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An Optimization Model for the Production Planning of Overall Refinery*

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Abstract This article addresses a production planning optimization problem of overall refinery. The authors formulated the optimization problem as mixed integer linear programming. The model considers the main factors for optimizing the production plan of overall refinery related to the use of run-modes of processing units. The aim of this planning is to decide which run-mode to use in each processing unit in each period of a given horizon, to satisfy the demand, such as the total cost of production and inventory is minimized. The resulting model can be regarded as a generalized lot-sizing problem where a run-mode can produce and consume more than one product. The resulting optimization problem is large-sized and NP-hard. The authors have proposed a column generation-based algorithm called branch-and-price (BP) for solving the interested optimization problem. The model and implementation of the algorithm are described in detail in this article. The computational results verify the effectiveness of the proposed model and the solution method.
Keywords refinery planning, lot-sizing, optimization, column generation

1 INTRODUCTION

The main aim of production planning is to decide what to produce, how much to produce and when to produce for a given plan horizon in a company. The production plan includes yearly plan, seasonal plan and monthly plan in terms of time horizon. The objective of production planning in a refinery is to generate as many valuable products as possible, such as gasoline, jet fuel, diesel, and so on, and at the same time satisfying market demand and other constraints.

Oil refining is one of the most complex chemical industries, which involves many different and complicated processes with various possible connections. It is well known that the oil refining is a typical continuous production process. Maybe a typical refinery includes tens of units. Therefore the optimization of the production planning of the overall refinery is considered as one of the most difficult and challenging tasks, which is also often formidable, even impossible [1]. Nevertheless, the production plan optimization is an important profit growth point thus it also becomes a burning hot topic in both industry and academia. Various optimization models have been developed for individual units with specific technological characteristics. However, the optimization of the production units does not achieve the global economic optimization of the plant. Usually the objectives of the individual units are conflicting and many times infeasible thus many production paths are restricted or disabled. The production planning optimization for refinery-wide has been addressed by using linear programming in the past decades. Although the linear programming models are not good enough to consider the discrete features of the planning problem, such as the dynamic feature of demand, uneven features of the supplement of crude oil and the production of processing units in terms of time periods. Recent studies for optimization of production planning have been toward the development of nonlinear programming and mixed integer linear programming models [2, 3]. The main study of this article is to propose a production planning model and algorithm for refinery-wide optimization.

2 PROBLEM STATEMENT

The problem studied by the authors is at Jinxi Refinery of Liaoning Province, China. Jinxi Refinery is a large-scale fuel oil-lubricant oil type oil refining plant. It has over 50 production units including two distillation units (AVU), two catalytic cracking units (FCC), one continuous catalytic reforming unit (CCR), one delayed coking unit, two hydrotreating and hydrofining units and some auxiliary units. The processing ability of crude oil is over six million tons per year. A simplified technology flow chart of the refinery is as follows:

A run-mode indicated in Fig. 1 may be explained as follows: the crude oil is processed by the atmospheric and vacuum distillation unit (AVU) producing gas, liquid petroleum gas (LPG), light naphtha, vacuum gas oil (VGO), and vacuum residue (VR). The naphtha is processed by CCR producing reforming gasoline. The atmospheric and vacuum distillation diesel and FCC diesel are fed to the Hydrotreating unit producing refining diesel. The atmospheric and vacuum distillation VGO, Delayed coking VGO and VR are fed to the FCC producing gasoline. VR is fed to the Delayed coking unit producing gasoline, diesel and VGO. These are the most typical run-mode for the main units. If different run-modes are used for these processing units, changes will take place in the yield levels and structures of the products in these units.

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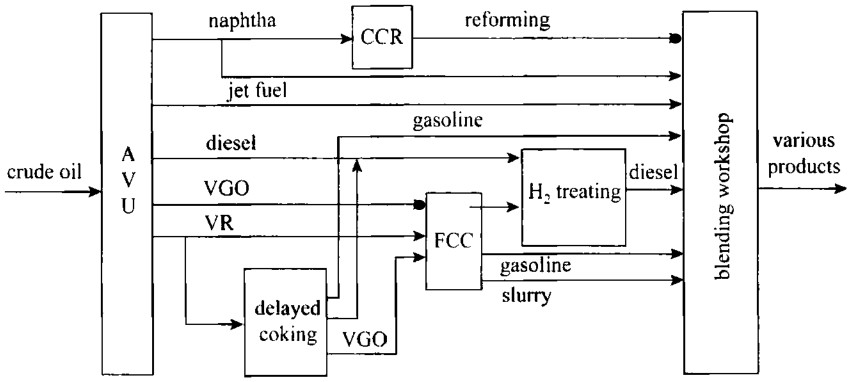

Figure 1 A simplified refinery flow chart

The production planning problem at Jinxi Refinery comprises of the optimal yearly production plan consisting of yield level of each product in each month, given customer demand, capacities of units, and initial inventories of crude oil, components and products. The optimization of production planning is equivalent to selecting the best operating routes as well as run-modes for all the processing units. A run-mode of operation for a processing unit is specified by the combination of products consumed and produced in the process, and by the yield levels of the products.

At Jinxi Refinery, the main factors considered for the planning problem are fulfillment of the demand, prices of products, inventories of products, and crude oil processing capacity. Currently, the planning is carried out manually with the help of spreadsheet models and is time consuming. No optimization tools are used for the planning.

For optimizing the planning, a reference was made to the model in the literature [1], attempts have been made to update it for production plan problems. The length of the time period has been extended to one month to suit the production plan horizon and to add a capacity constraint to the problem. The authors have also redefined the cost for the use of a run-mode of a processing unit to make it include costs of utilities such as water, electricity, steam and wind power. The model for the problem is a mixed integer linear programming (MILP) which is a generalized lot-sizing optimization problem where according to a run-mode, more than one product can be produced and consumed. The problem formulation is as follows:

$$\min \sum_{t\in T}\sum_{p\in P} C^{I}_{pt} I_{pt} + \sum_{t\in T}\sum_{q\in Q}\sum_{m\in M} C^{S}_{qmt} y_{qmt} \tag{1}$$

s.t.

$$x_{pt} - \sum_{q\in Q}\sum_{m\in M} a_{qmp} y_{qmt} = 0, \quad p\in P,\ t\in T \tag{2}$$

$$z_{pt} - \sum_{q\in Q}\sum_{m\in M} b_{qmp} y_{qmt} = 0, \quad p\in P,\ t\in T \tag{3}$$

$$I_{pt-1} + x_{pt} - z_{pt} - I_{pt} = d_{pt}, \quad p\in P,\ t\in T \tag{4}$$

$$\sum_{m\in M} y_{qmt} = 1, \quad q\in Q,\ t\in T \tag{5}$$

$$\sum_{p} l_p x_{pt} \leqslant L_t, \quad t\in T \tag{6}$$

$$I_{pt}, x_{pt}, z_{pt} \geqslant 0, \quad p\in P,\ t\in T \tag{7}$$

$$y_{qmt} \in \{0,1\}, \quad m\in M,\ q\in Q,\ t\in T \tag{8}$$

The objective function (1) expresses minimizing the total cost consisting of inventory and production costs. Constraints (2) express production balance and constraints (3) express consumption balance. Constraints (4) express supplement-demand balance. Constraints (5) explain for each processing unit in each period one and only one run-mode can be taken. Constraints (6) help in capacity restriction. Constraints (7) and (8) explain that backorder is not to be allowed. The model can be regarded as a generalized lot-sizing problem in which a run-mode leads to many products being produced. The lot-sizing problems have been extensively studied in literature and have been proved to be NP-hard [4-6]. The authors propose a branch-and-price algorithm for solving the generalized lot-sizing problem. Branch-and-price algorithms are the generalization of branch-and-bound algorithms that solve LP relaxations using column generation. Branching occurs when no column enters the basis and the LP solution does not satisfy the integrality conditions. Branch-and-price algorithms have been used for solving many difficult integer and combinatorial programming problems [7-10].

3 ALGORITHM

The algorithm proposed in this article mainly includes three parts. The first part is the original problem's set-partitioning reformulation, and the second and third parts are a column generation procedure and a branch and bound procedure respectively, which help to solve the resulting set partitioning problem.

3.1 Set-partitioning reformulation

Given a set of production schedules for each unit q, the single-level multi-item capacitated lot-sizing problem can be formulated as the following set partitioning problem: