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Appendix A:
KKT conditions of the operational model

In the full-space approach, the results from the slave optimization problem (operational) are fed back to the master model (tactical) for further optimization. The oil purchase at the spot market in the operational model is not allowed in the full-space approach which means that the integrated solution must accommodate the uncertainties in both planning levels. Thus, the term $-\sum_{c\in C_u}\sum_{u\in UC}\sum_{s\in SO_{u,c}}\sum_{t\in T} CFPA_{u,s}^{t} ca_{u,c,s}^{t}$ is removed from the operational objective function (4.20), the constraint (4.33) is changed to $qo_{u,c,s}^{t,sc^o} = QOCF_{u,c,s}^{t,sc^o}$, and the constraint (4.34) does not exist anymore. The other constraints remain unchanged.

The solution strategy for the full-space approach was formulated using bilevel programming. First, the lower level model (operational) was reformulate by including the KKT optimality conditions and these conditions were added to the tactical model, resulting in one single model. The KKT multipliers λe and λ were attributed to the equality and inequality constraints, respectively. Slack variables ($sl, sl \geq 0$) were added to the inequality constraints in order to have a mathematical model with only equality constraints. Then, complementarity constraints ($\lambda * sl = 0$) were added to the model. Finally, the operating margin (4.17) plus the sum of the k operational constraints multiplied by their related KKT multipliers, i.e., $OM + \sum_{k=1}^{K}\left[(\lambda_k + \lambda e_k)*\text{Constraint}_k\right]$, were derived according to each one of the operational model variables presented in Table 7. Because the operational model is a maximization problem, the KKT multipliers of the inequalities constraints (λ) must be negatives. The KKT multipliers of the equalities constraints (λe) can be positives or negatives.

Let K the set of $k = 1,2...,27 \in K$ constraints of the operational model, the sl ($sl \geq 0$) is the slack variable, and λe and λ are the KKT multipliers of the equality and inequality constraints, respectively. The KKT conditions of the operation model proposed in this thesis can be formulated as follows:

Process constraints and material balances

$$qi_{u,c}^{t,sc^o} - \sum_{(u',c',s)\in F} q_{u',c',s,u,c}^{t,sc^o} = 0 \quad \forall u \in UP \bigcup UT \bigcup UD, \forall c \in C_u, \forall t \in T, \forall sc^o \in SC^o \quad \textbf{(A.1)}$$

$$qis_{u,c,s}^{t,sc^o} - \sum_{(u',c')\in F} q_{u',c',s,u,c}^{t,sc^o} = 0 \quad \forall u \in UPS \bigcup UT \bigcup UD \bigcup UE, \forall c \in C_u, \forall s \in SI_{u,c}, \forall t \in T, \forall sc^o \in SC^o \quad \textbf{(A.2)}$$

$$qo_{u,c,s}^{t,sc^o} - \sum_{(u',c')\in F} q_{u,c,s,u',c'}^{t,sc^o} = 0 \quad \forall u \in UP \bigcup UT \bigcup UD \bigcup UC, \forall c \in C_u, \forall s \in SO_{u,c}, \forall t \in T, \forall sc^o \in SC^o \quad \textbf{(A.3)}$$

$$vo_{u,c}^{t,sc^o} - vo_{u,c}^{t-1,sc^o} - qi_{u,c}^{t,sc^o} + \sum_{s\in SO_{u,c}} qo_{u,c,s}^{t,sc^o} = 0 \quad \forall u \in UA, \forall c \in C_u, \forall t \in T, \forall sc^o \in SC^o \quad \textbf{(A.4)}$$

$$\sum_{s\in SO_{u,c}} qo_{u,c,s}^{t,sc^o} - qi_{u,c}^{t,sc^o} = 0 \quad \forall u \in UD \bigcup UM, \forall c \in C_u, \forall t \in T, \forall sc^o \in SC^o \quad \textbf{(A.5)}$$

$$qo_{u,c,s}^{t,sc^o} - \sum_{s'\in SI_{u,c}} qis_{u,c,s'}^{t,sc^o} YUPS_{u,c,s,s'} = 0 \quad \forall u \in UPS, \forall c \in C_u, \forall s \in SO_{u,c}, \forall t \in T, \forall sc^o \in SC^o \quad \textbf{(A.6)}$$

$$qo_{u,c,s}^{t,sc^o} - qi_{u,c}^{t,sc^o} YUPC_{u,c,s} = 0 \quad \forall u \in UPC, \forall c \in C_u, \forall s \in SO_{u,c}, \forall t \in T, \forall sc^o \in SC^o \quad \textbf{(A.7)}$$

$$\sum_{(u',c')\in F} q_{u',c',s,u,c}^{t,sc^o} - RUT_{u,c,s} qi_{u,c}^{t,sc^o} = 0 \quad \forall u \in UTR, \forall c \in C_u, \forall s \in SI_{u,c}, \forall t \in T, \forall sc^o \in SC^o \quad \textbf{(A.8)}$$

Demand constraints

$$qis_{u,c,s}^{t,sc^o} - DEM_{u,c,s}^{t} = 0 \quad \forall u \in UE, \forall c \in C_u, \forall s \in SI_{u,c}, \forall t \in T, \forall sc^o \in SC^o \quad \textbf{(A.9)}$$

Supply plant constraints

$$qo_{u,c,s}^{t,sc^o} - QOCF_{u,c,s}^{t,sc^o} = 0 \quad \forall u \in UC, \forall c \in C_u, \forall s \in SO_{u,c}, \forall t \in T, \forall sc^o \in SC^o \quad \textbf{(A.10)}$$

Process unit capacities

$$-qi_{u,c}^{t,sc^o} + \sum_{k=11\in K} sl_{k,u,c}^{t,sc^o} = QIL_{u,c}^{t} \quad \forall u \in UP \bigcup UT \bigcup UD, \forall c \in C_u, \forall t \in T, \forall sc^o \in SC^o \quad \textbf{(A.11)}$$

$$qi_{u,c}^{t,sc^o} + \sum_{k=12\in K} sl_{k,u,c}^{t,sc^o} = QIU_{u,c}^{t} \quad \forall u \in UP \bigcup UT \bigcup UD, \forall c \in C_u, \forall t \in T, \forall sc^o \in SC^o \quad \textbf{(A.12)}$$

$$-qis_{u,c,s}^{t,sc^o} + \sum_{k=13\in K} sl_{k,u,c,s}^{t,sc^o} = QISL_{u,c,s}^{t}$$
$$\forall u \in UPS \bigcup UT \bigcup UD, \forall c \in C_u, \forall s \in SI_{u,c}, \forall t \in T, \forall sc^o \in SC^o \quad \textbf{(A.13)}$$

$$qis_{u,c,s}^{t,sc^o} + \sum_{k=14\in K} sl_{k,u,c,s}^{t,sc^o} = QISU_{u,c,s}^{t}$$
$$\forall u \in UPS \bigcup UT \bigcup UD, \forall c \in C_u, \forall s \in SI_{u,c}, \forall t \in T, \forall sc^o \in SC^o \quad \textbf{(A.14)}$$

$$-\sum_{c\in C_u} qi_{u,c}^{t,sc^o} + \sum_{k=15\in K} sl_{k,u}^{t,sc^o} = QL_{u}^{t,sc^o} \quad \forall u \in UP \bigcup UT \bigcup UD, \forall t \in T, \forall sc^o \in SC^o \quad \textbf{(A.15)}$$

$$\sum_{c\in C_u} qi_{u,c}^{t,sc^o} + \sum_{k=16\in K} sl_{k,u}^{t,sc^o} = QU_{u}^{t,sc^o} \quad \forall u \in UP \bigcup UT \bigcup UD, \forall t \in T, \forall sc^o \in SC^o \quad \textbf{(A.16)}$$

Stock constraints

$$-vo_{u,c}^{t,sc^o} + \sum_{k=17\in K} sl_{k,u,c}^{t,sc^o} = VOLL_{u,c}^{t} \qquad \forall u \in UA, \forall c \in C_u, \forall t \in T, \forall sc^o \in SC^o \qquad \textbf{(A.17)}$$

$$vo_{u,c}^{t,sc^o} + \sum_{k=18\in K} sl_{k,u,c}^{t,sc^o} = VOLU_{u,c}^{t} \qquad \forall u \in UA, \forall c \in C_u, \forall t \in T, \forall sc^o \in SC^o \qquad \textbf{(A.18)}$$

Property constraints

$$vo_{u,c}^{t-1,sc^o}\left(POL_{u,c,p}^{t} - POL_{u,c,p}^{t-1}\right) + qi_{u,c}^{t,sc^o} POL_{u,c,p}^{t} - \sum_{(u',c',s)\in F}\left(q_{u',c',s,u,c}^{t,sc^o}\right) POE_{u,c,p}^{t} + \sum_{k=19\in K} sl_{k,u,c,p}^{t,sc^o}$$
$$= 0 \qquad \forall u \in UA, \forall c \in C_u, \forall p \in PV_{u,c}, \forall t \in T, \forall sc^o \in SC^o \qquad \textbf{(A.19)}$$

$$vo_{u,c}^{t-1,sc^o}\left(POU_{u,c,p}^{t-1} - POU_{u,c,p}^{t}\right) - qi_{u,c}^{t,sc^o} POU_{u,c,p}^{t} + \sum_{(u',c',s)\in F}\left(q_{u',c',s,u,c}^{t,sc^o}\right) POE_{u,c,p}^{t} + \sum_{k=20\in K} sl_{k,u,c,p}^{t,sc^o}$$
$$= 0 \qquad \forall u \in UA, \forall c \in C_u, \forall p \in PV_{u,c}, \forall t \in T, \forall sc^o \in SC^o \qquad \textbf{(A.20)}$$

$$vo_{u,c}^{t-1,sc^o}\left(POL_{u,c,p}^{t} POL_{u,c,p}^{t} - POL_{u,c,p}^{t-1} POL_{u,c,p}^{t-1}\right) + qi_{u,c}^{t,sc^o} POL_{u,c,p}^{t} POL_{u,c,p}^{t} - \sum_{(u',c',s)\in F}\left(q_{u',c',s,u,c}^{t,sc^o}\right) POE_{u,c,p}^{t} POE_{u,c,p}^{t}$$
$$+ \sum_{k=21\in K} sl_{k,u,c,p}^{t,sc^o} = 0 \qquad \forall u \in UA, \forall c \in C_u, \forall p \in PM_{u,c}, \forall t \in T, \forall sc^o \in SC^o \qquad \textbf{(A.21)}$$

$$vo_{u,c}^{t-1,sc^o}\left(POU_{u,c,p}^{t-1} POU_{u,c,p}^{t-1} - POU_{u,c,p}^{t} POU_{u,c,p}^{t}\right) - qi_{u,c}^{t,sc^o} POU_{u,c,p}^{t} POU_{u,c,p}^{t} + \sum_{(u',c',s)\in F}\left(q_{u',c',s,u,c}^{t,sc^o}\right) POE_{u,c,p}^{t} POE_{u,c,p}^{t}$$
$$+ \sum_{k=22\in K} sl_{k,u,c,p}^{t,sc^o} = 0 \qquad \forall u \in UA, \forall c \in C_u, \forall p \in PM_{u,c}, \forall t \in T, \forall sc^o \in SC^o \qquad \textbf{(A.22)}$$

Non-negativity constraints

$$-q_{u',c',s,u,c}^{t,sc^o} + \sum_{k=23\in K} sl_{k,u',c',s,u,c}^{t,sc^o} = 0$$
$$\forall u \in UP \cup UT \cup UD \cup UE \cup UC, \forall c \in C_u, \forall s \in SI_{u,c} \cup SO_{u,c}, \forall t \in T, \forall sc^o \in SC^o \qquad \textbf{(A.23)}$$

$$-qis_{u,c,s}^{t,sc^o} + \sum_{k=24\in K} sl_{k,u,c,s}^{t,sc^o} = 0 \quad \forall u \in UPS \cup UT \cup UD, \forall c \in C_u, \forall s \in SI_{u,c}, \forall t \in T, \forall sc^o \in SC^o \qquad \textbf{(A.24)}$$

$$-qi_{u,c}^{t,sc^o} + \sum_{k=25\in K} sl_{k,u,c}^{t,sc^o} = 0 \qquad \forall u \in UP \cup UT \cup UD, \forall c \in C_u, \forall t \in T, \forall sc^o \in SC^o \qquad \textbf{(A.25)}$$

$$-qo_{u,c,s}^{t,sc^o} + \sum_{k=26\in K} sl_{k,u,c,s}^{t,sc^o} = 0 \quad \forall u \in UP \cup UT \cup UD \cup UC, \forall c \in C_u, \forall s \in SO_{u,c}, \forall t \in T, \forall sc^o \in SC^o \qquad \textbf{(A.26)}$$

$$-vo_{u,c}^{t,sc^o} + \sum_{k=27\in K} sl_{k,u,c}^{t,sc^o} = 0 \qquad \forall u \in UA, \forall c \in C_u, \forall t \in T, \forall sc^o \in SC^o \qquad \textbf{(A.27)}$$

KKT for $q_{u',c',s,u,c}^{t,sc^o}$

$$\sum_{sc^o\in SC^o}\sum_{t\in T}\left(\begin{array}{l} -\sum_{k=1\in K}\sum_{\forall u\in UP\bigcup UT\bigcup UD}\sum_{c\in C_u}\lambda e_{k,u,c}^{t,sc^o} \\ -\sum_{k=2\in K}\sum_{\forall u\in UP\bigcup UT\bigcup UD\bigcup UC}\sum_{c\in C_u}\sum_{s\in SI_{u,c}}\lambda e_{k,u,c,s}^{t,sc^o} \\ -\sum_{k=3}\sum_{\forall u\in UP\bigcup UT\bigcup UD\bigcup UC}\sum_{c\in C_u}\sum_{s\in SO_{u,c}}\lambda e_{k,u,c,s}^{t,sc^o} \\ +\sum_{k=8}\sum_{\forall u\in UTR}\sum_{c\in C_u}\sum_{s\in SI_{u,c}}\lambda e_{k,u,c,s}^{t,sc^o} \\ -\sum_{k=19}\sum_{\forall u\in UA}\sum_{c\in C_u}\sum_{p\in PV_{u,c}}POE_{u,c,p}^{t}\lambda_{k,u,c,p}^{t,sc^o} \\ +\sum_{k=20}\sum_{\forall u\in UA}\sum_{c\in C_u}\sum_{p\in PV_{u,c}}POE_{u,c,p}^{t}\lambda_{k,u,c,p}^{t,sc^o} \\ -\sum_{k=21}\sum_{\forall u\in UA}\sum_{c\in C_u}\sum_{p\in PM_{u,c}}POE_{u,c,p}^{t}POE_{u,c,p}^{t}\lambda_{k,u,c,p}^{t,sc^o} \\ +\sum_{k=22}\sum_{\forall u\in UA}\sum_{c\in C_u}\sum_{p\in PM_{u,c}}POE_{u,c,p}^{t}POE_{u,c,p}^{t}\lambda_{k,u,c,p}^{t,sc^o} \\ -\sum_{k=23}\sum_{\forall u\in UP\bigcup UT\bigcup UD\bigcup UE\bigcup UC}\sum_{c\in C_u}\sum_{\forall s\in SI_{u,c}\bigcup SO_{u,c}}\lambda_{k,u',c',s,u,c}^{t,sc^o} \end{array}\right)=0 \qquad \textbf{(A.28)}$$

KKT for $qis_{u,c,s}^{t,sc^o}$

$$\sum_{sc^o\in SC^o}\sum_{t\in T}\left(\begin{array}{l} \sum_{s\in SI_{u,c}}\sum_{u\in UE}P^{sc^o}PFP_{u,s}^{t}+\sum_{k=2\in K}\sum_{\forall u\in UP\bigcup UT\bigcup UD\bigcup UC}\sum_{c\in C_u}\sum_{s\in SI_{u,c}}\lambda e_{k,u,c,s}^{t,sc^o} \\ -\sum_{k=6\in K}\sum_{\forall u\in UPS}\sum_{c\in C_u}\sum_{s\in SO_{u,c}}\sum_{s'\in SI_{u,c}}YUPS_{u,c,s,s'}\lambda e_{k,u,c,s}^{t,sc^o} \\ +\sum_{k=9\in K}\sum_{\forall u\in UE}\sum_{c\in C_u}\sum_{s\in SI_{u,c}}\lambda e_{k,u,c,s}^{t,sc^o} \\ -\sum_{k=13\in K}\sum_{\forall u\in UPS\bigcup UT\bigcup UD}\sum_{c\in C_u}\sum_{s\in SI_{u,c}}\lambda_{k,u,c,s}^{t,sc^o} \\ +\sum_{k=14\in K}\sum_{\forall u\in UPS\bigcup UT\bigcup UD}\sum_{c\in C_u}\sum_{s\in SI_{u,c}}\lambda_{k,u,c,s}^{t,sc^o} \\ -\sum_{k=24\in K}\sum_{\forall u\in UPS\bigcup UT\bigcup UD}\sum_{c\in C_u}\sum_{s\in SI_{u,c}}\lambda_{k,u,c,s}^{t,sc^o} \end{array}\right)=0 \qquad \textbf{(A.29)}$$

KKT for $qi_{u,c}^{t,sc^o}$

$$\sum_{sc^o\in SC^o}\sum_{t\in T}\left(\begin{array}{l}\sum_{k=1\in K}\sum_{\forall u\in UP\bigcup UT\bigcup UD}\sum_{c\in C_u}\lambda e_{k,u,c}^{t,sc^o}\\ -\sum_{k=4\in K}\sum_{\forall u\in UA}\sum_{c\in C_u}\lambda e_{k,u,c}^{t,sc^o}-\sum_{k=5\in K}\sum_{\forall u\in UD\bigcup UM}\sum_{c\in C_u}\lambda e_{k,u,c}^{t,sc^o}\\ -\sum_{k=7}\sum_{\forall u\in UPC}\sum_{c\in C_u}\sum_{s\in SO_{u,c}}YUPC_{u,c,s}\lambda e_{k,u,c,s}^{t,sc^o}\\ -\sum_{k=8}\sum_{\forall u\in UTR}\sum_{c\in C_u}\sum_{s\in SI_{u,c}}RUT_{u,c,s}\lambda e_{k,u,c,s}^{t,sc^o}\\ -\sum_{k=11\in K}\sum_{\forall u\in UP\bigcup UT\bigcup UD}\sum_{c\in C_u}\lambda_{k,u,c}^{t,sc^o}+\sum_{k=12\in K}\sum_{\forall u\in UP\bigcup UT\bigcup UD}\sum_{c\in C_u}\lambda_{k,u,c}^{t,sc^o}\\ -\sum_{k=15\in K}\sum_{\forall u\in UP\bigcup UT\bigcup UD}\lambda_{k,u}^{t,sc^o}+\sum_{k=16\in K}\sum_{\forall u\in UP\bigcup UT\bigcup UD}\lambda_{k,u}^{t,sc^o}\\ +\sum_{k=19}\sum_{\forall u\in UA}\sum_{c\in C_u}\sum_{p\in PV_{u,c}}POL_{u,c,p}^{t}\lambda_{k,u,c,p}^{t,sc^o}\\ -\sum_{k=20}\sum_{\forall u\in UA}\sum_{c\in C_u}\sum_{p\in PV_{u,c}}POU_{u,c,p}^{t}\lambda_{k,u,c,p}^{t,sc^o}\\ +\sum_{k=21}\sum_{\forall u\in UA}\sum_{c\in C_u}\sum_{p\in PM_{u,c}}POL_{u,c,p}^{t}POL_{u,c,p}^{t}\lambda_{k,u,c,p}^{t,sc^o}\\ -\sum_{k=22}\sum_{\forall u\in UA}\sum_{c\in C_u}\sum_{p\in PM_{u,c}}POU_{u,c,p}^{t}POU_{u,c,p}^{t}\lambda_{k,u,c,p}^{t,sc^o}\\ -\sum_{k=25}\sum_{\forall u\in UP\bigcup UT\bigcup UD}\sum_{c\in C_u}\lambda_{k,u,c}^{t,sc^o}\end{array}\right)=0 \qquad \textbf{(A.30)}$$

KKT for $qo_{u,c,s}^{t,sc^o}$

$$\sum_{sc^o\in SC^o}\sum_{t\in T}\left(\begin{array}{l}\sum_{k=3}\sum_{\forall u\in UP\bigcup UT\bigcup UD\bigcup UC}\sum_{c\in C_u}\sum_{s\in SO_{u,c}}\lambda e_{k,u,c,s}^{t,sc^o}\\ +\sum_{k=4\in K}\sum_{\forall u\in UA}\sum_{c\in C_u}\sum_{s\in SO_{u,c}}\lambda e_{k,u,c}^{t,sc^o}+\sum_{k=5\in K}\sum_{\forall u\in UD\bigcup UM}\sum_{c\in C_u}\sum_{s\in SO_{u,c}}\lambda e_{k,u,c}^{t,sc^o}\\ +\sum_{k=6\in K}\sum_{\forall u\in UPS}\sum_{c\in C_u}\sum_{s\in SO_{u,c}}\lambda e_{k,u,c,s}^{t,sc^o}+\sum_{k=7}\sum_{\forall u\in UPC}\sum_{c\in C_u}\sum_{s\in SO_{u,c}}\lambda e_{k,u,c,s}^{t,sc^o}\\ -\sum_{\forall u\in UC}\sum_{s\in SO_{u,c}}\sum_{c\in C_u}\sum_{k=10\in K}\lambda e_{k,u,c,s}^{t,sc^o}\\ -\sum_{k=26}\sum_{\forall u\in UP\bigcup UT\bigcup UD\bigcup UC}\sum_{c\in C_u}\sum_{s\in SO_{u,c}}\lambda_{k,u,c,s}^{t,sc^o}\end{array}\right)=0 \qquad \textbf{(A.31)}$$

KKT for $vo_{u,c}^{t,sc^o}$

$$\sum_{sc^o\in SC^o}\sum_{t\in T}\left(\begin{array}{l}-\sum_{u\in UA}\sum_{c\in C_u}\sum_{s\in SO_{u,c}}P^{sc^o}CINV_{u,s}^{t}+\sum_{k=4\in K}\sum_{\forall u\in UA}\sum_{c\in C_u}\lambda e_{k,u,c}^{t,sc^o}\\ -\sum_{k=17\in K}\sum_{\forall u\in UA}\sum_{c\in C_u}\lambda_{k,u,c}^{t,sc^o}+\sum_{k=18\in K}\sum_{\forall u\in UA}\sum_{c\in C_u}\lambda_{k,u,c}^{t,sc^o}\\ -\sum_{k=27}\sum_{\forall u\in UA}\sum_{c\in C_u}\lambda_{k,u,c}^{t,sc^o}\end{array}\right)=0 \qquad \textbf{(A.32)}$$

KKT for $vo_{u,c}^{t-1,sc^o}$

$$\sum_{sc^o \in SC^o} \sum_{t \in T} \left(\begin{array}{l} -\sum_{k=4 \in K} \sum_{\forall u \in UA} \sum_{c \in C_u} \lambda e_{k,u,c}^{t,sc^o} \\ +\sum_{k=19} \sum_{\forall u \in UA} \sum_{c \in C_u} \sum_{p \in PV_{u,c}} \left(POL_{u,c,p}^{t} - POL_{u,c,p}^{t-1} \right) \lambda_{k,u,c,p}^{t,sc^o} \\ -\sum_{k=20} \sum_{\forall u \in UA} \sum_{c \in C_u} \sum_{p \in PV_{u,c}} \left(POU_{u,c,p}^{t-1} - POU_{u,c,p}^{t} \right) \lambda_{k,u,c,p}^{t,sc^o} \\ +\sum_{k=21} \sum_{\forall u \in UA} \sum_{c \in C_u} \sum_{p \in PM_{u,c}} \left(POL_{u,c,p}^{t} POL_{u,c,p}^{t} - POL_{u,c,p}^{t-1} POL_{u,c,p}^{t-1} \right) \lambda_{k,u,c,p}^{t,sc^o} \\ -\sum_{k=22} \sum_{\forall u \in UA} \sum_{c \in C_u} \sum_{p \in PM_{u,c}} \left(POU_{u,c,p}^{t-1} POU_{u,c,p}^{t-1} - POU_{u,c,p}^{t} POU_{u,c,p}^{t} \right) \lambda_{k,u,c,p}^{t,sc^o} \end{array} \right) = 0 \qquad \textbf{(A.33)}$$

Complementarity Constraints

$$\lambda_{k,u,c}^{t,sc^o} sl_{k,u,c}^{t,sc^o} = 0 \qquad \forall u \in UP \bigcup UT \bigcup UD \bigcup UA, \forall c \in C_u, \forall t \in T, \forall sc^o \in SC^o, k \in K \middle| k = 11,12,17,18,25,27 \qquad \textbf{(A.34)}$$

$$\lambda_{k,u,c,s}^{t,sc^o} sl_{k,u,c,s}^{t,sc^o} = 0 \qquad \forall u \in UPS \bigcup UT \bigcup UD \bigcup UC \bigcup UE, \forall c \in C_u, \forall s \in SI_{u,c} \bigcup SO_{u,c}, \forall t \in T, \forall sc^o \in SC^o, k \in K \middle| k = 13,14,17,24,26 \qquad \textbf{(A.35)}$$

$$\lambda_{k,u}^{t,sc^o} sl_{k,u}^{t,sc^o} = 0 \qquad \forall u \in UP \bigcup UT \bigcup UD, \forall t \in T, \forall sc^o \in SC^o, k \in K \middle| k = 15,16 \qquad \textbf{(A.36)}$$

$$\lambda_{k,u,c,p}^{t,sc^o} sl_{k,u,c,p}^{t,sc^o} = 0 \qquad \forall u \in UA, \forall c \in C_u, \forall p \in P_{u,c,s}, \forall t \in T, \forall sc^o \in SC^o, k \in K \middle| k = 19,20,21,22 \qquad \textbf{(A.37)}$$

$$\lambda_{k,u',c',s,u,c}^{t,sc^o} sl_{k,u',c',s,u,c}^{t,sc^o} = 0 \qquad \forall u \in UP \bigcup UT \bigcup UD \bigcup UE \bigcup UC, \forall c \in C_u, \forall s \in SI_{u,c} \bigcup SO_{u,c}, \forall t \in T, \forall sc^o \in SC^o, k \in K \middle| k = 23 \qquad \textbf{(A.38)}$$

$$\lambda_{k,u,c}^{t,sc^o}, \lambda_{k,u,c,s}^{t,sc^o}, \lambda_{k,u,c,s}^{t}, \lambda_{k,u,c,p}^{t,sc^o}, \lambda_{k,u',c',s,u,c}^{t,sc^o} \in \Re^- \qquad \forall k \in K \middle| k = \{11,10...27\} \qquad \textbf{(A.39)}$$

$$\lambda e_{k,u,c}^{t,sc^o}, \lambda e_{k,u,c,s}^{t,sc^o} \in \Re \qquad \forall k \in K \middle| k = \{1,2,...,10\} \qquad \textbf{(A.40)}$$

Appendix B:
Tactical oil allocation x quantity/type of fixed oil received at the operational level

Table 19 illustrated the tactical allocation and the quantity/types of oil from long-term contracts (fixed oil) that the refinery R3 effectively received in t=1 for the three case studies. In this Appendix, the results for the other refineries and periods are presented. Table 27 summarizes the results for R3 in t=2. Tables 28 and 29 present the results for refinery R2, whereas Tables 30 and 31 illustrate the results for refinery R1.

Table 27. Tactical allocation and oils received by R3 in t=2

		Tactical allocation (thousand m^3/ month)						**Oils received by the refinery** (thousand m^3/ month)							
Cases	**Scenarios**	**Types of oil**						**Types of oil**							
		F1	**H1**	**H2**	**H3**	**H4**	**H5**	**A1**	**B1**	**F1**	**H1**	**H2**	**H3**	**H4**	**H5**
1	1	77	908	-	-	236	-	-	-	77	908	-	-	236	-
	2	77	-	-	-	236	908	-	-	77	908	236	-		-
	3	77	1144	-	-	-	-	-	-	77	1144	-	-		-
	4	77	-	-	-	-	1144	-	-	77	1144	-	-		-
	5	77	951	193	-	-	-	-	-	77	951	193	-		-
	6	77	-	-	-	464	680	-	-	77	680	464	-		-
2	1	77	-	-	244	719	180	-	-	77	-	719	425	-	-
	2	77	-	-	-	-	1144	299	845	-	-	77	-	-	-
	3	77	-	-	-	-	1144	-	-	77	-	-	-		1144
	4	77	29	1115	-	-	-	29	1115	-	-	77	-	-	-
	5	77	-	-	1144	-	-	-	-	77	-	-	764	380	-
	6	77	264	-	-	880	-	264	880		-	77	-	-	-
3	1	77	1144	-	-	-	-	-	-	77	1144	-	-	-	-
	2	77	1144	-	-	-	-	-	-	26	381	-	-	-	-
	3	77	1134	10	-	-	-	-	-	77	1134	10	-	-	-
	4	77	1144	-	-	-	-	-	-	26	381	-	-	-	-
	5	77	726	418	-	-	-	-	-	77	726	418	-	-	-
	6	77	421	723	-	-	-	-	-	26	140	241	-	-	-

Table 28. Tactical allocation and oils received by R2 in t=1

		Tactical allocation (thousand m^3/ month)				**Oils received by the refinery** (thousand m^3/ month)			
Cases	**Scenarios**	**Types of oil**				**Types of oil**			
		C1	**C2**	**D1**	**E1**	**C1**	**C2**	**D1**	**E1**
1	1	197	-	-	-	197	-	-	-
	2	-	197	-	-	197	-	-	-
	3	197	-	-	-	197	-	-	-
	4	-	197	-	-	197	-	-	-
	5	197	-	-	-	197	-	-	-
	6	33	164	-	-	164	33	-	-
2	1	197	-	-	-	197	-	-	-
	2	-	197	-	-	-	197	-	-
	3	197	-	-	-	197	-	-	-
	4	-	197	-	-	-	197	-	-
	5	135	62	-	-	197	-	-	-
	6	197	-	-	-		197	-	-
3	1	153	43	-	-	153	43	153	43
	2	197	-	-	-	66	-	66	-
	3	197	-	-	-	197	-	197	-
	4	197	-	-	-	66	-	66	-
	5	138	59	-	-	138	59	138	59
	6	197	-	-	-	66	-	66	-

Table 29. Tactical allocation and oils received by R2 in t=2

		Tactical allocation (thousand m^3/ month)				**Oils received by the refinery** (thousand m^3/ month)			
Cases	**Scenarios**	**Types of oil**				**Types of oil**			
		C1	**C2**	**D1**	**E1**	**C1**	**C2**	**D1**	**E1**
1	1	203	-	-	-	-	-	-	-
	2	-	203	-	-	-	-	-	-
	3	203	-	-	-	-	-	-	-
	4	-	203	-	-	-	-	-	-
	5	203	-	-	-	-	-	-	-
	6	20	183	-	-	-	20	-	-
2	1	203	-	-	-	203	-	-	-
	2	203	-	-	-	203	-	-	-
	3	203	-	-	-	203	-	-	-
	4	-	203	-	-	203	-	-	-
	5	203	-	-	-	203	-	-	-
	6	-	203	-	-	183	20	-	-
3	1	138	65	-	-	138	65	138	65
	2	203	-	-	-	68	-	68	-
	3	203	-	-	-	203	-	203	-
	4	203	-	-	-	68	-	68	-
	5	203	-	-	-	203	-	203	-
	6	203	-	-	-	68	-	68	-

Table 30. Tactical allocation and oils received by R1 in t=1

		Tactical allocation (thousand m³/ month)			Oils received by the refinery (thousand m³/ month)		
Cases	Scenarios	Types of oil			Types of oil		
		A1	A2	A3	A1	A2	A3
1	1	26.2	2.3	4.5	26.2	2.3	4.5
	2	-	33.0	-	33.0	-	-
	3	27.4	5.4	0.2	27.4	5.4	-
	4	5.2	27.8	-	27.8	5.2	-
	5	29.0	-	4.0	29.0	-	4.0
	6	-	33.0	-	33.0	-	-
2	1	26.2	0.5	6.3	29.5	-	3.5
	2	3.3	29.7	-	-	21.6	11.4
	3	27.4	5.4	0.2	27.4	5.6	-
	4	5.2	27.8	-	-	24.9	8.1
	5	23.5	-	9.5	23.5	-	9.5
	6	-	33.0	-	-	24.9	8.1
3	1	26.2	0.5	6.3	26.2	-	6.3
	2	20.5	-	12.5	6.8	-	4.2
	3	27.4	5.4	0.2	27.4	5.4	-
	4	20.5	-	12.5	6.8	-	4.2
	5	23.5	-	9.5	23.5	-	9.5
	6	20.5	-	12.5	6.8	-	4.2

Table 31. Tactical allocation and oils received by R1 in t=2

		Tactical allocation (thousand m³/ month)			Oils received by the refinery (thousand m³/ month)		
Cases	Scenarios	Types of oil			Types of oil		
		A1	A2	A3	A1	A2	A3
1	1	33.4	0.7	-	34.1	-	-
	2	-	32.8	1.3	32.8	1.3	-
	3	30.7	3.0	0.4	30.7	3.0	-
	4	2.5	31.6	-	31.6	2.5	-
	5	30.5	-	3.6	30.5	-	3.6
	6	-	34.1	-	34.1	-	-
2	1	26.8	2.4	4.8	23.5	2.4	8.1
	2	-	34.1	-	-	22.7	11.4
	3	30.7	3.0	0.4	30.7	3.4	-
	4	2.5	31.6	-	-	25.4	8.7
	5	25.0	-	9.1	25.0	-	9.1
	6	-	23.1	11.0	-	26.0	8.1
3	1	26.8	2.4	4.8	26.8	2.4	4.8
	2	22.5	-	3.9	7.5	-	3.9
	3	30.7	3.0	0.4	30.7	3.0	-
	4	22.5	-	3.9	7.5	-	3.9
	5	25.0	-	3.9	25.0	-	9.1
	6	22.5	-	3.9	7.5	-	3.9

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Publications related to this thesis

- Refereed Publications in Journals:

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