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Simultaneous scheduling of front-end crude transfer and refinery processing

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ABSTRACT

Scheduling of front-end crude-oil transfer and refinery processing are two critically important and challenging tasks to petroleum refineries. However, the simultaneous scheduling of front-end crude-oil transfer and refinery operations has never been considered in previous studies due to the large scale and complexity of the resultant optimization problem. In this paper, a systematic methodology for simultaneous scheduling of front-end crude transfer and refinery processing has been developed. It provides a large-scale continuous-time based scheduling model for crude unloading, transferring, and processing (CUTP) to simulate and optimize the front-end and refinery crude-oil operations simultaneously. The CUTP model consists of a newly developed refinery processing sub model, a crude processing status transition sub-model, and a borrowed front-end crude transferring sub model. The objective is to maximize the total operational profit while satisfying various constraints such as operation and production specifications, inventory limits, and production demands. The efficacy of the proposed scheduling model has been demonstrated by an industrial-scale case study.

1. Introduction

The petroleum refinery is a leading segment of the entire petrochemical industry. It processes crude oils to produce various fuels such as gasoline, aviation kerosene, diesel, heavy fuel oil, and chemical raw materials such as naphtha and benzene. The petroleum refinery plays a vital role in the national economic development. It was reported by the Energy Information Administration (EIA) that U.S. crude oil and dry natural gas production levels have increased rapidly in recent years. From 2008 to 2013, the crude oil production grew from 5.0 million barrels per day to 7.4 million barrels per day. In 2014, 142 operable refineries in the U.S. processed 5.78 billion barrels of crude oil and produced 14.0 million barrels of petroleum and other liquids per day (EIA, 2014). Even in the slow market of 2015, the crude oil production associated with 140 operable refineries in U.S. reached 10.6 million barrels per day (EIA, 2015). Because of the increasingly strict economic competitions, refineries are eager to improve production efficiency and lower the operational cost to leverage profitability margins in current volatile oil markets.

Generally, the majority of a refinery's expenditure is used for crude oil purchasing. Thus, the crude availability and crude movement should be optimally integrated with the crude processing, so that the potential profitability of a refinery can be improved. This is also the reason why the front-end crude scheduling and planning is extremely important in the supply chain management of refineries, especially under current conditions of increasingly global competitions, more volatile feedstock/product markets, and stricter environmental regulations. As shown in Fig. 1, the scope of this study contains two major sections: (i) front-end crude transfer, which covers the crude unloading from vessels to portside storage tanks at onshore berths, and the crude transferring to charging tanks of an inland refinery to prepare blends for plant processing with satisfied property specifications; (ii) crude processing in the refinery, which includes crude distillation, reforming, cracking, hydrotreating, blending, gas processing, sulfur recovering facilities, as well as refinery product blending and storage illustrated in Appendix A. Obviously, the supply chain management for a petroleum refinery should consider the simultaneous scheduling of front-end crude transfers and in-plant processing. Lots of published studies have addressed these two major sections, separately.

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Nomenclature

Indices

$c \in C$ Crude types
$k \in K$ Key components
$n \in N$ Global time events
$unt \in UNT$ All the units including parcels, tanks, and CDUs
$v \in V$ Vessels
i, i' General process streams
j Raw material feed of a plant
$p \in PP$ Product of a plant
m Component
s, s' Process streams
u,v,w Process units in refinery plant
ui , uo Virtual plant input and output units

Sets

C Set of crude oil types
$CT \subset UNT$ Set of charging tanks
$DU \subset UNT$ Set of distillation CDUs
$IU \subset UNT$ Set of units as input unit sources: $IU = P \cup ST \cup CT$
$IU_{ct} \subset IU$ Set of input sources for charging tank
$IU_{du} \subset IU$ Set of input sources for CDU
$IU_{st} \subset IU$ Set of input sources for storage tank
K Set of key components (e.g. sulfur concentration)
N Set of global time events
$OU \subset UNT$ Set of output units: $OU = ST \cup CT \cup DU$
$OU_{ct} \subset OU$ Set of output units for crudes from charging tanks
$OU_p \subset OU$ Set of output units for crudes from parcels
$OU_{st} \subset OU$ Set of output units for crudes from storage tanks
$P \subset UNT$ Set of crude parcels
P_v Set of crude parcels carried by vessel v
$SCT = ST \cup CT$ Union of storage and charging tank sets
$SCT*$ Set of malfunctioning tanks
$ST \subset UNT$ Set of storage tanks
$UNT = P \cup ST \cup CT \cup DU$ Set of all the units including parcels, tanks, and CDUs
V Set of vessels
I Process stream set
J Raw material feed set of a plant
PP Plant product set
M General component set
$S_{v,u}$ Special stream set defined as $S_{v,u} = \{s|\text{the}s\text{-th stream that flow from}v\text{to}u\}$
$S_{u,w}$ Special stream set defined as $S_{u,w} = \{s|\text{the}s\text{-th stream that flow from}u\text{ to }w\}$
$S_{v,uo}$ Special stream set defined as output from unit v
$S_{ui,w}$ Special stream set defined as feedstock to unit w
SF_j Stream set that contains the j-th plant feed
SO_p Stream set that contains the p-th plant output
V_u Unit set defined as $V_u = \{v|\text{units that have streams flowing to}u\}$
W_u Unit set defined as $W_u = \{w|\text{units that have streams flowing from}u\}$
V_{uo} Unit set defined as output units
W_{ui} Unit set defined as feedstock units
$UALL$ All the units of the plant
$UINV$ Inventory unit set
$UMIX$ Mixer set
$USEP$ Separator set
$UREA$ Reactor set
$UTIT$ Utility generation unit set

Parameters

BST Brine settling and removal time
ETT Extra transitional time (RPST time) since charging tank change when feed a distilation column
$SPG(c)$ Specific gravity of crude c
C^{cho} Changeover cost for a CDU switching different feeds