RIGOROUS SIMULATION SUPPORTS ACCURATE REFINERY DECISIONS

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Abstract

This paper assesses critical issues in the refinery supply chain and determines how the benefits of rigorous modeling can be extended to LP models and the supply chain.

Keywords

LP modeling, refinery supply chain, process modeling, refining, crude oil economics.

Introduction

Process industry planning largely relies on Linear Program (LP) models for decisions that have direct impact on plant profitability. To illustrate, in refinery operations, LP models are used for a variety of refinery-wide business decisions including crude purchases, product slates, CapEx reviews, and adjustment of plan after operational upsets.

In parallel, process engineering and operations have relied on rigorous models to supply detailed unit performance information. For the most part, these rigorous models have been a point solution to address a current operational question. For example, rigorous models have been used extensively to supply process design data, performance monitoring, and operational troubleshooting.

This paper will explore a number of relevant industry examples highlighting the impact of incorporating rigorous models in daily decisions. These examples will give testimony that this practice has a direct impact on plant profitability. Extending the rigorous models from their traditional role as engineering tools will have a positive impact on plant margins throughout the Refinery supply chain.

Background

Refiners face significant economic challenges. Environmental regulations, weak refining margins, very demanding safety requirements, and fierce competition all erode profits. In order to gain a competitive advantage, refiners use their staff, consultants, other outside sources, and technology. Refiners attempt to optimize the plant by finding the best operating conditions to maximize the value of the products, minimize costs, and comply with environmental regulations. Some companies have attempted to fully automate the process of collecting data and making the necessary changes to the plant. Others feel that refineries are so complex that automation techniques may cost more than they deliver. There is no question that refiners continually look to increase their margins by even a few cents per barrel.

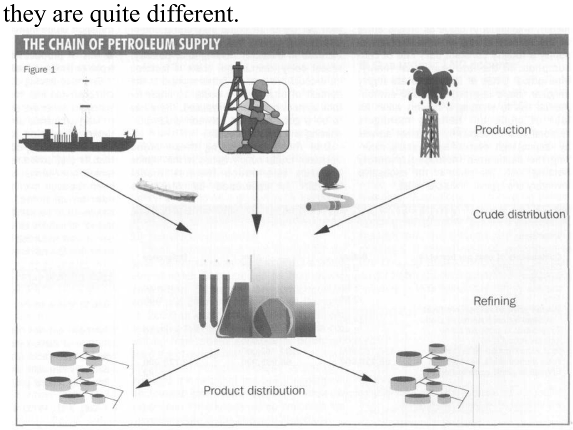
In recent years, the oil industry has turned to information technology as an important tool to increase profits. The theory is that tremendous benefit can be gained by exploring for and producing oil that refiners really needed and using refineries to make the specific products that customers actually want. The argument is quite compelling. It is a mistake for a refinery to maximize its high-octane gasoline production if there is an oversupply and under demand of the product. A refinery should not purchase low cost crude if the actual cost of running the crude through the refinery results in higher costs than the value of the products. Up to this point, efforts at supply chain management have been disappointing. However, most of the technologies and their deployment are in their infancy in the oil industry. Refiners still expect to make gains through better supply chain management.[1]

The Refinery Supply Chain

The supply chain for a typical integrated oil company consists of the following components:

- Exploration – Searching for new sources of oil and gas.
- Production – Producing the oil and gas and transporting it via pipelines and/or tankers to gas processing and refining facilities for further processing.
- Gas Processing – Separates the gas mixture into natural gas (mostly methane) and gas liquids.
- Refining – converts crude oil into useable products such as gasoline, heating oil, diesel, jet fuel, and lube oils.
- Supply and Transportation – Delivers the refinery products to the point of use, such as a gasoline station.

"The world crude supply is a free market. You can go out and buy almost any crude you want."[2] Every crude has a relative value based on market pricing and the makeup of the crude itself. Many crudes look very similar, but when the details of the makeup are analyzed, they are quite different.



In order to determine the value of the crudes, the information is run through refinery optimization software based on Linear Programming (LP). Oil companies that make extensive use of their LP Models run them at least monthly and sometimes weekly. Some hope to automate the process to the point that it can be done daily.[3]

After the value of the crude is determined, the information is fed to a group of people responsible for moving the crude. "The people who make the schedules to get product from one point to another look at the realities of pipelines and terminal constraints".[4] The schedules can become rather complex and change almost hourly.

The refinery processes the crude into products, where it moves into the downstream supply chain involving retail distribution. The downstream part of an oil company is actually very similar to other manufacturing industries. The goal is to "realize the greatest return from every unit of delivered product by minimizing the cost of ownership while identifying and exploiting market value."[5] Full asset utilization and inventory reduction are important to achieve these objectives. Companies use optimization software to determine the most profitable route to move product from the refinery to the pump.

Gasoline pumps contain technology to record transactional information such as the amount and type of gas purchased, the price, and the date of the purchase. This information is transmitted to the computer of a distributor, which passes it on to refineries owned by such companies as Exxon-Mobil and Petro-Canada.[6] If used effectively, such information allows for automatic scheduling of road tankers to deliver refills and automatically adjusting the prices to reflect demand. It is not enough to optimize a single refinery by itself. The optimization must reflect demand down the entire supply chain.

Crude Oil Economics

The economics of the supply chain are dictated by accurate demand forecasting and crude valuation. As gasoline demand increases, for example, during the summer months, refining margins tend to improve and the value of a crude is higher. The price of crude oil is governed by worldwide supply and demand. The refining value or "technical value" of a crude oil is the value a refinery expects to realize for the products, less operating costs, from processing the crude.[7] Differences in refinery configuration and location mean no two refineries will achieve the same margin for a given crude oil. It is therefore critical for producers and refiners to fully understand the refining value of a crude oil being sold or purchased. The refinery that best understands their true operating window will have the competitive advantage as they will purchase the crudes that enable them to meet the market need at the lowest cost.

[1] Based on several presentations at NPRA (National Petrochemical and Refiners Association) general conference held in San Antonio in March 2001.

[2] Nick Trombley, Refinery Economist for Shell Canada.

[3] Schwartz, p. 53.

[4] Schwartz, p. 53.

[5] Schwartz, p. 54

[6] McGuire, p. 174.

[7] Birch, p. 55.

Business Trends

The number of refineries in North America peaked in 1981 at 324. Throughout the 1980s, refineries shut down even though demand for refinery products rose. The refineries that continued operating increased their capacity by 1.1 million barrels per day during the last 10 years.[8] As the total number of refineries decreased, the number of companies doing refining has also decreased. At the end of 1990, 20 refiners accounted for slightly more than 75% of capacity. In 2000, the top 20 refiners accounted for more than 91% of refining capacity.[9] This trend is expected to continue on the announcement of other mergers.

Foreign ownership of North American refineries is also increasing. Royal Dutch Shell, BP, TotalFinaElf, Saudi Aramco, and Petroleos de Venezuela SA (PDVSA) all have at least partial ownership of U.S. refineries. The percentage of foreign ownership has increased by nearly 5% in the 1990s and is expected to increase in the future. The motivation for foreign ownership is not that the North American refining industry is perceived as a high profit, growth business. Foreign interest is motivated by a desire for a secure outlet for the foreign country's crude production, especially for countries with heavy, sour (high sulfur) crude. A risk of foreign ownership is that shutdown is more likely if there is no longer a strategic fit.

The number of independents owning refineries is also increasing. At the beginning of 2001 independents owned 64% of refining capacity compared with 51% in 1990.[10] This trend may reflect that there has not been significant benefit in the past from having the entire supply chain under one company.

Regulations

Refineries in North America face three major regulation challenges during the next few years: gasoline sulfur reduction, diesel fuel sulfur reduction, and minimum requirements for oxygenated fuels. To comply with these regulations requires significant capital expenditures. Premcor cited a cost of $70 million as a reason for shutting down its refinery outside Chicago. Environmental expenditures in refining have averaged $5-6 billion/year. The National Petrochemical and Refiners Association (NPRA) estimates the industry will need to spend an additional $8 billion to comply with gasoline desulfurization.[11]

The mandate is that gasoline sulfur levels be reduced to 30 ppm from 300 by January 1, 2005. Similarly, diesel fuel sulfur content must be reduced to 50 ppm and possibly as low as 15 ppm from 350 ppm. To meet these specifications will require significant capital investment as well as better crude selection

Ultra low sulfur road diesel has been legislated in the US; this regulation is implemented through phased approach. Phase 1 mandates that 80% of the pool meets a 15ppm sulfur specification for 2007, and phase 2 mandates 100% of the pool for 2010. It is estimated this regulation could cause a national supply shortfall of 12%, with some regions such as the Rocky Mountains, facing a 37% shortfall (Charles River Associates).

The clean air act requires that gasoline contain at least 2.0-wt % oxygen. The oxygenate of choice has been MTBE, which may be banned in many regions. Refiners may need to replace MTBE with ethanol or other oxygenates. Unfortunately, these substitutes are lower in octane. To increase the octane, refiners will need to increase the aromatics (benzene, toluene, etc.) content of the gasoline. However, aromatics content is also regulated. This bill has not yet been voted on in the US senate. The earliest it will be passed is next fall, and this is optimistic considering the new Senate elected recently. MTBE is another unknown in the refiner's future.

To meet all of the regulations will require capital expenditure, careful crude selection, and optimization of the refinery in conjunction with the entire supply chain.

Technology

Refineries are able to derive very little competitive advantage from process technology. Most of the process technology comes from technology licensors such as UOP and Stone & Webster. The same technology is available to all refiners at similar costs. In fact, UOP has partnered with various refiners to develop technology and provide engineering services. Such information is shared across the industry. As one VP of process technology said of UOP's partnering agreement with a major oil company, "this is the most drastic example of a company making the statement that refining technology is not a competitive advantage."[12]

In order to derive an advantage, refiners will need to find ways to optimally use their process technology and other assets to maximize return. This includes deployment of engineering software as well as other applications throughout the supply chain.

Historically, determining the actual capabilities of the plant was not feasible, and even if it was, leveraging the knowledge up and down the supply chain was not possible. Today, rigorous simulation software is available which will increase the accuracy in which

[8] Loftus, p. 57.

[9] Loftus, p. 59.

[10] Loftus, p. 60.

[11] Loftus, p. 62.

[12] Moore, p. 42.

important decisions are made. Although today this practice is far from the industry norm.

Successes with Rigorous Models

Oil companies regularly report successes using various software packages. The success is based on proper selection of technology, and, perhaps more importantly, the people who use it. The industry has used rigorous models to benefit the refinery.

The Role of Technology

Solomon and Associates out of Dallas, Texas studies and benchmarks firms in the refining industry. Especially, when money is scarce for significant capital expenditures, they have identified successful IT management as central to survival. They cite that firms must implement integrated-information management systems to improve operational reliability, capacity, planning and scheduling, regulatory compliance, and administration.[13] The supply chain decision support tools help a company decide where to make what. However, an accurate representation of what is feasible is critical to successful implementation.

It is important to be "model centric". The process model is used to identify product yields, environmental compliance, and optimize the operation. Up to this point, the central model for refiners has been the LP Model. However, since it is known that this model is too simplistic to accurately represent a refinery, attempts have been made to improve these models.

The possibilities are much greater than ever before for integrating tools and using a more complex model rigorous simulation modes to optimize the refinery. This is for at least three reasons:

1. Computing speed has increased dramatically and continues to increase. Moore's law states that computer speed is doubling every 18 months. Additionally, internet bandwith is increasing at a similar pace.
2. Integration - Standards in the computing and engineering industry such as OLE, Cape-open, XML, and PDXI make it possible to integrate disparate software applications to optimize the business rather than a niche of the business. Even competitive applications can be integrated.
3. Improvements in underlying Science - complex optimization and simulation technology is faster and more robust.

The refining industry has yet to fully embrace the possibilities of using sophisticated software to optimize refinery operations. Part of the challenge is that it not only involves technology but also changes to the business process. A study of two major refineries indicated that embracing IT in general was a critical predecessor. "Of the [refineries] studied, those which had developed a rich set of IT infrastructure capabilities, before or concurrent with undertaking business process redesign, were able to implement dramatic changes to their business process in relatively short time frames. A rich set of infrastructure capabilities includes the boundary-crossing services across multisite business units."[14] In summary, oil companies need to be committed to removing silos and leveraging IT in order to improve supply chain management.

The Role of People

Successful supply chain management requires having the right tools. However, the tools by themselves do not guarantee success. A survey of various companies in different industries showed that the top performers in supply chain management actually spend only 4.2% of revenue on their supply chains, compared to 10% for the average company.[15] The key to success is that the executives at the more successful companies are committed to getting the big issues under control.

Recommendations specific to the refining industry may help make optimizing the supply chain a reality. First, it is important to put the best people on the problem. The supply chain is not viewed as a glamour job in the oil industry, but companies like Wal-Mart prize the role. Second, the best companies align many departments under a senior executive whose job is to plan, measure, and optimize the performance of the whole chain. Third, hunches must be replaced with metrics. Supply chain management cannot be run by gut feel.

The company will have to be committed to all of the recommendations in order to derive the most value. Valero, an independent refiner reported, "successful installations usually depend far more on how companies prepare themselves to use the software than on the technology itself."[16]

A study at a major Midwestern refinery revealed similar recommendations. They found to generate return on investment it is critical to have corporate support as well as trust between the Union and Management. An additional recommendation they had was "Go slow to go fast". The refining culture rewards a fire fighting mentality. However, they found, "the most profound changes occurred when the pace was slowed and [they] really looked at what was taking place."[17]

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[13] Harkins, p. 92.

[14] Broadbent, p. 182.

[15] www.businessday.co.za/bday/content/direct/1,3523,1005882-6131-0,00.html

[16] Stedman, p. 4.

[17] Clute, p. 35.

Examples

The oil industry has had to cope with supply chain management without the benefit of accurate models of the refinery. This means inventory management, production of product, expected throughput, and so forth often does not reflect plan. In order to cope with the shortcomings of LP Models, refiners have made attempts to improve these models with promising results.

Product Blending

The following examples highlight the benefits of using Aspentech's ORION Scheduling System to optimize the refinery operations from the point at which streams arrive from various process units for product blending. The program considers options for intermediate pooling, blending of finished grades, and final storage of the product. Since gasoline blending is very non-linear and very critical to refinery profitability, this is an ideal application to improve upon LP Model results.

One US 110,000 bbl/day refinery, during a time when Kerosene/Jet inventories were getting dangerously high, used ORION to make the decision to either back off total crude throughput or keep the crude units full. Prior to implementing scheduling, no one would have had the confidence in their existing tools to keep throughput at a maximum, however, with the scheduling system in place, they were able to determine precisely how inventories would build, the timing of the build, the additional tanks that they could deploy if required and as a result, maintained full throughput. Benefit was estimated at $1,350,000 million.

Another refiner used ORION to reduced Inventory levels in their two refineries, one 100,000 bbl/day and the other 110,000 bbl/day the scheduling tool has provided what they term "Avoiding comfort zone decisions" by maintaining lower than normal inventory levels. For the two refineries combined, they have documented $1,000,000 per year savings. Recently, Senior VP at Valero, John Honholt stated reducing inventory for just one day in their system would save 9.6 MM/year[18]. Refiners can improve competitive advantage by applying rigorous models to better understand the critical area of refinery blending,

Maintenance Optimization

BP Whiting refinery used HX -Net process energy analysis tool to compare a number of operating options. HX-Net enabled BP to better understand the economic impact of various cleaning schedules. The engineers determined that not cleaning an exchanger could cost them as much as 15% in throughput over a period of one year. This amounts to as much as 5 - 7 MM$ in one year. Furthermore, it was found that cleaning certain exchangers could save the refinery as much as 3 MM$ in one year

The tool enabled BP to screen many possible scenarios, and quickly and quantify each of them. Maintenance costs are a significant contributor to refinery operating costs, and using simulation can optimize the economic impact of maintenance on production.

LP Upgrade

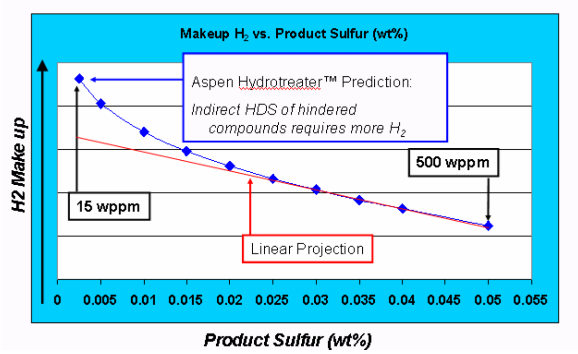
It is well known that optimizing based solely on LP Models leaves money on the table. Refining consultants attempt to capture some of this money through improving the LP Models.

To improve the LP results, the refinery can utilize data from non-linear process simulation models to tune the LP Models. In addition, some non-linear capability based on the process models can be directly included within the LP Model structure. These added capabilities increase the use of the LP Models for "what-if" studies. The models will more accurately predict what the value of crude is to the refinery. To maintain sustainable benefits the refinery must continually monitor plans vs. actual, and use the data from the refinery to decrease the gap.

For an LP model to truly optimize refinery operations, it must have yield data that is valid for a wide range of feed qualities and operating conditions. Plant data is limited in range of feed quality and severity based on the economics of refinery operations. In addition, the inherent, variable inaccuracies of plant data can be greater so that the yield shifts the need to be captured. Therefore, use of simulation models is essential in developing an accurate LP.

The conversion units must be accurately represented within the LP model. One example of non-linear conversion behavior is in the Hydrotreater. To meet the new gasoline sulfur regulations, refiners will be forced to produce low sulfur fuels consistently. The Hydrotreating units will need to run at higher severity and higher hydrogen rates to archive the lower sulfur specifications. The following data generated from the Aspen Hydrotreater™ model shows the shortcomings of assuming linear behavior for Hydrogen make up requirements. With a linear relationship in the LP, the refiner will under-estimate the hydrogen required to meet the low sulfur fuel specification.

[18] John Honholt – AW 2002 presentation, Oct 28,2001



Rigorous reactor models are important tools to both understand and optimize refinery reactors. This data can be fed into the LP to enable it to better match reality in the refinery.

An additional example was published by Marathon Ashland Petroleum (MAP). MAP increased their LP model accuracy by improving the representation of the Crude topper column. The imperfect fractionation in the crude column gave products with a much different range of properties than the straight cut model the LP was using. The use of the data from the rigorous model significantly changed the predictions in their LP model.[19]

It should be emphasized that in all of these examples, combinations of software and talented people were necessary to improve profits. These examples and many other examples like them illustrate the benefit of using detailed models to improve planning and maintenance decisions. These decisions do not only impact the refinery itself, but upstream production planning, purchasing decisions, and sales strategies.

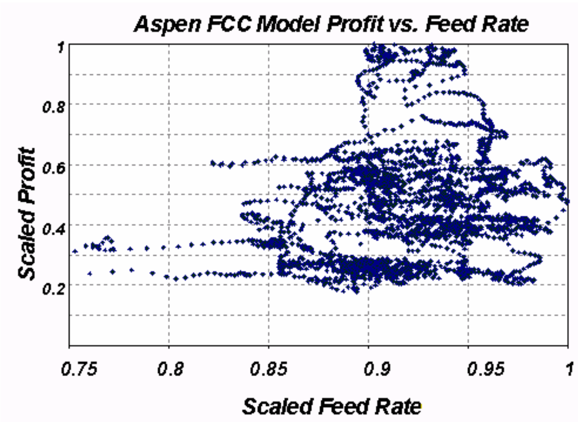
Optimizing Throughput

Typically, supply chain management decisions are made based on running the refinery at maximum capacity. Many refinery managers receive bonuses based on requirements to maximize refinery capacity. However, most refiners would have higher profits if they reduced crude runs. The incremental economics of the refinery are based on LP Models, which mistakenly assume the incremental value of processing an additional barrel of crude is the same as the previous barrel. Accurately determining incremental yields requires collecting a wealth of statistical data or using a very rigorous model. John Hanholt, Senior VP Valero recently stated, Valero's goal over the next year is to increase profitability, not capacity.[20] This recognizes an important learning; higher throughput does not necessarily correspond with higher profitability.

Alkylation is an important process in the refinery to increase gasoline production. Studies of incremental alkylation production indicate that the last increments are 3 or more octane numbers below the average.[21] This makes it more profitable to run the alkylation unit slightly below capacity.

The most important process of most refineries is the FCC. The FCC "cracks" heavy oil components into gasoline and other products. Studies of this unit indicate that the last 2% increment of feed yield values of about 3 cents/gallon less than the average yields.[22] According to surveys it is probable than no refiner has ever cut the feed rate to the FCC to improve profits, but possibly they should [23].

Using rigorous models, refiners can better understand the limits of the refinery units. The following data is taken from the Aspen FCC ® model, supports the findings of Petkus. The following data shows the maximum throughput does not correspond with maximum profit. The profit is highest in the 90 to 95% of capacity range[23].



The crude unit, which separates crude oil into various products such as gasoline, kerosene, gas oil, and so forth has similar results. For the last 1% of incremental feed, the loss in product value was 50 cents/barrel. The Fina Oil Co. refinery in Port Arthur, Texas cut the feed rate to the crude unit from 137,000 barrels/day to 130,000 barrels/day. They discovered the "extra" 7,000 barrels per day was actually costing them $30,000 per day. This is because at the high crude column rates, the column was so inefficient that 42% of the additional feed was yielding in the low-value crude column bottoms. Rigors distillation models can be used to better understand the impact of extra throughput on column conditions by monitoring key performance indicators (tray flooding and vapor velocities) to predict column efficiency.

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[19] Miller, p 24.

[20] John Hanholt – AW 2002, Oct 28,2002

[21] Petkus, p. 65.

[22] Petkus, p. 66.

[23] Adams

Process units running at their maximum capacity require higher utility use and may negatively impact downstream units if they do not have sufficient capacity. But there are also other hidden effects such as increased pressure drop and poorer conversion that result in diminishing plant profits. These effects are all non-linear and best captured by rigorous simulation models. The savings reported here are on a unit by unit basis. It is expected that the savings would be more dramatic by analyzing the impact of the entire refinery. If the industry were to optimize throughput rather than simply maximize throughput, it may also result in better margins. Low gasoline prices are a direct result of refineries overproducing. This is why considering the entire supply chain is critical.

Capital Improvements

Three important trends are impacting capital requirements in the refinery.

1. Available crude oils are becoming heavier and higher in sulfur. This increases the demand for processing units, which handle heavy oil. These units include the Coker, FCC, and Hydrocracker.
2. Environmental regulations, as discussed earlier, require refineries to invest in Hydrotreating and other technology to remove the sulfur.
3. To be profitable, refiners must produce the most profitable products, which requires investing in Reformers, Alkylation units, and other processes to boost octane and increase product yields.

To meet these challenges, refiners have increased global coking capacity by more than 70% in the past 15 years. About half of North American refineries have hydrocrackers. The FCC's and other units are being designed to process heavier feeds.[24] Refiners have a variety of choices as they make enormous capital investment decisions. The equipment selected, the routing of the feeds, and capacities will all dramatically impact the profitability of the refinery and affect decisions in the entire supply chain. For example, a decision to use a coker and not a hydrocracker will impact crude selection, product delivery, and overall profitability.

The capital evaluation has been the domain of rigorous modeling for some time, for example Sunoco, Inc. a Canadian Refiner, showed how rigorous models could be used to plan for changing environmental regulations. Sunoco connected rigorous Connect rigorous Aspen FCC ® and Aspen Hydrotreater™ to form a single pre-treater-plus-FCC model. The combined model allowed them to quantify the non-linear aspects of FCC feed pre-treating, including the effects of pre-treating severity on the distribution of sulfur in the FCC products. The severity of hydrotrating directly impacts FCC conversion so it is critical refiners understand this highly non-linear relationship to maximize production and meet regulations.[25]

To make these decisions correctly requires rigorous modeling with a "base case". The base case can then be adjusted to determine the ROI of various capital projects.

Conclusions

The purpose of this paper is to assess critical issues in the refinery supply chain and determine how the benefits of rigorous modeling can be extended to supply chain management. While the refining industry is very mature it is undergoing tremendous change. The changes in the industry as well as competitive pressures, environmental regulations, and new technology are threats to those that cannot adapt, and tremendous opportunity for those that leverage technology and people to improve their operations.

The research has uncovered some specific areas where Rigorous modeling of unit operations and reactors offers tremendous promise. Some of the applications that warrant highlighting are as follows:

1. Crude Valuation
2. Environmental Compliance
3. Demand Pull rather than Product Push
4. Real Time Plant Capabilities
5. Multi-Unit Optimization
6. Maintenance Decisions
7. Benchmark and Evaluation
8. LP-Model Upgrade

As the paper outlined, the largest hurdles to successful deployment of technology are the entrenched business processes and IT infrastructure. Most of the oil industry still operates its planning, central engineering, upstream operations, refining, and supply and transportation groups as completely separate entities. Capturing value across these boundaries will prove difficult in the near term. Oil companies also lack the personnel to develop, use, and deploy complex simulation software. This is especially true if the value to their individual area is marginal compared to the entire enterprise.

On the positive side, the industry recognizes these shortcomings, and is already taking steps to improve their processes. Frequently, this involves using outside consultants. With success in these new software applications, barriers may be removed and it will be extended into a broader array of applications to improve the entire supply chain.

[24] Nielsen, p. 57.

[25] Robinson p.3

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