CHAPTER IV
RESULTS AND DISCUSSION

4.1 Blending

The blending calculation was tested by blending six types of crude oil. The composition and property of products from each crude oil can be found in Appendix C. The composition of the crude oil mixtures is shown in Table 4.1.

Table 4.1 Composition of crude oil mixture

Crude oil \ Mixture	A	B	C	D
% Oman	35.26	43.10	40.25	25.00
% Tapis	19.71	6.74	11.46	15.00
% Labuan	0.00	0.00	0.00	10.00
% SLEB	0.00	7.21	4.59	10.00
% Phet	45.03	0.00	16.39	25.00
% Murban	0.00	42.95	27.32	15.00
Total	100.00	100.00	100.00	100.00

The result of product composition calculated from each type of the crude oil mixtures was compared to the assay blending report from Bangchak Refinery. This assay report is generated by the CAMS (Crude Assay Management System) program provided by KBC Advanced Technologies. The results are shown in Table 4.2.

From Table 4.2, most compositions from the calculation are comparable with the assay report. The difference is less than 1% except for FG. However, the quantity of FG contained in the crude oil is insignificant compared to the other components.

The calculation of product properties from the crude oil mixture D was compared to the assay blending report from Bangchak Refinery. The result is shown in Table 4.3. The results from the calculation are in good agreement to the assay blending report even for some properties such as Reid vapour pressure (RVP), viscosity, and pour point that are not additive since these properties have to be calculated by using indices value in order to make the blending linear. The calculation of indices used in the properties that are not additive can be found in Appendix B. In Table 4.3, the calculation of IK, DO, and FO properties has error less than 2% compared to the assay report. Slight differences in the naphtenes content of LN and RVP of HN can be observed. Nonetheless, the difference of other LN, MN and HN properties are still low and reasonable.

Table 4.2 Comparison between composition of crude blending assay report blending and calculation blending

Blend A	%FG	%LPG	% LN	% MN	% HN	% IK	% DO	% FO
Assay	0.150	1.880	3.870	3.800	8.200	15.900	26.500	37.700
Calculation	0.145	1.878	3.897	3.742	8.158	15.937	26.544	37.674
% Difference	3.33	0.11	-0.70	1.53	0.51	-0.23	-0.17	0.07

Blend B	%FG	%LPG	% LN	% MN	% HN	% IK	% DO	% FO
Assay	0.080	1.920	5.400	3.300	8.600	17.900	25.400	35.500
Calculation	0.075	1.914	5.413	3.254	8.589	17.851	25.351	35.566
% Difference	6.25	0.31	-0.24	1.39	0.13	0.27	0.19	-0.19

Blend C	%FG	%LPG	% LN	% MN	% HN	% IK	% DO	% FO
Assay	0.100	1.900	4.900	3.400	8.400	17.200	25.800	36.300
Calculation	0.101	1.901	4.861	3.431	8.432	17.155	25.785	36.333
% Difference	-0.54	-0.06	0.79	-0.92	-0.38	0.26	0.06	-0.09

Blend D	%FG	%LPG	% LN	% MN	% HN	% IK	% DO	% FO
Assay	0.120	1.770	4.210	3.700	8.800	17.900	28.800	32.800
Calculation	0.116	1.769	4.196	3.670	8.850	17.885	28.840	32.775
% Difference	3.33	0.08	0.34	0.81	-0.57	0.08	-0.14	0.08

Table 4.3 Property of crude oil mixture D compared with the assay blending report from Bangchak Refinery

		LN			MN			HN		
		Assay	Calc.	%Diff	Assay	Calc.	%Diff	Assay	Calc.	%Diff
Aromatics content	lv%	1.860	1.862	-0.095	4.640	4.471	3.653	12.540	12.504	0.288
RONC		74.600	74.325	0.369	66.000	66.041	-0.063	59.700	59.675	0.041
RVP	kg/cm^2	0.700	0.703	-0.476	0.160	0.158	1.447	0.040	0.042	-4.641
Freeze point	°C	-	-	-	-	-	-	-	-	-
Cetane index		-	-	-	-	-	-	-	-	-
Specific gravity	S.G.	-	-	-	-	-	-	-	-	-
Sulfur	wt%	-	-	-	-	-	-	-	-	-
Viscosity @ 50 °C	cSt	-	-	-	-	-	-	-	-	-
Viscosity @ 100 °C	cSt	-	-	-	-	-	-	-	-	-
Pour point	°C	-	-	-	-	-	-	-	-	-

		IK			DO			FO		
		Assay	Calc.	%Diff	Assay	Calc.	%Diff	Assay	Calc.	%Diff
Aromatics content	lv%	18.050	18.048	0.011	-	-	-	-	-	-
RONC		-	-	-	-	-	-	-	-	-
RVP	kg/cm^2	-	-	-	-	-	-	-	-	-
Freeze point	°C	-54.600	-55.058	-0.839	-	-	-	-	-	-
Cetane index		41.400	41.747	-0.838	52.400	53.026	-1.195	-	-	-
Specific gravity	S.G.	0.795	0.795	0.004	0.848	0.848	-0.001	0.923	0.923	0.003
Sulfur	wt%	0.045	0.045	-0.804	0.313	0.313	-0.141	0.976	0.976	0.018
Viscosity @ 50 °C	cSt	0.600	0.595	0.840	2.000	2.006	-0.320	104.960	104.974	-0.013
Viscosity @ 100 °C	cSt	0.420	0.423	-0.612	1.030	1.030	0.002	17.110	17.113	-0.016
Pour point	°C	-66.000	-64.905	1.658	-	-	-	41.800	41.437	0.868

4.2 Computational Results

The LP planning model was implemented in GAMS using CPLEX 9.0. The time horizon of this problem was divided into three equal time periods.

4.2.1 Input Data

Data in Table 4.4 is the values of crude oil cost and available quantity in the model runs. It is assumed that the crude oil cost is the same in all periods. Table 4.5 shows mean values for demand and price of all products in each time period while Table 4.6 shows standard deviations of these values. These standard deviations were estimated only from historical data in EPPO Thai Energy Data Notebook (2003).

Table 4.4 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

4.2.2 Deterministic Model Results

Optimization results of the deterministic model using mean values show a GRM of US$M 7.376 with less than a second of execution time. The amount of the crude oil purchased is shown in Table 4.7 whereas the percentage of the crude oil fed to each CDU is shown in Table 4.8.

Table 4.5 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 4.6 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 4.7 Volume and percentage of petroleum purchased for each period from the deterministic model

unit : 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 4.8 Percentage of crude feed 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
Total		100.00	100.00	100.00	100.00	100.00	100.00
Total (kbd)		29.61	49.61	39.72	49.61	40.00	61.02

From Table 4.7, the crude SLEB, PHET, and MB are purchased at the maximum available quantity. This would be the result from the high margin of these crudes, which are corresponding to the situation nowadays. Crude PHET is fed to CDU2 only due to the high pour point in the fuel oil portion. This high pour point property is not suitable for the production of FO1 and FO2 (low pour point fuel oil). In addition, PHET crude has to be desalted before feeding, which is possible with CDU2 only. For OM crude, Table 4.8 shows that OM is the major supply for CDU3. This can be understood since OM is an important crude in low pour point fuel oil (FO1 and FO2) production, which is produced from CDU3. The FO portion of OM crude is the only one with pour point in the range of FO1 and FO2 specification. In the second and third periods, LB crude is used because the demand in HSD product is higher. From Appendix C, DO portion of LB is the highest volume of all crude oils.

The production and inventory levels can be found in Table 4.9 while sale volume and lost demand are in Table 4.10. These tables show that the production satisfies the demand of most products.

Table 4.9 Volumes of production and inventory

unit : m^3

Product	Production			Inventory			
	First Period	Second Period	Third Period	Initial	First Period	Second Period	Third Period
LPG	12,805	14,100	14,484	1,500	205	0	26
SUPG	40,450	50,575	56,975	14,100	12,150	7,725	16,000
ISOG	20,620	17,979	34,502	8,400	9,020	1,998	14,000
JP-1	58,190	32,910	53,250	15,400	27,090	0	0
HSD	104,092	157,608	167,465	54,000	12,392	0	9,615
FO1	15,000	10,000	17,500	0	0	0	5,000
FO2	78,822	83,592	93,370	0	0	0	15,000
FOVS	43,353	54,240	54,980	0	0	13,808	24,779

Table 4.10 Volumes of sales and lost demand

unit : m^3

Product	Sales			Lost Demand		
	First Period	Second Period	Third Period	First Period	Second Period	Third Period
LPG	14,100	14,027	14,458	0	510	0
SUPG	42,400	55,000	48,700	0	0	0
ISOG	20,000	25,000	22,500	0	0	0
JP-1	46,500	60,000	53,250	0	0	0
HSD	145,700	170,000	157,850	0	0	0
FO1	15,000	10,000	12,500	0	0	0
FO2	67,100	80,000	73,500	0	0	0
FOVS	33,600	30,000	31,800	0	0	0

Table 4.11 Product properties (x = maximum, n = minimum)

Product	Property		Specification	Period		
				1	2	3
SUPG	RON		91n	91.00	91.00	91.00
	ARO	lv%	35x	35.00	35.00	35.00
	RVP	kPa	62x	48.51	48.51	48.51
ISOG	RON		95n	95.00	95.00	95.00
	ARO	lv%	35x	35.00	35.00	35.00
	RVP	kPa	62x	57.45	57.45	48.99
JP-1	ARO	lv%	25x	17.79	16.88	18.16
	FPI	index	11.8x	10.14	10.17	9.78
HSD	CI	index	47n	51.45	47.15	46.66
	S	wt%	0.05x	0.05	0.05	0.04
FO1	S	wt%	2x	1.71	1.71	1.62
	Vis50	cSt	7-80	72.70	75.17	96.81
	PP	°C	24x	17.57	17.57	19.55
FO2	S	wt%	2x	1.78	1.78	1.68
	Vis50	cSt	7-180	173.37	175.81	195.24
	PP	°C	24x	18.65	18.65	20.64
FOVS	S	wt%	0.5x	0.50	0.50	0.50
	Vis100	cSt	3-30	16.26	16.77	16.43
	PP	°C	57x	45.22	43.83	44.84

In Table 4.11, the optimization result shows that the products can attain almost all specifications. Some properties, e.g. octane number, aromatic content of gasoline, and sulfur content of FOVS are at the maximum limit. This shows that the model try to optimize the products by reducing giveaway in product properties. In addition, viscosity of FO1 and FO2 in the third period is over spec., however, in the production level, this can be manipulated in the schedule of operating plan.

4.2.3 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 are randomly generated independently for each variable by using normal distribution. The rest of the parameters are the same as the one in the base case of the deterministic model. The Sampling Algorithm is used to obtain optimal solutions. This method was illustrated and discussed by Barbaro and Bagajewicz (2003). The volume of petroleum purchased of this model is shown in Tables 4.12.

The solutions in Tables 4.12 suggest the higher amount of crude oil purchased. Type of primary crude oil selected is the same as deterministic model, i.e. PHET, MB, and SLEB. This circumstance insists the high margin of these crudes.

4.2.4 Risk Curves Analysis

The risk curves of the stochastic solution and deterministic solution are compared in Figure 4.1. This plot shows that the stochastic solution can provide the 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.

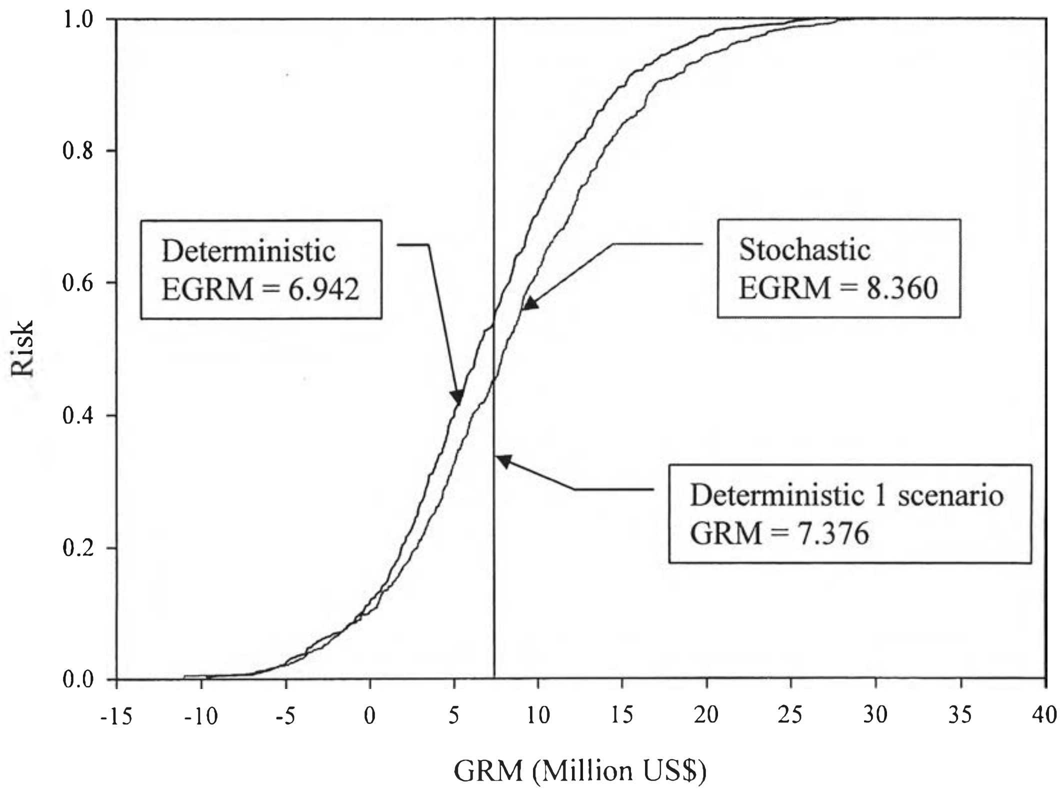

Figure 4.1 Risk curves of the deterministic model and stochastic model solutions.

Table 4.12 Volume and percentage of petroleum purchased for each period from the stochastic model

unit : m^3

Crude oil	Available Quantity	First Period		Second Period		Third Period	
OM	No limit	153,856	36.53	154,436	36.13	220,126	38.46
TP	No limit	0	0.00	0	0.00	8,815	1.54
LB	95,392	19,315	4.59	24,962	5.84	95,392	16.67
SLEB	95,392	95,392	22.65	95,392	22.32	95,392	16.67
PHET	57,235	57,235	13.59	57,235	13.39	57,235	10.00
MB	95,392	95,392	22.65	95,392	22.32	95,392	16.67
Total		421,191	100.00	427,418	100.00	572,353	100.00
Total (kbd)		88		90		120	

A plan that reduces risk and does not have a large effect on EGRM (1.32% difference) was also obtained by using the Sampling Algorithm. This alternative plan for purchasing crude oil can be found in Table 4.13.

This alternative plan suggests to purchase TAPIS crude in the second period and lower amount of crude oil purchased in the third period. Figure 4.2 shows the risk curve of the stochastic solution and its alternative choice.

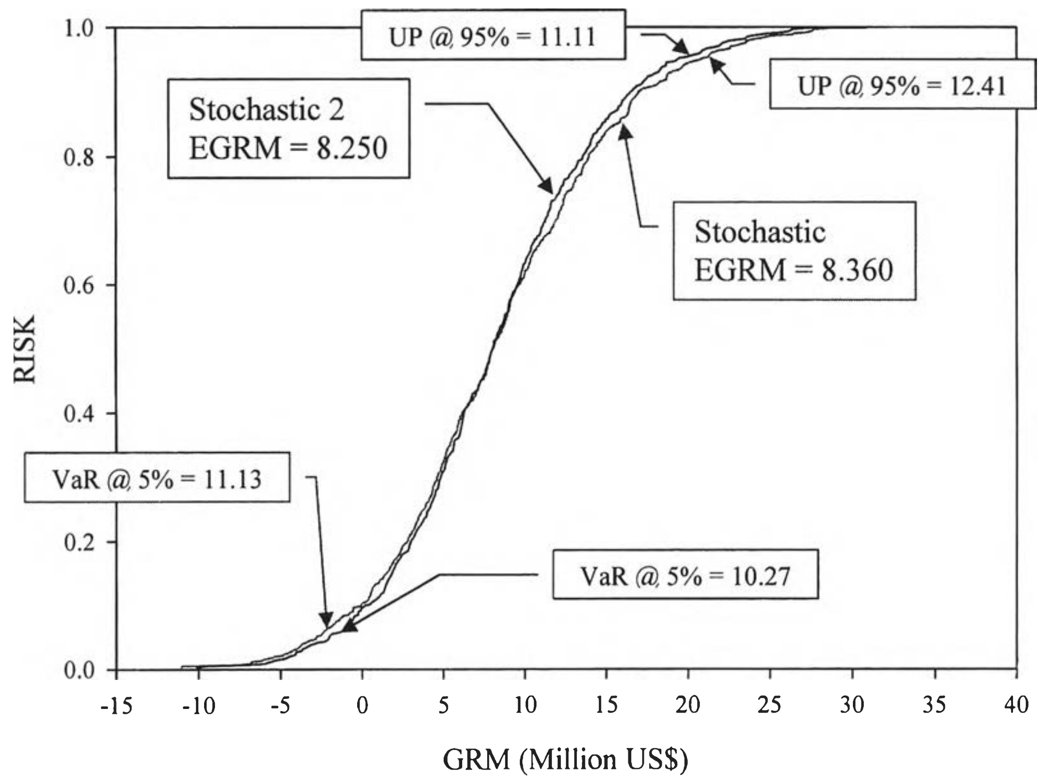

Figure 4.2 Risk curves of the first and second plan of stochastic model solutions.

From the above figure, decreasing in crude oil purchase resulted in lower risk in loss while also lower a chance to make the higher profit. This second plan may be preferred by a risk-averse who want to have low risk for some conservative profit aspiration levels, while a risk-taker decision maker would prefer to see lower risk at higher profit aspiration level, even if the risk at lower profit values increases as in the first plan.

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

unit : m^3

Crude oil	Available Quantity	First Period		Second Period		Third Period	
OM	No limit	155,884	36.13	164,416	39.72	180,136	36.29
TP	No limit	0	0.00	6,433	1.55	0	0.00
LB	95,392	27,543	6.38	0	0.00	95,392	19.22
SLEB	95,392	95,392	22.11	90,415	21.85	68,198	13.74
PHET	57,235	57,235	13.27	57,235	13.83	57,235	11.53
MB	95,392	95,392	22.11	95,392	23.05	95,392	19.22
Total		431,447	100.00	413,892	100.00	496,353	100.00
Total (kbd)		90		87		104	

Value at Risk (at 5% percentile or 0.05 quantile) and Upside Potential (at 95%) for the two curves on Figure 4.2 are shown in Table 4.14. The VaR reduces from 11.13 to 10.27 or 7.73% in the result of the second versus first plan and the UP is reduced from 12.41 to 11.11 or 10.47%. This result shows that the second plan is more robust than the first plan. In other word, the GRM at 5% and 95% risk of second plan has less deviation from the expected GRM than the first plan.

Table 4.14 Value at Risk and Upside Potential for the alternative solution

Plan	VaR (5%)	UP (95%)
First	11.13	12.41
Second	10.27	11.11

The Risk Area Ratio (RAR) is equal to 1.6. This means that the loss in opportunity of second plan is more than one half of gain in risk reduction. The closer this number to one, the better the alternative solution.

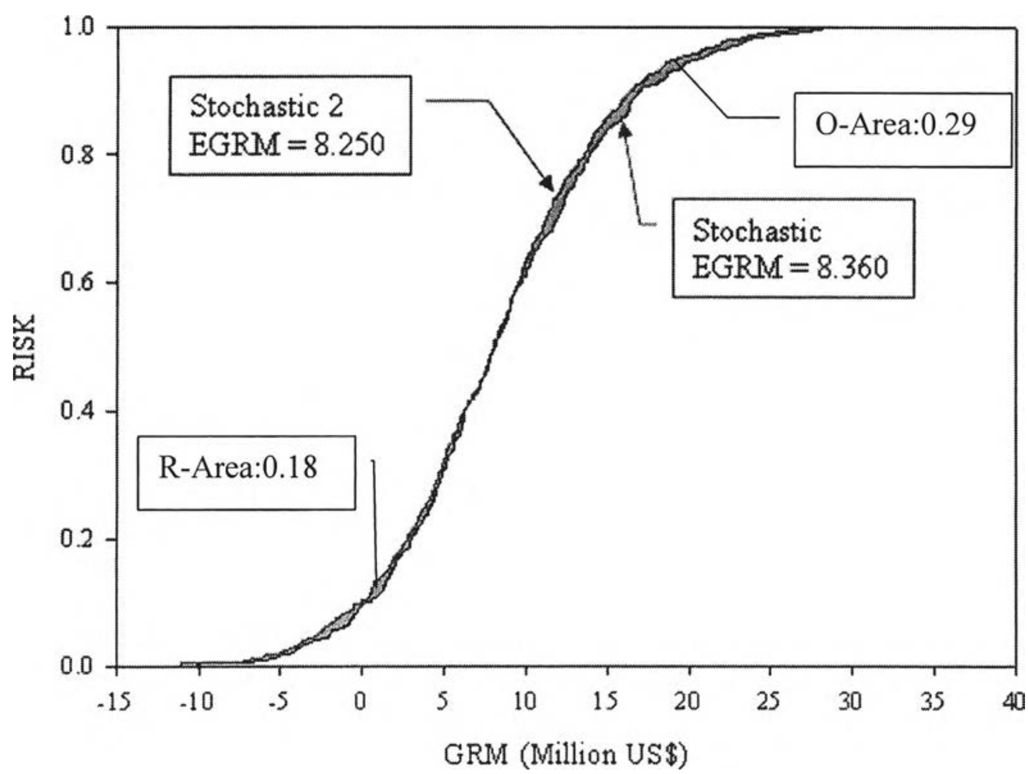

Figure 4.3 Area of risk and opportunity ratio.

Figure 4.4 shows the upper bound risk curve for the solution from the stochastic model and curves from the first and second plans. It was found that the first and second plans are positioned entirely to the left of the upper bound risk curve. This indicates that both plans are feasible since the upper bound risk curve, by definition, is the curve constructed by plotting the set of GRM for the best design under each scenario.

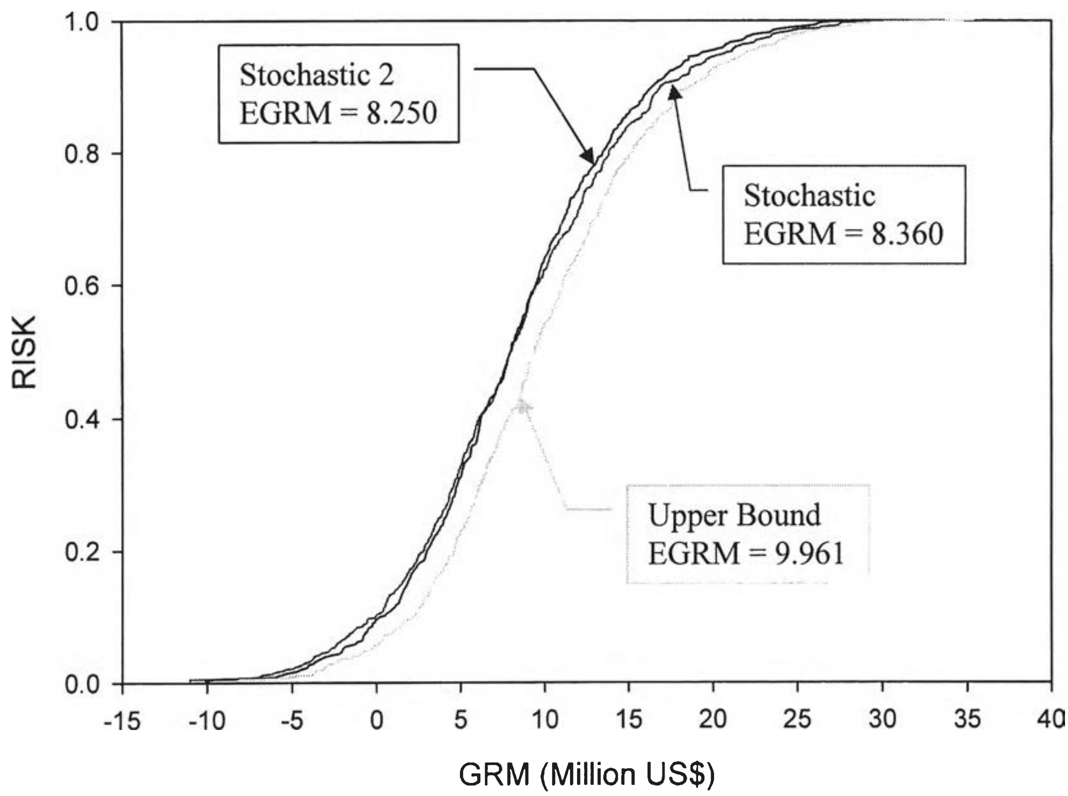

Figure 4.4 Upper bound risk curve for the stochastic solution.