Utilizing Pipeline Quality and Facility Sustainability to Optimize Crude Oil Supply Chains

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***Abstract*— In this paper, the distribution center (DC) model shown in Shapiro's *Modeling the Supply Chain* is modified to show optimal locations to place small and large refineries based on transportation distances, refinery building costs, and the costs associated with refinery sustainability and pipeline quality. Though this model was originally used to determine the optimal locations to place distribution centers based on transportation distances and the size of the distribution centers, this model was modified to allow the use of different costs associated with the quality condition of the pipeline and the costs of sustaining an environmentally friendly facility. The case used to prove the model is the Indonesian oil industry due to how an increase in efficiency and excess capacity could provide another viable country to supply oil to the United States. The outputs of this paper are efficiency frontiers that show how the costs of pipeline quality and facility sustainability affect the overall costs of the Indonesian oil industry and a model that can be used to evaluate the oil industries in other countries.**

***Keywords*—** *supply chain management, quality, sustainability incentives, optimization, crude oil supply chain*

1. Introduction

The United States' dependence on foreign sourced oil is necessary to sustain the American people's needs based on the current policies. The current U.S. sources for oil are not limited to politically stable countries and, though stable now, rely heavily on OPEC member Saudi Arabia. There is a concern about the impact to the U.S. economy if Saudi Arabia decides to manipulate demand and possibly stops exporting oil to the United States. There has been a lot of change in the Middle East in just the past 24 months. Libya, Egypt, and Syria are just a few of the countries that have seen shifts in power and leadership, some that are now more anti-American than before. Add to this shift the belief that the dependence on foreign oil does not present strategic challenges to the United States and that it does not negatively affect the nation's economy and national security. This dependency has had a large impact on the U.S. foreign policy and continues to influence international relationships. Today, the consideration is more in regards as to which foreign oil sources are the most challenging and what steps could be taken by the U.S. government to help alleviate these challenges.

1.1 Dependency

The New York Times explained that the United States increased its dependence on oil from Saudi Arabia by more than 20 percent in 2012 [10]. However, according to the United States Energy Information Administration (U.S. EIA), the net imported oil of the U.S. has declined since peaking in 2005 – see Figure 1 [35].

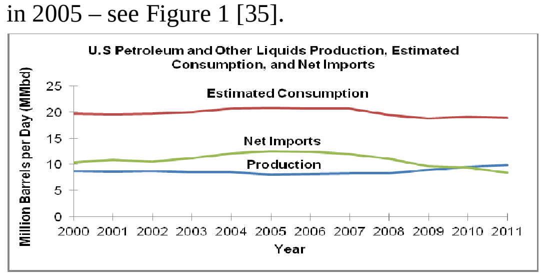

Figure 1. U.S. Petroleum and Other Liquids Production, Estimated Consumption, and Net Imports from 2000 – 2011 [35]

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Krauss described that the increase in oil imports from Saudi Arabia began last summer for a number of reasons:

> "Saudi Arabia increased oil production and exportation to all countries including the U.S. to keep oil prices stable, because Iran is exporting less oil due to sanctions imposed by the U.S. which gives some fear to make nuclear weapons; several domestic oil refining companies in the U.S. have found it necessary to buy more crude oil from Saudi Arabia to make up for declining production from Mexico and Venezuela; Canadian oil production has been increasing rapidly in recent years, unfortunately, there is not enough pipeline capacity; and there are also echoes from the disastrous British Petroleum (BP) well explosion and spill in 2010, which led to yearlong drilling moratorium in the Gulf Mexico" [10].

The U.S. EIA stated that the U.S. consumed an estimated 18.8 million barrels per day (MMbd) of petroleum products and produced 10.4 MMbd of crude oil and petroleum products during 2011 [35]. Therefore, the U.S. net imports of crude oil and petroleum products equaled 8.4 MMbd, making the U.S. dependent on foreign oil – see Figure 1 [35]. The Western hemisphere including North, South, and Central America, the Caribbean, and the U.S. territories; and the Persian Gulf countries such as Iraq, Kuwait, Qatar, Saudi Arabia, and United Arab Emirates, exported 52 percent and 22 percent, respectively of crude oil and petroleum products to the U.S. in 2011 [35]. Oil from Canada and Saudi Arabia accounted for 29 percent and 14 percent, respectively, of the U.S. crude oil and petroleum products imports, resulting in those countries representing the top two foreign oil sources for the U.S. in 2011 – see Figure 2 [35]. This is problematic due to the fact that 14 percent of the U.S. net crude oil and petroleum products imports come from one country, Saudi Arabia, which threatens U.S. homeland security by leaving the U.S. susceptible to Middle Eastern manipulation. While the U.S. does import a larger percentage of crude oil and petroleum products from Canada, Canada is considered an ally due to treaties signed during World War II and during the Cold War.

The significance of this research is to seek impacts of the U.S. dependency on foreign oil problems by introducing a mixed-integer programming (MIP) model that identifies how other nations such as Indonesia can be more efficient in their crude oil supply chain a produce more crude oil products for export.

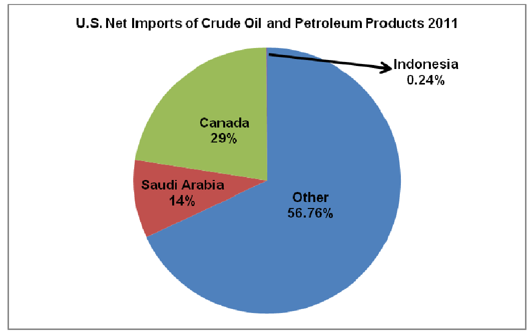

Figure 2. U.S. Net Imports of Crude Oil and Petroleum Products from Saudi Arabia, Canada, and Indonesia in 2011. [35].

This model was built with respect to the tradeoff between crude oil supply chain quality, sustainable environmental incentives, and supply chain costs. Furthermore, the broader impact is how investments into other countries crude oil supply chains can be quantified and optimized and how countries such as Indonesia can be identified as possible candidates for investment for future global crude oil needs. This paper hypothesizes that the crude oil supply chain quality will impact the crude oil supply chain costs and the environmental sustainability will have an impact on crude oil supply chain costs, and suggests that the crude oil supply chains each of these countries will dictate their ability to produce crude oil for export. The overall objective is to investigate a mixed-integer programming (MIP) model that supports decisions about providing economic and environmental incentives to improve the supply chain quality of crude oil, specifically in Indonesia so that it becomes more cost effective for the U.S. to import crude oil from Indonesia as opposed to other global sources.

The remainder of this paper is organized as follows: Section II provides background of the problem; Section III organizes the components and discusses the methodology of the model; Section IV discusses the results from the model; and Section V concludes the paper and addresses some of the limitations of the research.

2. Background

Bjorklund outlined important aspects to consider in the design of environmental performance measurements in supply chain management [2]. Platts suggested measuring the actual total acquisition costs to gain profitability in supply chain network [16]. Additionally, this research follows a similar methodology as Rodrigo, et al.

which provided a set of objectives that were forming Pareto efficient frontiers [22]. In order to optimize the profit and quality objective function Rodrigo, et al. utilized a ε-constrained method [22]. The specific model that was derived for use this paper is the Distribution Center model from Shapiro's Modeling the Supply Chain [24].

There are three quality metrics that are considered for pipelines performance. The first metric is the failure of a pipeline segment. This involves a complete loss of a particular segment of a pipeline to transport crude oil. Possible causes include unplanned maintenance, accidental excavation damage, or sabotage. The second metric is the loss of crude oil transmission compressor. This focuses on partial reductions in deliverability due to removal from service of one or more crude oil compressor. Possible causes include forced outage of a compressor driver, an explosion or fire in the compressor station, or the failure of ancillary systems. The third metric is the loss of deliverability from storage facilities. This includes the loss of deliverability from one or more of the major underground storage fields.

The United States Environmental Protection Agency (EPA) classifies two types of wastes in the case of crude oil; exempt and non-exempt wastes. The EPA defines exempt wastes as follow:

"Wastes that are generated before the end point of primary field operations are exempt. The term end point of initial product separation means the point at which crude oil leaves the last vessel in the tank battery associated with the wells. This tank battery separates crude oil from the produced water and/or gas." [29]

Pipelines are not part of primary field operations, thus, oil wastes that are generated by pipelines are non-exempt. Failure of a pipeline segment caused by accidental excavation damage is an example of non-exempt wastes, which will result in oil companies paying fines to the EPA as well as settlements to clean the surrounding environment. This pipeline segment failure is chosen as the sampling plan of supply chain quality level performance.

Globalization has resulted in pressure on multinational firms to improve environmental performance. In order to achieve improvement in environmental performance, a company must integrate its environmental management strategies, while maintaining production quality and cost goals, into the supply chain which includes all of the operational life cycle stages such as unique partnerships with suppliers. Environmental sustainability has been defined as "meeting the needs of the present without compromising the ability of the future generations to meet their needs" [27].

For oil companies, the concept of sustainability is most appropriately used when evaluating their business strategies. Sustainability concerns the degree to which they not only reduce negative impacts on the natural environment through their operations, but also invest in business practices that promote policies to make wide reaching progress toward sustainable development. In the industry, the operations of oil companies are examined for their impact on the surrounding environment annually. To distinguish from the above definition of sustainability, environmentally conscious operations are referred to as green operations. However, green operations are not necessarily sustainable in the long run, but minimizing the negative impact of operational processes is still environmentally conscious. Company operations deal with energy usage necessary for operating refineries, emissions, and waste. Meanwhile, sustainability of the products deals with oil, natural gas, and possible alternatives to fossil fuels.

In the oil industry exploration and production processes, sustainability involves the products, and as such, the petroleum industry itself is environmentally unsustainable because like all fossil fuels, oil is a limited resource. Additionally, drilling in previously undisturbed areas requires clearing vegetation in order to build roads, to haul in equipment, and to construct wells. Wildlife is displaced. All of these actions are temporary and when the oil field reservoir is depleted, the area could be restored to its pre-developed condition. Indirect permanent effect comes from exhaust gases emitted by construction and haul vehicles. Also, drilling in the ocean has the potential for accidents as in the case of Deepwater Horizon explosion in the Gulf of Mexico. The subsequent oil spill killed an unknown numbers of fish and birds. This was the largest spill in history and caused extensive damage to the environment. It was a single event which can be recovered from. At this time, any permanent impacts to sustainability are not fully known, but history shows that over time, in some instances decades, nature recovers. In the refining process, sustainability deals with the company operations which involve in energy usage necessary for operating refineries, emissions, and waste. For example, refinery produces waste gases that cannot be recaptured and are emitted into the atmosphere. This is an instance of an unsustainable practice. Sustainability involved in pipelines, both above and below ground have the potential to break and spill petroleum during transport into the surrounding environment. Some risks of accidental spills of oil have the potential to pollute water, contaminate soil, harm species, and affect livelihoods.

Oil companies need to plan all significant operations in advanced and manages their costs throughout the entire supply chain to enhance the profit margin. Both sustainability that deals either with oil companies' processes or products, will have positive and negative impacts on the supply chain costs. An example of the negative impact is definitely the disastrous British Petroleum (BP) drill explosion and oil spill in 2010 which impacted wildlife in the Gulf of Mexico. This accident resulted in damaging the environment as well as costing BP a settlement of billions of dollars. Contrary, an example of the positive impact is the ability to be able to preserve the productivity of oil itself as a natural resource asset which leads to supply chain costs savings.

Unlike the quality metrics which focused on pipelines performance, this research considers refining process as a good candidate to determine its sustainability metrics. Refinery is a complex process. In this process, crude oil is heated and broken down into its components. Then, the conversion process transforms lower-valued products into higher-valued products by removing impurities. This conversion process dictates the different types of crude oil, thus, distinguishing the differences in refineries. The refining sector of the oil industry has significantly affected the crude oil global marketplace due to the demand growth of petroleum products. As the petroleum products demand increases, the demand for conversion capacity increases. Refineries affect supply chain profit margin such that refineries' variable costs vary on the petroleum products demand.

There are two sustainability metrics that are considered for refineries performance. The first metric is the refining operations which deal with energy usage necessary for operating refineries, emissions, and waste. The second metric is the refining products which deal with oil to fossil fuels. Refining processes that deal with energy usage are chosen as environmental sustainability according to the performance sampling plan.

3. Methodology

This research establishes a mixed-integer programming (MIP) baseline models and an efficient frontier curve, which incorporate both sampling plans of pipeline quality and refinery sustainability performance to evaluate the economic impacts of inspection tools (quality) and environmental incentives (sustainability) tools on operational strategies in supplier networks. This research utilizes SAS Statistical software and Excel Solver to solve for optimal solutions. Crude oil supply chain quality data are collected from the Organization of the Petroleum Exporting Countries (OPEC) public databases, the U.S. Energy Information Administration (EIA) website, and the Indonesia Directorate General of Oil and Gas (MIGAS) website. Data involve in sustainability are collected from the U.S. Energy Information Administration (EIA) website and the U.S. Environmental Protection Agency (EPA) website.

This paper evaluates whether or not the crude oil supply chain quality and the environment sustainability will impact the supply chain costs from the research question. These two hypothesis statement are stated as follow:

Hypothesis Statement #1

H_0: The crude oil supply chain quality will not impact the supply chain costs.

H_1: The crude oil supply chain quality will impact the supply chain costs.

Hypothesis Statement #2

H_0: The environment sustainability will not impact the crude oil supply chain costs.

H_1: The environment sustainability will impact the crude oil supply chain costs.

The rejection region for the H_0 is verified or rejected for both of the hypothesis statements if both supply chain quality and environment sustainability metrics change the supply chain costs by more than 20 percent.

In this research, the distribution center (DC) model shown in Shapiro's book is utilized to show optimal locations to place distribution centers based on transportation distances and the size of the distribution centers. The model was worked in Microsoft Excel and used GRG nonlinear engine in Solver to minimize the objective function. The objective function was solved for based on the costs for oil transportation, the fixed costs for pipeline quality and refinery efficiency, and the variable costs for pipeline quality and refinery efficiency. Several scenarios were run that varied the fixed and variable costs in order to compare how pipeline quality and refinery sustainability impact the supply chain costs. These factors are identified in Table 1 and Table 2.

Table 1. Pipelines Quality Level Performance

Quality Level	Pipeline Quality Description
1	Damaged and Causing Non-Exempt Wastes
2	Damaged and Not Causing Non-Exempt Wastes
3	New and Not Causing Non-Exempt Wastes

Table 2. Refinery Sustainability Level Performance

Sustainability Level	Refinery Sustainability Description
4	High Energy Usage Consumption
5	Medium Energy Usage Consumption
6	Low Energy Usage Consumption

The scenarios that were run are identified in Table 3. In this paper the following terminologies are used to identify the components of the scenarios:
QP_{Duri} = Pipeline Quality at Duri location
QE_{Duri} = Refinery Sustainability at Duri location
QP_{Minas} = Pipeline Quality at Minas location
QE_{Minas} = Refinery Sustainability at Minas location

Table 3. Scenarios Summary

Exploration Production Location	Sampling Plan	Performance Level	Scenario
Duri	Pipeline Quality (QP_{Duri})	1	1
		2 (Baseline)	2
		3	3
	Refinery Sustainability (QE_{Duri})	4	4
		5 (Baseline)	5
		6	6
Minas	Pipeline Quality (QP_{Minas})	1	7
		2 (Baseline)	8
		3	9
	Refinery Sustainability (QE_{Minas})	4	10
		5 (Baseline)	11
		6	12

For the objective function, Eq. (1) was derived:

$$MIN: \sum_{i\to 4} A_{ij}X_{ij}Y_{ij} + \sum_{i\to 4} B_{ij}X_{ij}Y_{ij} + \sum_{i\to 4} C_{ij}X_{ij}Y_{ij} \quad (1)$$

Where:

A is the total pipeline costs from field *i* to refinery *j*

B is the QP/QE fixed costs from field *i* to refinery *j*

C is the QP/QE variable costs from field *i* to refinery *j*

i is the oil field from where the oil originates

j is the refinery to where the oil is shipped and processed

X is the number of barrels of oil shipped from field *i* to refinery *j*

Y is the binary selection of moving oil from field *i* to refinery *j*

Table 4 and Table 5 identify the *i* and *j* values for each of the oil fields and refineries.

Table 4. Oil Field Numbering

I	Oil Field
1	Duri Small
2	Duri Large
3	Minas Small
4	Minas Large

Table 5. Refinery Numbering

i	Refinery
1	Pangkalan Brandan
2	Dumai
3	Sungai Pakning
4	Musi
5	Balongan Langit Biru
6	Cilacap
7	Cepu
8	Balikpapan

The following equations were used as constraints to ensure that capacities of the pipelines were met:

$$\sum_{i \to 4} X_{ij} \geq D_{ij} \qquad (2)$$

Where Dij is the pipeline capacity for the pipeline from field i to refinery j

The selection of the refineries used at each location was constrained using a binary constraint. Because only one refinery would be used at each location the sum of the two constraints needed to be less than or equal to 1 in order to work in Solver. These equations are shown in Eq. (3) and Eq. (4).

$$Y_{1j} + Y_{2j} \leq 1 \qquad (3)$$

$$Y_{3j} + Y_{4j} \leq 1 \qquad (4)$$

A snapshot of the model in Excel is shown in Figure 7 and 8. This model allows the user to enter the scenario they wanted to run in cells B4 and B5. Based on these inputs, a look up table populates The objective function was comprised of the transportation costs in cell L47, the small refinery costs in cell L53, and the large refinery costs in cell L58. The total number of facilities built at each refinery location should be 1. This could be either the large or small refinery but not both. These constraints can be seen in cells C35 through J38 and in Solver a binary constraint was made on the selection cells C21 through J21, C25 through J25, C29 through J29, and C33 through J33.

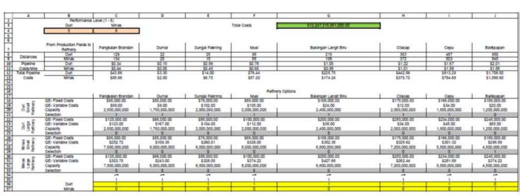

Figure 7. Pipeline Distance Costs and Refinery Selection

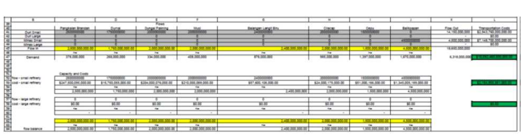

Figure 8. Refinery Selection Costs

4. Expected Results

There are three expected results from this research. First, we expected to reject our null hypothesis in favor of our hypothesis that the crude oil supply chain quality and sustainability impact crude oil supply chain costs. Second, we expected the crude oil supply chain quality metrics such as to impact the supply chain cost model by more than 20 percent. Finally, we expected the crude oil supply chain sustainability factor which based on to impact nodes of the supply chain by more than 20 percent.

The solution of the objective function during the 12 scenarios provided information for 4 efficiency curves, seen in Figure 9 through 12, which show the regions for refinery efficiencies and pipeline quality for the Duri and Minas oil fields.

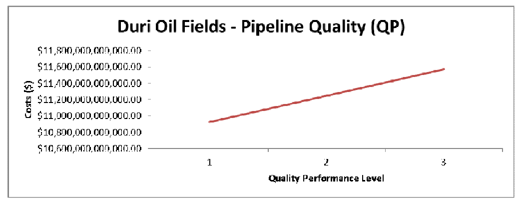

Figure 9. Duri Oil Fields Pipeline Quality

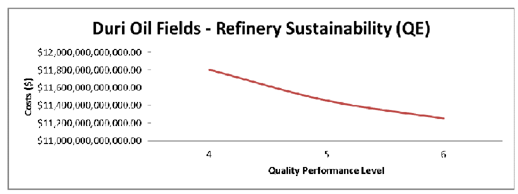

Figure 10. Duri Oil Fields Refinery Sustainability

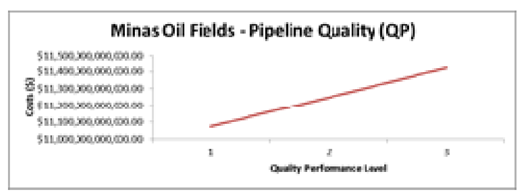

Figure 11. Minas Oil Fields Pipeline Quality

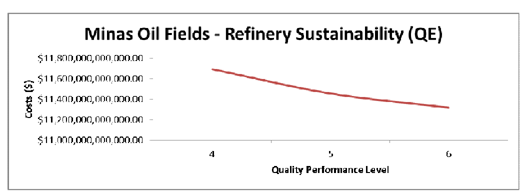

Figure 12. Minas Oil Fields Refinery Sustainability

The results of the model fail to reject the null hypotheses. In order to reject each hypothesis, the model needed to show that both the pipeline quality and refinery sustainability changed the supply chain costs by 20%. The most that is seen in the model is a change of approximately 6% in costs. The largest impact occurred with the pipeline quality. Both Duri and Minas pipeline quality affected the supply chain costs by 5% to 6%. The costs that were associated with the refinery sustainability affected both Duri and Minas by 3%. This also shows that the second and third null hypothesis could not be rejected either because neither the supply chain quality nor the refinery sustainability caused a change of 20% in the supply chain costs.

5. Conclusion

There are some expected limitations for this research such as the availability of data and scope of the research. The U.S. EIA provides numerous useful data for the U.S. oil industry. Meanwhile there are limitations concerning the data collection of the Indonesia oil industry due to lack of information. The scope of this research is only the Indonesia oil industry as prior to interaction with the U.S. oil industry. This scope is already broad enough considering the nature of supply chain activities on both countries. Future work can be conducted as the continuation of this research which uses the proposed model that includes other countries.

The intellectual merit of the proposed research is a model that demonstrates the trade-offs between quality and supply chain profit for Indonesia that can be expanded to other countries. The broader impacts of the proposed research are how investments into other countries' crude oil supply chains can be quantified and optimized; and exporting countries such as Indonesia can be identified as possible candidates for investment for future global needs.

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