Application of the Theory of Constraints (TOC) to Batch Scheduling in Process Industry

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ABSTRACT

This paper presents a practical daily batch scheduling problem at one leading global food company for multi-stage, multi-batch scheduling with no-wait. After investigated different approaches of both traditional optimization and simulation technique, the concept of the Theory of Constraint (TOC) was adopted to identify the bottleneck activity first, then the problem was converted from a multi-product batch scheduling to a multi-project critical chain based scheduling, and the scheduling technique of Drum-buffer-rope (DBR) in TOC was specifically adopted to solve the company’s routine scheduling problem. With the help of professional computer software and customized output, it is very efficient and effective for the daily scheduling personnel to operate due to no complicated algorithm or programming involved. This new TOC approach has been implemented in its several plants in headquarter and is expected to expand to other plants.

Keywords: Case Study, Computer Software, Critical Chain, Process Industry, Scheduling, Theory of Constraint (TOC)

INTRODUCTION

Scheduling is fundamental to most organizations. During the past several decades, an extensive amount of research has been conducted and a variety of scheduling techniques or algorithms has been done (e.g., Gang et al., 2007; Chen et al., 2008a). Many studies have focused on discrete manufacturing rather than on process industries. Since there are major differences between discrete and process industries, scheduling techniques developed for discrete industries can rarely be applied directly to process industries. As a result, the process industries continue to fall behind the discrete industries in the identification and implementation of effective scheduling technique (Daina & Meredith, 2000).

Processes industries may use either continuous or batch processes. Economies of scale often require large-scale equipment with a high capital investment. Batch operations usually have the following characteristics (Fransoo & Rutten, 1994): 1) long lead time, 2) much work in process (WIP), 3) less impact of changeover times, 4) a large number of production/process steps and 5) a large number of products. Examples in this category are the oil, drug, and food industries. There are two reasons that make the batch scheduling much more chal-
lenging than discrete scheduling. First, batch production usually involves a large number of production protocols, or process sequences for a given product. Each production protocol contains numerous steps utilizing a variety of materials and equipment. While processing multiple batches simultaneously, the schedule dictates the use of particular equipment at a specific time. Equipment conflicts arise frequently. Second, some process industries, such as the food industry studied in this paper, have a no-wait constraint on batch scheduling. A no-wait constraint means no interruption or waiting is allowed during the processing of a batch between successive machines/equipment (Lin & Cheng, 2001). So as long as a batch gets started at the first stage, resources must be guaranteed to be available for all the following stages whenever they are needed. Otherwise the process has to be interrupted and serious consequences would occur that adversely affect the quality and/or productivity of the product. This constraint makes the batch scheduling very challenging for process industries.

In this paper we conducted a case study on one global manufacturer with operations in more than 30 counties. We developed a batch scheduling technique to solve the multi-stage and multi-product no-wait batch-scheduling problem, and then implemented this technique in one of its main plants. This company is the world’s largest supplier of fragrances, flavors, and colors to the food beverage, pharmaceutical, cosmetic, home and personal care products, specialty printing and digital imaging industries.

LITERATURE REVIEW

In this project, we aim to minimize the total time needed to complete a group of batches from the beginning of processing on the first batch until the completion of processing on the last batch. This objective is often referred to as minimizing the “makespan” in scheduling theory. Traditionally mathematical programming (e.g., mixed integer programming) can be used to find optimal solutions to such scheduling problem. For example, Sadykov and Wolsey (2006) combined integer programming and global constraint to find minimum cost assignment of jobs. Magatão et al. (2004) also developed an optimization structure to schedule activities in the pipeline industry based on mixed integer programming. For large-scale batch scheduling involving multiple batches, too many variables and constraints would have to be considered. As such, it is very difficult, if possible, to find the optimal solution to the mathematical programming. Therefore many heuristic algorithms have been widely investigated in the scheduling research to approximate the optimal solution to the mathematical programming. For example, Chen et al. (2008b) presented a hybrid approach of genetic algorithm and extremal optimization to solve a class of manufacturing scheduling problems. Guo et al. (2008) adopted bi-level genetic algorithm to solve a flexible assembly scheduling problem. Hansen and Mladenovic (2001) also introduced the application of Variable neighborhood search on scheduling problem. However, it was extremely difficult to set up constraints for no wait conditions by mathematical programming. In addition, the implementation of these kinds of algorithms would require expertise at the plant level that was not generally available.

Another approach to the batch scheduling problem is to use simulation (e.g., Senior, 1995; Yang et al., 2007). Simulation software (e.g., ProModel) is used to simulate the process and to obtain various scheduling sequences. The best schedule is picked from among the feasible ones. However, there are several disadvantages using the simulation approach. First, simulation is extremely time-consuming. It takes weeks or even months to get familiar with the simulation program. Afterwards, it takes another several weeks to program and prepare the batch protocols in the program for simulation runs. In order to prepare a production sequences, it usually takes hours to simulate different scheduling sequences and to come up feasible schedules. Second, simulation only provides information of resource conflicts for different simulated sequences. Thus trial and
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