FINANCIAL RISK MANAGEMENT IN THE PLANNING OF REFINERY OPERATIONS

Arkadej Pongsakdi[1], Pramoch Rangsunvigit[1], Kitipat Siemanond[1], Miguel J. Bagajewicz[21]

[1]The Petroleum and Petrochemical College, Chulalongkorn University, Thailand

[2]School of Chemical Engineering and Materials Science, University of Oklahoma, USA.

ABSTRACT: Most models for refinery planning are deterministic, that is, they use nominal parameter values without considering the uncertainty. This paper addresses the issue of uncertainty and studies the financial risk aspects. The problem addressed here is that of determining the crude to purchase and decide on the production level of different products given forecasts of demands. The profit is maximized taking into account revenues, crude oil costs, inventory costs, and lost demand costs. The model was tested using data form the Refinery owned by the Bangchak Petroleum Public Company Limited, Thailand. The results show that the stochastic model can predict higher expected profit and lower risk compared to the deterministic model. The paper is under consideration for publication and a full version can be obtained from the authors.

INTRODUCTION

We constructed a model which is similar to several existing ones in the the literature: Lee *et al.* (1996), Jia *et al.* (2003), Wenkai *et al.* (2002) , Göthe-Lundgren *et al.* (2002), Moro *et al.* (1998), Pinto and Moro (2000), Pinto *et al.* (2000), Joly *et al.* (2002), Moro and Pinto (2004), Jia and Ierapetritou (2003), Zhang and Zhu (2000), among others.

Stochastic cases have been considered by Bopp *et al.* (1996), Guldmann and Wang (1999), Escudero *et al.* (1999), Hsieh and Chiang (2001), Neiro and Pinto (2003), Lababidi *et al.* (2004). We use the two-stage stochastic programming approach for process planning under uncertainty (Liu and Sahinidis,1996).

Financial Risk Management

Barbaro and Bagajewicz (2003, 2004) presented a methodology to include financial risk management in the framework of two-stage stochastic programming for planning under uncertainty. The definition of risk and the methodology outlined there was used in this article. Based on this definition, several theoretical expressions were developed, providing new insights on the trade-offs between risk and profitability. Thus, the cumulative risk curves were found to be very appropriate to visualize the risk behavior of different alternatives. New measures and procedures to manage financial risk were later introduced by Aseeri and Bagajewicz (2004). The concept of Value at Risk and Upside Potential as means to weigh opportunity loss versus risk reduction as well as an area ratio were used in this article and, in addition, upper and lower bounds for risk curves corresponding to the optimal stochastic

---

1 Corresponding Author. (Bagajewicz@ou.edu)

solutions were developed. Finally, a new measure to evaluate risk was introduced. The method takes advantage of the sampling average algorithm.

In this paper, a model was developed for the production planning in the Bangchak Petroleum Public Company Limited in Bangkok, Thailand. Uncertainty of product demand and price was considered to build a stochastic model. We omit presenting the model for space reasons.

RESULTS AND DISCUSSION

Input Data

Table 1 give the values of crude oil cost and available quantity. It is assumed that the crude oil cost is the same in all periods. Table 2 shows the mean values for demand and price of all products in each time period while Table 3 shows standard deviations of these values. These standard deviations were estimated only from historical data given by the EPPO Thai Energy Data Notebook (2003).

Table 1. Crude oil cost and available quantity

Crude oil	**Cost ($/bbl)**	**Max Volume (m^3/month)**	**Min Volume (m^3/month)**
Oman (OM)	27.40	No limit	0
Tapis (TP)	30.14	No limit	0
Labuan (LB)	30.14	95,392.2	0
Seria lt (SLEB)	30.14	95,392.2	0
Phet (PHET)	25.08	57,235.32	0
Murban (MB)	28.19	95,392.2	0

Deterministic Model Results

Optimization results of the deterministic model using mean values show a gross refinery margin (GRM) of US$M 7.376. The amount of the crude oil purchased is shown in Table 4 whereas the percentage of the crude oil fed to each CDU is shown in Table 5.

Table 2. Product demand, price, and cost of lost demand penalty

		LPG	SUPG	ISOG	JP-1	HSD	FO #1	FO #2	FOVS
Demand (period1)	m^3	14,100	42,400	20,000	46,500	145,700	15,000	67,100	33,600
Demand (period 2)	m^3	14,815	55,000	25,000	60,000	170,000	10,000	80,000	30,000
Demand (period 3)	m^3	14,458	48,700	22,500	53,250	157,850	12,500	73,500	31,800
Price (period 1)	US$/bbl	22.97	33.64	35.61	32.47	33.59	25.43	25.43	25.43
Price (period 2)	US$/bbl	22.46	33.91	35.92	31.65	32.75	26.64	26.64	26.64
Price (period 3)	US$/bbl	22.55	34.90	36.26	33.90	34.98	26.64	26.64	26.64
Penalty for demand lost	US$/bbl	22.97	33.64	35.61	32.47	33.59	25.43	25.43	25.43

Table 3. Standard deviation of demand and price

Description		LPG	SUPG	ISOG	JP-1	HSD	FO #1	FO #2	FOVS
Demand	m^3	465	1,374	800	6,091	7,489	896	5,272	2,280
Price	US$/bbl	3.75	3.10	3.12	2.88	3.21	1.92	1.92	1.92

Table 4. Volume and percentage of petroleum purchased for each period from the deterministic model (m^3)

Crude oil	Available Quantity	First Period		Second Period		Third Period	
OM	No limit	149,822	39.65%	154,311	36.22%	174,909	36.30%
TP	No limit	0	0.00%	0	0.00%	0	0.00%
LB	95,392	0	0.00%	23,739	5.57%	95,392	19.80%
SLEB	95,392	75,416	19.96%	95,392	22.39%	58,876	12.22%
PHET	57,235	57,235	15.15%	57,235	13.43%	57,235	11.88%
MB	95,392	95,392	25.25%	95,392	22.39%	95,392	19.80%
Total		377,865	100.00%	426,070	100.00%	481,805	100.00%
Total (kbd)		79		89		101	
GRM	7.376 US$M						

Table 5. Percentage of crude fed to each CDU

Crude oil	Cost ($/bbl)	First Period		Second Period		Third Period	
		CDU2	CDU3	CDU2	CDU3	CDU2	CDU3
OM	27.40	13.80	55.08	12.66	55.08	12.64	51.82
TP	30.14	0.00	0.00	0.00	0.00	0.00	0.00
LB	30.14	0.00	0.00	12.53	0.00	31.70	12.00
SLEB	30.14	45.67	4.61	44.60	4.61	25.67	3.41
PHET	25.08	40.53	0.00	30.21	0.00	30.00	0.00
MB	28.19	0.00	40.31	0.00	40.31	0.00	32.78

Stochastic Model Results

The stochastic model takes into account that the demand and price of products are uncertain. The model was solved for 600 scenarios. The demand and price were randomly generated independently for each variable by sampling from a normal distribution. The rest of the parameters are the same as the one in the base case of the deterministic model. The methodology used is based on running the deterministic models using the parameters for each scenario, followed by running the same model for all the scenarios with the first stage variables obtained in the first run fixed as explained in Aseeri and Bagajewicz (2004). The type of primary crude oil selected is the same as in the case of the solution obtained using deterministic model, i.e. PHET, MB, and SLEB. This reflects simply that these crudes provide a high margin. The volumes purchased are, however, different.

Risk Management

The risk curves of the stochastic solution and deterministic solution are compared in Figure 1. As stated above, the stochastic solution was obtained by choosing the solution with highest EGRM from all the solutions obtained. This plot shows that the stochastic solution provides a higher expected GRM than deterministic solution with the lower risk. The risk curves of the stochastic solution are fairly stretched around the GRM of the deterministic solution.

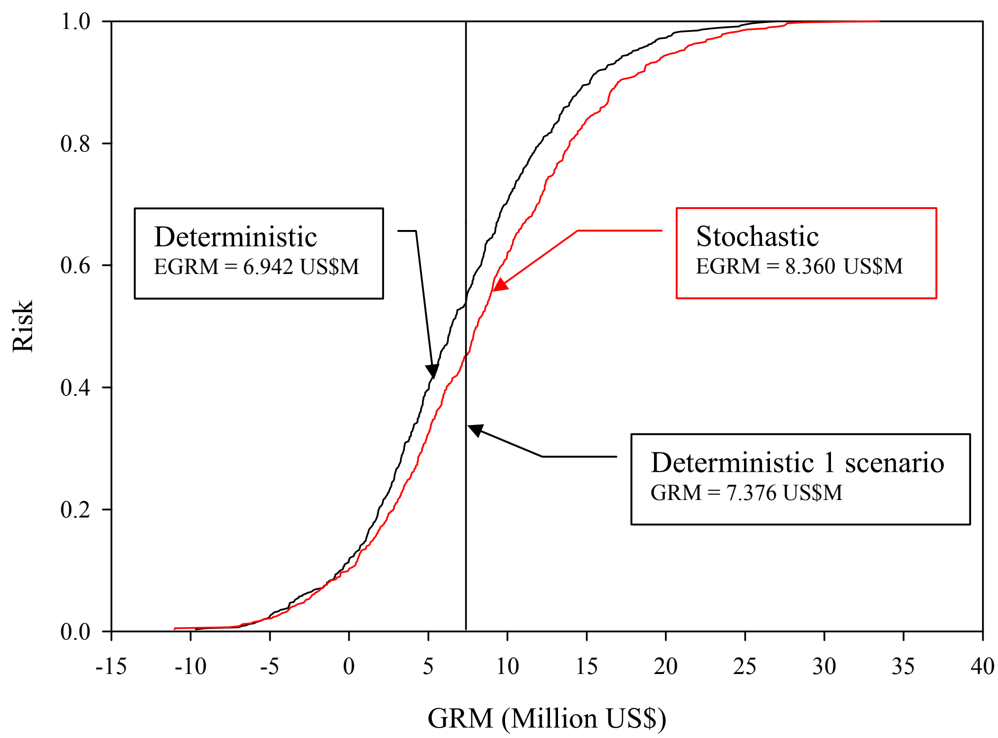

Figure 1. Risk curves of the deterministic and stochastic model solutions.

After all dominated solutions (solutions whose risk curve lies entirely on the left of the stochastic solution) have been removed, we identified a series of non-dominated solutions (solutions that cross the stochastic solution). The expected GRM , VaR and opportunity value (or upside potential, as well as the area ratio for these solutions is shown in Table 6. The solutions are ordered in descending order of expected GRM.

Table 6. Expected profit VaR for selected nondominated solutions (in US$M)

Generating Scenario	EGRM	VaR (5%)	VaR reduction	EGRM reduction
309	8.250	10.268	12.22%	1.32%
576	8.064	9.912	12.28%	3.54%
553	8.034	10.596	11.95%	3.89%
145	7.999	9.798	7.73%	4.32%
74	7.985	9.769	9.89%	4.48%
600	7.971	9.666	4.78%	4.65%
445	7.890	10.028	10.93%	5.62%
112	7.903	9.762	13.14%	5.47%

We will discuss these results in a lot more detail during our presentation and will introduce a few other risk measures that are discussed in the full paper.

CONCLUSIONS

In this work, a two-stage stochastic optimization approach to the refinery planning was used to show how one can manange financial risk. The models were tested on the simplified process of the Bangchak Petroleum Public Company Limited. When uncertainty was considered, the risk curve of the deterministic solution provided a lower expected GRM and a higher risk. It was also shown that the procedure used, which is based on the use of the sampling average algorithm to solve two stage stochastic problems, one can find alternative solutions with smaller risk but also with not so much loss in expected profit or upside potential.

ACKNOWLEDGEMENTS

We gratefully acknowledge the Bangchak Petroleum Public Company Limited and Ms. Usakanok Thamnijkul for providing useful information and recommendation on this work.

REFERENCES

Aseeri, A. and Bagajewicz, M.J. (2004) New measures and procedures to manage financial risk with applications to the planning of gas commercialization in Asia. Computers & Chemical Engineering, To appear.

Barbaro A. and M. Bagajewicz (2003). *Financial Risk management in Planning under Uncertainty.* FOCAPO 2003. (Foundations of Computer Aided Process Operations) Coral Springs, FL, USA, January, 2003).

Barbaro, A. and Bagajewicz, M.J. (2004) Managing financial risk in planning under uncertainty. AIChE Journal, Vol. 50, No. 5, pp. 963-989

Bopp, A.E., Kannan, V.R., Palocsay, S.W., and Stevens, S.P. (1996) An optimization model for planning natural gas purchases, transportation, storage and deliverability. Omega, 24(5), 511-522.

EPPO (2003) Energy Data Notebook Quarterly Report. Energy Policy and Planning Office, Ministry of Energy, Thailand.

Escudero, L.F., Quintana, F.J., and Salmerón, J. (1999) CORO, a modeling and an algorithmic framework for oil supply, transformation and distribution optimization under uncertainty. European Journal of Operational Research, 114, 638-656.

Göthe-Lundgren, M., Lundgren, J.T., and Persson, J.A. (2002) An optimization model for refinery production scheduling. International Journal of Production Economics, 78, 255-270.

Guldmann, J.M. and Wang, F. (1999) Optimizing the natural gas supply mix of local distribution utilities. European Journal of Operational Research, 112, 598-612.

Hsieh, S. and Chiang, C.C. (2001) Manufacturing-to-sale planning model for fuel oil production. Advanced Manufacturing Technology, 18, 303-311.

Jia, Z. and Ierapetritou, M. (2003) Mixed-integer linear programming model for gasoline blending and distribution scheduling. Industrial & Engineering Chemistry Research, 42, 825-835.

Jia, Z., Ierapetritou, M., and Kelly, J.D. (2003) Refinery short-term scheduling using continuous time formulation: crude-oil operations. Industrial & Engineering Chemistry Research, 42, 3085-3097.

Joly, M., Moro, L.F.L., and Pinto, J.M. (2002) Planning and scheduling for petroleum refineries using mathematical programming. Brazilian Journal of Chemical Engineering, 19(2), 207-228.

Lababidi, H.M.S., Ahmed, M.A., Alatiqi, I.M., and Al-Enzi, A.F. (2004) Optimizing the supply chain of a petrochemical company under uncertain operating and economic conditions. Industrial & Engineering Chemistry Research, 43, 63-73.

Lee, H., Pinto, J.M., Grossmann, I.E., and Park, S. (1996) Mixed-integer linear programming model for refinery short-term scheduling of crude oil unloading with inventory management. Industrial & Engineering Chemistry Research, 35, 1630-1641.

Liu, M.L. and Sahinidis, N.V. (1996) Optimization in process planning under uncertainty. Industrial & Engineering Chemistry Research, 35, 4154-4165.

Moro, L.F.L., Zanin, A.C., and Pinto, J.M. (1998) A planning model for refinery diesel production. Computers & Chemical Engineering, 22, Suppl., S1039-1042.

Moro, L.F.L. and Pinto, J.M. (2004) Mixed-integer programming approach for short-term crude oil scheduling. Industrial & Engineering Chemistry Research, 43, 85-94.

Neiro, S.M.S. and Pinto, J.M. (2003) Supply chain optimization of petroleum refinery complexes. FOCAPO proceedings, Coral Springs, FL, 59-72.

Pinto, J.M., Joly, M., and Moro, L.F.L. (2000) Planning and scheduling models for refinery operations. Computers & Chemical Engineering, 24, 2259-2276.

Pinto, J.M. and Moro, L.F.L. (2000) A planning model for petroleum refineries. Brazilian Journal of Chemical Engineering, 17(4-7), 575-586.

Wenkai, L., Hui, C.W., Hua, B., and Tong, Z. (2002) Scheduling crude oil unloading, storage, and processing. Industrial & Engineering Chemistry Research, 41, 6723-6734.

Zhang, N. and Zhu, X.X. (2000) A novel modeling and decomposition strategy for overall refinery optimization. Computers & Chemical Engineering, 24, 1543-1548.