Available online at www.sciencedirect.com
ScienceDirect
European Journal of Operational Research 182 (2007) 1–14
EUROPEAN JOURNAL OF OPERATIONAL RESEARCH
www.elsevier.com/locate/ejor

Discrete Optimization

Mathematical model for scheduling operations in cascaded continuous processing units

Subir Bhattacharya *, Sumit Kumar Bose

Indian Institute of Management Calcutta, MIS Group, Joka, Diamond Harbour Road, Kolkata 700 104, India

Received 22 April 2005; accepted 30 June 2006
Available online 3 November 2006

Abstract

The scenario under consideration involves n cascaded continuous processing units responsible for processing m product lines. Each product line needs to be processed by all the units in the same sequence, and has dedicated finite capacity storage tanks before and after every processing unit. A unit can process only one product line at a time. Inputs for all the product lines arrive continuously and simultaneously on the input side of the first unit in the sequence. There are multiple intermediate due dates for the final products. An optimal schedule for the units calls for a trade-off among spillage costs, upliftment failure penalties and changeover costs. A mathematical model is developed for the purpose and the resulting MINLP is linearized using standard techniques. The MILP has been tested using GAMS for three units and three product lines as encountered in a refinery situation. The model could output optimal schedules for a ten day scheduling horizon within reasonable time.

Keywords: Scheduling; Continuous processing units; Discrete optimization; Process industry

1. Introduction

Continuous processing units are quite common in refineries and other chemical processing industries. In continuous processing units, input streams for a product line are fed in continuously at one end and the output streams flow out simultaneously from the other end. A typical example would be a fractionating column. In contrast, in a batch processing unit, inputs in right amount and proportion are fed into the unit, 'treated' for a fixed amount of time in non-preemptive style, and outputs are taken out after the complete batch gets processed. In both the cases, the unit may be responsible for processing a range of products. In this situation, the unit works in a 'blocked-out' fashion, i.e., at any point of time it processes only one product line or stream. Input streams for the other product lines flowing in at the same point of time from some upstream units have to be either stored in tanks for future processing or they have to be 'spilled' to lower valued products if there is no space in the tanks. Scheduling of 'blocked-out' batch processing units addresses the issue of determining the optimal sequence in which the product batches should be taken up for processing. In a continuous processing unit, one product

* Corresponding author. Tel.: +91 33 24678300x409; fax: +91 33 467 7851.
E-mail address: subir@iimcal.ac.in (S. Bhattacharya).

0377-2217/$ - see front matter
doi:10.1016/j.ejor.2006.06.040

line can be processed in number of stretches interleaved with the processing of other streams. The length of each stretch of each product line is a decision variable. The problem of scheduling a continuous processing unit involves deciding the number and durations of the stretches for each product, and interleaving these production stretches of the various product lines in an optimal manner. The authors encountered this problem while scheduling operations of the units responsible for producing lube oils in a refinery. Scheduling problems in batch processing industries have received good deal of attention in the literature. However, interest in scheduling units in continuous processing industry is more recent. This paper proposes a mathematical model for optimal scheduling of cascaded continuous processing units separated by fixed capacity buffers with multiple intermediate due dates for the finished products. The initial MINLP formulation was converted to MILP and tested using GAMS. The model could output optimal schedules for ten day horizons within reasonable time.

2. Problem scenario

The set of units under consideration consists of a sequence of n 'blocked-out' processing units, $U_1, U_2, \ldots, U_n$, buffered by fixed capacity storage tanks to hold intermediate products (Fig. 1). Each unit can process only one product line (also referred to as stream) at a time. Each product line has its exclusive set of tanks before and after every processing unit. We consider m product lines, $P_1, P_2, \ldots, P_m$, each of which requires to be processed by the n units in the same sequence. The processing capacity (f_{ij} known as the feedrate measured in MtPD, Metric tons Per Day) of a unit for a product line is considered fixed, but varies from product to product. The processing of a unit involves splitting the feed with the help of reagents into intermediate streams according to a yield percentage fixed for a product line for the unit. The intermediate streams that are relevant for the final products under consideration get deposited in the tanks on the output side. What happens to the other output streams is beyond the purview of this discussion. For our purpose, if p_{ij} is the yield percentage corresponding to product P_i in unit U_j, then x units of input to U_j gives rise to $x^* p_{ij}$ units of output from U_j. Thus, each unit processes one stream at a time, taking its input from the corresponding input tank if it has enough stock and depositing the output into corresponding output tank if it has enough room (ullage). The presence of intermediate storage tanks obviates the need for the units to process the same product in tandem. To facilitate our discussion, we categorize the storage tanks into certain *level*s. The tanks to the left of U_1 belong to level 0 (l_0) and the tanks immediately after a unit U_k are said to be in level k (l_k).

The finished products coming out of the last unit (U_n) also get stored in fixed capacity tanks to be uplifted according to some pre-specified upliftment schedule. A product can be uplifted several times by specified quantities during the scheduling horizon. Penalty is incurred if the required amount of a finished product is not ready on the specified due date. Shortfall in one upliftment of a product cannot be compensated by providing more during the next upliftment of the same product.

The inputs for the product lines arrive at the input tanks of unit U_1 simultaneously at constant rates, a_i. The rates at which these inputs arrive depend on factors that are beyond the control of this block of units. Each of these streams gets stored in a fixed capacity tank if there is ullage in it; otherwise it spills, and is downgraded to lower valued products. Note that spillage is not allowed for intermediate or finished products. In essence, spillage can occur only at the input of U_1 because the inputs for all the product lines are arriving simultaneously and also because these units have no control on the rates at which these inputs arrive. Spillage implies opportunity lost, and hence, has a penalty associated with

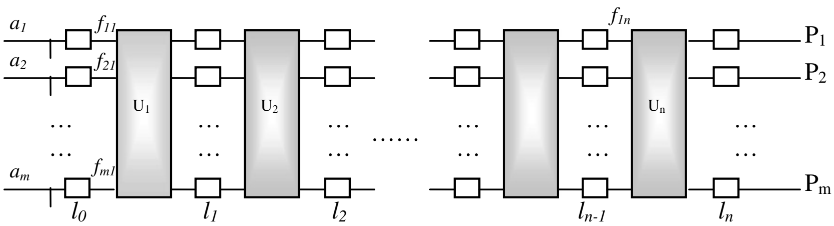

Fig. 1. Continuous Processing Plant with n stages and m products.