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Identifying Added Value in Integrated Oil Supply Chain Companies – a Case Study

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Abstract

Investors in oil companies are interested in identifying sections of the oil supply chain that provide the best returns. This paper demonstrates a systems engineering approach (previously tested on a Russian example) to determine where in the supply chain value is added. Four segments of the oil supply chain of the Malaysian oil company, Petronas, were modeled and optimized dividing the supply chain in three different ways to determine where value is added and how parts of the company are best aggregated.

Keywords: Oil industry, supply chain, optimization

1. Introduction

Investors do not necessarily want to invest in the entire supply chain of an oil company, as there are certain sections of this chain where the value is clearly added. This methodology aims to help investors determine which section of the supply chain adds greater value. This research extends the work of Bogle et al. [1] who modelled the Russian oil supply chain. Here the Malaysian oil industry is used to verify whether this approach can be used for any vertically integrated oil company.

2. Modelling the Oil Supply Chain

The following discrete stages of the oil supply chain can be identified: 1. oilfield production, 2. transportation of crude oil from oilfields to refineries and oil terminals, 3. refinery production operations, and 4. transportation of refined products to oil terminals and distribution centres. Mathematical models have been developed which describe each discrete section of the chain (the completely discretised approach), select combined sections of the chain (partially discretised approach where crude oil production and distribution are integrated, as are refining and refined product distribution, making two echelons) and the supply chain as a whole (an integrated approach where all elements are integrated into one echelon). Each model is designed as a planning tool over a desired time horizon of six months to determine the optimal levels of operational variables such as production rates, inventory levels and transported quantities. The objective is to maximise the overall supply chain profit. This gives the best possible operating conditions of the parts of the supply chain helping to guide investment decisions.

The **oilfield production model** was derived from Ortiz-Gomez et al. [2] and is an NLP model designed to find the optimal flow rates from a series of wells, contained within a number of oilfields (i.e. reservoirs), in order to meet overall customer demand and account for the differing production capabilities of the wells. The model aims to minimise the oil production costs for all periods:

$$\min \sum_i \sum_t \gamma_{it}\, q_{it}\, P$$

where γ_{it} is the production cost coefficient for well i in period t, q_{it} is the oil flow rate from well i in period t, and P is the time period. The model has constraints for demand within each time period, for the final well bore pressure at the end of each period, for a lower limit for the lower bore pressure, for flow as a function of well bore pressure, for a maximum allowable flowrate because of operating constraints, for a flowrate minimum to avoid clogging, and for pressure constraints linking one time period to the next.

The **crude oil distribution model** has been built from Dantzig's classic transportation problem [3]. It aims to provide the following plans for company cost reduction: a transportation plan and an inventory management policy, which determines the optimum inventory levels. The model is a linear programming model which aims to minimise transportation costs and oilfield inventory costs for all periods:

$$\mathrm{Min}\ \sum_f \sum_j \sum_t tc_{fj} X_{fjt} + \sum_f \sum_t IC_{ft}$$

where tc_{fj} is the transportation cost between oilfield f and demand site j, X_{fjt} is the amount of crude oil transported from oilfield f to destination j in period t, and IC_{ft} is the crude oil inventory cost for each oilfield f in each period t. The constraints to be satisfied are the mass balance constraint at each oilfield, minimum inventory levels at each oilfield, demand constraints for each site, inventory costs, and non-negativity constraints.

The **refinery production model** is a mixed-integer linear programming model based on the model of Gjerdrum, Shah and Papageorgiou [4] which determines: a production plan for each product, an inventory management plan, and a workforce management plan. The model aims to minimise inventory costs, refined product production costs and labour costs:

$$\min \sum_i \sum_t c_i Q_{it} + \sum_t IC_t^{C} + \sum_i \sum_t IC_{it}^{P} + \sum_t W_t + \sum_t H_t + \sum_t L_t$$

where c_i are production cost associated with each product I, Q_{it} the amount of product i produced in period t, IC_t^C the crude oil inventory cost in period t, IC_{it}^P the inventory cost for each product i in each period t, W_t is the number of workers employed in period t, H_t the number of workers hired in period t, and L_t the number of workers laid off in period t. These last three are integer variables.

The final stage of the supply chain considered is the **distribution of the refined products** from the refinery to the distribution centres and export terminals. The logistics problems for this stage are the determination of the refined product inventory levels, and the optimum quantities of refined product transported. The objective is to minimise the cost of the product quantities transported from the refinery, inventory costs at the refinery and at distribution centres:

$$\min \sum_i \sum_j \sum_t td_{ij} X1_{ijt} + \sum_i \sum_j \sum_t to_{ik} X2_{ikt} + \sum_i \sum_j \sum_t IC_{ijt}^{P} + \sum_i \sum_t ICR_{it}^{P}$$

where td_{ij} are transportation costs for each product i to each distribution centre j, $X1_{ijt}$ is the amount of product i transported to distribution centre j in period t, to_{ik} are transportation costs for each product i to each oil terminal k, $X2_{ikt}$ the amount of product i transported to oil terminal k in period t, IC_{ijt}^P the inventory cost of holding product i at distribution centre j in period t , and ICR_{it}^P the inventory cost of holding product i at the refinery in period t. The constraints that must be satisfied are mass balances at the refinery and at distribution centres, extremum inventory policies at the refinery and at distribution centres, demand constraints, inventory costs, and non-negativity constraints.

2.1 The Petronas Case Study

Petronas is Malaysia's national petroleum corporation. The case study incorporates 13 of the oil fields present in the country producing and distributing crude oil to both the Kertih and Melaka refineries as well as exportation to South Korea, Singapore, Australia, Chile, Thailand and Japan via the Lubuan oil terminal. The refined products, motor gasoline, diesel, lubricants, jet fuel, kerosene, naphtha and residual fuel oils are distributed, subject to demand, to the Lubuan oil terminal for exportation and to the five national distribution centres. This complex logistical operation provides the case study upon which the models will be optimised.

The Petronas supply chain was modelled over a period of 6 months from May 2005 to October 2005 (http://www.petronas.com.my). The average of the prices of different types of crude oil produced by Petronas i.e. Tapis Blend, Labuan Crude, Miri Light Crude, Bintulu Crude and Terengganu crude in this six month period have been used. The selling prices for crude oil and refined products are assumed to be fixed over the 6 months period. Demands from external customers are also assumed constant over the period. Crude oil demands at the refinery are allowed an additional 10% so that each stage of the supply chain can be optimised. If flexibility of supply to the refinery is not allowed, only one possible solution will be given and this will not ensure the optimality of the solution.

2.2 Results & Discussion

The models were linked together within a GAMS implementation, using transfer price and material flow information, so that optimised values from a model of a previous section could be utilised in the next. Detailed results are shown in Table 1 at the end of the paper. The completely discretised approach to the supply chain provides marginally better overall results, with an increase in profit of over US$203 million over the base case, an increase of 1.11%. The partially discretised model gives an overall improvement of profit 0.7%, and for the fully integrated model 0.23%.

Of more interest are the details of the solutions in terms of inventory and flows. The complete discretisation approach utilised the product inventory and distribution channels most effectively thereby yielding greater sales revenue with just an increase of 0.15% in costs. The partially discretised model, on the other hand, leans towards a large increase in upstream costs for a more favourable reduction in downstream costs that result in an overall increase in profit over the base case model for a minimal overall cost increase of 0.03%.

The completely integrated model follows a unique procedure that optimises the inventory distribution scheduling at both the crude oil and refined product distribution echelons, against the increased storage cost experience at the refinery. This approach reduces overall cost by 10.6% against the base case model.

The transfer pricing mechanism was written so that no echelon would produce a loss. This results in a transfer pricing mechanism that favours an increased profit in the refinery stage by drawing on a low transfer price of inlet crude oil and a higher transfer price of the outlet refined products. This yields a lower than anticipated cost of refining and consequently a higher profit than the industrial equivalent.

3. Conclusions

The approach identifies that major investment in the refinery operations will yield the most significant return. Oilfield operations (upstream) contribute to the majority of a fully integrated oil company's costs and therefore focus on this operational area will bring higher value to the company. Refined product distribution costs have the next most significant effect on company cost reduction, after oilfield operations resulting in the fact that refinery operations have the least impact on company cost reduction.

References

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Table 1. Details of Components of Base case and Optimised Costs for Alternative Models of the Supply Chain

	Base Model	**Complete Integration**	**Partial Discretisation**	**Complete Discretisation**
Total Costs	$\$27,190*10^6$	$\$ 24,317*10^6$ **(- 10.6 %)**	$\$ 27,198*10^6$ **(+ 0.03 %)**	$\$ 27,233*10^6$ **(+ 0.15 %)**
Total Profit	$\$18,621*10^6$	$\$18,664*10^6$ **(+ 0.23 %)**	$\$18,752*10^6$ **(+ 0.7 %)**	$\$18,828*10^6$ **(+ 1.11 %)**

COMPLETE DISCRETISATION OF THE SUPPLY CHAIN

Oilfield Operations ($ '000)

Production cost	Transportation costs to refinery	Transportation costs to Oil Terminals	Crude Oil Inventory costs	**Total costs**	**Total Profit**
4,049,623	44,046	22,811,500	14,020	**26,919,189**	**461,492**

Refinery Production Planning ($ '000)

Production cost	Crude oil inventory costs	Refinery product inventory costs	Labour costs	**Total costs**	**Total Profit**
170,082	1,535	443	721	**172,781**	**18,335,400**

Refined Product Distribution ($ '000)

Transport to oil terminals	Transport to dist. centres	Dist. Centre inventory costs	**Total costs**	**Total Profit**
86,377	8,840	3,657	**98,874**	**31,107**

Transfer Price of Refined Products from Refinery to Distribution Echelon ($)

MGASO	**DIESEL**	**LUB**	**JETF**	**KERO**	**NAPHTHA**	**RESIFO**
4	4.32	3.36	4	4	5.28	3.36

PARTIAL DISCRETISATION OF THE SUPPLY CHAIN

Upstream Operations ($ '000)

Production cost	Transportation costs to refinery	Transportation costs to Oil Terminals	Crude Oil Inventory costs	**Total costs**	**Total Profit**
4,049,623	29,364	22,855,700	14,020	**26,948,707**	**461,492**

Downstream Operations ($ '000)

Production cost	Crude oil inventory costs	Refinery product inventory costs	Labour costs	Transportation costs to Oil Terminals
185,992	1,883	25,586	720	13,651

Transport to dist. centres	Product Inv. Costs	**Total costs**	**Total Profit**
14,429	7,918	**250,178**	**18,290,700**

COMPLETE INTEGRATION OF THE SUPPLY CHAIN ($ '000)

Oilfield Production & Transp. Costs	Refinery Production costs	Distribution costs	**Total costs**	**Total Profit**
23,573,426	597,488	142,531	**24,317,214**	**18,664,200**