REFERENCES

Al-redhwan, S.A., Crittenden, B.D., Lababidi, H.M.S. (2005) Wastewater minimization under uncertain operational conditions. Computer & Chemical Engineering, 29(5), 1009-1021.

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, 28, 2791-2821.

Barbaro, A. and Bagajewicz, M.J. (2004) Managing financial risk in planning under uncertainty. AIChE Journal, 50(5), 963-989.

Birge, J.R. and Louveaux, F. (1997) Introduction to Stochastic Programming. New York: Springer.

Bonfill, A., Cantón, J., Bagajewicz, M.J., Espuña, A., and Puigjaner, L. (2004) Risk management in scheduling of batch plants under uncertain market demand. Industrial Engineering Chemical Research, 43, 741-750.

Chapra, S.C., and Canale R.P. (2003) Numerical Methods for Engineers: with Software and Programming Applications. New York: McGraw-Hill.

Cheng, L., Subrahmanian E., and Westerberg, A.W. (2003) Design and planning under uncertainty: Issues on problem formulation and solution. Computers and Chemical Engineering, 27(6), 781–801.

Csáji, B. and Monostori, L. (2005) Stochastic Reactive Production Scheduling by Multi-Agent Based Asynchronous Approximate Dynamic Programming. In: Multi-Agent Systems and Applications IV (CEEMAS 2005). Lecture Notes in Artificial Intelligence, 3690. Springer, Germany, 388-397.

Edgar, T.F., Himmelblau, D.M., and Lasdon, L.S. (2001) Optimization of Chemical Processes 2nd edition. New York: McGraw-Hill.

Floudas, C.A. (1995) Nonlinear and Mixed-Integer Optimization Fundamentals and Applications. Oxford: Oxford University Press.

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

Guillén, G., Mele, F.D., Bagajewicz, M.J., Espuña A., and Puigjaner, L. (2005) Multiobjective supply chain design under uncertainty. Chemical Engineering Science, 60, 1535-1553.

Guldimann, T. (2000) The story of risk metrics. Risk, 13(1), 56-58.

Gupta A. and Maranas C. (2003) Market-based pollution abatement strategies: Risk management using emission option contracts. Industrial Engineering Chemical Research, 42, 802–810.

Herroelen, W. and Leus, R. (2005) Project scheduling under uncertainty: Survey and research potentials. European Journal of Operational Research, 165, 289–306.

Ierapetritou, M.G. and Pistikopoulos, E.N. (1994) Simultaneous incorporation of flexibility and economic risk in operational planning under uncertainty. Computers and Chemical Engineering , 18(3),163–189.

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. Brazilien Journal of Chemical Engineering, 19(2), 207-228.

Jorion, P. (2000) Value At Risk. The New Benchmark For Managing Financial Risk. 2nd edition. New York: McGraw-Hill.

Karwan, M. H., andKeblis, M. F. (2007) Operations planning with real time pricing of a primary input. Computers & Operations Research, 34(3), 848-867.

Kendall, G., Burke E.K., Petrovic, S., and Gendreau, M. (2005) Multidisciplinary Scheduling: Theory and Applications, 1st International Conference on Scheduling. New York: Springer Science+Business Media.

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.

Liao, Z. and Rittscher, J. (2006) A multi-objective supplier selection model under stochastic demand conditions. International Journal of Production Economics, article in press.

Linsmeier, T.J., and Pearson, N.D. (2000) Value at risk. Financial Analysts Journal, 56(2).

Lowe, T.J., Wendell, R.E., and Hu, G. (2002) Screening location strategies to reduce exchange rate risk. European Journal of Operational Research, 136(3), 573-590.

Méndez, C.A., Grossmann, I.E., Harjunkoski, I., and Kaboré, P. (2006) A simultaneous optimization approach for off-line blending and scheduling of oil-refinery operations. Computer & Chemical Engineering, 30(4), 614-634.

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

Mulvey, J.M., Rosenbaum, D.P., and Shetty, B. (1997) Strategic financial risk management and operations research. European Journal of Operational Research, 97(1), 1-16.

Neiro, S.M.S. and Pinto, J.M. (2004) A general modeling framework for the operational planning of petroleum supply chains. Computers & Chemical Engineering, 28(6-7), 871-896.

Persson, J.A. and Göthe-Lundgren, M. (2005) Shipment planning at oil refineries using column generation and valid inequalities. European Journal of Operational Research , 163(3), 631-652.

Pindyck, R.S., and Rubinfeld, D.L. (1997) Microeconomics 3rd edition. China: Prentice-Hall Inc.

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.

Porterfield, J.T.S. (1995) Investment Decisions and Capital Costs. New Jersey: Prentice-Hall.

Rejowski, R. Jr. and Pinto J. M. (2003) Scheduling of a multiproduct pipeline system. Computers & Chemical Engineering, 27(8-9), 1229-1246.

Reddy, P.C.P., Karimi, I.A., and Srinivasan, R. (2004) A new continuous-time formulation for scheduling crude oil operations. Chemical Engineering Science, 59(6), 1325-1341.

Reklaitis, G.V., Ravindran, A., and Ragsdell, K.M. (1983) Engineering Optimization: Methods and Applications. Canada: John Wiley & Sons.

Shah, N. (1996) Mathematical programming techniques for crude oil scheduling. Computers & Chemical Engineering, 20, Suppl., S1227-S1232.

Shah, N. (1998) Single and multisite planning and scheduling: Current status and future challenges. FOCAPO AIChE symposium series, 94(320), 91-110.

Shimizu Kiyotaka, Ishizuka Yo, and Bard, J.F. (1997) Nondifferentiable and Two-Level Mathematical Programming. Massachusetts: Kluwer Academic.

Simons, R. (1997) MIMI brings OR tools together. MP in Action, December.

Singh, A., Forbes, J.F., Vermeer, P.J., and Woo, S.S. (2000) Model-based real-time optimization of automotive gasoline blending operations. Journal of Process Control, 10(1), 43-58.

Swift, A.O. (2000) Control and optimization. In A.G. Lucas (Ed.), Modern Petroleum Technology: Volume 2 Downstream. 6th ed. Chichester (UK): John Wiley & Sons.

Varian, H. R. (1992) Microeconomic Analysis 3rd edition. New York: Norton.

Voeth, M., and Herbst, U. (2006) Supply-chain pricing-A new perspective on pricing in industrial markets. Industrial Marketing Management , 35(1) , 83-90

Zhang, J., Zhu, X.X., and Towler, G.P. (2001) A level-by-level debottlenecking approach in refinery operation. Industrial & Engineering Chemistry Research, 40, 1528-1540.

Zhang, B.J. and Hua, B. (2005) Effective MILP model for oil refinery-wide production planning and better energy utilization. Journal of Cleaner Production, article in press.

http://stoprog.org/index.html?spintroduction.html

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APPENDICES

Appendix A Nomenclature

Indices

t	Set of time periods
c	Set of all commodities
o	Set of crude oils
p	Set of products
i	Set of intermediates
u	Set of productive units
q	Set of properties
s	Set of scenarios
k	Set of discrete prices
Y	Set of demand from budget constraint
D	Set of demand from total demand constraint

Parameter

$pro_{u,c,q}$	Property q of commodity c from unit u	
$px_{p,q}$	Maximum property q of product p	
$pn_{p,q}$	Minimum property q of product p	
$cyield_{o,c}$	Percent of component c in crude oil o	(%)
$yield_{u,c}$	Percent yield of commodity c from unit u	(%)
$dem_{p,t}$	Demand of product p in time period t	(m^3)
ux_u	Maximum capacity of unit u	(m^3)
un_u	Minimum capacity of unit u	(m^3)
ox_o	Maximum monthly purchase of crude oil o	(m^3)
on_o	Minimum monthly purchase of crude oil o	(m^3)
$stox_p$	Maximum storage capacity of product p	(m^3)
$cp_{p,t}$	Unit sale price of product p in time period t	($/m^3$)
$co_{o,t}$	Unit sale price of crude oil o in time period t	($/m^3$)

$ci_{i,t}$	Unit purchase price of intermediate I in time period t	($/m^3)
$cl_{p,t}$	Unit cost of lost demand penalty for product p in time period t	($/m^3)
$density_u$	Density of feed to unit u	(ton/m^3)
$fuel_u$	Percent energy consumption for unit u based on tFOE	(%)
disc	Percent discount from normal price	(%)
u	Consumer utility function	
Y	Consumer budget	($)
D	Total product demand	(m^3)
ρ	Price-Demand relation parameter	
α	Product inferiority and superiority parameter	
β	Product inferiority and superiority parameter	

Variables

$PO_{u,c,q,t}$	Property q of commodity c from unit u in time period t	
$AF_{u,t}$	Amount of feed to unit u in time period t	(m^3)
$AO_{u,c,t}$	Amount of outlet commodity c from unit u in time period t	(m^3)
$A_{u,t,u',t}$	Amount of commodity c flow between unit u and unit u' in time period t	(m^3)
$MANU_{p,t}$	Amount of product p produced in time period t	(m^3)
$AC_{o,t}$	Amount of crude oil o refined in time period t	(m^3)
$AI_{i,t}$	Amount of intermediate I added in time period t	(m^3)
$AS_{p,t}$	Amount of product p stored in time period t	(m^3)
$AL_{p,t}$	Amount of lost demand for product p in time period t	(m^3)
$AD_{p,t}$	Amount of discount product sold in time period t	(m^3)
$Burnt_{p,t}$	Amount of product p burnt in time period t	(m^3)
$Used_t$	Amount of fuel used in time period t	(tFOE)
$TP_{p,t}$	Income from selling product p in time period t	($)
$TO_{o,t}$	Expense from purchasing crude oil o in time period t	($)
$TI_{i,t}$	Expense from purchasing intermediate in time period t	($)
$TS_{p,t}$	Expense from storage product p in time period t	($)

$TL_{p,t}$	Expense from lost demand of product p in time period t	($)
$TD_{p,t}$	Expense from discount sales of product p in time period t	($)
$Sales_{p,t}$	Sales of product p in time period t	(m^3)
P_1	Price of product 1	($/m^3$)
P_2	Price of competition product 2	($/m^3$)
d_1	Demand of product 1	(m^3)
d_2	Demand of competition product 2	(m^3)

Appendix B Data of commodities and productive units

Table B1 Fuel used in processing unit (expressed in fuel oil equivalence) (Favennec, 2001)

Units	Fuel used (wt%)
CDU2	1.8
CDU3	1.8
NPU2	2
NPU3	2
ISOU	4
CRU2	2.5
CRU3	2.5
KTU	2
GO-HDS	2
DGO-HDS	2

Table B2 Oman crude specification

API Gravity	34.80		**% Sulfur**	1.16	
Methane	Vol%	0.00	Iso-butane	Vol%	0.30
Ethane	Vol%	0.02	N-butane	Vol%	0.92
Propane	Vol%	0.33			

Description		**Component Fraction (%vol)**							
		FG	**LPG**	**LN**	**MN**	**HN**	**IK**	**DO+GO**	**FO**
Vol. yield on crude	lv%	0.02	1.55	5.33	2.70	6.30	13.80	22.40	46.30
Aromatics content	lv%	-	-	1.20	4.25	8.24	11.94	20.94	-
Cetane index		-	-	-	-	30.10	46.40	54.10	-
Freeze point	°C	-	-	-	-85.50	-74.60	-53.50	-8.80	-
RONC		-	-	69.50	49.20	40.60	27.60	-	-
RVP	kg/cm^2	-	-	0.70	0.16	0.04	0.00	-	-
Specific gravity		-	-	0.6517	0.7119	0.7385	0.7844	0.8447	0.9367
Sulfur	wt%	-	-	0.012	0.027	0.03	0.108	0.687	1.938
Viscosity @ 50°C	cSt	-	-	-	0.41	0.54	1.01	3.64	609.00
Viscosity @ 100°C	cSt	-	-	-	0.34	0.40	0.62	1.66	52.22
Pour point	°C	-	-	-	-	-	-77.90	-	7.00

Table B3 Tapis crude specification

API Gravity	44.50		**% Sulfur**	0.025	
Methane	Vol%	0.00	Iso-butane	Vol%	0.82
Ethane	Vol%	0.54	N-butane	Vol%	1.21
Propane	Vol%	0.66			

Description		**Component Fraction (%vol)**							
		FG	**LPG**	**LN**	**MN**	**HN**	**IK**	**DO+GO**	**FO**
Vol. yield on crude	lv%	0.54	2.69	3.27	5.70	10.70	21.90	30.40	21.50
Aromatics content	lv%	-	-	1.78	5.11	13.09	16.82	17.41	-
Cetane index		-	-	-	-	20.90	45.10	59.30	33.30
Freeze point	°C	-	-	-	-	-83.50	-51.10	6.00	-
RONC		-	-	81.70	76.00	68.20	60.30	-	-
RVP	kg/cm^2	-	-	0.66	0.15	0.05	0.00	-	-
Specific gravity		-	-	0.6713	0.7247	0.7557	0.7857	0.8271	0.9175
Sulfur	wt%	-	-	0.000	0.000	0.001	0.004	0.034	0.056
Viscosity @ 50°C	cSt	-	-	-	0.43	0.55	0.96	2.88	15.26
Viscosity @ 100°C	cSt	-	-	-	0.31	0.37	0.58	1.37	4.59
Pour point	°C	-	-	-	-	-	-63.40	-	58.40

Table B4 Labuan crude specification

API Gravity	31.80		**% Sulfur**	0.080	
Methane	Vol%	0.00	Iso-butane	Vol%	0.18
Ethane	Vol%	0.02	N-butane	Vol%	0.36
Propane	Vol%	0.22			

Description		**Component Fraction (%vol)**							
		FG	**LPG**	**LN**	**MN**	**HN**	**IK**	**DO+GO**	**FO**
Vol. yield on crude	lv%	0.02	0.76	2.42	3.20	9.00	20.30	42.70	20.70
Aromatics content	lv%	-	-	7.05	0.64	16.13	26.36	41.67	-
Cetane index		-	-	-	-	11.30	30.20	39.20	-
Freeze point	°C	-	-	-	-	-	-67.80	-8.10	-
RONC		-	-	83.20	76.40	73.60	50.20	-	-
RVP	kg/cm^2	-	-	0.64	0.16	0.04	0.00	-	-
Specific gravity		-	-	0.6898	0.7402	0.7759	0.8280	0.8911	0.9530
Sulfur	wt%	-	-	0.001	0.001	0.002	0.017	0.083	0.175
Viscosity @ 50°C	cSt	-	-	-	0.53	0.62	1.04	3.11	132.07
Viscosity @ 100°C	cSt	-	-	-	0.35	0.41	0.63	1.46	14.50
Pour point	°C	-	-	-	-	-	-86.50	-	45.10

Table B5 Seria light crude specification

API Gravity	35.80		**% Sulfur**	0.068	
Methane	Vol%	0.00	Iso-butane	Vol%	0.26
Ethane	Vol%	0.00	N-butane	Vol%	0.62
Propane	Vol%	0.25			

Description		**Component Fraction (%vol)**							
		FG	**LPG**	**LN**	**MN**	**HN**	**IK**	**DO+GO**	**FO**
Vol. yield on crude	lv%	0.00	1.33	4.77	4.00	11..30	23.10	35.00	19.50
Aromatics content	lv%	-	-	2.65	8.19	15.88	24,28	53.56	-
Cetane index		-	-	-	-	12.80	31.60	43.00	-
Freeze point	°C	-	-	-	-	-	-59.60	-6.40	-
RONC		-	-	79.50	68.00	60.70	49.60	-	-
RVP	kg/cm^2	-	-	0.69	0.16	0.04	0.00	-	-
Specific gravity		-	-	0.6798	0.7415	0.7696	0.8200	0.8781	0.9506
Sulfur	wt%	-	-	0.000	0.001	0.003	0.020	0.080	0.155
Viscosity @ 50°C	cSt	-	-	-	0.21	0.21	0.21	0.34	132.96
Viscosity @ 100°C	cSt	-	-	-	0.21	0.21	0.21	0.27	16.87
Pour point	°C	-	-	-	-	-	-65.80	-	35.90

Table B6 Phet crude specification

API Gravity	40.70		**% Sulfur**	0.050	
Methane	Vol%	0.00	Iso-butane	Vol%	0.37
Ethane	Vol%	0.07	N-butane	Vol%	1.04
Propane	Vol%	0.37			

Description		**Component Fraction (%vol)**							
		FG	**LPG**	**LN**	**MN**	**HN**	**IK**	**DO+GO**	**FO**
Vol. yield on crude	lv%	0.07	1.78	3.05	3.70	8.50	15.00	28.10	38.00
Aromatics content	lv%	-	-	1.05	5.93	12.15	14.42	14.58	-
Cetane index		-	-	-	-	22.60	45.60	61.40	-
Freeze point	°C	-	-	-	-	-88.80	-48.90	13.40	-
RONC		-	-	70.00	61.40	53.50	41.60	-	-
RVP	kg/cm^2	-	-	0.71	0.16	0.04	0.00	-	-
Specific gravity		-	-	0.6662	0.7200	0.7502	0.7840	0.8236	0.8941
Sulfur	wt%	-	-	0.000	0.000	0.001	0.006	0.047	0.087
Viscosity @ 50°C	cSt	-	-	-	0.35	0.48	0.94	3.12	39.72
Viscosity @ 100°C	cSt	-	-	-	0.22	0.26	0.52	1.50	10.59
Pour point	°C	-	-	-	-	-	-51.50	-	55.90

Table B7 Murban crude specification

API Gravity	40.80		**% Sulfur**	0.867	
Methane	Vol%	0.00	Iso-butane	Vol%	0.45
Ethane	Vol%	0.07	N-butane	Vol%	1.32
Propane	Vol%	0.52			

Description		**Component Fraction (%vol)**							
		FG	**LPG**	**LN**	**MN**	**HN**	**IK**	**DO+GO**	**FO**
Vol. yield on crude	lv%	0.07	2.29	5.94	3.30	10.10	20.40	25.90	29.70
Aromatics content	lv%	-	-	1.76	0.41	12.41	20.48	25.48	-
Cetane index		-	-	-	-	27.90	43.50	53.20	-
Freeze point	°C	-	-	-	-	-90.20	-56.10	-2.60	-
RONC		-	-	76.00	72.20	70.10	56.30	-	-
RVP	kg/cm^2	-	-	0.75	0.16	0.04	0.00	-	-
Specific gravity		-	-	0.6609	0.7145	0.7438	0.7883	0.8455	0.9268
Sulfur	wt%	-	-	0.000	0.000	0.000	0.107	1.051	1.688
Viscosity @ 50°C	cSt	-	-	-	0.39	0.52	0.93	3.09	88.41
Viscosity @ 100°C	cSt	-	-	-	0.28	0.35	0.57	1.42	13.84
Pour point	°C	-	-	-	-	-	-73.00	-	33.40

Table B8 Product specifications (x = maximum, n = minimum)

Description		LPG	SUPG	ISOG	JP-1	HSD	FO #1	FO #2	FOVS
RON			91n	95n					
RVP @ 37.8 °C	kPa		62x	62x					
Aromatic Content	vol%		35x	35x	25x				
Freezing point	°C				-47x				
Cetane Index						47n			
Viscosity @ 50°C	cSt						7-80	7-180	
Viscosity @ 100°C	cSt								3-30
Sulfur Content	wt%					0.05x	2x	2x	0.5x
Pour point	°C						24x	24x	57x

Product specifications are based on rules from Ministry of Commerce (MOC.).

Table B9 Product storage data

Description		LPG	SUPG	ISOG	JP-1	HSD	FO #1	FO #2	FOVS
Product stored at initial	m^3	1,500	14,100	8,400	15,400	54,000	-	-	-
Storage capacity	m^3	5,000	16,000	14,000	28,000	80,000	5,000	15,000	35,000

Appendix C Members of sets

aref	∈	{RON, ARO, RVP}
AV_q	∈	{YD, RON, RVP, ARO, CI, SG}
AW_q	∈	{FP, S, V50, V100}
C_{CDU}	∈	{FG, LPG, LN, MN, HN, IK, DO, FO}
C_{CRU}	∈	{FG, LPG, REF}
CDU	∈	{CDU2, CDU3}
C_{ia}	∈	{MTBE, DCC}
C_o	∈	{OM, TP, LB, SLEB, PHET, MB}
C_p	∈	{LPG, SUPG, ISOG, JP-1, HSD, FO1, FO2. FOVS}
CRU	∈	{CRU2, CRU3}
ctank	∈	{OMT, TPT, LBT, SLEBT, PHETT, MBT}
GSP	∈	{GSP91, GSP95}
HDS	∈	{GO-HDS, DGO-HDS}
in	∈	{MTBE, DCC, REF, ISO, LN, HN}
int	∈	{MTBET. DCCT, REFT, ISOT, LNT, HNT}
itank	∈	{MTBET, DCCT}
nap	∈	{LN, MN, HN}
ptank	∈	{LPGT, GSP91, GSP95, JPT, DSP, FO1P, FO2P, FOVSP}
UC_u	∈	{(OM, OMT), (TP, TPT), (LB, LBT), (SLEB, SLEBT), (PHET, PHETT), (MB< MBT)}
UI_u	∈	{(MTBE, MTBET), (DCC, DCCT)}
UP_u	∈	{(LPG, LPGT), (SUPG, GSP91), (ISOG, GSP95), (JP-1, JPT), (HSD, DSP), (FO1, FO1P), (FO2, FO2P), (FOVS, FOVSP)}

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