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Short-term Planning Model for Petroleum Refinery Production Using Model Predictive Control

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Abstract: A model predictive control (MPC) strategy is developed to determine the optimal solution of the short-term refinery production planning problem. The main objective of the proposed algorithm is to maximize the total profit and to minimize the costs regarding the refinery process over a planning horizon. The refinery planning problem is solved in discrete time over a pre-determined prediction horizon and this prediction horizon is shifted by one time interval at each subsequent step where the optimization is repeated. To demonstrate the performance of this receding horizon strategy, two literature examples are introduced where the refinery process comprises the oil fields, crude oil vessels, the storage, charge and production tanks, as well as the crude distillation units (CDU). The performance of the strategy for different moving horizon lengths is presented and discussed.

Keywords**:** planning problem; refinery process; moving horizon, model predictive control.

1. INTRODUCTION

The planning processes are considered as one of the most important problems for the process industries. This is especially important for petroleum refineries where the planning is used to create production, distribution, sales and inventory plans regarding customer and market information under all relevant constraints (Kallrath, 2002). A number of commercial software tools based on linear programming models are available for generating production plans such as RPMS (Refinery and Petrochemical Modeling System) from Honeywell and PIMS (Process Industry Modeling System) from Aspen Technology (Mendez et al., 2006; Kuo & Chang, 2008). The deterministic programming models, such as Linear Programming (LP), Mixed Integer Linear Programming (MILP), Nonlinear Programming (NLP), have been used for most of the refinery production planning (Pinto et al., 2000; Moro et al., 1998; Joly et al., 2002).

The petroleum refinery production planning has been widely studied in the literature. Moro et al. (1998) proposed a nonlinear planning model for a refinery diesel production. Their solution approach was based on the generalized reduced gradient method. Chufu et al. (2008) developed a stochastic programming (SP) based model and a hybrid model, which integrates the LP model and SP model, for refinery production planning under demand uncertainty. Gao et al. (2008) presented a generalized lot-sizing problem model for a typical refinery planning problem and proposed a branch-price approach to solve the optimization problem. Alabi and Castro (2009) studied the large scale integrated refinery-planning problem and they developed two decomposition techniques to overcome the computational load. Zhang et al. (2007) proposed an effective MILP model to maximize the overall profit during oil refinery production planning system for better energy efficiency. Guyonnet et al. (2009) developed the integrated model which consists of the production and distribution models for refinery production planning problem.

Traditional methods in the optimization of planning problems may yield solutions at local optima and the global solution point may not be found due to modeling complexities and prohibitive computational effort. Model predictive control (MPC), which is an advanced control algorithm, has been widely used in the chemical process industries (Camacho & Bordons, 1999). Its main feature is to solve an open-loop optimal control problem over a finite horizon considering the current state as the initial state for the problem (Sarimveis et al., 2008). The basic concept of MPC has been utilized extensively in the operations management literature, such as production planning, scheduling and supply chain management. Kapsiotis et al. (1992) proposed a MPC approach for an inventory/production planning management problem. Tzafestas et al. (1997) developed a MPC based structure for production, inventory and marketing decisions in production planning problem. Bose and Pekny (2000) focused on the coordination between the production and demand units in the supply chain and they proposed a MPC based approach that includes a forecasting model and an optimization model. Mestan et al. (2006) proposed three different MPC configurations to solve the optimization problem of multiproduct supply chain networks.

In this paper, the short-term refinery planning problem for crude oil over unloading, storage and processing stages is considered. This problem consists of unloading from vessels to storage tanks, transferring between units, charging to CDUs and refining processes. The paper is organized as follows. The refinery planning model is presented in Section 2. MPC structure used to solve the planning problem is given in the next section. In Section 4, two examples regarding the refinery planning are presented to evaluate the performance of the proposed MPC approach. Finally, the paper is concluded.

2. THE REFINERY PLANNING MODEL

The general overview of the refinery planning problem is shown in Fig.1. The system consists of a set of oil fields, crude oil vessels, docking stations, a set of storage and charging tanks, crude distillation units and a set of production tanks. The vessels move the different types of the crude oil from the oil fields to docking stations. Then the crude oil is transferred from a predetermined vessel to the assigned storage tank. In the charging tanks, different crude oils are blended according to component concentrations and they are transferred to CDUs. In the CDUs, different crude mixes are separated into different oil fractions and these fractions are transferred to the production tanks. Over a given planning horizon, the problem is to compute inventory levels in each tank, the flow rates between the units, amount of final products, sales from all final products, and total revenue of process using the necessary data, such as the cost of raw materials, capacity of processing units, demand of products, initial inventory level and capacity of tanks.

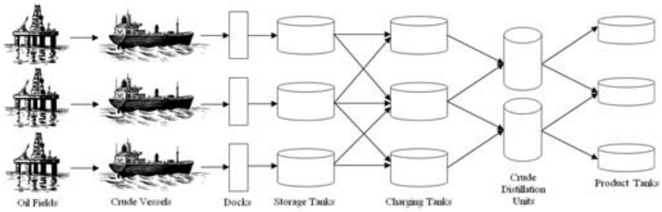

Fig. 1. General overview of a refinery system.

The model comprises binary decision variables regarding the units in the process and the variables determining the operating plan of the refinery process, such as operating levels, purchases, and sales. Objective function is constructed by combining the revenues from all products and the costs in all units of the process during the predetermined planning horizon. These are the cost of purchased crude oil, the inventory costs for the vessel, storage, charging, and production tanks, the unloading cost of vessels and the changeover cost for crude oil charging in CDU. To reduce to the complexity of the modeling, the following assumptions are presented for the planning model used in this paper:

Only mass balance of materials in the tanks and CDUs and inventory management of the tanks are considered; energy balance is neglected. Only one vessel docking station is used for unloading of crude oil.

There is no crude oil remaining in the pipeline. Only key component concentration in crude or blended oil, which is defined as a bilinear equation, determine the property of crude and blended oil.

Perfect mixing in the charging tanks is considered and no extra time is consumed for mixing. Changeover times are small values in comparison with the scheduling horizon and they are neglected in the modeling.

Flow rate of materials is constant during the time period. The mathematical formulation is based on discrete time. The objective function and all constraints regarding refinery planning problem are given by the following equations:

$$
\begin{aligned}
\max(\mathrm{Profit}) = & \sum_{p=1}^{NP} C_{PRICE,p} \cdot \left[\sum_{t=1}^{NPLAN} V_{p,t} \right] - \sum_{p=1}^{NP} C_{PRICE,p} . disc_p . \left(\sum_{t=1}^{NPLAN} V_{p,t} - Dm_{p,min} \right) - \sum_{(cr,v)=1}^{(NCR,NV)} C_{OIL,cr} V_{V,v,0} \\
& - \sum_{v=1}^{NV} C_{UNL,v} \left(T_{L,v} - T_{F,v} + 1 \right) - \sum_{m=1}^{NST} \sum_{t=1}^{NPLAN} C_{INVST,m} \left(\frac{V_{S,m,t} + V_{S,m,t-1}}{2} \right) \\
& - \sum_{n=1}^{NCT} \sum_{t=1}^{NPLAN} C_{INVCT,n} \left(\frac{V_{C,n,t} + V_{C,n,t-1}}{2} \right) - \sum_{t=2}^{NPLAN} \sum_{n=1}^{NCT} \sum_{p=1}^{NCT} \sum_{k=1}^{NCDU} C_{CHNG,n,p,k} Z_{n,p,k,t} \\
& - \sum_{p=1}^{NP} C_{INVPT,p} \cdot \left(\sum_{t=1}^{NPLAN} V_{p,t} - Dm_{p,min} \right)
\end{aligned} \quad (1)
$$

$$\sum_{t=1}^{NPLAN} X_{F,v,t} = 1, \ \sum_{t=1}^{NPLAN} X_{L,v,t} = 1, \ \forall v \in S_V \quad (2)$$

$$T_{F,v} = \sum_{t=1}^{NPLAN} t X_{F,v,t}, \ T_{L,v} = \sum_{t=1}^{NPLAN} t X_{L,v,t}, \ \forall v \in S_V \quad (3)$$

$$T_{F,v+1} \geq T_{L,v} + 1, \ T_{L,v} - T_{F,v} \geq 1, \ \forall v \in S_V \quad (4)$$

$$X_{W,v,t} \le \sum_{i=1}^{t} X_{F,v,i}\ ,\ X_{W,v,t} \le \sum_{i=t}^{NPLAN} X_{L,v,i} \quad \forall v \in S_V\ ,\ \forall t \in S_{PLAN} \tag{5}$$

$$V_{V,v,t} = V_{V,v,0} - \sum_{m=1}^{NST}\sum_{i=1}^{t} F_{VS,v,m,i}\ ,\forall v \in S_V\ ,\ \forall t \in S_{PLAN} \tag{6}$$

$$F_{VS,v,m,min} X_{W,v,t} \le F_{VS,v,m,t} \le F_{VS,v,m,max} X_{W,v,t}\ ,\forall v \in S_V\ ,\ \forall m \in S_{ST}\ ,\ \forall t \in S_{PLAN} \tag{7}$$

$$F_{VS,v,m,min}\left(1 - D_{SC,m,n,t}\right) \le F_{VS,v,m,t} \le F_{VS,v,m,max}\left(1 - D_{SC,m,n,t}\right),\ \forall v \in S_V\ ,\forall m \in S_{ST}\ ,\ \forall n \in S_{CT}\ ,\forall t \in S_{PLAN} \tag{8}$$

$$\sum_{m=1}^{NST}\sum_{t=1}^{NPLAN} F_{VS,v,m,t} = V_{V,v,0}\ ,\ \forall v \in S_V \tag{9}$$

$$V_{S,m,t} = V_{S,m,0} + \sum_{v=1}^{NV}\sum_{i=1}^{t} F_{VS,v,m,i} - \sum_{n=1}^{NCT}\sum_{i=1}^{t} F_{SC,m,n,i}\ ,\ \forall m \in S_{ST}\ ,\ \forall t \in S_{PLAN} \tag{10}$$

$$F_{SC,m,n,min}\left(1 - \sum_{k=1}^{NCDU} D_{CD,n,k,t}\right) \le F_{SC,m,n,t} \le F_{SC,m,n,max}\left(1 - \sum_{k=1}^{NCDU} D_{CD,n,k,t}\right),\ \forall m \in S_{ST}\ ,\ \forall n \in S_{CT}\ ,\ \forall t \in S_{PLAN} \tag{11}$$

$$F_{SC,m,n,min} D_{SC,m,n,t} \le F_{SC,m,n,t} \le F_{SC,m,n,max} D_{SC,m,n,t}\ ,\ \forall m \in S_{ST}\ ,\ \forall n \in S_{CT}\ ,\ \forall t \in S_{PLAN} \tag{12}$$

$$V_{S,m,min} \le V_{S,m,t} \le V_{S,m,max}\ ,\ \forall m \in S_{ST}\ ,\ \forall t \in S_{PLAN} \tag{13}$$

$$V_{C,n,t} = V_{C,n,0} + \sum_{m=1}^{NST}\sum_{i=1}^{t} F_{SC,m,n,i} - \sum_{k=1}^{NCDU}\sum_{i=1}^{t} F_{CD,n,k,i}\ ,\ \forall n \in S_{CT}\ ,\ \forall t \in S_{PLAN} \tag{14}$$

$$F_{CD,n,k,min} D_{CD,n,k,t} \le F_{CD,n,k,t} \le F_{CD,n,k,max} D_{CD,n,k,t}\ ,\ \forall n \in S_{CT}\ ,\ \forall k \in S_{CDU}\ ,\ \forall t \in S_{PLAN} \tag{15}$$

$$V_{C,n,min} \le V_{C,n,t} \le V_{C,n,max}\ ,\ \forall n \in S_{CT}\ ,\ \forall t \in S_{PLAN} \tag{16}$$

$$V_{Comp,q,m,t} = V_{Comp,q,m,0} + \sum_{i=1}^{t}\sum_{v=1}^{NV} f_{VS,q,v,m,i} - \sum_{i=1}^{t}\sum_{n=1}^{NCT} f_{SC,q,m,n,i}\ ,\forall q \in S_{COMP}\ ,\forall m \in S_{ST}\ ,\forall t \in S_{PLAN} \tag{17}$$

$$f_{VS,q,v,m,t} = F_{VS,v,m,t}\,\omega_{V,v,q}\ ,\ \forall q \in S_{COMP}\ ,\ \forall v \in S_V\ ,\ \forall m \in S_{ST}\ ,\ \forall t \in S_{PLAN} \tag{18}$$

$$F_{SC,m,n,t}\,\omega_{S,m,q,min} \le f_{SC,q,m,n,t} \le F_{SC,m,n,t}\,\omega_{S,m,q,max}\ ,\forall q \in S_{COMP}\ ,\forall m \in S_{ST}\ ,\forall n \in S_{CT}\ ,\forall t \in S_{PLAN} \tag{19}$$

$$V_{S,m,t}\,\omega_{S,m,q,min} \le V_{Comp,q,m,t} \le V_{S,m,t}\,\omega_{S,m,q,max}\ ,\forall q \in S_{COMP}\ ,\forall m \in S_{ST}\ ,\forall t \in S_{PLAN} \tag{20}$$

$$V_{Comp,q,n,t} = V_{Comp,q,n,0} + \sum_{i=1}^{t}\sum_{m=1}^{NST} f_{SC,q,m,n,i} - \sum_{i=1}^{t}\sum_{k=1}^{NCDU} f_{CD,q,n,k,i}\ ,\forall q \in S_{COMP}\ ,\ \forall n \in S_{CT}\ ,\ \forall t \in S_{PLAN} \tag{21}$$

$$F_{CD,n,k,t}\,\omega_{C,n,q,min} \le f_{CD,q,n,k,t} \le F_{CD,n,k,t}\,\omega_{C,n,q,max}\ ,\forall q \in S_{COMP}\ ,\forall n \in S_{CT}\ ,\forall k \in S_{CDU}\ ,\forall t \in S_{PLAN} \tag{22}$$

$$V_{C,n,t}\,\omega_{C,n,q,min} \le V_{Comp,q,n,t} \le V_{C,n,t}\,\omega_{C,n,q,max}\ ,\forall q \in S_{COMP}\ ,\forall n \in S_{CT}\ ,\forall t \in S_{PLAN} \tag{23}$$

$$\sum_{k=1}^{NCDU} D_{CD,n,k,t} \le 1\ ,\ \forall n \in S_{CT}\ ,\ \forall t \in S_{PLAN} \tag{24}$$

$$\sum_{n=1}^{NCT} D_{CD,n,k,t} = 1\ ,\ \forall k \in S_{CDU}\ ,\ \forall t \in S_{PLAN} \tag{25}$$

$$Z_{n,p,k,t} \ge D_{CD,p,k,t} + D_{CD,n,k,t-1} - 1\ ,\ (n \ne p),\forall n,p \in S_{CT}\ ,\ \forall k \in S_{CDU}\ ,\forall t \in S_{PLAN} - \{1\} \tag{26}$$

$$V_{p,t} = \sum_{n=1}^{NCT}\sum_{k=1}^{NCDU} Y_{p,n,k} F_{CD,n,k,t}\ ,\ \forall p \in S_{PROD}\ ,\ \forall t \in S_{PLAN} \tag{27}$$

$$Dm_{p,min} \le \sum_{t=1}^{NPLAN} V_{p,t} \le Dm_{p,max}\ ,\ \forall p \in S_{PROD} \tag{28}$$

In this model, the objective function (Eq. 1) is defined as the difference between the total revenue and all costs and expenses, such as the unloading cost for the vessels, the inventory costs for the tanks, the CDU changeover cost, and the cost of the purchased crude. The operating rules for arrival and departure of crude vessels are given by Eqs. (2)-(5). Start time and end time of unloading are presented in Eq. (3) for each vessel. Unloading of crude for the previous vessel must finish in one time interval before the next vessel arrives at the dock station and starts to unload. The unloading for each vessel is limited by two time intervals (Eq. 4). Unloading is only possible between its start and stop times according to the decision constraint given Eq. (5). The volume of crude oil inside each vessel at time t is given by Eq. (6) according to the material balance for vessels.

The operating constraints on flow rate of crude oil from vessel to the storage tank are presented by Eq. (7) for no blending inside the storage tank and by Eq. (8) for the case of blending in the storage tank. If there is any crude oil transfer from the storage tank to any charging tanks, there is no crude oil flow from the vessel to this storage tank. In the planning horizon, the total volumetric flow rates of crude oil from vessel to storage tanks should be equal to the initial volume of the crude oil in vessel (Eq. 9). The material balance equations for the storage tank are presented in Eqs. (10)-(13).

If there is any crude oil flow from a charging tank to the CDU, the crude oil transfer from any storage tank to this charging tank can not be realized. Eq. (14) represents the material balance for the charging tanks. The operating constraint of crude oil flow from charging tank to CDU is given by Eq. (15). The volume capacity limitation regarding charging tank is captured by Eq. (16).

In case where the storage tanks include blending functions, material balance for component of the crude oil inside the storage tank is presented in Eq. (17). The constraints of the volumetric flow rate of the component in the crude oil from vessel to storage tank and from storage tank to charging tank are given by Eqs. (18)-(19). The limitation of the component volume inside the storage tank is defined as Eq. (20). In the same way, Eqs. (21)-(23) show the material balance of the crude oil component inside the charging tank, and the operating constraints. Equations (24)-(26) yield the operating rules concerning crude oil transferring from charging tank to CDUs. At any time during planning horizon, at most one CDU should be charged with blended crude oil by one charging tank and only one charging tank can charge to any CDU. In case a CDU is charged by blended crude oil inside the charging tank at time t-1 and then it is charged by the different one charging tank at time t, the changeover cost regarding switching from crude oil mix n to crude oil mix p must be calculated.

According to the production yields in CDUs, the product volume is given by Eq. (27) at any time over the planning horizon. The limitation of volume capacity concerning the production tanks is presented in Eq. (28). If the production exceeds the minimum predetermined demand during the planning horizon, extra production needs to be sold at a discounted sales price.

3. MODEL PREDICTIVE CONTROL (MPC)

Model predictive control (MPC) MPC is based on obtaining model outputs from a process and predicting future outputs based on a future set of input moves (Maciejowski, 2002; Camacho and Bordons, 1995). The components of the MPC algorithm are a prediction model of the system, an objective function and the control law. The general MPC structure is shown in Fig.2.

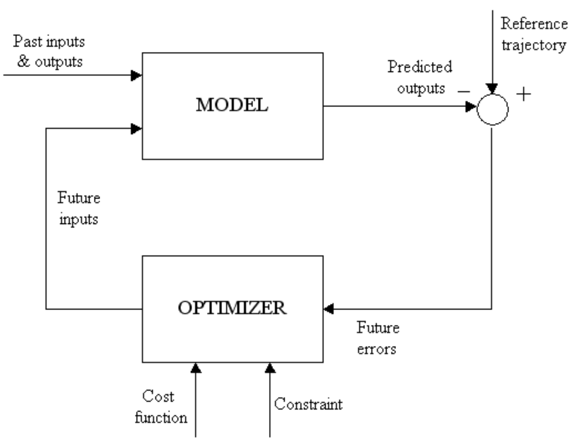

Fig. 2. MPC Block diagram (Camacho and Bordons, 1995).

The goal of the optimizer is to compute the current control signal using the current plant output, predicted model outputs and reference trajectory. In the model block, predicted model outputs, are calculated using past and current measurements over the prediction horizon. The latest measured plant output and the previous model outputs have to be known. The future model outputs are predicted by process model for each time interval over a prediction horizon.

Subtracting the prediction model output at time k from the current plant output, the mismatch between model and plant is calculated. Then, this mismatch is added to future model output again. Using the reference signal and future model output, the future control actions are computed by the solution of a constrained optimization problem during the control horizon. Among the future control action sequence, only the current or first control action is applied to the plant.

In this paper, the refinery planning problem is solved by this moving horizon approach. The control action is only implemented in the time interval $[t_0, t_0 + \Delta t]$. At each step, the prediction moving horizon is shifted by one time interval, Δt, and the planning problem is solved again for this new horizon $[t_0 + \Delta t, t_0 + (N+1)\Delta t]$. In addition, the computed solutions for the prior horizon are used as initial values of the optimization process at the next time interval.

4. RESULTS AND DISCUSSION

To evaluate the performance of an MPC strategy proposed for the short-term refinery planning problem, two refinery examples are presented. First example comprises two oil fields, two vessels, two storage tanks, two charging tanks, one CDU and eight product tanks. The second planning example includes three oil fields, three vessels, three storage and charging tanks, two CDUs and eight product tanks. For the first example, there are two types of crude oil transferred from oil fields in Saudi Arabia (Arabian Light) and Kuwait. Iranian Heavy type oil is used additionally in the second example. The price per unit volume concerning these crude oil types are taken from the paper by Song et al. (2002): Saudi Arabia (Arabian Light) 16.951 $/bbl; Kuwait 15.071 $/bbl; Iran (Iranian Heavy) 15.852 $/bbl. Eight products are considered for both planning examples: LPG, Naphtha, Gasoline, Kerosene, Diesel, Bunker, Asphalt, and Fuelgas. The production yields in CDUs are shown in Table 1 for the first example and in Table 2 for the second example. Further details on both examples can be found in the papers by Lee et al. (1996) and Yüzgeç et al. (2010). In the first example, the planning horizon is 8 days. The optimization model includes 385 variables, 403 constraints and 48 binary variables.

In the second model where the planning horizon is 10 days, 1022 variables, 1280 constraints and 120 binary variables are used. These models are constructed in LP format and the MILP problems are solved by lp_solve 5.5. An Intel(R) Pentium(R) 4 CPU 3.20-GHz, 3.00-GB RAM computer and the MATLAB® 7.0.1 platform were used. The discount rate was considered as 0.3%. Fig.3 shows the products and the progression of total revenue during the planning horizon when the 4-day moving horizon is used.

Table 1. Product Yields in CDUs for example 1. CT denotes the charging tank.

CT→CDU	LPG (wt %)	Naphtha (wt %)	Gasoline (wt %)	Kerosene (wt %)	Diesel (wt %)	Bunker (wt %)	Asphalt (wt %)	Fuelgas (wt %)
X→1	12	8	5	15	20	35	4	1
Y→1	1	2	25	20	15	30	5	2
price ($/bbl)	53.42	42.13	45.79	44.99	43.56	32.59	30.53	40.70
min. demand (bbl/8 days)	13	10	30	35	35	65	9	3

Table 2. Product Yields in CDUs for example 2.

CT→CDU	LPG (wt %)	Naphtha (wt %)	Gasoline (wt %)	Kerosene (wt %)	Diesel (wt %)	Bunker (wt %)	Asphalt (wt %)	Fuelgas (wt %)
X→1	10	10	19	10	15	30	5	1
Y→1	2	11	10	20	17	35	3	2
Z→1	1	8	7	18	19	45	1	1
X→2	1	8	10	22	13	40	5	1
Y→2	3	12	14	12	12	42	3	2
Z→2	4	13	11	14	16	36	3	3
price ($/bbl)	53.42	42.13	45.79	44.99	43.56	32.59	30.53	40.70
min. demand (bbl/10 days)	10.5	31	35.5	48	46	114	10	5

As can be seen from these figures, Bunker had the highest production amount among all of the products. The production amounts were computed as more than the minimum demand values at the end of the planning process. The revenue profile shows an increase over the planning horizon. The changes of crude oil in the storage and charging tanks are shown in Fig.4. The crude oil in the storage and charging tanks exhibit fluctuations over the planning horizon. Noting from this figure, the crude in charging tank is depleted at the end of the planning process.

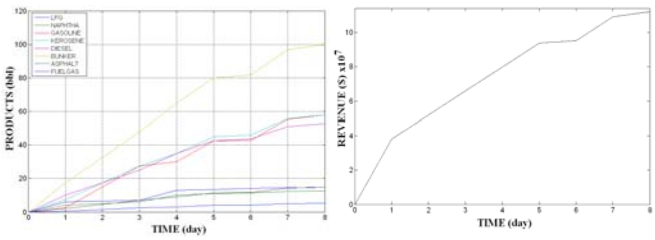

Fig.3. Profiles of the products and revenue during the planning horizon for 4-day moving horizon.

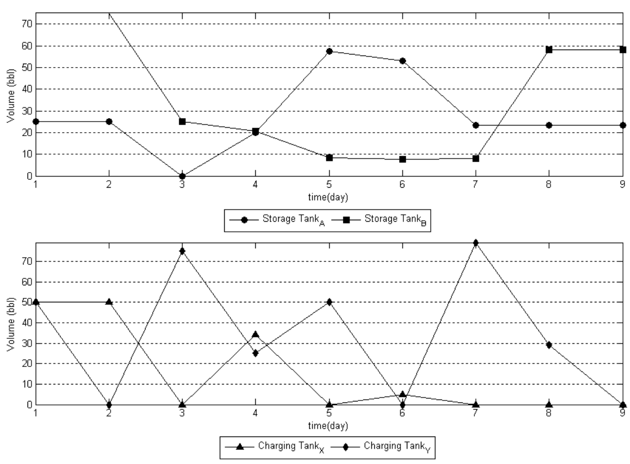

Fig. 4. The volumes of storage and charging tanks during planning process for 6-day moving horizon (N=6).

This is because the inventory cost regarding these tanks is larger than the cost of the storage tanks. While the total profit was calculated as $80,293,000 for the 3-day moving horizon implementation, it was $82,172,000 for the 6-day moving horizon. In the second example, the results are presented in Fig.5 for the 7-day moving horizon. The arrival times for vessels were computed as 1st, 3rd and 5th days. To obtain the maximum profit, the flow rates from storage tanks to the charging tanks are realized more than once over the planning horizon. These results show 5 changeovers for CDU 1 and 3 changeovers for CDU 2. Amounts of all products were obtained as more than the minimum demands. The Bunker product has the maximum amount among all the products. The maximum total profit for this example was calculated as $102,130,000 in MPC with a 7-day moving horizon. For both examples, these show slight improvements over the MILP solution with a fixed planning horizon.

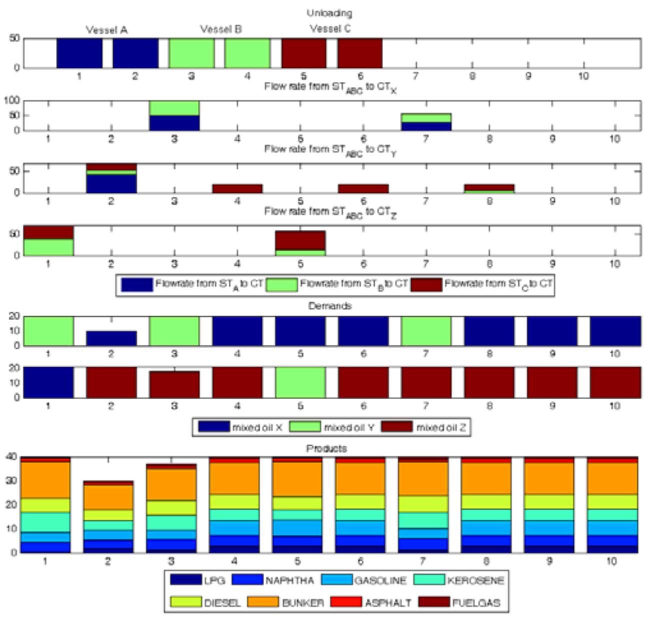

Fig. 5. The results of the second refinery planning example for 7-day moving horizon (N=7).

5. CONCLUSIONS

An MPC based planning model was introduced for the short-term refinery processes. The main objective of this tool is to provide to maximize the total profit during planning horizon. The proposed MPC based structure was carried out for two examples taken from the literature regarding the refinery process. The results show that not only the operating costs are reduced for different moving horizon values, but the total profit also increases. We are currently focusing on the long-term refinery planning problem using discrete time formulation and also plant to consider uncertainty on the product demands during the planning process. This latter problem is expected to fully demonstrate the benefits of the moving horizon strategy.

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Nomenclature

C_{CHNG}	changeover cost for change of mixed crude oil in CDU
C_{INVCT}	inventory cost for charging tank per unit time interval
C_{INVPT}	inventory cost for product tank per unit time interval
C_{INVST}	inventory cost for storage tank per unit time interval
C_{OIL}	price of the crude oil per unit volume
C_{PRICE}	price of the product per unit volume
C_{SEA}	sea waiting cost of vessel per unit time interval
C_{UNL}	unloading cost of vessel per unit time interval
disc	discount rate
D_{CD}	0-1 variable to denote whether crude oil transfer from charging tank to CDU
D_{SC}	0-1 variable to denote whether crude oil transfer from storage tank to charging tank
DM	demand of product during planning horizon
f_{VS}	flow rate of component in crude oil from vessel to storage tank
f_{SC}	flow rate of component in crude oil from storage to charging tank
f_{CD}	flow rate of component in crude oil from charging tank to CDU
F_{VS}	volumetric flow rate from vessel to storage tank
F_{SC}	volumetric flow rate from storage tank to charging tank
F_{CD}	volumetric flow rate from charging tank to CDU
NCDU	number of crude distillation unit
NCOMP	number of key component in crude oil
NCT	number of charging tanks
NPLAN	number of planning time interval
NPROD	number of products
NST	number of storage tanks
NV	number of vessels
S_{CDU}	set of crude distillation units (CDU) {1,…, NCDU }
S_{COMP}	set of key components of crude oil {1,…, NCOMP }
S_{CT}	set of charging tanks {1,…, NCT }
S_{PLAN}	set of time intervals in planning {1,…, NPLAN }
S_{PROD}	set of products {1,…, NPROD}
S_{ST}	set of storage tanks {1,…, NST }
S_V	set of vessels {1,…, NV}
t	time interval
T_F	stop time of unloading and departure time for vessels
T_L	start time of unloading for vessels
V_C	volume of crude oil in charging tank
V_{COMP}	volume of component of crude oil
V_P	volume of product in product tank
V_S	volume of crude oil in storage tank
V_V	volume of crude oil in vessel
w_C	concentration of component in crude oil of charging tank
w_S	concentration of component in crude oil of storage tank
X_F	0-1 variable to denote whether vessel start unloading at dock
X_L	0-1 variable to denote whether vessel complete unloading at dock
X_W	0-1 continuous variable to denote vessel is unloading its crude oil
Y	product yield in CDUs
Z	0-1 continuous variable to denote change regarding charging tanks during charging of mixed crude oil to CDU

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