An MILP Model for Oil Vessel at Refinery

Quse M.H. Shihab[1] and V.H. Bajaj[2]

{[1]Research Student, [2]Professor} Department of Statistics, Dr.B.A.M. University, Aurangabad-431004(MS) INDIA.

Corresponding Addresses:

[1]Qshihab@yahoo.com, [2]vhbajaj@gmail.com

Research Article

Abstract: Oil refinery is receiving its crude oil through a pipeline, which is linked to docking station where oil vessels or any other's tankers unloaded. The unloading schedule of these tankers is defend at corporate level cannot be changed easily. This paper is focused on the production scheduling optimization of operation modes concerning crude oil vessel unloading, storage, blending and feed to crude distillation units (CDUS). The model minimizes the operation cost for the total system shown. The model is formulated using general notation and MILP formulation, showing the possibility of using the model for a general problem of this matter.

Key Words: Oil Refinery, Oil Vessel, Crude oil, Unloading, Storage, Charging, MILP Model.

1. Introduction:

This paper is focused on the production scheduling optimization of operation models concerning crude oil vessel unloading, storage, blending and feed to crude distillation units (CDUS) [4].

The model proposes the strategic operation for the system the strategic operation for the system in accordance with the given condition and the optimal operational cost calculated [7].

The strategic operation if it is feasible must follow the proposed suitable unloading days for vessels and the proposed flow rates among vessels and tanks, among storage and charging tanks and among tanks and plants for keeping the optimal production scheduling given by the model results [8]. This model can be used as a viable tool not only for supporting the shipment planning also for discovering system infeasibilities and for strategic decisions concerning investments in storage and pumping systems [5], [9].

2. Problem Definition:

The crude oil is unloaded into storage tanks at the docking station and the problem considers one pre-selected storage tank per vessel that manages the same crude oil composition of the vessel that manages the same crude oil composition of the vessel. Then, the crude oil is transferred from storage tanks to charging tanks. Each crude oil inside the charging tank must carry out to be within a range of blended crude oil composition determined at the planning level for the scheduling horizon. The fulfilment of this blended composition range is made per tanks having in account the material balance of the remaining volume and the different flows coming in or coming out the tank with their different compositions per time interval. Then, blended crude oils from charging tanks are charged into the CDUS and whenever that it is optimally required feed switches are done from one kind of blended crude oil to another for each CDU. Finally, it is important to mention that whether a charging tank is feeding a CDU; it must not be fed by any storage tank or vice versa [3], [4], [8].

The problem will focus on determine the following operating variables to minimum costs:

a) Waiting time for each vessel in the sea after arriving.

b) Unloading duration time for each vessel.

c) Crude oil unloading rate from vessels to storage tanks.

d) Crude oil transfer and blending rates from storage tanks to charging tanks.

e) Inventory volumes of storage and charging tanks.

f) Crude distillation unit charging rates fulfilling the demand pee each CDU.

g) Sequence of type of blending crude oil to be charge in each CDU in accordance with the optimal model changeovers.

On the other hand these are the following operating constrains that must be met:

a. Equipment capacity limitations; Tank capacity and pumping rate.

b. Quality limitations of each blended crude oil; Range of component concentration in each blended crude oil.

c. Demand per interval of time (day) of each CDU.

3. Nomenclature and Model Assumptions:

3.1.Set:

a. VE = {v = 1, 2, …V/ Crude Oil **or** Tankers}.

b. ST = {i=1, 2, ...I/ Storage Tanks}.

c. SCH ={t= 1, 2,…T/ Time intervals along the scheduling horizon}.

d. CT= {j, y = 1, 2, …J/ Charging tanks}.

e. CDU = {L= 1, 2,… L/ Crude distillation units}.

3-2. Parameters:

CU_V = Unloading cost of vessel v per unit time interval.

$TARR_V$= Crude oil vessel arrival date to the docking station.

$CSEA_V$= Sea waiting cost of vessel v per unit time interval.

$CSINV_i$ = Inventory cost of storage tank i per unit time interval.

$CBINV_j$= Inventory cost of charging tank j per unit time interval.

$CCHANG_L$=Changeover cost of CDU_L.

$TLEA_V$= Crude oil vessel maximum departure date from the decking station.

VS_i^{min}= Storage tank minimum capacity.

VS_i^{max}= Storage tank maximum capacity.

VB_j^{min}= Charging tank minimum capacity.

VB_j^{max}= Charging tank maximum capacity.

3.3 Variables:

3.3.1.Binary Variables

$Z_{j,y,l,t}$= Variable to denote switch of the blended crude oil fed to
CDU_L from charging tank j to charging tank y.

$XF_{v,t}$= Variable to denote if vessel v starts unloading at time t.

$XL_{v,t}$= Variable to denote if vessel v finishes unloading at time t.

$D_{j,l,t}$= Variable to denote if the crude oil blended in charging tank
j charges CDU_L at time t, otherwise charging tank j couldbe being fed by
Storage tanks.

3.3.2Integer Variables.

TL_v= Vessel v unloading Completion time.

TF_v= Vessel v unloading initiation time.

3.3.3Continuous Variables.

$VS_{i,t}$ = Volume of crude oil in storage tank i at time t.

$VB_{j,t}$ = Volume of crude oil in charging tanks j at time t.

$FVS_{v,i,t}$ = Volumetric flow rate from vessel v to storage tank i at time t.

$FSB_{i,j,t}$ = Volumetric flow rater from storage tank i to charging tank j at time t.

$FBC_{j,L,t}$ = Volumetric flow rate from charging tank j to CDU_L at time t.

The following are the ***assumptions*** for the proposed model:

1.Only one vessel docking station for crude oil unloading is considered.

2. The time applied for the changeovers are neglected and also the transient flows
Generated during either start up or shut down when a changeover is done.

3. Perfect blending is assume for each charging tank while it is being fed by different Crude oils, and additional blending time inside the tank is not required before it Chargesthe CDU.

4.The composition of the crude oil is decided by the amount of key Component presented in the crude oil or in the blended crude oil. Ingeneral, sulphur is at least one of the key components, for differentiating between crude oils.

4. Model Mathematical formulation:

The model focus on minimizing the following operation cost of the system for the operations of crude oil vessel unloading, storage, blending and feeding to crude distillation units in an oil refinery [7], then this is the main objective equation that represents the total operation cost of the system:

$$\text{Cost} = \sum_{v=1}^{V}[(TL_v - TF_v + 1)CU_v] + \sum_{v=1}^{V}[(TF_v - TARR_v)\, CSEA_v] + \sum_{i=1}^{I}\sum_{t=1}^{T} [(VS_{i,t,} + VS_{i,t,+1})\left(\frac{CSINV_i}{2}\right)] + \sum_{j=1}^{J}\sum_{t=1}^{T}[\,(VB_{j,t} + VB_{j,t+1})\ CBINV_J/2] + \sum_{j=1}^{J}\sum_{y=1}^{Y}\sum_{l=1}^{L}\sum_{t=1}^{T} [CCHANG_L\,.Z_{j,y,l,t}] \quad \ldots.(1)$$

The above equation is subject to the following constrains:

4.1 Vessel Arrival and Departure Operation Rules.

Each Vessel must arrive to the docking station for unloading only once:

$$\sum_{t=1}^{T} X\,F_{v,t} = 1 \quad , \quad \forall\ v \in VE \ldots (2)$$

Each vessel leaves the docking station only once:

$$\sum_{t=1}^{T} X\,L_{v,t} = 1 \quad , \quad \forall\, v \in VE \ \ldots (3)$$

The unloading initiation time is:

$$TF_v = \sum_{t=1}^{T} t\,x\,F_{v,t} \quad , \quad \forall\, v \in VE \ldots (4)$$

The unloading completion time is:

$$TL_v = \sum_{t=1}^{T} t\,x\,L_{v,t} \quad , \quad \forall\ v \in VE \ \ldots (5)$$

Each vessel must start unloading either after or on the arrival time
established atthe planning level:

$$TF_v \geq\ TARR_v \quad , \quad \forall\ v \in VE \ldots\ (6)$$

Each vessel must finish unloading up to one interval of time before the maximum
departure time established at the planning level:

$$TL_v < TLEA_v \quad , \quad \forall\ v \in VE, \forall\ \ v \neq V \ldots (7)$$

Except for the last vessel:

$TL_v \le TLEA_v \quad , \quad \forall \ v = V \ \ldots (8)$

Minimum duration of the vessel unloading is two time intervals:

$TL_v - TF_v \ge 1 \quad , \quad \forall \ v \in VE \ \ldots (9)$

The preceding vessel must finish unloading one time interval before the next vessel in the sea arrives and start to unload:

$TF_{v+1} \ge TL_v + 1 \quad , \quad \forall \ v \in VE \ldots (10)$

4.2 Material Balance Equations for the Storage Tank.

The crude oil in storage tank i at time t+1 must be equal to the crude oil in storage tank i at time t plus the crude oil transferred from vessel v to storage tank i at time t taking a way the crude oil transferred to charging tanks j at time t:

$VS_{i,t} = VS_{i,1} \quad , \quad \forall t = 1 \ \ldots (11)$

$$VS_{i,t+1} = VS_{i,t} + \sum_{v=1}^{v} FVS_{v,i,t,} - \sum_{J=1}^{J} FSB_{i,j,t} \ , \forall i \in ST, \forall t \in SCH \ldots (12)$$

Volume capacity limitation for storage tank i:

$VS_i^{min} \le VS_{i,t} \le VS_i^{max} \quad , \quad \forall i \in ST, \quad \forall \ t \in SCH \ldots (13)$

4.3 Material Balance Equation for the Charging Tank.

The crude oil blended in the charging tank j at timet+1 must beequal to the crude oil in the charging rank j at time t plus the crude oil transferred from the storage tanks taking away the crude oil transferred to the CDU_L at time t:

$VB_{j,t} = VB_{j,1} \quad , \quad \forall \ t = 1 \ldots (14)$

$$VB_{j,t+1} = VB_{j,t} + \sum_{i=1}^{I} FSB_{i,j,t} - \sum_{L=1}^{L} FBC_{j,l,t} \ , \forall j \in CT, \forall t \in SCH \ldots (15)$$

Volume capacity limitation for charging tank j:

$VB_j^{min} \le VB_{j,t} \le VB_j^{max} \quad , \ \forall \ j \in CT, \forall t \in SCH \ldots (16)$

4.4 Operating Rules for Crude Oil Charging to Crude Distillation Units.

As it was stated above each CDU_Lonly can be charged by one charging tank j at time t:

$$\sum_{J=1}^{J} D_{j,l,t} = 1, \quad \forall L \in CDU, \ \forall t \in SCH \ldots (17)$$

On the other hand, each charging tank j can charge at most one CDU_Lat time t:

$$\sum_{L=1}^{L} D_{j,l,t} \le 1 \ , \ \forall j \in CT \ , \quad \forall t \in SCH \ldots \ (18)$$

If the CDU_L is charged by crude oil blended j at time t and after is charged by crude oil blended y at time t+1 then, changeover cost must be involved. The following is the condition that confirms that changeover cost shall be charged:

$$Z_{j,y,L,t} \ge D_{j,L,t} + D_{y,L,t+1} - 1 \ , \forall j, y \ (j \ne y) \in CT, \forall L \in CDU, \forall t \in SCH \qquad (19)$$

5. Numerical Example:

Table1.Shows the system information for numerical example [2].

Scheduling Horizon (# of unit times : days)			8
No. of Vessel arrivals			2
	Arrival time	Amount of crude Oil	Key component concentration
Vessel 1	1	100	0.01
Vessel 2	5	100	0.06
No. of Storage Tanks			2
Storage Tanks	Capacity	Initial oil Amount	Key component concentration
Tank 1	100	25	0.01
Tank 2	100	75	0.06
No. of Charging Tanks			2
Charging Tanks	Capacity	Initial oil Amount	Initial component concentration (Min-Max)
Tank 1	100	50	0.02 (0.015–0.025)
Tank 2	100	50	0.05 (0.045 – 0.055)
No. of CDUS			1

Unit Costs involved in vessel operation	Unloading Cost = 8, Sea waiting Cost = 5
Tank Inventory Unit Cost	Storage Tank = 0.08, Charging Tank = 0.05
Unit changeover cost for charged oil switch	50 (independent of sequence and CDU)
Blended oils demand from charging tanks To CDU_S	Blended oil 1 : 100, Blended oil 2 : 100, Blended oil 3: 100.
Maximum flow rate from vessel to one storage tank	50
Maximum flow from one storage tank to one charging tank	40
Maximum total flow rate from one storage tank to charging tanks at any time	40

The given data for quantifying volumes and flow rates are given in barrels x 10,000 and barrels per time interval x 10,000 respectively, changeover costs are given in US$ x 1.000; sea waiting costs and unloading costs are given in US$ x1.000 per time interval (day) and tank inventory unit cost are given in US$ x 0.1 per oil barrel. Therefore, optimal value results will be in US$ x 1.000.

Table 2. Optimal Unloading Starting Date for Vessels.

Vessels	Model A	Model B
1	3	2
2	7	7

Table 2. points out the comparisons of the optimal unloading starting up date results from both models for numerical example vessel 1 stars to unload on day (s) for model'A'; that is one day more than model 'B'which considers this operation on day 2. Instead, for vessel 2 both coincide starting unloading on day7.

The optimization model Table 3.Involved36 discrete variables, 192 single variables, and 331 constraints [2]. The modelling system G.A.M.S. [1]. Was used for setting up the optimization model and the numbers of variables and constraints were reduced by considering the data structure of binary variables. The problem was solved by OSL, IBM [6]. An IBM RS- 6000 in 17.5 of CPU time.

Table 3. Comparison of Optimal Result

Items	Model A	Model B
Optimal value (US$ X 1.000)	217.667	206.95
Equations and constrains	331	552
Single Variables	192	337
Discrete Variables	36	116
Iterations	1.695	4.393
Solving time (second)	17.1	5.21

The optimal results generated by model 'B' with No omission of any data given by model 'A' are shown and compared in advance with the optimal results of model 'A' in table 3.

6. Concluding Remarks:

1) The situations may be causing a big part of the difference between both optimal value since the optimal operational schedule of Model 'A' should be paying more money in inventory total cost. On the other hand, Model 'A' results is paying one day more of sea waiting ***cost (US $ 5,000)*** than model 'B' results as is indicated in table (2).

2)The optimal results for numerical example are better for model 'B' indicating a total operational cost saving for the problem conditions of ***US$ 10,717 (4.92%) cost*** reduction with respect to model 'A' during the 8 day scheduling horizon in accordance with the results showed in table (1).

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