CHAPTER IV
RESULTS AND DISCUSSION

4.1 The general planning model

4.1.1 Input data

Table 4.1 gives the value of crude oil cost and available quantity. The mean values of the demand and price for all products and the standard deviation of these values are shown in Table 4.2 and Table 4.3 respectively. All of these values were estimated and taken from historical data given by the website of the Energy Policy and Planning Office, Ministry of Energy (EPPO, 2006).

Table 4.1 Crude oil cost and available quantity

Crude oil	Cost ($/bbl)			Max Volume (m^3/month)	Min Volume (m^3/month)
	Time period 1	Time period 2	Time period 3		
Oman (OM)	56.38	64.16	58.03	No limit	0
Tapis (TP)	65.56	72.72	65.24	No limit	0
Labuan (LB)	62.31	65.73	63.24	95,392.2	0
Seria light (SLEB)	62.31	65.73	63.24	95,392.2	0
Phet (PHET)	58.03	63.65	58.12	57,235.32	0
Murban (MB)	59.74	67.13	63.04	95,392.2	0

Table 4.2 Product demand and price

Product	Product demand (m3)			Product price ($/bbl)		
	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
LPG	38,020	42,368	44,185	32.64	31.49	30.8
SUPG	35,365	37,155	39,093	71.87	83.76	62.63
ISOG	24,173	22,530	22,063	73.74	85.75	64.53
JP-1	38,693	35,898	38,373	80.63	88.68	80.54
HSD	160,653	149,210	147,933	76.98	88.33	75.15
FO1	56,823	54,960	34,503	55.21	56.35	47.47
FO2	56,823	54,960	34,503	55.21	56.35	47.47
FOVS	56,823	54,960	34,503	55.21	56.35	47.47

Table 4.3 Standard deviation of demand and price

Description		LPG	SUPG	ISOG	JP-1	HSD	FO1	FO2	FOVS
Demand	m^3	3,049	2,064	1,310	2,272	10,267	11,517	11,517	11,517
Price	US$/bbl	1.45	9.82	9.88	6.32	8.11	5.60	5.60	5.60

4.1.2 The general deterministic model results

Optimization results of the general deterministic model using mean values show a Gross Refinery Margin (GRM) of US$M 9.574 with 754 variables and 655 constraints. The amount of the crude oil purchased is shown in Table 4.4 and the percentage of the crude oil fed to each CDU is shown in Table 4.5.

Table 4.4 Volume and percentage of petroleum purchased for each period from the general deterministic model (m^3)

Crude oil	Available Quantity	Period 1		Period 2		Period 3	
		(m^3)	(%)	(m^3)	(%)	(m^3)	(%)
OM	No limit	176,065	36.30	211,937	37.03	117,966	29.63
TP	No limit	0	0.00	17,004	2.97	0	0.00
LB	95,392	95,392	19.67	95,392	16.67	95,392	23.96
SLEB	95,392	60,938	12.56	95,392	16.67	95,392	23.96
PHET	57,235	57,235	11.80	57,235	10.00	57,235	14.38
MB	95,392	95,392	19.67	95,392	16.67	32,158	8.08
Total		485,022	100.00	572,353	100.00	398,143	100.00
Total (kbd)		101.69		120.00		83.47	
GRM	9.574 US$M						

Table 4.5 Percentage of crude fed to each CDU

Crude oil	Period 1		Period 2		Period 3	
	CDU2	CDU3	CDU2	CDU3	CDU2	CDU3
OM	12.64	51.64	12.89	49.10	12.88	43.21
TP	0.00	0.00	7.11	0.90	0.00	0.00
LB	31.70	11.87	50.00	0.00	38.02	12.56
SLEB	25.66	4.07	0.00	25.00	16.99	29.61
PHET	30.00	0.00	30.00	0.00	32.11	0.00
MB	0.00	32.42	0.00	25.00	0.00	14.62
Total	100%	100%	100%	100%	100%	100%
Total (kbd)	40.00	61.69	40.00	80.00	37.37	46.11

From the general deterministic model result. Crude LB, PHET, and MB are purchased at the maximum available quantity. Crude PHET is fed to CDU2 only due to the limitation of unit. In addition PHET is not suitable for the production of FO1 and FO2 (low pour point fuel oil) from CDU3 because it has the high pour point and low viscosity factor @50C (V50) in the fuel oil portion. From Table 4.5, OM is the major supply for CDU3 since it gives the best property needed for low pour point fuel oil (FO1 and FO2) production of CDU3. The smallest amount of crude oil used is that of TP crude because of its highest cost. It is chosen in time period 2 due to the higher product price in this period.

4.1.3 The General Stochastic Model Results

The general stochastic model takes into account of uncertainty in demand and price of products. The model was solved for different 200 scenarios. The demand and price were randomly generated independently by sampling from a normal distribution with mean values and standard deviation as shown in Table 4.2 and Table 4.3.

The methodology used is based on running the different 200 scenarios using the different uncertain parameters for each scenario. The first stage variables obtained are fixed and then the same model is run again under different scenarios to see the results of second stage variables. The results of the crude oil purchased obtained from best design is shown in Table 4.6.

Table 4.6 Volume and percentage of petroleum purchased for each period from the general stochastic model.

Crude oil	Available Quantity	Period 1		Period 2		Period 3	
		(m^3)	(%)	(m^3)	(%)	(m^3)	(%)
OM	No limit	211,937	37.03	211,937	37.03	126,125	30.29
TP	No limit	17004.3	2.97	17,004	2.97	0	0.00
LB	95,392	95,392	16.67	95,392	16.67	95,392	22.91
SLEB	95,392	95,392	16.67	95,392	16.67	95,392	22.91
PHET	57,235	57,235	10.00	57,235	10.00	57,235	13.75
MB	95,392	95,392	16.67	95,392	16.67	42,202	10.14
Total		572.353	100	572,353	100	416,347	100
Total (kbd)		120		120		87.29	
GRM	15.131 US$M						

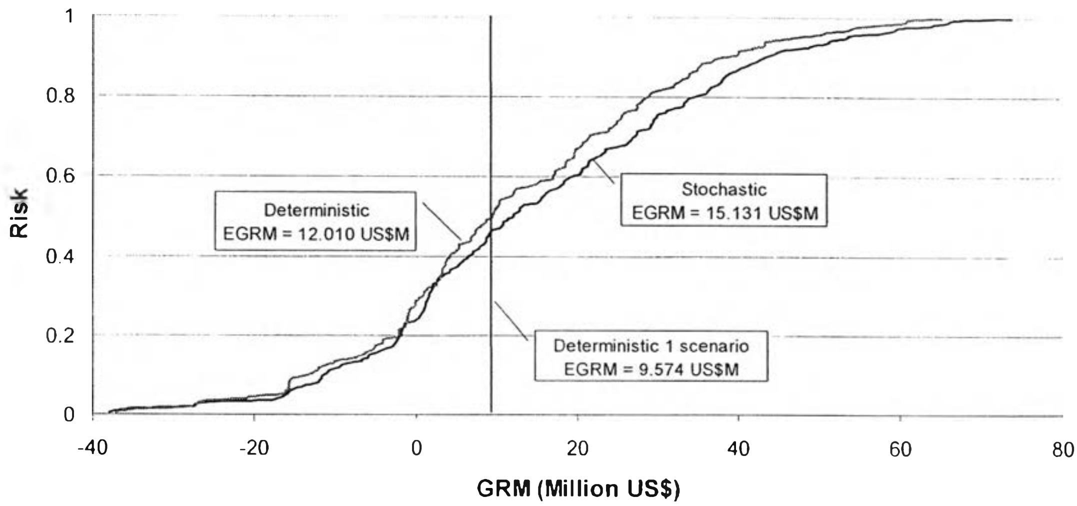

Figure 4.1 Risk curves of the deterministic and stochastic model solutions.

Figure 4.1 demonstrates the risk curves of the stochastic solution and the deterministic solution. The stochastic solution is the highest EGRM taken from all solutions obtained. The deterministic risk curve is constructed by running the stochastic model under each scenario with the first stage variable fixed to that of the deterministic model result. The EGRM obtained from the deterministic model under 200 scenarios of uncertain parameters is different from that of the deterministic model with 1 scenario. This can be described that it is because the uncertainty is taken into account in the 200 scenarios case so. the EGRM obtained under uncertainty may different from what predicted by the deterministic model. In this case it is higher, but in fact, it may be higher or lower. However, the plot shows that the deterministic solution provides a lower EGRM than the stochastic solution with a higher risk.

4.2 The Planning Model with Pricing

4.2.1 Effects of price-demand relation factors

Different values of three factors of price-demand relation, alpha(α), beta(β) and rho(ρ), are set to the pricing model and their results are compared to see their roles in the model. Different market shares of product demand are obtained with these various factors. Figure 4.2 shows the demand ratio, which is the demand of product 1 divided by competition product demand, obtained from different values of α and the results of β is shown in Figure 4.3.

From Figure 4.2, the demand ratio of product 1 compared to competition product increases as the value of α increase. Because α is a measure of how much the consumer population aware of the quality of product 1 so when α increases, people would tend to buy more product 1. And when α=1, knowledge of product 1 is equal to that of competition product so, they consume the product 1 as much as the competition one. This makes the demand of both products equal to each other.

The results of β are shown in Figure 4.3. When the value of β increases, the demand ratio decreases. This can be described that β is a measure how much a consumer prefers product 1 to competition product so, with a higher β, a larger amount of product 1 is consumed. When β = 1 a consumer would think of product 1 as same as competition product and so, their consumptions are equal.

Figure 4.4 shows the demand ratios obtained by varying values of ρ. With ρ = -1 the demand ratio is about 1.4:1 and then decreases to 1:1 with ρ = 0. When ρ is approached to 1, the demand of competition product is about zero. This is because the elasticity of substitution utility (σ_{ES}) = 1/(ρ-1) and with $\rho \rightarrow 1$, $\sigma_{ES} \rightarrow \infty$. When the elasticity of substitution is infinity, the consumption of one product could not be replaced by consumption of the other one so, the demand of competition product is about zero in the last case.

4.2.2 Input data

For the planning model with pricing, three factors of the price-demand relation (α, β and ρ) are set to be 1.0, 1.0 and 0 respectively. Table 4.7 shows the competition product price and the total demand of product. The consumer budget is shown in Table 4.8. Table 4.9 shows the standard deviation of the total demand and consumer budget.

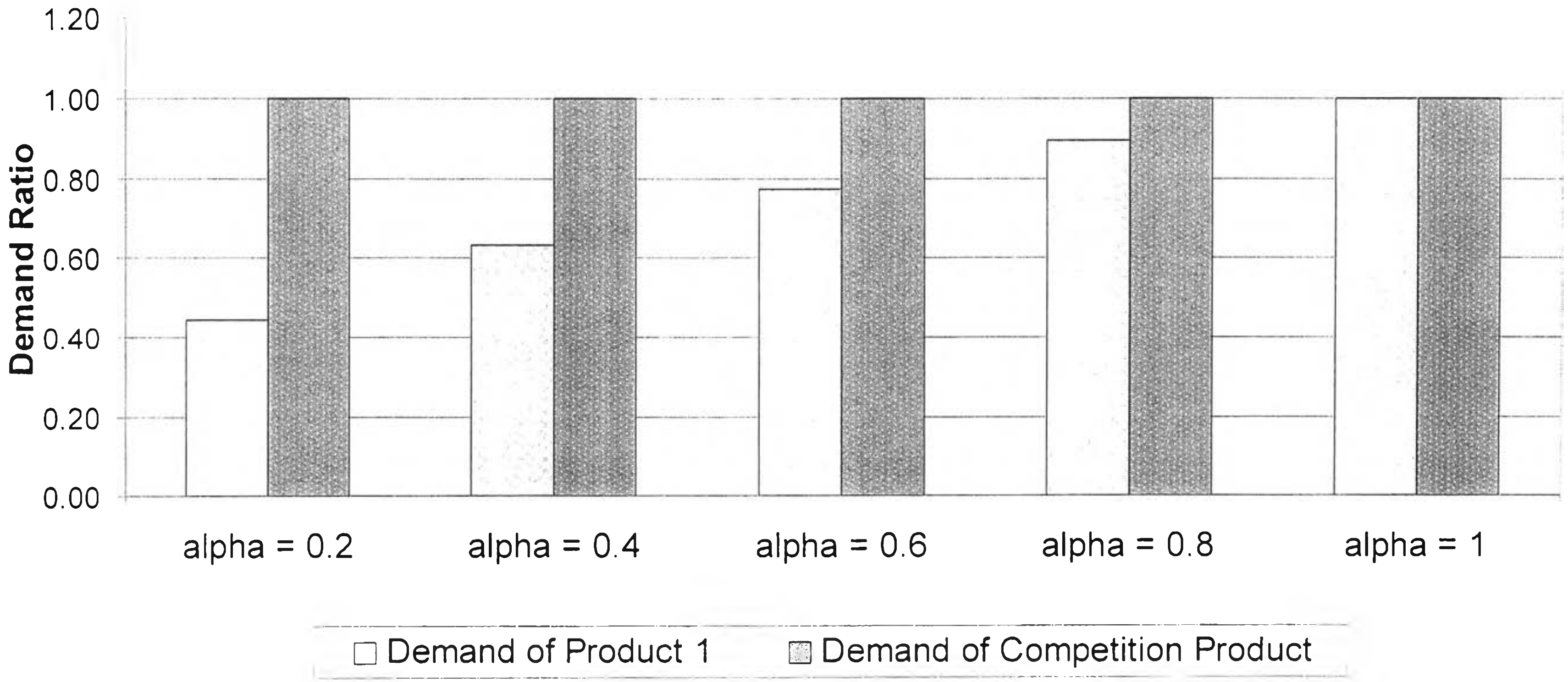

Figure 4.2 The demand ratio of product 1 compared to competition product obtained from different values of alpha.

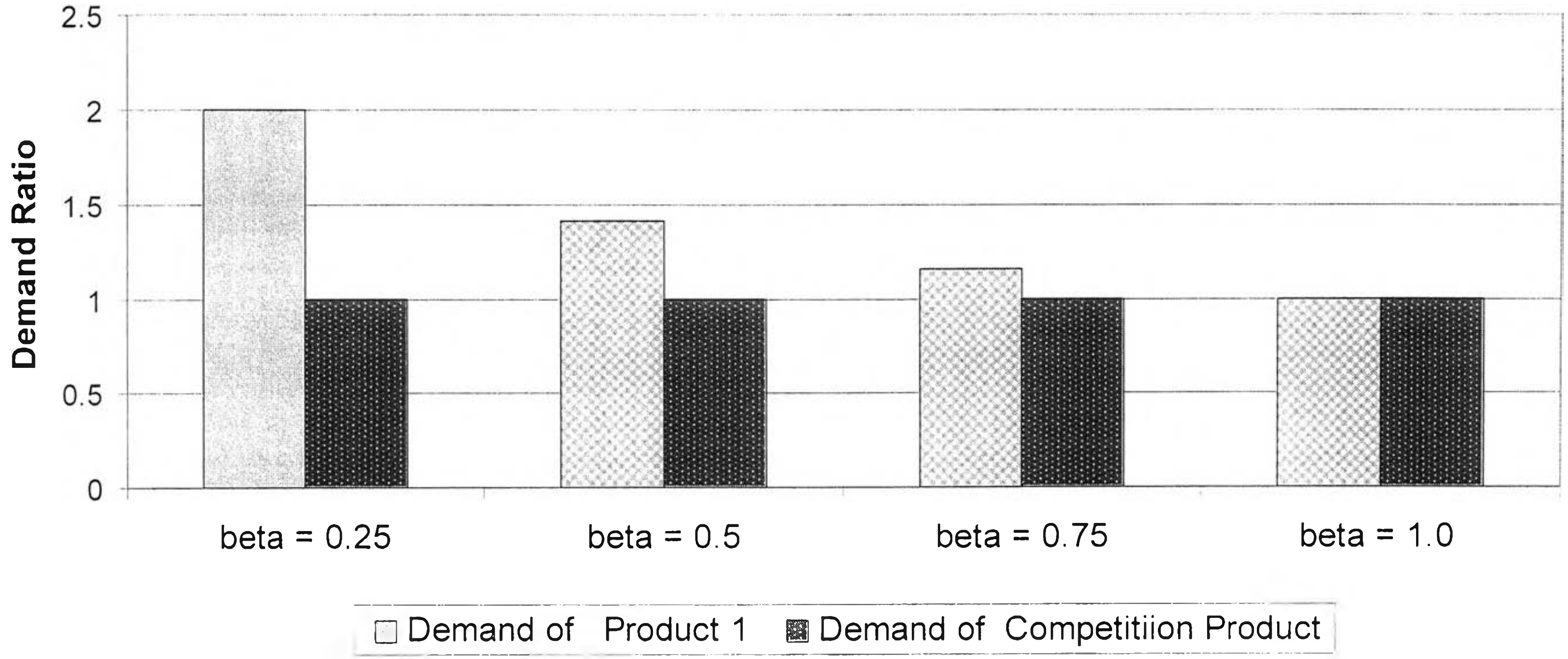

Figure 4.3 The demand ratio of product 1 compared to competition product obtained from different values of beta.

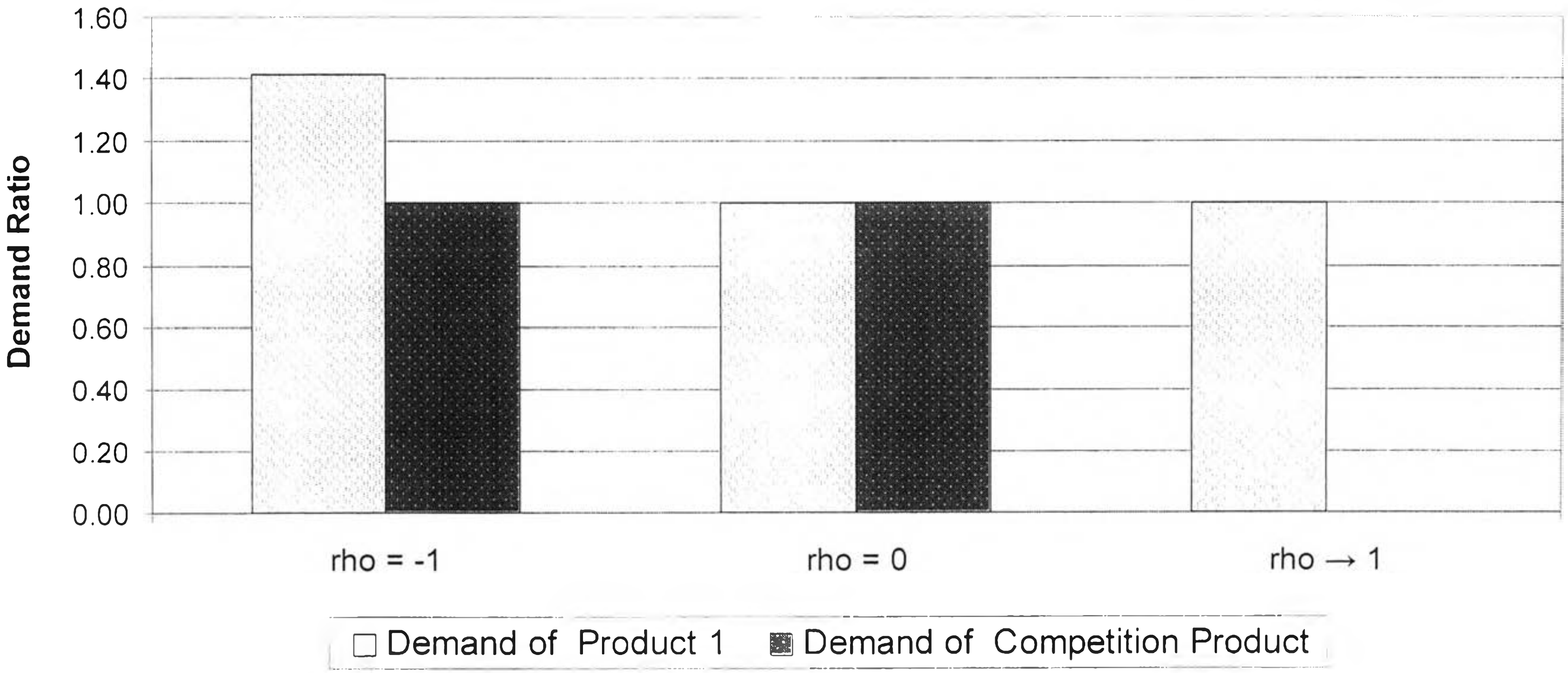

Figure 4.4 The demand ratio of product 1 compared to competition product obtained from different values of ρ.

Table 4.7 The competition product price and the total demand of product

Product	Competition product price ($/bbl)			Total demand of product (m^3)		
	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
LPG	32.64	31.49	30.8	76,040	84,735	88,370
SUPG	71.87	83.76	62.63	70,730	74,310	78,185
ISOG	73.74	85.75	64.53	48,345	45,060	44,125
JP-1	80.63	88.68	80.54	77,385	71,795	76,745
HSD	76.98	88.33	75.15	321,305	298,420	295,865
FO1	55.21	56.35	47.47	113,645	109,920	69,005
FO2	55.21	56.35	47.47	113,645	109,920	69,005
FOVS	55.21	56.35	47.47	113,645	109,920	69,005

Table 4.8 Consumer Budget in time period t

Product	Consumer budget ($)		
	Period 1	Period 2	Period 3
LPG	15,610,000	16,783,000	17,119,000
SUPG	31,973,000	39,149,000	30,799,000
ISOG	22,422,000	24,303,000	17,909,000
JP-1	39,245,000	40,045,000	38,877,000
HSD	155,572,000	165,796,000	139,849,000
FO1	39,464,000	38,959,000	20,603,000
FO2	39,464,000	38,959,000	20,603,000
FOVS	39,464,000	38,959,000	20,603,000

Table 4.9 Standard deviation of total demand and consumer budget

Description		LPG	SUPG	ISOG	JP-1	HSD	FO1	FO2	FOVS
Total demand	m^3	24,204.48	18,891.88	12,869.76	20,377.96	61,181.05	33,297.50	27,693.54	36,254.69
Consumer budget	US$M	4.24	8.20	6.18	9.15	34.55	9.70	9.70	9.70

4.2.3 The deterministic model with pricing results

Optimization results of the deterministic model with pricing suggest a higher Gross Refinery Margin (GRM) than that of the general deterministic model. The EGRM obtained from this pricing model is of US$M 10.712 with 159 discrete variables. Table 4.10 shows the product demand and price predicted and suggested by the deterministic pricing model. The amount of crude oil purchased corresponded to the predicted demand is shown in Table 4.11.

Table 4.10 Product demand and price for each time period from the deterministic pricing model

Product	Product price ($/bbl)			Demand of product (m^3)		
	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
LPG	33.00	31.60	30.60	38,020.00	42,367.50	44,185.00
SUPG	71.00	83.60	62.30	35,365.00	37,155.00	39,092.50
ISOG	74.30	86.00	64.60	24,172.50	22,530.00	22,062.50
JP-1	79.70	87.70	79.70	38,692.50	35,897.50	38,372.50
HSD	77.00	89.00	75.70	160,652.50	149,210.00	147,932.50
FO1	55.60	57.00	47.70	56,822.50	54,960.00	34,502.50
FO2	54.60	56.30	47.70	56,822.50	54,960.00	34,502.50
FOVS	55.60	57.00	47.70	56,822.50	54,960.00	34,502.50

Table 4.11 Volume and percentage of petroleum purchased for each period from the deterministic pricing model

Crude oil	Available Quantity	Period 1		Period 2		Period 3	
		(m^3)	(%)	(m^3)	(%)	(m^3)	(%)
OM	No limit	175,969	36.1235	211,937	37.0291	117,965	29.629
TP	No limit	0	0	17,004	2.97094	0	0
LB	95,392	63,144	12.9623	95,392	16.6667	95,392	23.9593
SLEB	95,392	95,392	19.5824	95,392	16.6667	95,392	23.9593
PHET	57,235	57,235	11.7494	57,235	10	57,235	14.3756
MB	95,392	95,392	19.5824	95,392	16.6667	32,157	8.07679
Total		487,133	100	572,353	100	398,142	100
Total (kbd)		102.13		120.00		83.47	
GRM	10.712 US$M						

The results of the deterministic pricing model suggest a highest EGRM of 10.712 US$M with is near the results of the general deterministic model. The alpha(α), beta(β) and rho(ρ) in this model are set to the case that give the equal demand of two products. So the demand of product 1 predicted by the model is about one-half of the total product demand.

4.2.4 The stochastic model with pricing results

The stochastic model takes into account that the total demand of products and the consumer budget are uncertain. The model was solved for 50 scenarios. These scenarios are computed assuming that the total demand and consumer budget follow a normal probability distribution with mean and standard deviation given in Table 4.7, 4.8 and 4.9.

Table 4.12 and Table 4.13 display the results of the stochastic model with pricing decision. Product demand predicted by the model and product price suggested by the model are shown in Table 4.12. The volume of petroleum purchased of this model is shown in Table 4.13.

Table 4.12 Product demand and price for each time period from the stochastic pricing model

Product	Product price ($/bbl)			Demand of product (m^3)		
	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
LPG	33.00	31.00	30.60	32,958.00	51,390.00	44,127.00
SUPG	72.00	83.60	63.00	29,950.50	40,520.50	30,493.00
ISOG	73.60	86.00	64.60	15,167.50	26,655.00	21,017.50
JP-1	80.00	88.30	80.00	39,985.00	31,324.00	31,616.50
HSD	77.30	89.00	75.30	126,165.50	114,410.50	213,757.50
FO1	55.60	57.00	47.30	60,170.50	42,659.50	33,014.00
FO2	55.00	56.30	47.70	76,564.50	62,049.50	35,390.50
FOVS	55.60	55.60	47.30	56,895.50	66,667.50	46,406.50

Table 4.13 Volume and percentage of petroleum purchased for each period from the stochastic pricing model

Crude oil	Available Quantity	Period 1		Period 2		Period 3	
		(m^3)	(%)	(m^3)	(%)	(m^3)	(%)
OM	No limit	207,796	37.40	211,937	37.03	105,350	26.41
TP	No limit	4,422	0.80	17,004	2.97	12,857	3.22
LB	95,392	95,392	17.17	95,392	16.67	95,392	23.92
SLEB	95,392	95,392	17.17	95,392	16.67	95,392	23.92
PHET	57,235	57,235	10.30	57,235	10.00	57,235	14.35
MB	95,392	95,392	17.17	95,392	16.67	32,601	8.17
Total		555,630	100	572,353	100	398,828	100
Total (kbd)		116.49		120.00		83.62	
GRM	8.049 US$M						

The solutions in Table 4.13 suggest the higher amount of crude oil purchased in time period 1. Major types of crude oil purchased from the stochastic pricing model are the same as those from the deterministic pricing model. From the results TP is selected in time period 1 and 3 because the higher demand of fuel oil in time period 1 and high-speed diesel in time period 3. This is because TP gives the high fraction in fuel oil and diesel oil intermediates.

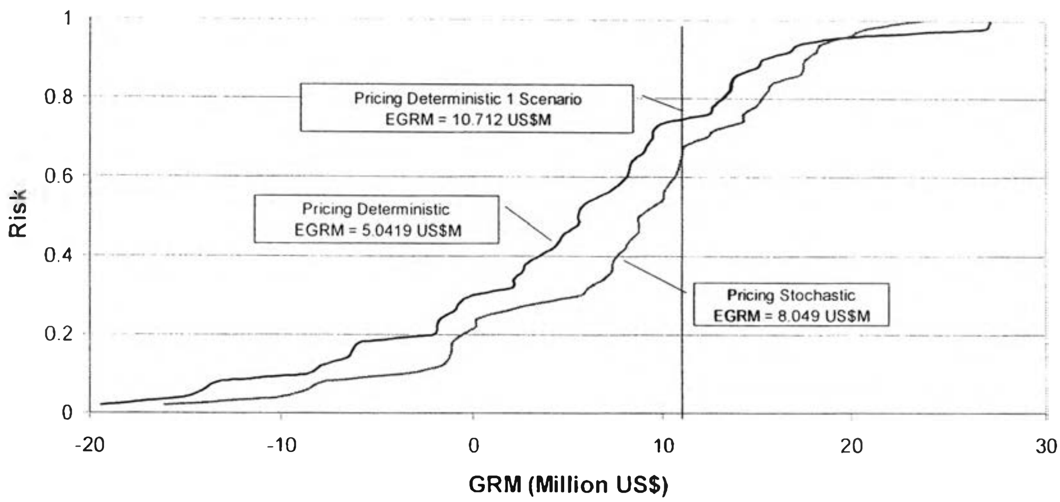

Figure 4.5 Risk curves of the deterministic and stochastic pricing model solutions.

For comparison purpose, the solution obtained by the deterministic model using the mean values of total demand of product and consumer budget is evaluated against the same 50 scenarios of stochastic model by fixing the first-stage variables (amount of crude oil purchased) and computing the second-stage ones with the stochastic formulation. The risk curve of the deterministic pricing model against 50 scenarios is compared with the risk curve of the stochastic pricing model as shown in Figure 4.5. This plot shows that the stochastic solution can provide a higher expected GRM than the deterministic solution with lower risk. Notice that the expected GRM suggested by the stochastic planning model with pricing is lower than that of the stochastic model without pricing. This is because the difference in how the demand and price of product are generated. In the general stochastic model, demand and price of product are generated independently for each scenario as the uncertain parameters. However, in the stochastic model with pricing, the demand and price are the model variables. Product demand is predicted corresponding to which discrete price is selected to maximize the expected GRM and this leads to the difference in the average expected GRM. However, it appeared that the results of the pricing model can fit better with the real situations so it is more reliable when compared to the non-pricing one.

4.3 Financial risk management

Although stochastic models optimize the total expected GRM, they do not provide any control of their variability over the different scenarios; i.e., they assume that the decision maker is risk neutral. Actually, different attitudes toward risk may be encountered. In this section, approach to manage financial risk is applied to compare the results.

The alternative plan that can reduce risk was considered. Figure 4.6 shows the risk curves of this plan compared with the stochastic solution. This plan suggests a lower amount of crude oil purchased in time period 1 and 3 as shown in Table 4.14.

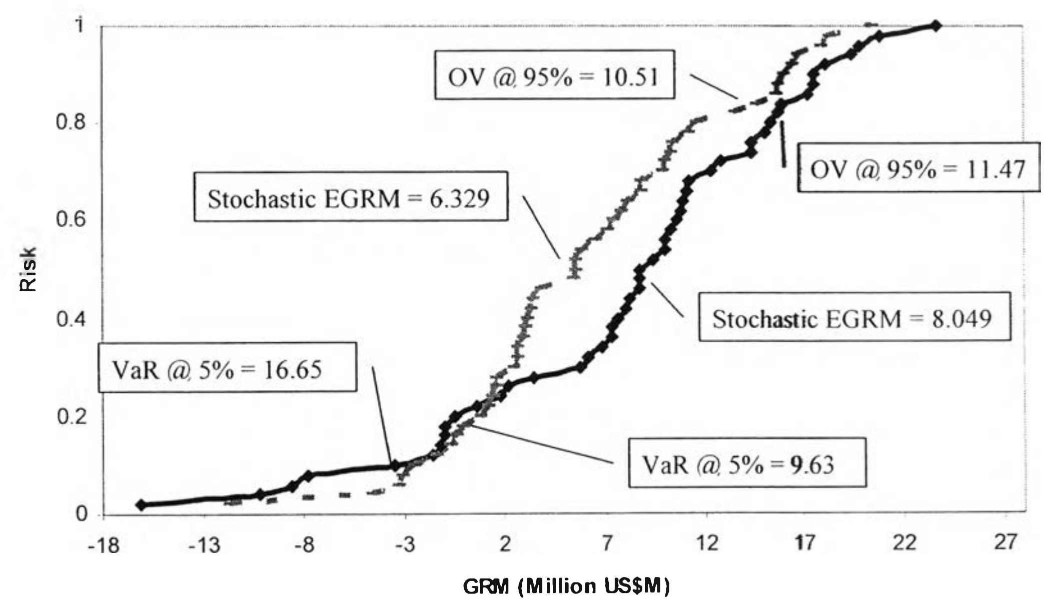

Figure 4.6 Risk curves of the stochastic pricing solution and the alternative solution with lower Value at Risk (VaR).

From the above figure, decreasing in crude oil purchased resulted in lower risk at low targets but with a lower chance to make a higher profit. Value at Risk (at 5%) and Opportunity Value (at 95%) for the two curves on Figure 4.6 are shown in Table 4.15. The VaR of the alternative plan reduces from 16.65 of the stochastic solution to 9.63 or 42% but the OV is also reduced from 11.47 to 10.51 or 8%. Therefore this plan may be preferred by a risk-averse decision maker.

Table 4.14 Volume and percentage of petroleum purchased for each period from the alternative solution with lower risk

Crude oil	Available Quantity	Period 1		Period 2		Period 3	
		(m^3)	(%)	(m^3)	(%)	(m^3)	(%)
OM	No limit	169,801.15	36.31	211,937.01	37.03	132,318.95	35.44
TP	No limit	0.00	0.00	17,004.28	2.97	0.00	0.00
LB	95,392	95,392.20	20.40	95,392.20	16.67	22,752.17	6.09
SLEB	95,392	49,767.31	10.64	95,392.20	16.67	95,392.20	25.55
PHET	57,235	57,235.32	12.24	57,235.32	10.00	57,235.32	15.33
MB	95,392	95,392.20	20.40	95,392.20	16.67	65,678.77	17.59
Total		467,588.18	100	572,353.21	100	373,377.41	100
Total (kbd)		98.03		120.00		78.28	
GRM	6.329 US$M						

Table 4.15 Value at Risk and Opportunity Value for the alternative solution with lower risk

Plan	VaR (5%)	OV (95%)
Stochastic Solution	16.65	11.47
Alternative Solution	9.63	10.51

The alternative plan that suggests a higher opportunity of profit is also considered. Figure 4.7 shows the risk curves of the alternative plan with a higher opportunity of profit compared with the stochastic solution. The amount of crude oil purchased corresponding to this alternative plan is shown in Table 4.16.

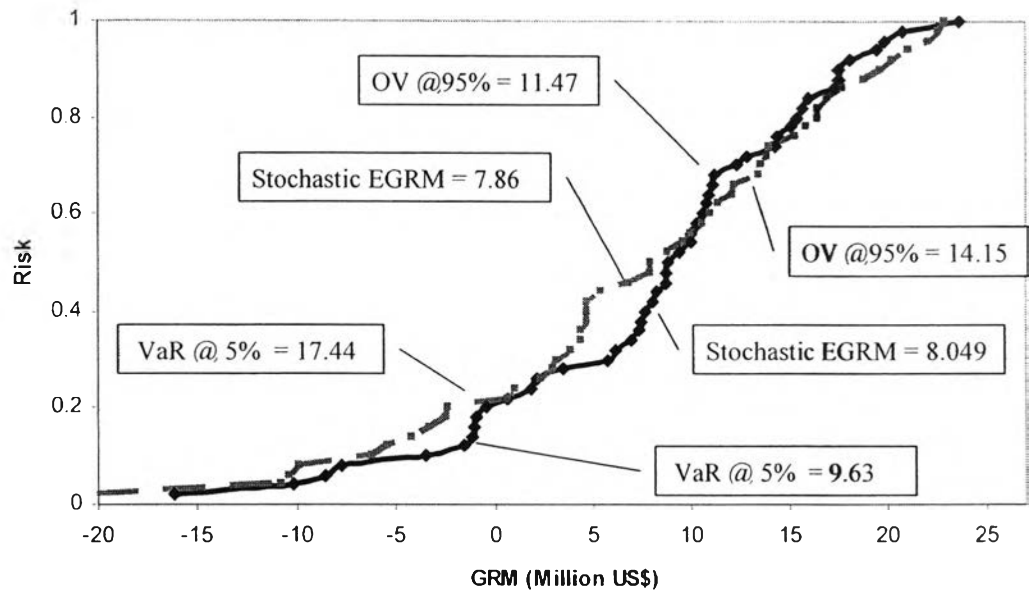

Figure 4.7 Risk curves of the stochastic pricing solution and the alternative solution with higher Opportunity Value (OV).

Table 4.16 Volume and percentage of petroleum purchased for each period from the alternative solution with opportunity of higher profit

Crude oil	Available Quantity	Period 1 (m^3)	Period 1 (%)	Period 2 (m^3)	Period 2 (%)	Period 3 (m^3)	Period 3 (%)
OM	No limit	181,862.96	36.17	212,345.86	37.10	123,206.99	32.38
TP	No limit	0.00	0.00	16,595.42	2.90	0.00	0.00
LB	95,392	72,933.12	14.50	95,392.20	16.67	56,023.10	14.72
SLEB	95,392	95,392.20	18.97	95,392.20	16.67	95,392.20	25.07
PHET	57,235	57,235.32	11.38	57,235.32	10.00	57,235.32	15.04
MB	95,392	95,392.20	18.97	95,392.20	16.67	48,667.57	12.79
Total		502,815.80	100	572,353.20	100	380,525.17	100
Total (kbd)		105.42		120.00		79.78	
GRM	7.863 US$M						

From Figture 4. 7, The alternative plan suggests a higher Opportunity Value (OV) of 14.15 compared to 11.47 of the stochastic solution. It increases about 23%. The VaR of the alternative design also increases from 16.65 to 17.44 or 4.7%. The VaR and OV of this alternative plan is shown in Table 4.17. This alternative solution with higher opportunity of profit may be preferred by the risk-taker decision makers who prefer a higher chance of getting higher profit.

Table 4.17 Value at Risk and Opportunity Value for the alternative solution with higher opportunity of profit

Plan	VaR (5%)	OV (95%)
Stochastic Solution	16.65	11.47
Alternative Solution	17.44	14.15

Figure 4.8 shows the upper bond risk curve compared to the risk curves of the stochastic solution and two alternative plans. From this figure the stochastic solution curve and both alternative curves are entirely positioned on the left side of the upper bond risk curve. This indicates that both alternative plans are feasible since the upper bond risk curve is constructed by plotting the set of GRM from the best design under each scenario.

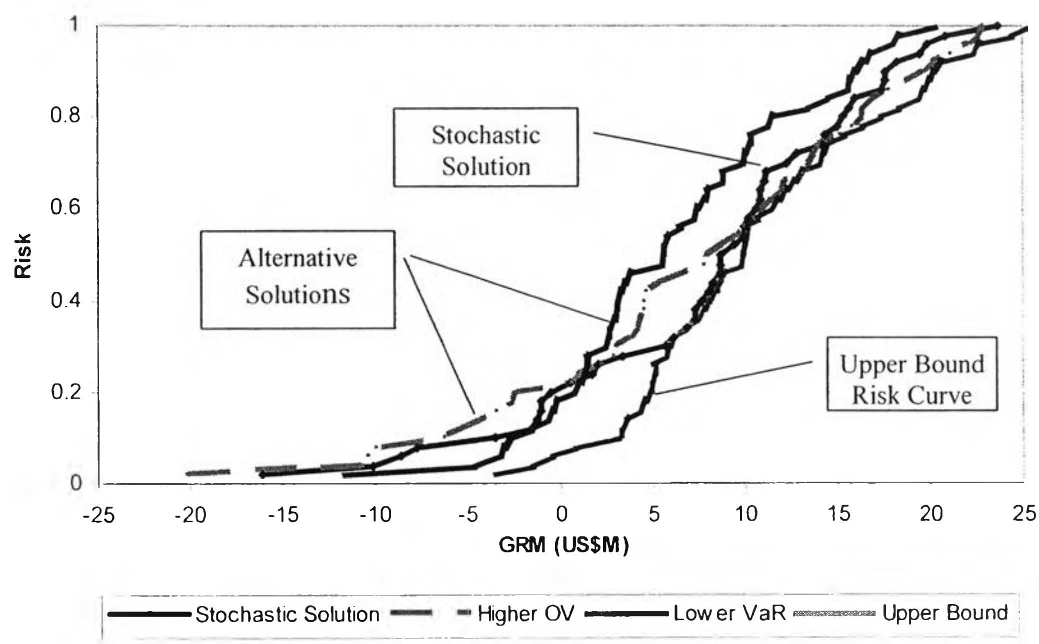

Figure 4.8 Upper bound risk curve for the stochastic and alternative solution.