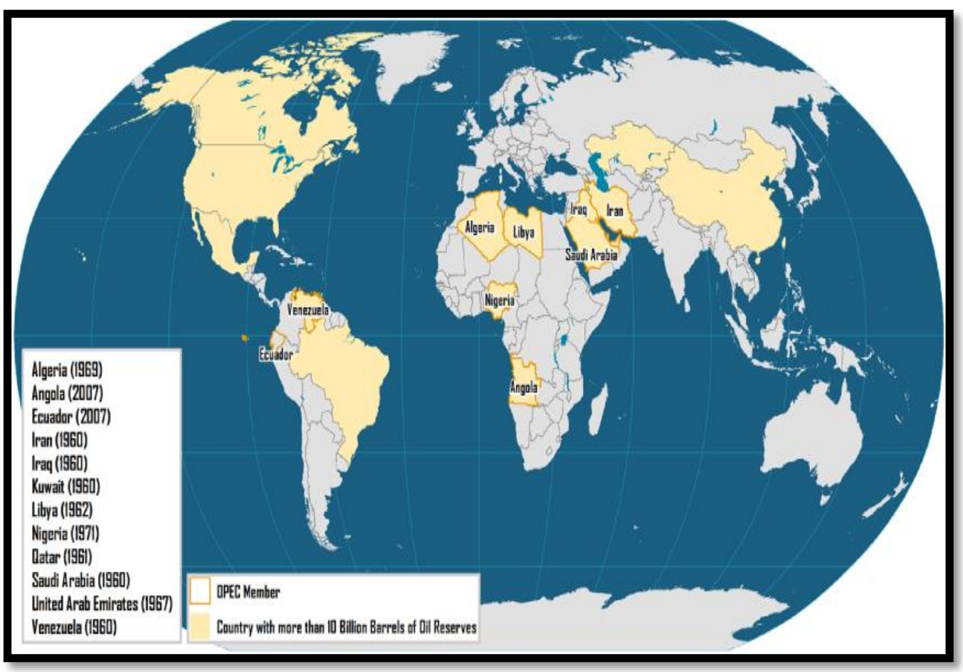
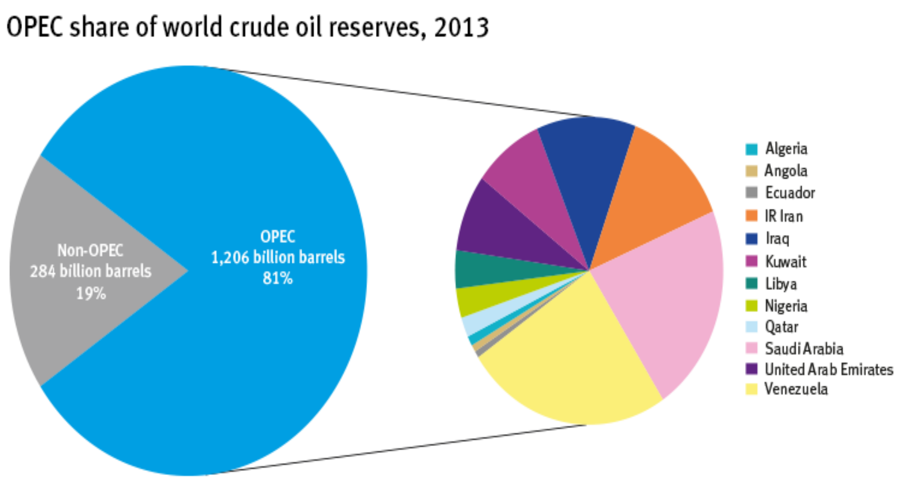


Figure 8 - Location of Organization of the Petroleum Exporting Countries

According to the U.S. Energy Information Administration the OPEC crude oil production is an important factor affecting the global oil prices. OPEC sets production targets for all its member nations when these targets are not met the oil price are increased. Current estimates are that 81 percent of the world's proven oil reserves are in the OPEC member countries. OPEC's proven oil reserves currently stand at 1,206.17 billion barrels (Sources: OPEC Annual Statistical Bulletin 2014).



OPEC proven crude oil reserves, at end of 2013 *(billion barrels, OPEC share)*

Venezuela	298.4	24.7%	Iraq	144.2	12.0%	Libya	48.4	4.0%	Algeria	12.2	1.0%
Saudi Arabia	265.8	22.0%	Kuwait	101.5	8.4%	Nigeria	37.1	3.1%	Angola	9.0	0.7%
IR Iran	157.8	13.1%	UAE	97.8	8.1%	Qatar	25.2	2.1%	Ecuador	8.8	0.7%

Source: OPEC Annual Statistical Bulletin 2014.

Figure 9 - OPEC Share of World Crude oil Reserves. Sources: OPEC Annual Statistical Bulletin 2013.

U.S. Energy Institute Administration estimated that OPEC crude oil production in 2014 averaged to 30.1 million barrels per day. EIA forecast, says that the crude oil production will rise by 0.4 million barrels per day in 2015 and fall by 0.2 million barrels per day in 2016. Non-OPEC producers contribute to the oil production. Seven of the world's fifteen largest oil producers are outside of OPEC.

Oil production affects the oil prices. There are many misunderstanding regarding how the petroleum and products prices are related to the production and crude oil price. The American Petroleum Institute (API) has explained its three probable factors that affect the petroleum product prices in terms with crude oil prices. First, being a global commodity there is a need with the supply and demand at a global market, the production if less than the target the crude oil price are affected and they in turn affect the product price. Second, the price paid for petroleum product is determined by the crude oil price. Third, the two organization OPEC and Non-OPEC members set targets and prices at a global marketplace to keep it stabilize. Also oil prices are determined by the quality and ease of refining. Investors invest in oil futures, wherein they have the right to influence the price of oil.

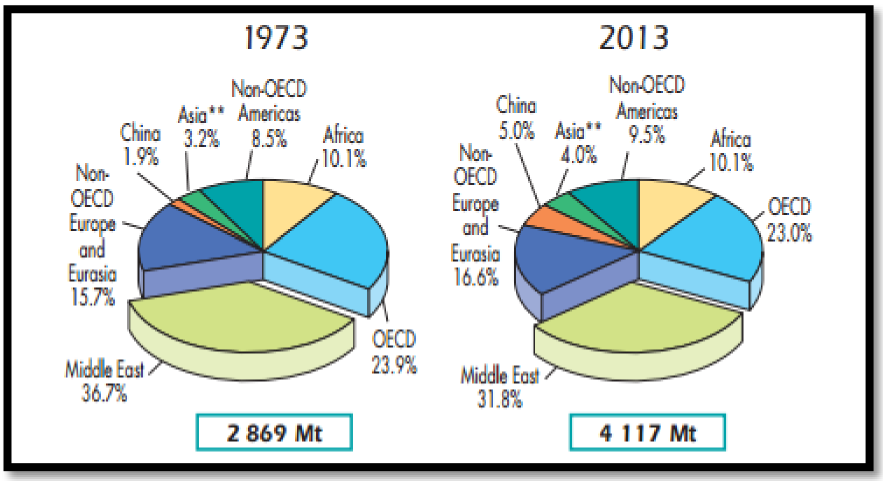


Figure 10 - Regional shares of crude oil production. Sources: U.S. EIA 2014 Publications

2.3 Indian Oil Industry

The history of the Indian oil industry extends back to the period where India was ruled by the British. The British realized the importance of petroleum and set it as a primary source of energy for all its transportation means especially for the transportation of its troops. To understand the Indian oil industry we must understand its growth in the various time periods. The Indian history can be studied in three particular time periods they are, India pre independence up to – 1947, India after Independence 1947 – 1991, India after Liberalization 1991 – present.

2.3.1 India Pre Independence upto – 1947

In early 1825, there were discoveries about the oil seepages at Sapkhong a small town in the upper parts of Assam. Between 1828 and 1845 there were reports of coal and oil discoveries in the Assam valley. In 1866 at Nahorprung near Assam the first well was drilled but was abandoned as nothing could be recovered even after hitting 100 feet. Most impacting year was 1889 when the British discovered the first oil deposit in India, in the state of Assam near the town of Digboi. The oil deposit being close to the East India Company Headquarters was the first to see the industrial revolution and after the discovery the British set up the first well by 1890 and established a company named Assam Oil Company in 1899 to oversee the production. As per sources it has been noted that during the Second World War the oil field in Digboi produced 7000 barrels of oil per day. In 1911 the Burmah oil company limited (BOC) an organization with established exploration and production activities came over to India and in the Surma valley, acquired the exploration rights at Badarpur. They started production in 1920 but was closed down in 1933 and stated that they produced about 1.86 million barrels of crude oil in its term of operation.

However during its operation the Burmah Oil Company (BOC) took over the technical and financial rights of the Assam oil company (AOC). After which the systematic approach by Burmah Oil Company increased the oil production at the Digboi oil production site. After the war India won independence in the year 1947.

2.3.2 India after independence 1947-1991

After independence the new government wanted to change the colonial rule on the exploited resources. The government in 1956 adopted the industrial policy which placed oil as a “schedule A industry” and thus putting the future in the hands of the state. After three years in 1959, an act of parliament was passed which gave the state owned Oil and Natural Gas (ONGC) the powers to plan, organize and implement programs for the development of oil resources or exploration, production and sale of the petroleum products.

ONGC drilled India's first exploratory well near the Kangra district, Punjab in 1957 under the supervision and technical expertise of soviet scientists. Simultaneously in 1958 the well was drilled in the Cambay Basin and in 1959 in Ankleswar. The success of Burmah Oil Company and the government of India led the foundation for "Oil India Private Limited" to deliver the crude oil produced to refineries by pipelines. India made a significant progress in the first twelve years after independence. Production of crude oil went from 0.25 Million tons (76962544.76 US gallons per year) in 1948 to about 0.39 Million tons (120061569.92 US gallons per year) by 1959. The Indian Refineries Ltd. & Indian Oil Company Ltd. were set up in 1958 and was later merged into Indian Oil Corporation in 1964.

2.3.3 India after Liberalization 1991-present

Economic liberalization in India began in the year 1991. The government plays a pivotal role and ONGC is responsible for 77% of oil and 81% of gas production. India imports 75% of oil so as to meet the energy demands for its expanding population. India thus for its demand has pursued drilling rights in Iran, and Kazakhstan and has acquired shares in Indonesia, Libya, Nigeria and Sudan. Major companies like ONGC and OIL operated most of the exploration and development activities in all the basins in India. ONGC carried out exploration activities in Gujarat, Offshore basins of India starting around the year 1959. While Oil India Ltd controlled the upper regions in the northeast particularly in Assam. During the 60's ONGC carried out exploratory surveys in other states like Jammu and Kashmir, Himachal Pradesh, Assam, Rajasthan, Punjab, Cambay Basin, Kutch and East Coast of India. Exploration and drilling activities were undertaken in Punjab, Assam and Gujarat. A number of oil and gas fields were discovered in Gujarat and Assam. The achievement of the Oil Industry was during the early sixties and it was designing the longest pipeline in south – East Asia from Duliajan, Assam to Barauni in Bihar to transport the crude oil produced by the Oil India Limited (OIL) to the eastern sector refineries. The total length was 1157 kilometer (720 miles). In 1962, for transporting the oil to Digboi, Guwahati and Barauni refineries by pipeline the first crude oil conditioning plant was set up (COCP). In 1964-65, the Bombay offshore region was surveyed for possible oil discovery. In 1974 oil was discovered near 160 Kilometer from Mumbai called Bombay high. Production of oil from Bombay High was at 40,000 barrels of oil per day (bopd). In 1977, the production reached to 60,000 bopd. At present it has been noted that Bombay High produces about 70 percent India's total oil demand.

Commercial production of gas was established at Tripura and the nearby states of Assam, Arunachal Pradesh. Also Oil India Ltd. Carried out exploration in the western part of India in Jaisalmer and Bikaner Nagaur basins. Besides the exploration and development by OIL and ONGC, in 1986 the government of India put forth new policy for exploration and production for foreign investors. India has total reserves (proved & indicated) of 1201 million metric tons of crude and 1437 billion cubic meters of natural gas (Sources: Ministry of Petroleum and Natural Gas Statistics 2010).

Petroleum exploration and production activities were initially carried out in India by two national oil companies, Oil and Natural Corporation Limited (ONGC) and Oil India Limited (OIL).

2.3.4 Exploration and Production Facts

According to Oil and gas Journal (OGJ), India held nearly 5.7 billion barrels of crude oil at the beginning of 2014. Onshore resources account for 44% while the rest 56% are offshore. ONGC dominates the upstream oil sector. The main oil producing reserves like Mumbai High Basin and its neighboring fields in the western part contribute to nearly 75% of the production.

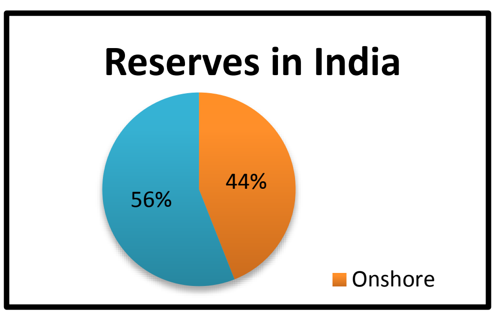


Figure 11 - Reserves in India

The Mumbai high, Gujarat, Assam – Arakan basin are the major oil fields but are now experiencing decline in production. The Assam – Arakan basin contains more than 23% of the countries reserves which contribute to 12% of the oil production. In recent years, major oil field reserves were discovered in the Barmer basin in Rajasthan and the offshore of Krishna-Godavari basin.

The Figure (Distribution of reserves in India) below displays the Indian map with the reserves around the country. Most of the oil reserves are found in the western part of India particularly the western offshore of the states of Gujarat and Rajasthan.

As of April 2014, India had 762.74 Million Metric tons (MMT) of proven oil reserves ("petroleum & natural gas statistics India 2014"). The countries oil production showed a decreasing trend from 773.34 MMT in 2009 to 762.74 MMT in 2014 ("petroleum & natural gas statistics India 2014"). There are a widely distributed proven oil reserves in India. In this dissertation we have focused our attention on the western coast of India which has the three oil producing reserves they are the state of Gujarat, Rajasthan and the Cambay basin. The state of Gujarat the oil reserves production was started from the year 1984 with 29 MMT of crude oil produced per day. There are 22 refineries in India. The first was the one in Digboi Assam with the capacity of 1 MMT and it started functioning in the year 1951. The total refining capacity of India is 215.066 MMT ("petroleum & natural gas statistics India 2014"). For this dissertation the refineries near the west coast were selected. The major companies that control the production of crude oil in the selected production sites.

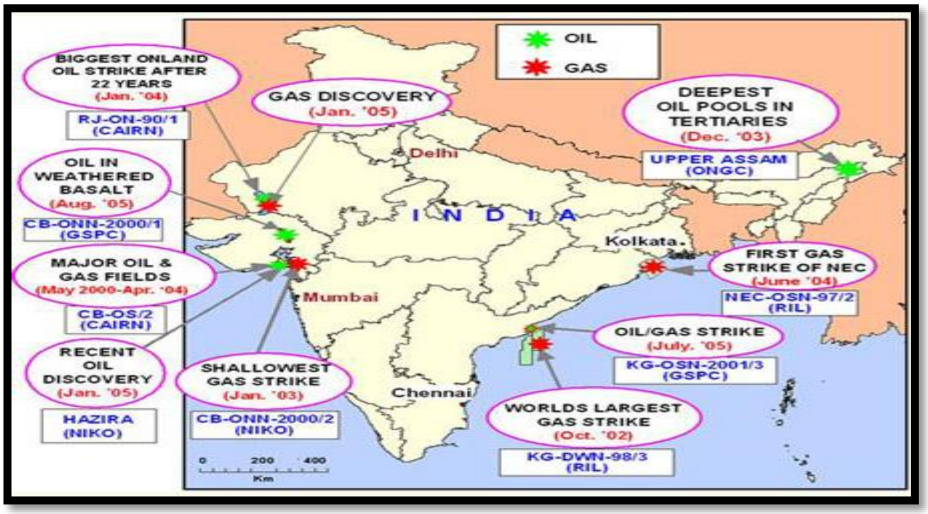


Figure 12 – Distribution of reserves in India

Oil and gas corporation of India (ONGC) and Oil India limited (OIL) are the major oil producing companies, they both together amount for more than 75 percentage of the country's total crude oil production ("Petroleum and natural gas statistics 2014"). The oil reserves are widely distributed around the country. According to the US Energy Information Agency (EIA) the onshore reserves account for 44 percentage whilst the offshore reserves make up the rest 56 percentage of crude oil. According to the oil and gas journal, India held nearly 5.7 billion barrels of proven oil reserves in the beginning of the year 2014.

Year	Crude Oil Production (MMT)	% Growth in Crude Oil Production	Natural Gas Production (BCM)	% Growth in Natural Gas Production
2007-08	34.118	0.38	32.417	2.11
2008-09	33.508	-1.79	32.845	1.32
2009-10	33.690	0.54	47.496	44.61
2010-11	37.684	11.85	52.219	9.94
2011-12	38.090	1.08	47.559	-8.92
2012-13	37.862	-0.60	40.679	-14.47
2013-14*	37.788	-0.19	35.407	-12.96

Figure 13 - Crude oil and Natural gas production

According to the “Petroleum and Natural gas statistics 2013-14” Crude oil production for the year 2013-14 was 37.788 million metric tons (MMT) which was a 2% increase compared to the previous year which was 37.862 MMT. The trend in the production of crude oil and natural gas are shown in the table and figure.

2.4 Downstream & Refining

The oil refining industry is the backbone of a modern economy (Senevirante, 2006). Refined petroleum product remain fundamental to our economic life – in everybody’s daily life and economic activities of a nation (Wauquier and Favennec, 2001) ranging from domestic cooking to transportation, employment, etc. In terms of the refining capacity India ranks eighth in the world (U.S. EIA 2009). The private sector owns about 38% of total capacity while the public sector owns the rest. End of 2013, India has 4.35 million bbl/day of refining capacity, making it the second largest refiner in Asia after china. There are projections that there would be an increase in the refining capacity to 6.3 million bbl/day by the year 2017. Indian oil Corporation Limited is the major company which controls most of the refineries in India. In total there are 22 refineries in India. The total refining capacity of India has increased from 175.9 Million metric tons (MMT) in 2007 to 215.06 Million metric tons (MMT) in the year 2014. Reliance industries a private owned petroleum company has the largest refining complex in the world and it is located in Gujarat in India. It has a capacity of 1.24 million barrels per day. Based on the current proposed growth and projections India plans to add 1.6 million bbl/day of refining capacity by the end of 2015. India is steadily emerging as an international destination for oil refining as the investment is less compared to other Asian counterparts. According to Deutsche Bank’s analysis in the next 5 years India is expected to enhance its world’s refining market share to 45 percent from the current 3 percent of its international capacity. India is a largely import dependent nation, and Indian refining industry faces challenges in a number of ways. Depending on the sources of crude oil imports, quality issue arises. India is located strategically in a major maritime route from Middle East to

Far East (Sarangi, 2009) giving it a geographical advantage to serve the western and the eastern markets.

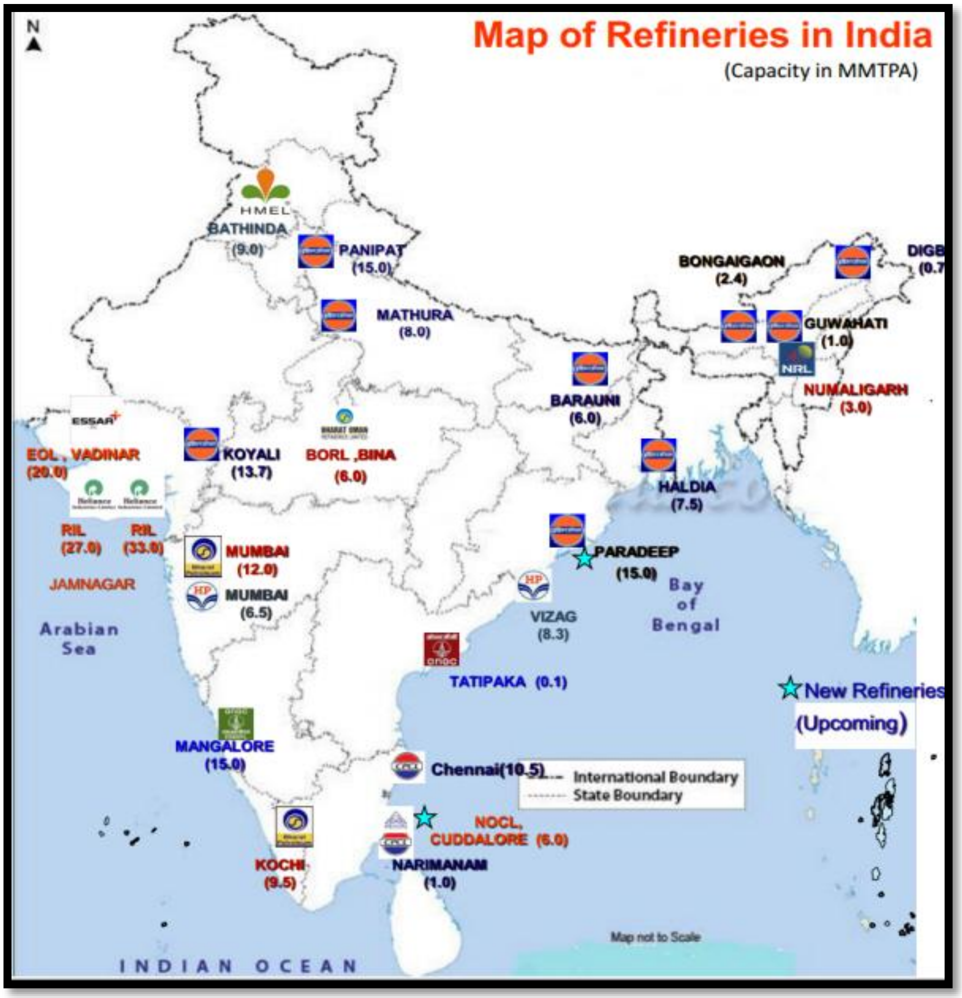


Figure 14 - Indian Oil refinery location, Sources: Indian oil and gas Administration.

2.4.1 History on the selected refineries.

A) KOYALI REFINERY (Gujarat) – Indian Oil Corporation Limited (IOCL):

The Koyali Refinery commissioned in 1965, was built with the soviet assistance at a cost of $4.33 (US) Million Dollars. The initial installed capacity of 2 MMTPA and was designed to process crude from the oil fields in Gujarat. In 1978, implementing the expansion project the capacity was increased to 7.3 MMTPA with the investment of $9.35 Million Dollars (US). In 1989, with the implementation of supplemental processing facilities, the refinery achieved capacity of 9.5 MMTPA. The present refining capacity of the plant is 13.7 MMTPA.

B) MUMBAI REFINERY (Maharashtra) – Hindustan Petroleum Corporation Limited (HPCL)

Mumbai refinery was first incorporated in 1952 as standard vacuum refining company of India (StanVac) which was then commissioned in 1954 with an installed capacity of 1.25 MMTPA. In 1962 StanVac was named ESSO India Limited. In 1969, the installed capacity was augmented to 2.5 MMTPA. On 15th July, 1974 the undertakings of ESSO and Lube India Ltd were nationalized and merged to form Hindustan Petroleum Corporation Limited (HPCL). In 1983, the refinery was debottlenecked to increase the capacity to 3.5 MMTPA. During 1985 a major augmentation was carried out by adding a new crude distillation unit with a capacity of 2.0 MMTPA taking the refinery capacity to 5.5 MMTPA. In 2009, further expansion was carried out and the refinery was enhanced to capacity of 6.5 MMTPA.

C) MUMBAI REFINERY (Maharashtra) – Bharat Petroleum Corporation Limited (BPCL)

The refinery in Mumbai was commissioned in 1955 under the ownership of Burmah Shell Refineries Ltd. With an original design capacity to process 2.2 MMTPA of crude oil. Following the government acquisition of the Burmah Shell, Bharat Petroleum Corporation came into existence in 1976. Since then, the crude throughput of the refinery has been consistently enhanced and in 1985 it was at an installed capacity of 6 MMTPA. Under the “Refinery Modernization Project” in 2005, the capacity was increased to 12 MMTPA and it stands today at this capacity.

D) RELIANCE INDUSTRIED LIMITED, (RIL-DTA) Jamnagar (Gujarat):

Reliance Industries Limited (RIL) has two refineries. The present capacity of the first refinery (RIL-DTA) is 33 MMTPA. RIL-DTA is the world’s largest grassroots Refinery having a petrochemical plant for the production of 1550 KTPA Paraxylene, a polymer plant for the production of 1000 KTPA.

F) RELIANCE INDUSTRIES LIMITED SEZ, (RIL-SEZ), Jamnagar (Gujarat):

The capacity of the refinery is 27 MMTPA. The SEZ refinery has a unique and path breaking configuration for “clean fuels” process plant.

G) ESSAR OIL LIMITED, Vadinar (Gujarat):

This is a private sector refinery and it was commissioned in 2006 with an installed capacity of 10.5 MMTPA. Capacity of the refinery was revamped to 14 MMTPA in 2009, and to 20 MMTPA in 2012.

H) GURU GOBIND SINGH REFINERY – HPCL – MITTAL ENERGY LIMITED (HMEL), Bhatinda (Punjab):

Guru Gobind Singh refinery (GGSR) is a refinery owned by Hindustan Mittal Energy Limited (HMEL) a joint venture between HPCL and Mittal Energy Limited, a company owned by Sh L. N. Mittal. It is located in village Phulokheri, Bhatinda, Punjab. The 9.0 MMTPA refinery was dedicated to the nation in 2012.

2.5 New Exploration Licensing Policy

Petroleum exploration and production activities are carried out in India by two national oil companies, Oil and Natural Gas Limited (ONGC) and Oil India Limited (OIL). In the year 1991 with economic liberalization the Indian government opened the Indian sedimentary basins for the private sector. At the end of 2012, nearly 282 blocks were awarded for exploration.

The New Exploration Licensing Policy (NELP) was formulated by the Government of India in 1997 to provide a level playing field to both the public and private sector companies for exploration and production of hydrocarbons. To attract more investments, NELP has ensured a healthy competition between National Oil Companies and private sector companies. Under NELP, acreages of land are offered to the participating companies by competitive bidding. The first round of blocks were offered in 1999. Under NELP, 360 exploration blocks have been offered and 254 blocks have been awarded. As of today 166 blocks are active and 88 have been abandoned.

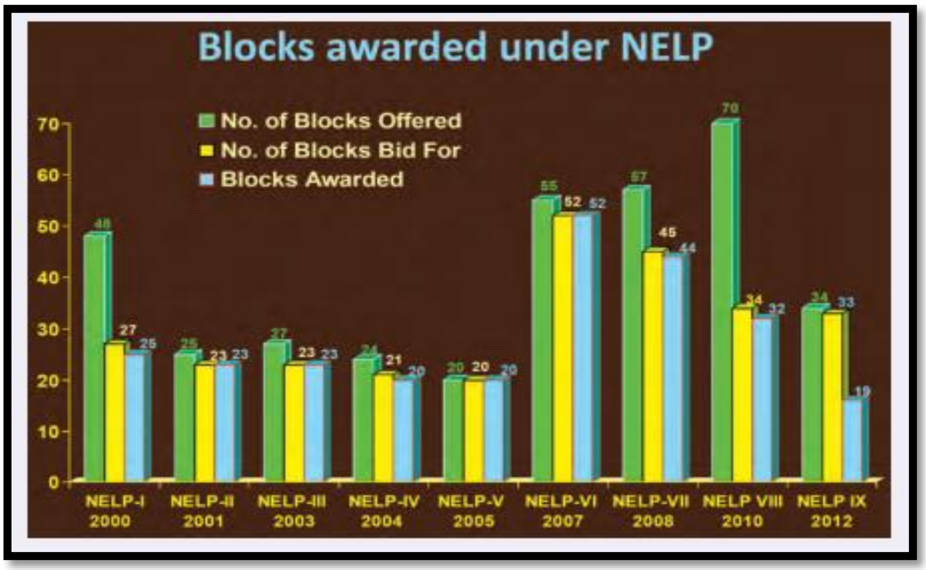


Figure 15 – New Exploration Licensing Policy Data (NELP – X, 2014)

NELP has resulted in important discoveries of oil and gas in various sedimentary basins of India. According to statistics, an investment of about US $ 21.3 Billion has been made in NELP blocks.

2.6 Supply chain Management in Oil Industry

The petroleum industry plays an important role in the economic development of the country. Thus the performance of its supply chain is very important. Supply chain by definition is the network created amongst different companies producing, handling and/or distributing a specific product. Specifically, the supply chain encompasses the steps it takes to get a good or service from the supplier to the customer.

Transportation in the oil and gas industry pertains to the movement of crude oil from oil deposits to the refineries to storage tanks and finally the customers or distribution centers. In its raw state crude oil is transported by mainly two means; tankers and pipelines. Once the oil has been refined and separated from the natural gas, pipelines transport the oil to another facility. All the petroleum products are the transported to the market by tanker, truck, railcar, or pipelines. Below are the major transport modes discussed in detail.

2.5.1 Oil Tankers

Tankers are major haulers of oil and the mainly used when transporting vast quantities of crude over a long route. Crude oil carriers are classified as either VLCCs (Very Large Crude Carriers) or ULCCs (Ultra Large Crude Carriers). They are mainly designed to transport vast quantities of oil over long and heavily traveled sea routes. Oil tankers are a major link in the Indian country's oil transport network. Crude oil flow in the inland coast accounted 907.172 MMT valued at Rs.14, 05,516. The originating ports are Mumbai, Rawa and Cuddalore and the discharge ports are to vizag, Cochin, Chennai and kandla.

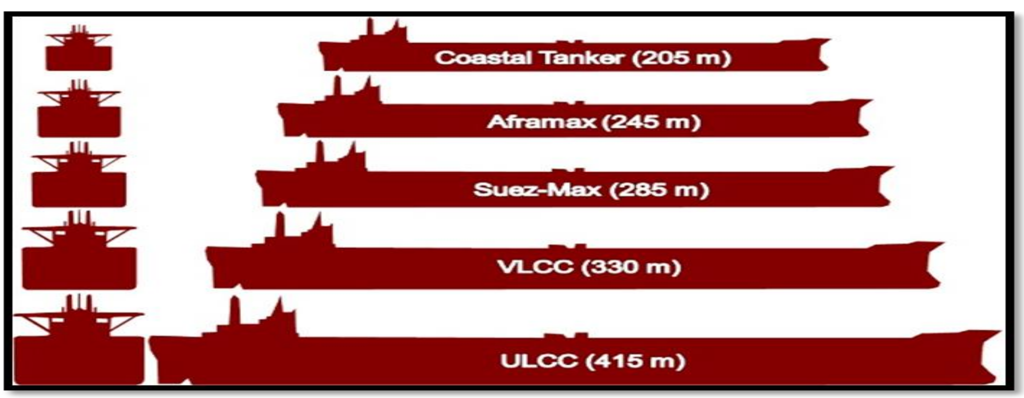


Figure 16 – Types of Oil Tankers

2.5.2 Pipelines

At least some part of the route the oil is transported through pipelines. After the crude oil is separated from natural gas, pipelines transport the oil to other facilities or refineries. Crude oil pipelines are the foundation of the liquid energy supply. Generally there are two types of energy pipelines – liquid petroleum pipelines and Natural gas pipelines. The Liquid Petroleum pipeline network contains the crude oil lines, refined product lines, highly volatile liquids (HVL) lines. Further crude oil lines are subdivided in to “Gathering Lines” and “Transmission Lines”. Transmission lines bring crude oil from crude oil producing areas to refineries. The pipelines vary in size from 8 to 12 inch in diameters to a much large one that can go up to 42 inches.

Figure 17 - Crude oil Pipeline

According to the ministry of oil and natural gas the crude oil pipeline network spans up to 9573 kilometers and has a capacity of 129.20 MMT (Million metric tons) and a throughput of 99942 TMT (Thousand metric tons) (Sources: Petroleum and natural gas statistics 2014). If all the network is considered i.e. gas pipeline, product pipeline the total network then covers almost 41,442 kilometers. The pipeline network has seen an increase from its initial of just 2,517 kilometers in the year 2007.

Crude oil imports are taken by the terminals that are mostly located northwest coast. The pipeline infrastructure are concentrated mostly to major oil refineries states like Gujarat, Uttar Pradesh and Haryana. Refineries are generally located near coastal areas. The Indian oil Corporation control and operates the oil product pipelines and supplies for India domestic market. Indian Oil Corporation plans to build additional lines for growing demand.

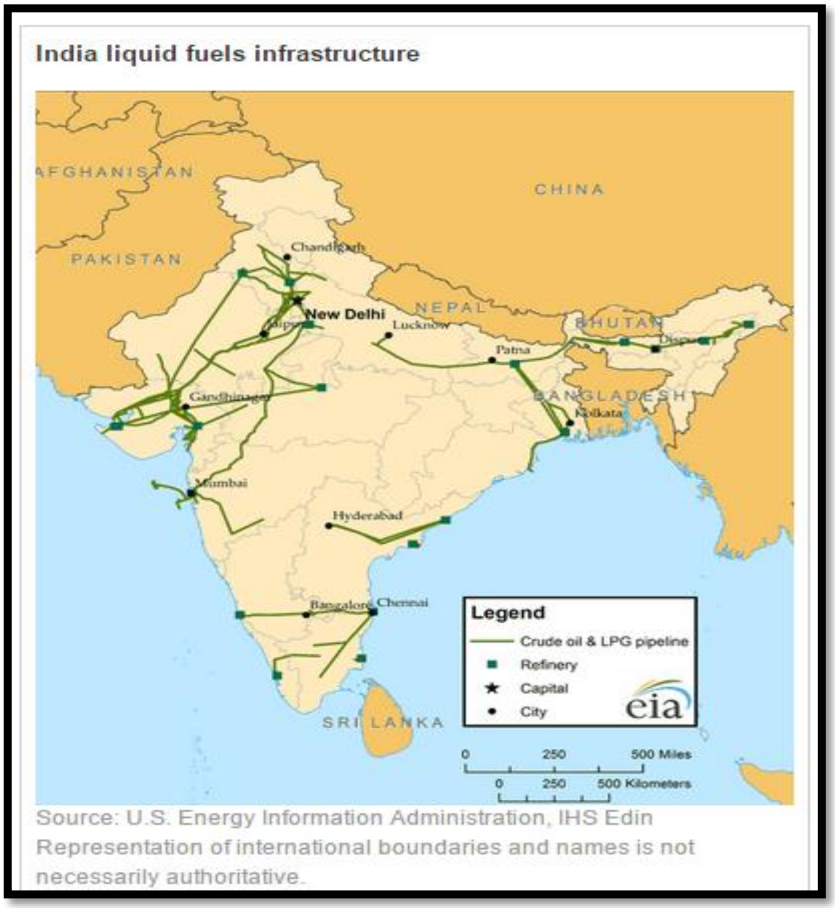


Figure 18 – Crude Oil Pipeline network in India.

2.5.3 Railroad Tank Cars

Indian Railways is one of the world's largest railway networks and plays a major role in the country's economic development. The railway network is managed under a single management "Government of India". The Government of India has focused on investing in the railway infrastructure. Total approximate earnings of Indian Railways in the year 2014 was

Rs.128, 928.28 crore (US$ 20.41 Billion) compared to Rs.114, 428.52 crore (US$18.12 Billion). According to IBEF the total revenue generated from goods in 2014 was Rs.87, 291.87 crore (US$ 13.82 Billion).

Figure 19 – Rail tankers in India

Chapter 3

Methodology

3.1 Description

The significance of this dissertation is to evaluate the minimum transportation cost that will be incurred in the domestic oil and gas transportation to the refineries in India by introducing the mixed-integer linear programming (MIP) model that identifies how production sites can supply crude oil and natural gas to the refineries with respect to the tradeoff between the flow in the pipe, the pipe diameter, and thus finally evaluating the supply chain costs. Furthermore, the broader impact is the investment in India crude oil supply chain can be optimized and quantified as new production sites are being explored.

This research strives to answer the research question of “How economically beneficial is it to invest in the pipeline transportation of crude oil in the domestic oil and gas supply in the Indian subcontinent?” hypothesizes that the crude oil supply chain transportation cost is affected by the pipeline diameter and the flow through the pipeline. This dissertation has an overall objective to investigate a mixed – integer programming (MIP) model that supports decisions about providing the minimum transportation cost and also help in improving the supply chain quality of crude oil supply chain.

Most companies must decide on conflicting strategies of maximizing short term profits or seeking long term sustainability through high quality standards (Franka 2009). Usually supply chain decisions are evaluated by analysis that considers the logistics costs and the quality initiatives independently. This independent decision making process does not effectively determine the impacts of quality defects and can lead to ineffective strategic decisions that do not comprehensively account for the complexity of the problem. This dissertation has the objective to introduce the mixed-integer programming (MIP) model that supports decisions about providing the minimum transportation cost and also help in improving the supply chain quality of crude oil supply chain. In addition, the model also concentrates on the most optimization decisions as they are based on forecasts that have some degrees of uncertainty. The model takes uncertainty into account for robustness and consistency. A hypothesis statement by definition is a prediction that can be tested or verified with the help of a test statistic. This dissertation proposes two answers whether or not the crude oil supply chain transportation cost will be affected by the diameter of the pipeline used and the refinery sustainability for the research question.

In this Research, The book “Modelling The Supply Chain” textbook by Shapiro is used to calculate the transportation costs, considering the oil producing states or location the distance between the oil deposit and the refinery, also the associated transportation costs and the capacity of the oil producing districts. The model is optimized by using Microsoft Excel and GRG Non – Linear engine solver to minimize the objective function. The Objective function in this based on the transportation cost, the fixed cost for the pipeline material and the construction of pipe cost while the variable cost includes engineering cost, labor cost and the freight cost. Scenarios are then run that change the variable and the fixed cost to evaluate the impacts of the pipe diameter selection and the oil percent transportation on the total cost and the profit.

3.2 Hypothesis statement

“How economically beneficial is it to invest in the pipeline transportation of crude oil in the domestic oil and gas supply in the Indian subcontinent”? Below are the hypothesis statements

Hypothesis Statement #1

H_0: The pipeline diameter used and flow through pipe will not affect the supply chain costs.

H_1: The pipeline diameter used and the flow through the pipe will affect the supply chain costs.

A test statistic is conducted to determine whether or not Null hypothesis H_0 is verified or rejected for both the hypothesis statements. The rejection region lies if both pipeline diameter and flow through the pipe change the supply chain costs by 20 percent.

3.3 Model datasets

For this dissertation we have focused on the west coast and particularly three crude oil production sites the state of Gujarat, Rajasthan and the Cambay basin. As per the “Petroleum and natural gas statistics 2014”, the oil production in the state of Gujarat is controlled by the government sector to be specific the Oil and Natural gas Corporation of India (ONGC), some percentage of the production is contributed by the joint ventures and private sector like Reliance Industries Limited, and Essar oil Limited.

On the other hand the state of Rajasthan is controlled solely by a private company i.e. Cairn India limited. The Cambay basin is the offshore reserve near to the state of Gujarat is controlled by the government. The data include distance from the Gujarat, Rajasthan and Cambay Basin deposits to the selected refineries, fixed/variable costs of operation of refineries, refinery capacity, the crude oil demand at each refinery, transportation costs per barrel per mile. Distance, refinery demand and the transportation costs per barrel per mile is not affect the selected pipeline diameter and the flow through the pipeline.

Table 1 – Flow Level Performance

Scenario	Pipeline Condition
1	Select pipe 8 5/8 inch outside diameter and flow less than 50 perfect
2	Select pipe 8 5/8 inch outside diameter and flow more than 50 perfect
3	Select pipe 10 ½ inch outside diameter and flow less than 50 perfect.
4	Select pipe 10 ½ inch outside diameter and flow more than 50 perfect.
5	Select pipe 12 1/3 inch outside diameter and flow less than 50 perfect
6	Select pipe 12 1/3 inch outside diameter and flow more than 50 perfect

Table 2– Distance from Oil Reserves to Refinery

From Refineries to Production Sites	Gujarat	Rajasthan	Cambay Basin
Koyali	113.3	333.8	116.06
Mumbai	196.35	567.3	227.35
Bhatinda	837.93	451.36	868.93
Mumbai	198.4	570.4	230.02
Jamnagar	328.23	239.16	359.23
Jamnagar Sez	350.42	352.16	381.42
Vadinar	358.67	330.22	389.67

Table 3 – Transportation Cost per pipeline per mile in US Dollar

From Refineries to Production Sites	Gujarat	Rajasthan	Cambay Basin
Koyali	0.01901	0.04247	0.01901
Mumbai	0.02871	0.07780	0.03357
Bhatinda	0.11279	0.06230	0.12053
Mumbai	0.02871	0.03656	0.03256
Jamnagar	0.04651	0.05626	0.05048
Jamnagar Sez	0.05048	0.05048	0.05442
Vadinar	0.05048	0.05048	0.05442

Table 4 – Refinery Crude Oil Demand

Refinery	Crude oil Demand in Barrels
Koyali	12330000
Mumbai	10560000
Bhatinda	6750000
Mumbai	6500000
Jamnagar	23760000
Jamnagar Sez	19440000
Vadinar	16000000

Table 5– Fixed and Variable Cost for Rajasthan for less than 50 % flow

Refinery	**Costs for 8 5/8 inch (US $/mile)**		**Costs for 10 ½ inch (US $/mile)**		**Cost for 12 1/3 inch (US $/mile)**	
	Fixed	**Variable**	**Fixed**	**Variable**	**Fixed**	**Variable**
Koyali	20.2952	21.2509	25.3690	25.0761	28.0074	25.9261
Mumbai	18.9518	19.9783	23.6898	23.5744	26.1535	24.3736
Bhatinda	15.1614	18.0198	18.9518	21.2633	20.9228	21.9841
Mumbai	9.69341	13.6080	12.1167	16.0575	13.3769	16.6018
Jamnagar	44.5213	31.8702	55.6516	37.6068	61.4394	38.8816
Jamnagar Sez	36.6796	21.8598	45.8495	25.7946	50.6178	26.6690
Vadinar	25.4769	21.0645	31.8461	24.8561	35.1581	25.6987

Table 6– Fixed and Variable Cost for Rajasthan for more than 50 % flow

Refinery	**Costs for 8 5/8 inch (US $/mile)**		**Costs for 10 ½ inch (US $/mile)**		**Cost for 12 1/3 inch (US $/mile)**	
	Fixed	**Variable**	**Fixed**	**Variable**	**Fixed**	**Variable**
Koyali	20.2952	25.5011	25.3690	33.9165	28.0074	35.7015
Mumbai	18.9518	23.3909	23.6898	31.1099	26.1535	32.7473
Bhatinda	15.1614	19.2936	18.9518	25.6605	20.9228	27.0110
Mumbai	9.6934	14.4158	12.1167	19.1730	13.3769	20.1821
Jamnagar	44.5213	3.73445	55.6516	49.6681	61.4394	52.2823
Jamnagar Sez	36.6796	24.7989	45.8495	32.9826	50.6178	34.7185
Vadinar	25.4769	23.9849	31.8461	31.9000	35.1581	33.5789

Table 7 - Fixed and variable cost for deposit at Gujarat for less than 50 % flow

Refinery	**Costs for 8 5/8 inch (US $/mile)**		**Costs for 10 ½ inch (US $/mile)**		**Cost for 12 1/3 inch (US $/mile)**	
	Fixed	**Variable**	**Fixed**	**Variable**	**Fixed**	**Variable**
Koyali	20.2952	21.2509	25.3690	25.0761	28.0074	25.9261
Mumbai	18.9518	19.9783	23.6898	23.5744	26.1535	24.3736
Bhatinda	15.1614	18.0198	18.9518	21.2633	20.9228	21.9841
Mumbai	9.6934	13.6080	12.1167	16.0575	13.3769	16.6018
Jamnagar	44.5213	31.8702	55.6516	37.6068	61.4394	38.8816
Jamnagar Sez	36.6796	24.7989	45.8495	32.9826	50.6178	34.718
Vadinar	25.4769	23.9849	31.8461	31.900	35.1581	33.578

Table 8- Fixed and variable cost for deposit at Gujarat more than 50 % flow

Refinery	Costs for 8 5/8 inch (US $/mile)		Costs for 10 ½ inch (US $/mile)		Cost for 12 1/3 inch (US $/mile)	
	Fixed	Variable	Fixed	Variable	Fixed	Variable
Koyali	20.2952	25.5011	25.3690	33.9167	28.0074	35.7015
Mumbai	18.9518	23.3909	23.6898	31.1099	26.1535	32.7473
Bhatinda	15.1614	19.2936	18.9518	25.6605	20.9228	27.0110
Mumbai	9.6934	14.4158	12.1167	19.1730	13.3769	20.1821
Jamnagar	44.5213	3.73445	55.6516	49.6681	61.4394	52.2823
Jamnagar Sez	36.6796	24.7989	45.8495	32.9826	50.6178	34.718
Vadinar	25.4769	23.9849	31.8461	31.9000	35.1581	33.5789

Table 9- Fixed and variable cost for deposit at Cambay Basin for less than 50 % flow

Refinery	Costs for 8 5/8 inch (US $)		Costs for 10 ½ inch (US $)		Cost for 12 1/3 inch (US $)	
	Fixed	Variable	Fixed	Variable	Fixed	Variable
Koyali	37.4377	28.73911	46.7971	33.9121	55.2206	42.3901
Mumbai	33.9269	18.7157	42.4086	22.0845	50.0422	27.6057
Bhatinda	22.8665	19.3868	28.5831	22.8764	33.7281	28.5955
Mumbai	15.9071	13.0488	19.8839	15.3976	23.4630	19.2470
Jamnagar	124.349	46.3202	155.437	54.6578	183.415	68.3223
Jamnagar Sez	77.3888	40.6700	96.7360	47.9907	114.148	59.9883
Vadinar	115.367	48.7479	144.209	57.5225	170.167	71.9032

Table 10- Fixed and variable cost for deposit at Cambay Basin for more than 50 % flow

Refinery	Costs for 8 5/8 inch (US $)		Costs for 10 ½ inch (US $)		Cost for 12 1/3 inch (US $)	
	Fixed	**Variable**	**Fixed**	**Variable**	**Fixed**	**Variable**
Koyali	37.4377	35.1473	46.7971	46.7459	62.2401	58.4324
Mumbai	33.9269	22.0369	42.4086	29.3091	56.4035	36.6364
Bhatinda	22.8665	20.2287	28.5831	26.904	38.0155	33.6303
Mumbai	15.9071	13.8019	19.8839	18.3565	26.4456	22.9457
Jamnagar	124.3497	52.5519	155.4371	69.8941	206.731	87.3676
Jamnagar Sez	77.3888	48.8181	96.7360	64.9281	128.658	81.1601
Vadinar	115.367	58.7613	144.209	78.1526	191.798	97.6907

Table 11 - Refinery Capacity

Refinery	Refinery Capacity (Barrels of oil per year)
	Full capacity
Koyali	13700000
Mumbai	12000000
Bhatinda	9000000
Mumbai	6500000
Jamnagar	33000000
Jamnagar Sez	27000000
Vadinar	20000000

The refinery selection is found by using the mixed integer programming algorithm. This dissertation uses the Solver of the Microsoft Excel to minimize the sum of production and exploration cost, the refinery operation and transportation cost. The minimized optimal value is calculated by selecting the best pipeline diameter and condition and also the refinery sustainability. The demand of oil is assumed to be constant.

Table 12- Selected Oil Deposits

No	Oil Field
1	Gujarat
2	Rajasthan
3	Cambay Basin

Table 13 – Selected Refineries

J	Refineries
1	Koyali
2	Mumbai
3	Bhatinda
4	Mumbai
5	Jamnagar
6	Jamnagar Sez
7	Vadinar

This dissertation uses solver of Microsoft Excel to minimize the transportation costs. While considering the mode of transport to be solely by pipeline. The next year's oil demand is assumed to be fixed. Seven refineries location and their distance to the three oil fields are listed in the "distance" section. At each location the oil field has the choice of selecting the flow through the pipeline. The flow can be 25 percent, 50 percent, 75 percent or 100 percent through the pipeline. In “refining options section” a fixed cost and variable cost for outbound flows are associated with each refinery. All costs are measured in US Dollar ($). The costs of the refineries selected in the optimal solution are calculated in the “refinery capacity” and “cost” selection.

	PRODUCTION FIELD TO REFINERY	Koyali	Mumbai HPCL	Bhatinda	Mumbai BPCL	Jamnagar	Jamnagar SEZ	Vadinar
DISTANCE (mile)	Gujarat	113.3	196.35	837.93	198.4	328.23	350.42	358.67
	Rajasthan	333.8	567.3	451.36	570.4	239.16	352.16	330.22
	Cambay Basin	116.06	227.35	868.93	230.02	359.23	381.42	389.67
COST PER MILE ($/mile)	Gujarat	0.01901	0.02871	0.11279	0.02871	0.04651	0.05048	0.05048
	Rajasthan	0.04247	0.07780	0.06230	0.03656	0.05626	0.05048	0.05048
	Cambay Basin	0.01901	0.03357	0.12053	0.03256	0.05048	0.05442	0.05442

Figure 20 – Excel distance (mile) and Cost per Mile ($/mile)

The screenshot in figure 19 above shows the distance and the cost per mile from the major oil producing districts to the refineries located across India and the cost ($/mile/barrel) associated with transporting oil from the districts to the refineries listed

The screenshot in figure 20 shows the fixed cost and variable costs of transporting oil through the pipelines from the respective oil producing districts to the refineries listed. The figure also shows the total capacity of each refinery (Last row), the maximum limit of oil (Barrels) a refinery can process.

		REFINERY OPTIONS ($/Barrel/Mile)						
		Koyali	Mumbai HPCL	Bhatinda	Mumbai BPCL	Jamnagar	Jamnagar SEZ	Vadinar
Gujarat	Fixed Cost	20.29527632	18.95186847	15.16149477	9.693414692	44.52135658	36.67963264	25.47690358
	Variable Cost	21.25094759	19.97837623	18.01980936	13.60806293	31.87020766	21.85989288	21.06453577
	Selection	1	1	1	1	1	1	1
Rajasthan	Fixed Cost	20.60658407	21.50011806	14.91294568	11.19340848	62.4168914	52.54638547	40.67319522
	Variable Cost	19.8901413	19.26069072	17.10142046	12.8338325	42.39626182	34.25255074	27.62312501
	Selection	0	0	1	0	1	0	0
Cambay Ba	Fixed Cost	37.43770738	33.92695142	22.86651671	15.90714206	124.3497334	77.38886749	115.3677905
	Variable Cost	28.73911044	18.71574683	19.38682938	13.04882747	46.32023065	40.67008836	48.74793394
	Selection	1	1	0	1	0	1	1
	DEMAND	13.7	12	9	6.5	33	27	20
		<=	<=	<=	<=	<=	<=	<=
		2	2	2	2	2	2	2
	SELECTION	2	2	2	2	2	2	2

Figure 21 – Excel file Refinery Options

The screenshot in figure 21 shows the total capacity and cost according the scenarios. The flow in row 52 shows the total flow in particular refinery according to the scenario. And the row 53 shows the total cost per refinery in transporting a barrel of crude oil per mile. This includes the fixed cost, the variable cost per mile, and the flow out all according to the selection.

The choice at each oil site location and refinery selection are modeled by two 0-1 variables. For if the refinery Koyali is selected from the refinery options there will be fixed costs and. If is 1, the model will open for 25 percent of oil flow through the pipeline. In refinery options section, the adjustable cells to Correspond to the 0-1variables.

	CAPACITY AND COST						
FLOW	2466000	2112000	1350000	1300000	4752000	3888000	3200000
COST	58581034.99	42194383.47	23086947.69	17690507.41	197454536.9	84991377.57	67406655.32
	2466000	2112000	1350000	1300000	4752000	3888000	3200000
	<=	<=	<=	<=	<=	<=	<=
	13700000	12000000	9000000	6500000	33000000	27000000	20000000

Figure 22 – Excel file on Capacity and cost calculation

		SCENARIO (1-6)				
GUJARAT	RAJASTHAN	CAMBAY BASIIN				
1	1	1			Total Cost	745384147.1

Figure 23 – Model description with scenarios

This research dissertation uses Solver of Microsoft Excel to minimize the transportation cost. The Objective function is defined as below

$\sum_{i-3} A_{IJ} X_{ij} Y_{ij} + \sum_{i-3} B_{ij} Y_{ij} + \sum_{i-3} C_{IJ} X_{ij} Y_{ij}$ (1)

Where

A_{IJ} = total pipeline cost from field i to refinery j

B_{ij}= fixed costs from field i to refinery j

C_{IJ} = Variable cost from field i to refinery j

i = the oil field from where oil is extracted

j = the refinery to which oil is shipped

X_{ij} = the oil shipped from field i to refinery j in Barrels of oil

Y_{ij} = the binary selection of moving oil from field I to refinery j

The following equations are used as constraints to ensure that the capacities of refinery are capacity.

$\sum_{i-3} X_{ij} \geq D_{ij}$ ……………… (2)

Where D_{ij} is the refinery capacity from field i to refinery j

$\sum_{J-6} X_{ij} \geq O_{ij}$ …………… (3)

Where O_{ij} is the operating capacity of refinery j

$\sum_{J-6} X_{ij} \geq F_{ij}$ …………….. (4)

Where $F_{ij\ the}$ flow capacity from field i to refinery j

Last we have the binary equation for the selection of refineries

$\sum Y_{I = 1 \ldots 3 \leq} 1$ ……………… (5)

Use of binary constraint, the selection of oil producing deposits for each refinery is done. The demand for the refineries is fulfilled by a single production or more than one for selection.

$Y_{1j} + Y_{2j} + Y_{3j} \leq 2$ ………….. (6)

The Excel model is used to minimize the total cost i.e. cell G5. All the different scenarios are plugged in the Excel programming and users can toggle it to have the minimum cost. The users can change the variable cost and the fixed cost also.

The objective function G3 is the sum of N42 (Transportation cost) and N54 (Refinery setup cost). The selection of the oil producing districts for particular refineries is decided based upon the binary variables C21:I20, C24:I24, C27:I27.

SCENARIO (1-6)

GUJARAT	RAJASTHAN	CAMBAY BASIIN		Total Cost	745384147.1
1	1	1			

	PRODUCTION FIELD TO REFINERY	Koyali	Mumbai HPCL	Bhatinda	Mumbai BPCL	Jamnagar	Jamnagar SEZ	Vadinar
	Gujarat	113.3	196.35	837.93	198.4	328.23	350.42	358.67
	Rajasthan	333.8	567.3	451.36	570.4	239.16	352.16	330.22
DISTANCE (mile	Cambay Basin	116.06	227.35	868.93	230.02	359.23	381.42	389.67
COST PER MILE ($/mile)	Gujarat	0.01901	0.02871	0.11279	0.02871	0.04651	0.05048	0.05048
	Rajasthan	0.04247	0.07780	0.06230	0.03656	0.05626	0.05048	0.05048
	Cambay Basin	0.01901	0.03357	0.12053	0.03256	0.05048	0.05442	0.05442

REFINERY OPTIONS ($/Barrel/Mil

		Koyali	Mumbai HPCL	Bhatinda	Mumbai BPCL	Jamnagar	Jamnagar SEZ	Vadinar
Gujarat	Fixed Cost	20.29527632	18.95186847	15.16149477	9.693414692	44.52135658	36.67963264	25.47690358
	Variable Cost	21.25094759	19.97837623	18.01980936	13.60806293	31.87020766	21.85989288	21.06453577
	Selection	1	1	1	1	1	1	1
Rajas from	Fixed Cost	20.60658407	21.50011806	14.91294568	11.19340848	62.4168914	52.54638547	40.67319522
	Variable Cost	19.8901413	19.26069072	17.10142046	12.8338325	42.39626182	34.25255074	27.62312501
	Selection	0	0	1	0	1	0	0
Cambay B	Fixed Cost	37.43770738	33.92695142	22.86651671	15.90714206	124.3497334	77.38886749	115.3677905
	Variable Cost	28.73911044	18.71574683	19.38682938	13.04882747	46.32023065	40.67008836	48.74793394
	Selection	1	1	0	1	0	1	1
	DEMAND	13.7	12	9	6.5	33	27	20
		<=	<=	<=	<=	<=	<=	<=
		2	2	2	2	2	2	2
	SELECTION	2	2	2	2	2	2	2

FLOWS (Barrels of oil per year)

	Koyali	Mumabi HPCL	Bhatinda	Mumbai BPCL	Jamnagar	Jamnagar SEZ	Vadinar	FLOW OUT			Transportation cost (US	Cost as per Scenario (US $ Dollar)
Gujarat	8206064.250	10560000.000	0.000	6500000.000	1906035.340	19440000.000	16000000.000	6E+07	<=	6E+07	776939288	155387858
Rajasthan	0.000	0.000	6750000.000	0.000	21853964.660	0.000	0.000	3E+07	<=	3E+07	483853527	96770705
Cambay Basin	4123935.750	0.000	0.000	0.000	0.000	0.000	0.000	4E+06	<=	2E+07	9100703.92	1820140.8
FLOW IN	12330000	10560000	6750000	6500000	23760000	19440000	16000000					
	<=	<=	<=	<=	<=	<=	<=					
CAPACITY	########	########	########	########	########	########	########					
	>=	>=	>=	>=	>=	>=	>=					
DEMAND	########	########	########	########	########	########	########					
											1269893519	253978704

FLOW ACCORDING TO SCENARIO

	Koyali	Mumabi HPCL	Bhatinda	Mumbai BPCL	Jamnagar	Jamnagar SEZ	Vadinar
Gujarat	1641212.85	2112000	0	1300000	381207.068	3888000	3200000
Rajasthan	0	0	1350000	0	4370792.932	0	0
Cambay Basin	824787.15	0	0	0	0	0	0
FLOW IN	2466000	2112000	1350000	1300000	4752000	3888000	3200000

CAPACITY AND COST

FLOW	2466000	2112000	1350000	1300000	4752000	3888000	3200000	
COST	58581034.99	42194383.47	23086947.69	17690507.41	197454536.9	84991377.57	67406655.32	491405443
	2466000	2112000	1350000	1300000	4752000	3888000	3200000	
	<=	<=	<=	<=	<=	<=	<=	
	13700000	12000000	9000000	6500000	33000000	27000000	20000000	

Figure 24 – Full Excel Model

Chapter 4

Results

The objective of this dissertation is to see if the supply chain costs of the Indian oil and gas industry can be solved by introducing a mixed-integer programming (MIP) model that can improve the supply chain quality of crude oil. In order to meet the objective, evaluate the economic impacts of pipeline infrastructure (quality) and refinery capacity (Sustainability) on the supply chain network. The results of the objective are below.

Table 14 – Cost of transportation from Gujarat oil deposit according to scenario

Pipe diameter with Flow Level percent	**Supply Chain Costs ($) Billion**
8 5/8 inch dia <50% flow	0.041469095
8 5/8 inch dia >50% flow	0.076995986
10 ½ inch dia <50% flow	1.115343160
10 ½ ich dia >50% flow	1.790528730
12 1/3 inch dia <50% flow	1.886979914
12 1/3 inch dia >50% flow	2.858750016

Table 15 - Cost of transportation from Rajasthan oil deposit according to scenario

Pipe diameter with Flow Level percent	**Supply Chain Costs ($) Billion**
8 5/8 inch dia <50% flow	0.305162981
8 5/8 inch dia >50% flow	0.57057496
10 ½ inch dia <50% flow	0.85668384
10 ½ inch dia >50% flow	1.305533496
12 1/3 inch dia <50% flow	1.404036860
12 1/3 inch dia >50% flow	2.088758260

Table 16 - Cost of transportation from Cambay Basin oil deposit according to scenario

Pipe diameter with Flow Level percent	**Supply Chain Costs ($) Billion**
8 5/8 inch dia <50% flow	0.025524068
8 5/8 inch dia >50% flow	0.539163885
10 ½ inch dia <50% flow	0.074476466
10 ½ inch dia >50% flow	0.131221037
12 1/3 inch dia <50% flow	0.1471325052
12 1/3 inch dia >50% flow	0.250072764

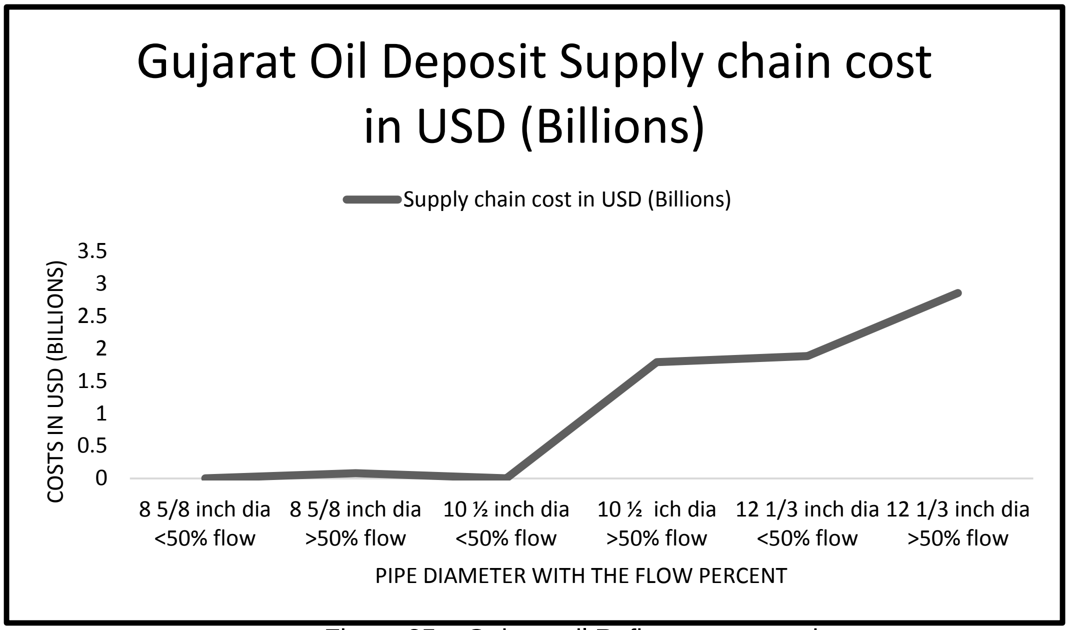


Figure 25 – Gujarat oil Refinery cost trend

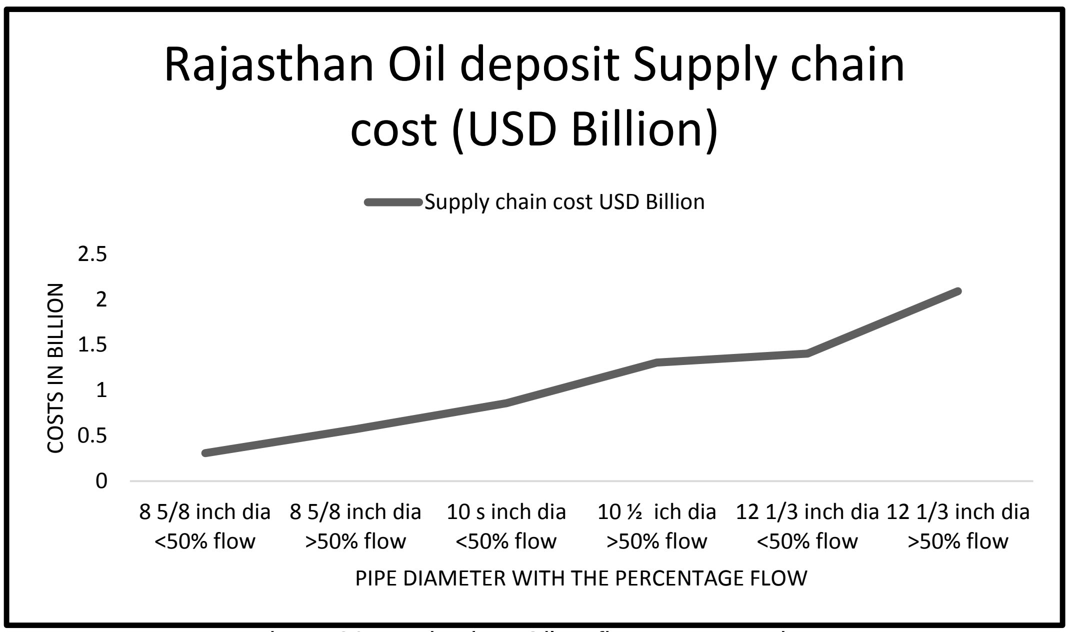


Figure 26 – Rajasthan Oil Refinery cost trend

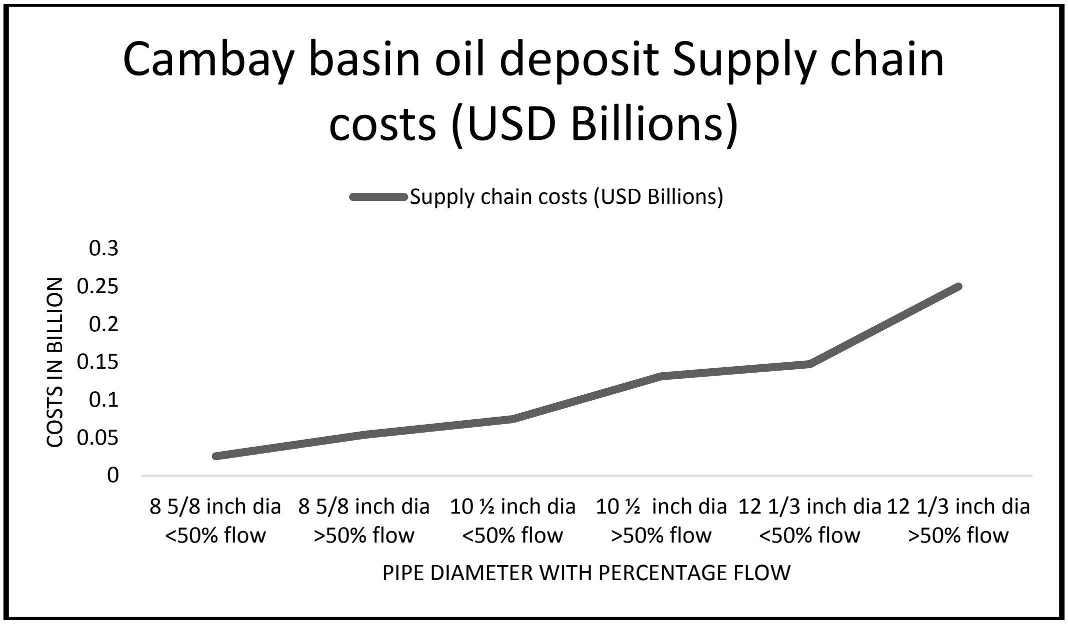


Figure 27 – Cambay Basin cost trend

Chapter 5

Contribution to the Body of Knowledge

5.1 Conclusion

According to the statistics India has increased its dependence on crude oil and petroleum products resources from other countries by more than 20 percent. The petroleum and natural gas statistics 2014 verbally expressed that India imported proximately 75 to 80 percent of oil in 2013. The consequentiality of this dissertation is to seek the impacts of the utilization of pipeline as a mode of transportation on the supply chain cost or the transportation cost. The quandary here is solved by introducing a mixed – integer programming (MIP) model. The broader impacts is whether the supply chain can be optimized by identifying the possible investments for the future global supply chain of crude oil needs.

What transpires to the Indian oil and gas supply chain when the transportation mode is transmuted? Over a period of time, the Indian oil and gas supply chain has visually perceived an incrementing demand in the crude oil. According to the Petroleum and Natural Gas Statistics India imports 75% of the crude oil for its domestic requisites. It is visually perceived that the refining capacity is much more preponderant than domestic crude oil production. Today, we face a question that if the present supply chain network can handle the incrementing ordinate dictation of crude oil. With most of the petroleum and gas products being imported thus the country faces the case if the current pipeline and the refinery capacity can handle the growing demand. "Is it economically salutary to invest in the supply chain quality of crude oil for India?" Hypothesizing that the pipeline infrastructure will impact crude oil supply chain costs, and suggests what will give us the minimum supply chain costs.

In Indian oil industry, the government own most of the production sites and the refinery operations. The Indian Petroleum and Natural Gas industry has set the main goal to maximize its profits. The regime has adopted incipient policies to magnetize the peregrine investment to sustain its growing demand. By amending the efficiency in the entire supply chain can lead to amend in the product performance, and additionally minimize the cost.

5.2 Limitations and Area of Disciplines

There are inhibitions for this dissertation such as the availability of data and the scope of the dissertation. The organization of Petroleum Exporting Countries (OPEC), Cumulated United States of Energy Information Administration (U.S. EIA), Ministry of Petroleum and Natural Gas of India provided subsidiary data and facts about the Indian Oil Industry. This dissertation is mainly fixated on the domestic Indian Oil industry supply chain due to very circumscribed data and information on the supply chain and the cost involved. This dissertation is mainly fixated on only three of the production sites and only seven oil refineries proximate to the culled production sites. Therefore, the scope of the dissertation is broad enough to consider the nature of the supply chain activities over the entire domestic crude oil supply chain. Additionally the import of crude oil and the export of refined petroleum products can be taken into consideration to solve the overall global supply chain for India. Future work as a continuation of this dissertation can be proposed when we include the entire supply chain of India considering the domestic and international market.

Several industrial engineering disciplines are included in this dissertation like optimization methodology, supply chain management (SCM) applications. Optimization methodology is utilized to develop and solve the mixed integer programming model that will defined how the pipeline mode of transportation to supply crude oil from the selected production sites to the refineries and calculate the transportation/supply chain cost. The Supply Chain Management application expounds how the oil supply works the kinetics of oil from where it is produced, to where it is refined and lastly where these products are sold.

5.3 Intellectual Merit and Broader Impact

The astute merit of this dissertation is a mixed – integer programming model that will avail us in determining the supply chain cost of the domestic oil distribution from the production sites to the refineries. Furthermore, the broader impacts of this dissertation is to look in how the future investments showed and can be made to optimize the countries supply chain for future global crude oil needs.

Appendix A

India crude oil Production, Consumption and Net Imports from 2007 to 2014.

In Million Metric Tons

Preliminary Data: Ministry of Petroleum and Natural Gas Statistics

Year	Production	Estimated Consumption	Net Imports
2007-08	34.118	128.946	94.828
2008-09	33.508	133.599	100.091
2009-10	33.690	137.808	104.118
2010-11	37.684	141.040	103.356
2011-12	38.090	148.132	110.042
2012-13	37.862	157.057	119.195
2013-14	37.788	158.197	120.409

Appendix B

State Wise/ Area wise Balance Recoverable reserves.

In Million Metric Tons

Preliminary Data: Ministry of Petroleum and Natural Gas Statistics

State	2009	2010	2011	2012	2013	2014
Arunachal Pradesh	3.65	3.49	3.39	3.41	3.37	2.95
Andhra Pradesh	4.21	3.49	5.22	5.59	7.42	11.45
Nagaland	2.69	2.69	2.69	2.69	2.69	2.69
Jharkhand	-	-	-	-	-	-
West Bengal	-	-	-	-	-	-
Madhya Pradesh	-	-	-	-	-	-
Tamil Nadu	7.97	7.84	8.48	8.86	9.21	9.12
Tripura	0.08	0.08	0.08	0.07	0.07	0.07
Assam	167.32	168.10	170.33	172.54	172.11	173.08
Rajasthan	84.68	80.48	75.33	68.87	60.19	45.00
Gujarat	134.97	136.67	137.43	135.72	136.73	135.01

Appendix C

Abbreviations

API – American Petroleum Institute

WTI – West Texas Intermediate Crude Oil

WTS – West Texas Sour

OPEC – Organization of the Petroleum Exporting Countries

ONGC – Oil and Gas Corporation

bopd – Barrels of Oil per day

MMT – Million Metric Tons

MMTPA – Million Metric Tons per Annum

OIL – Oil India Limited

NELP – New Exploration Licensing Policy

VLCC – Very Large Crude Carrier

ULCC - Ultra – Large Crude Carrier

HVL – High Volatile Liquids

TMT – Thousand Metric Tons

MIP – Mixed Integer Programming

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Biographical Information

Atul Vilas Kamble was born September 7, 1990 in Mumbai, India. He received the Bachelors of Engineering in Mechanical Engineering from Mumbai University in 2012. In August 2015, he graduated with Master of Science of Industrial Engineering. Mr. Atul Vilas Kamble is a member of a number of professional and student organizations including University of Texas at Arlington Chapter of Institute of Industrial Engineers (IIE) and Chapter American Production and Inventory Control Society (APICS).

It was during his Bachelors, Atul participated in mechanical engineering internship with Chandra Engg & Mechanical Pvt Ltd., a mechanical firm concentrating in the field of LPG safety fittings and industrial bulk systems. This experience provided him with valuable insight in the industrial engineering basics like layout design and facility planning, worker output efficiency calculations.

During Atul's academics at University of Texas at Arlington he was Graduate Research Assistant and Assistant Lab Manager at RAID (Radio Frequency and Auto Identification) Labs. Atul also received the RFID & AutoID (RAID) Labs research Excellence Scholarship to recognize his Excellence in research.