THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF FINANCE

REASSESSING CRUDE OIL PURCHASES BASED ON SHUTDOWN RISK

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ABSTRACT

This paper examines the process of how refineries obtain the crude oil that is necessary to run the plant. The thesis also examines if there are process improvements that can potentially be put in place to increase profit in refineries. Much of the research done on this topic has been in regards to recent high oil prices. This gap in research has led to a potential inefficiency in the refining process is examined in this paper. Modeling these previously unexamined variables could lead to a place where refiners can create additional profit in a time where the oil industry is suffering from recent lows in crude oil price.

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Chapter 1

Background of Refining

Since the early late 1800's, oil has been a key component of the US economy. From its use as a light and heat source to the energy used to power cars, oil has been a staple of technological development. However, oil is not the final product that people use on a day to day basis. Crude oil must first be refined in order to utilize many of the useful properties of substance. This leads to today where across the world, hundreds of refineries process millions of barrels of oil daily to create more useful petroleum products.

Today there are six major publically owned oil companies with another dozen or so that our nationalized by other foreign governments, which produce much of the world's oil supply. These companies are fully integrated and are responsible for all aspects of the supply chain from drilling for the oil beneath the earth's surface to refining this crude oil, which is sent to consumer markets as transport fuels, lube oils or other petroleum based products. Starting with the beginning of the supply chain, crude oil has two spectrums that determine the quality of the product. First, crudes can be either sour or sweet. This concept refers to the amount of sulfur in the crude, with high levels of sulfur corresponding with sour crudes. Sour crudes are lower in quality compared to sweet crudes, as the oil must be treated to remove the additional sulfur, as gasoline and diesel must meet all federal environmental standards. The other quality aspect of crude to consider is whether it is heavy or light. This is determined by looking at the specific gravity of crude oil or the weight of the oil compared to water (Laffer). Heavy crudes will sink in water where light crudes will float. More importantly to refiners, light crudes will distill to the components that make gasoline and diesel at lower temperatures than heavy crudes will. Thus, heavy crudes require additional machinery to be refined and use a different process than lighter crudes. The other issue with using lower quality crudes is that they often tend to be more corrosive and lead to equipment failure. This effect can be seen in Canadian pipelines that are starting to deteriorate because they have been transporting tar sand oil, which is a very low quality oil (Biello).

While quality is certainly one of the major components that go into deciding what grades of crude a refinery will run, there is another equally as important aspect, price. Most of a refinery's cost are variable costs associated with buying the crude oils for the plant, which far outweigh the fixed costs in the plant. This is why oil traders employ many tactics to try to ensure that they are minimizing cost when buying the supply for plants. This process also has a considerable amount of lead-time, often needing several months for the supply to reach its final destination (Stratiev). All of these factors are considered when buying supply for a refinery, which is why traders often have a support team that uses linear programming and along with other tools to minimize cost to the company, while still ensuring that their refinery runs to meet product demand.

Traded as a commodity, crude oil tends to have considerably more risk than that of bonds or stocks. Crude oil prices fluctuate for many reasons, but the largest reason is simply the quantity supplied and the quantity demanded (Investopedia). This was seen with steadily rising prices during the late 2000's when multiple nations in Europe and China were growing their economy needing more transport fuels coupled with a shrinking oil supply from OPEC. However, there are other reasons that account for some of the fluctuations such as natural disasters, instability of oil producer's economy, and war (Editorial Dept). All of which either cause uncertainty in the market place or simply decrease the global oil supply, which ultimately moves the price. This effect can be seen on all types of oil, as crude reserves exist across the world in countries with a wide range of potential risks. Thus, high and low grades move independently, despite a degree of correlation between the grades.

While there is a considerable amount effort that is put into minimizing the cost of the oil being purchased for the plant, other costs factor into the bottom line of a refinery. These other costs (often times including preventative maintenance) are small compared to the larger costs of goods sold that is present in these refineries. However, this is only true if unplanned shutdowns do not occur. When forced to shut down a unit, a refinery faces two separate kinds of cost. The first is simply the cost to fix the issue at hand. These costs can range from simply buying new parts to having to pay additional overtime to workers tasked with solving the problem. These costs while expensive, pale in comparison to that of the amount of lost profit by being unable to process a day's worth of crude oil. Worse, in continued shutdowns, semi-processed crude oils may sold in a separate intermediate market where the value is drastically lower than simply selling as finished goods. This is why maintenance is one of the focuses in many refineries, especially with many aging, built decades ago. Unfortunately, there is not a wealth of research on eliminating the cost of shutdowns. Most of this information is not only different from refinery to refinery, but not made readily available to the public. However, after consulting a process engineer at a major US refinery, a figure of approximately $2.8 million dollars per day is the standard that they use when referring to lost profits if a large unit was to shut down. Obviously, this is an estimate and will vary from refinery to refinery across the country.

The paper “Evaluation of Crude Oil Quality” by Stratiev et al. goes further into looking at the quality of crude oil products. The paper delves into the factors that make crude oil higher or lower quality and discusses the difference in prices between them. One of the major components for the difference in price between low and high grades of oil is due to the high cost of removing sulfur and the increase in non-energy variable costs such as increased hydrogen usage. They also found at higher oil prices, refineries should process lower quality crudes if possible, as they produce larger quantities of high value transport fuels. This paper also determined there is a discount on buying crudes with a higher acid value, which in turn, increases corrosion.

While the paper by Stratiev et al goes into detail about how quality factors into crude oil pricing, there are also differentials that are used to find a price that traders use. In a paper by Robert Bacon and Silvana Tordo, they determined that different differentials stemming from crude oil quality go into the pricing of various crude blends. What they found from various studies was that there were multiple factors that could raise or reduce price. They then created a regression that could measure the change in price of a barrel of oil by changing the quality variable. What they found is that API, sulfur content, and Total Acid Number (TAN) had the largest effects on prices and that shipping freight rates had a smaller, yet significant effect on the final price. This study also explained why there is a larger premium at high prices as many refineries do not have the capability to process lower grade crudes. Thus leading to a higher level of discount and more margin on which a refinery can profit.

Between looking at many of these papers and first-hand experience in a refinery, it is apparent there is already an extensive process that is in place for purchasing the types of crude oil that are processed in a refinery. There are many factors to consider and there are premiums in place for better quality crudes. There is also a significant difference in how these lower quality inputs are processed and how they affect a refinery. What I have noticed is that there seems to be a sentiment only the cost at purchase matters when considering the grades of crude oil to buy. However, experts readily admit that lower grades of crude oil are harder on a refinery than higher quality grades of crude oil. It seems like there is a disconnect in the process that does not link the increased risk of using low quality crude to the cost associated with a unit shutdown, especially since a unit shutdown cost is significant even by oil industry standards.

One of the other issues with much of the research completed in recent history is in respect to very high oil prices compared to historical averages adjusted for inflation. There has been a significant investment in processing these low-grade crudes during this period, yet with oil prices at 10-year lows, it makes sense to look at the larger process of refining as a whole. In addition, many of the decisions that made sense when oil was $100 a barrel no longer make sense when crude only costs $30 a barrel. Finding a way to increase profit on the margins is imperative for oil companies that have been hemorrhaging money during the recent price drop.

Chapter 2

Methodology

To see if there is a way to increase profit for oil refineries, a basic model using linear programming was created. This basic model acted as a point of reference when looking further into profit optimization. Using an optimization that maximized profit, while also containing several constraints such as volume, price, and failure probability allowed for a relatively realistic scenario of an actual refinery. In addition, oil traders routinely use linear programming tools to optimize usage in the plant itself. The one difference in this model is that it added a variable used to account for shutdown cost. With this new variable, an additional cost would affect profit if the probability of shutdown were too high. This model also was useful because it could show that at certain price points, it may be profitable to purchase higher quality crude oils as the premium would cost less than the cost of shutting the plant down.

While this simple model was useful as a jumping off point, a more extensive model was necessary to obtain a more accurate answer to whether there was a way to improve the crude purchasing process. To do this, a stochastic variable was added to the program that varied price. This created a more realistic scenario, because even though traders purchase crude with futures contracts (an agreement to buy or sell at a price now, but with future delivery), the price of oil fluctuates like any commodity, with no entity having the power to set the price. The other advantage is that this model showed expected profit, which would differ by the probability of each scenario happening.

Chapter 3

Quantitative Analysis

In any model based in linear programming, there is an objective function and multiple constraints that make up the model. Each of the constraints must be met in order for the model to give a valid output value. The objective function in this model maximizes expected profit by using profit margins on a volume basis while also including a failure cost term. The probability of this failure cost occurring increases with each barrel of low-grade oil processed in the plant. In addition, there are constraints on the number of barrels processed of the low-grade oil and combination of the low and high-grade oil. For the constraints, a maximum plant capacity of 600,000 barrels per day was used with a limit of 200,000 barrels of low grade crude. In addition, the fail cost of $2,000,000 per day was used in the model. These numbers come from an interview with refinery process engineers that use these as a baseline for their company. Further, the price margins when operating at low price environments are smaller than that in high environments. This is consistent with research of Stratiev, stating that low quality crude contains high profit margins at high price levels of crude futures.

Moving forward, by creating the model that included stochastic variables, there were several scenarios created by adjusting different variables. The first analysis focused on the likelihood of different probabilities of price environments. This analysis is used to represent the idea that commodity prices change day by day, in line with a random walk model. Further, by looking at price situations where there are different probabilities of high, low or average prices occurring, it allows for a more realistic model that shows real world circumstances. For instance, if prices are currently high, the probability of a low price environment occurring than that of medium or high price environments. By allowing the probabilities to change, a sensitivity analysis was created included ranges for probability of failure at set price margins. From there, this analysis was repeated for three different price environment probabilities: high, medium and low. The results of the analysis are displayed in the tables below

Table 1 High Price Environment Sensitivity Analysis

Failure Probability	Volume High Quality Crude	Volume Low Quality Crude
.01	600,000	0
.001	600,000	0
.0001	600,000	0
.00001	400,000	200,000
.000001	400,000	200,000
.0000001	400,000	200,000
.00000001	400,000	200,000
.0000000001	400,000	200,000

Table 2 Medium Price Environment Sensitivity Analysis

Failure Probability	Volume High Quality Crude	Volume Low Quality Crude
.01	600000	0
.001	600000	0
.0001	600000	0
.00001	600000	0
.000001	600000	0
.0000001	400000	200000
.00000001	400000	200000
.0000000001	400000	200000

Table 3 Low Price Environment Sensitivity Analysis

Failure Probability	Volume High Quality Crude	Volume Low Quality Crude
0.01	600000	0
0.001	600000	0
0.0001	600000	0
0.00001	600000	0
0.000001	600000	0
0.0000001	400000	200000
0.00000001	400000	200000
0.000000001	400000	200000

From Table 1 compared to Table 2 and 3, it is apparent that when there is an increased probability of high prices during the next period, there is a larger range of failure probabilities where it is profitable to buy the maximum amount of low quality crude that is available. Another conclusion from the analysis is that in likely high price environments, it is significantly more profitable to buy the lower quality crude. Despite the increased risk of failure at lower probabilities, the higher price margins in high price environments make it significantly more profitable to use low quality crude oils, even if the full cost of a shutdown were to occur. This is counterintuitive too much of the research and interviews from refinery managers which stated that a shutdown is the absolute worst outcome for a plant. It seems that the cost of goods sold in a refinery contributes significantly more to the bottom line than any of the fixed or variable costs of a plant. This would be consistent with the way trading and management structure, with large groups of traders, assistants and planners used to assess the most profitable combination of crude oils used in the plant.

Another finding was that there was little difference between the medium price environment and the low price environment. This was surprising as there was such a large difference between the high price environment compared to the low or medium. This shows that there is less incentive for oil companies in terms of expected profit for oil to use low-grade oil at these mid to lower prices. This is less consistent with much of the research, as the magnitude of recent research completed is with respect to oil prices near $100 per barrel. Because there is such little research, there is potential for process improvement by reevaluating the way refineries choose their crude oil blends at lower prices. With such a small margin between low grade and high-grade crudes, using a slightly better grade in times of economic downturn for oil futures may lead to an increase in profit when considering shutdown costs tied to crude oil blend. In addition, over the long term, using crudes that contain less sulfur and are less acidic would lead to an increase in longevity of the plant and its equipment itself, especially when considering the increased corrosion of crude oils like the tar sands.

Chapter 4

Conclusion

In conclusion, the rapid decline of oil prices during recent years has taken the world by storm, with very few people predicting a period lasting several years to become the norm. This has also called some business practices by oil companies to come into question. However, shifts in practices have been confined to drilling and exploration, not the actual refining. The practice of using futures and the belief that prices will rise have led to possible inefficiencies in the crude buying process for these refineries. When examining whether the these practices of crude buying need to be examined, it is important to look not only at the short run, but the long run of expected profit throughout the entirety of the plant.

With margins declining in periods of low crude prices, it is even more important to ensure that unnecessary costs are eliminated or contained. One of these costs is unplanned shutdowns, which result in lost profits of nearly $2,000,000 per day in large-scale operations. Clearly, this is a significant sum, and if there is a potential way to reduce this cost especially at smaller price margins, it would be prudent for refiners to do so. By considering using higher-grade crudes when the price of crude oil falls, refiners may be able to generate excess profit by reducing the risk of an unplanned shutdown.

In the model created, there was a clear correlation when low to medium prices were expected in the next period, that refiners should use higher grades of crude at more failure probability levels. While this model did not go completely into the depth of the decision making process used by oil traders, it did show that there is a potential market inefficiency.

Despite adding the stochastic variable, the model still has limitations. Considerable other variable exist that make it nearly impossible to create an exact model of the situation refineries face. Further, these models are not revealed to the public, as they are proprietary software.

While the model created is useful into looking into other ways refineries could increase profit, there is a limit to what the model can prove. Without access to one of the models that traders use, assessing the true impact of lower grade crude usage is nearly impossible. Despite that, re-examining a long-standing process is still a practical way to find profit opportunities without buying a single piece of equipment or land rights. The reality of the situation is that traders are hamstrung by many different factors in the marketplace ranging from quotas to deals that are not available to the public eye. While there is a standard for what an oil future contract may be, it does not factor in all of the variables that go into making a multimillion-dollar trade on the market. Despite the complexity of the process, the reality is that traders rarely talk to process engineers inside the refineries themselves to discuss the impact the product they buy has on the plant. By creating a dialogue where former best practices are re-examined, shareholders could benefit immensely, especially in times where shaky earnings reports are expected.

Appendix A

GAMS Code

```
Set c commmodity /priceL, priceh/;

Set s scenarios /Low, Med, High/;



table Margin(c,s)
         Low     Med     High
PriceL    3      13      23
PriceH    5      13      21
;

Parameter prob(s)
/Low  0.33
 Med  0.34
 High 0.33
/;


Parameters
Maxvol / 600000 /
```

```
Failprob /.000001/

Failcost /-2800000/

Limitlow /200000/

;



Positive Variables

Vol(c)



;


Variables

z total profit

;


Equations

eprofit

ecapactiy

elimit


;
```

```
eprofit.. z =e= sum(s, (margin('priceL', s)*vol('priceL') + margin('priceH',
s)*vol('priceh')+ vol('priceL')*failprob*failcost) * prob(s));

ecapactiy..  maxvol =g= vol('priceL') + vol('priceH');

elimit.. vol('pricel') =l= limitlow  ;

Model Oil includes all equations /all/;
Solve Oil using lp maximizing z;
display vol.l;
```

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