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Refinery scheduling of crude oil unloading with tank inventory management

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ABSTRACT

The aim of this study is to develop a methodology for short-term crude oil unloading, tank inventory management, and crude distillation unit (CDU) charging schedule using mixed integer linear programming (MILP) optimization model as an extension to a previous work reported by Lee et al. (1996). The authors attempt to improve the previous model by adding an interval–interval variation constraint to avoid CDU charging rate fluctuation, a shutdown penalty within the scheduling cycle and a set up penalty for tank-tank transfer and introducing demand violation permit for a more flexible model against obtaining infeasible solution. Three different cases from the original paper were used to test the validity of the improved model. Comparison between Cases 1 and 2 shows the advantage of using smaller time interval as the operating cost of Case 2 is lower. Two scenarios were created from Case 3 to show the benefits of the improved model in deciding the best schedule to use. The improved model was implemented using the CPLEX solver in GAMS.

1. Introduction

The processing of crude oil into useful petroleum products necessitates the establishment of a refining industry. This however is of serious concern to the refiner considering high and volatile crude oil prices, environmental legislation, crude oil and products quality, market demand and overall profit (Li, Li, Karimi, & Srinivasan, 2007). In order to overcome these challenges, researchers work towards developing computational algorithms for crude oil scheduling.

1.1. Scheduling and optimization of crude oil operation

Crude oil scheduling is a crucial part of the refinery supply chain (Saharidis, Minoux, & Dallery, 2009). It is a process that involves specifying the timing and sequence of operations in this order of vessel arrival, crude oil unloading to storage tanks, transferring crude oil from storage tanks to charging tanks and finally sent the mixed crude oil to crude distillation units (CDUs) for component separations and downstream processing. A typical schedule sets daily targets for production with consideration on storage and charging tanks' capacities, CDU capacity utilization and pumping capabilities. It also determines the quality and quantity of crude mixing materials in the charging tanks in order to produce blends that satisfy the requirements of planning team. Each of these activities is associated with cost. The objective of scheduling is to minimize the total cost while following the feasible operational procedures (Jia, Ierapetritou, & Kelly, 2003).

In research studies, refinery scheduling problems are often presented as optimization model with operating cost as the objective function. The challenge with building models for scheduling lies in knowing and including what is relevant for the specific decisions that are to be made using the model and neglecting the elements that are not relevant. Selection of units with arrangments on the sequence of operation with regards to modelling of refinery scheduling problems require a systematic approach. Optimization techniques are used extensively in this area of study to come up with schedules that are not only acceptable to the planning team but also to the satisfaction of the customers adequately.

1.2. Recent progress in refinery scheduling

Significant progress has been made over the years in scheduling of crude oil unloading, mixing and charging of the CDU. The trend involves using mathematical models with constraints and bounds on the stream connections. A number of researchers presented problems with continuous and discrete decisions for crude oil scheduling. For instance, the work of Bassett, Pekny,

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Nomenclature

Subscripts

- j charging tank
- i storage tank
- g other charging tank
- k key component
- l crude distillation unit
- m other time interval
- t time interval
- v crude oil vessel
- o initial value

Parameters

- CC charging tanks changeover cost
- $CINBT_j$ charging tanks j inventory cost per unit time per unit volume
- $CINST_i$ storage tanks i inventory cost per unit time per unit volume
- CS cost penalty for shutdown
- $CSEA_v$ sea waiting cost for vessel v
- $CSSU$ cost penalty for switching to another tank during tank-tank transfers
- $COPR$ operating cost
- $CUNL_v$ unloading cost for vessel v
- $D_{j,l,t}$ binary variable that denotes charging tank j is charging CDU l at time interval t
- $D_{g,l,t}$ binary variable that denotes charging tank g is charging CDU l at time interval t
- DM_q demand of crude mix q
- NBT number of charging tanks
- $NCDU$ number of CDUs
- $NCOMP$ number of key components
- NST number of storage tanks
- $NSCH$ number of time intervals in scheduling horizon
- NV number of vessels
- $TARR_v$ arrival time of vessel v
- TF_v time vessel v begins to unload
- TL_v time vessel v finishes unloading
- $\varepsilon 1_q$ violation parameter due to decrease in demand
- $\varepsilon 2_q$ violation parameter due to increase in demand
- μ_l user defined parameter that determines interval–interval variations for CDU l throughput

Variables

- $fbc_{j,l,k,t}$ volumetric flow rate of component k from charging tank j to CDU l at time t
- $fsb_{i,j,k,t}$ volumetric flow rate of component k from storage tank i to charging tank j at time t
- $fvs_{v,i,k,t}$ volumetric flow rate of component k from vessel v to storage tank i at time t
- $FBC_{j,l,t}$ volumetric flow rate from charging tank j to CDU l at time t
- $FBC\text{max}_{j,l}$ maximum volumetric flow rate from charging tank j to CDU l
- $FBC\text{min}_{j,l}$ minimum volumetric flow rate from charging tank j to CDU l
- $FSB_{i,j,t}$ volumetric flow rate from storage tank i to charging tank j at time t
- $FSB\text{max}_{i,j}$ maximum volumetric flow rate from storage tank i to charging tank j
- $FSB\text{min}_{i,j}$ minimum volumetric flow rate from storage tank i to charging tank j
- $FVS_{v,i,t}$ volumetric flow rate from vessel v to storage tank i at time t
- $FVS\text{max}_{v,i}$ maximum volumetric flow rate from vessel v to storage tank i
- $FVS\text{min}_{v,i}$ minimum volumetric flow rate from vessel v to storage tank i
- $vb_{j,k,t}$ volume of component k in charging tank j at time t
- $vs_{i,k,t}$ volume of component k in storage tank i at time t
- $VB_{j,t}$ volume of charging tank j at time t
- $VB\text{max}_j$ maximum volume of charging tank j
- $VB\text{min}_j$ minimum volume of charging tank j
- $VS_{i,t}$ volume of storage tank i at time t
- $VS\text{max}_i$ maximum volume of storage tank i
- $VS\text{min}_i$ minimum volume of storage tank i
- $VV_{v,t}$ volume of crude oil vessel v at time t
- $ws_{i,k}$ concentration of component k in storage tank i
- $ws\text{max}_{i,k}$ maximum concentration of component k in storage tank i
- $ws\text{min}_{i,k}$ minimum concentration of component k in storage tank i
- $wb_{j,k}$ concentration of component k in charging tank j
- $wb\text{max}_{j,k}$ maximum concentration of component k in charging tank j
- $wb\text{min}_{j,k}$ minimum concentration of component k in charging tank j
- $wv_{v,k}$ concentration of component k in crude oil vessel v
- $XD_{l,t}$ binary variable that indicates shutdown of CDU l at time t
- $XF_{v,t}$ binary variable that denotes that vessel v starts unloading at time t
- $XL_{v,t}$ binary variable that denotes that vessel v stops unloading at time t
- $XW_{v,t}$ binary variable that denotes that vessel v is unloading to storage tank i at time t
- $XWS_{i,j,t}$ binary variable that denotes that storage tank i is transferring charging tank j at time t
- $Z_{j,l,t}$ binary variable that denotes that charging tank j charges the CDU l at time t
- $Z_{j,g,l,t}$ binary variable that denotes that CDU l switched from charging tank j to charging tank g at time t
- $\alpha_{i,t}$ binary variable that denotes that storage i tank is set up for tank-tank transfer

and Reklaitis (1996) that considers a model based approach to address a large-scale scheduling problem while considering length of the scheduling horizon (time), the number of units/equipment involved and the number of operations and available resources. Since scheduling of crude oil operations usually involves continuous and discrete decisions, MILP is used in formulating the scheduling problems.

Two popular approaches based on time representation of the scheduling horizon have been used in formulating MILP: discrete-time formulation and continuous-time formulation. A third but less popular approach combines these two time formulations to develop mixed time formulation (Westerlund, Hastbacka, Forssell, & Westerlund, 2007). Mouret, Grossmann, and Pestiaux (2009) introduced a new approach for continuous-time formulation known as priority-slot based method. Pinto, Joly, and Moro (2000) used variable length time slot for creating short-term scheduling of crude oil operations in a 200,000 bpd refinery that receives about ten different crude types in seven storage tanks. They used uniform time discretization of 15 min to generate an MILP problem that could not be solved with the available optimization technology at that time.