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Lot sizing problem on a paper machine under a cyclic production approach

Hanen Bouchriha*, Mustapha Ouhimmou, Sophie D'Amours

Network Organization Technology Research Centre (CENTOR) - FOR@C Research Consortium, Faculty of Science and Engineering, Université Laval, Quebec City, Canada G1K-7P4

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Abstract

In this paper, we address the problem of defining the production campaigns on a paper machine. Each campaign is of a fixed duration (cycle time) and produces batches (lot sizes) of all or a set of the products. This paper presents a real case study discussing a specific lot sizing problem where a predetermined production sequence must be maintained. We propose a new approach where we compute first the cycle time by assuming constant demand, and then lot sizes are determined for each product within each cycle in order to satisfy demand. Finally, studying the context of a Canadian paper maker, we evaluate the impact of planning production under a cycling manner.

Keywords: Capacitated lot sizing problem; Dynamic demand; Production cycle; Pulp and paper mill

1. Introduction

In a pulp and paper mill, the paper machine often represents the bottleneck resource and therefore requires an efficient production planning approach, optimizing resource utilization and minimizing setup and inventory costs. In this industry, production is often planned within campaigns of fixed duration, called the production cycle time in this paper. In these campaigns, production volumes (lot sizes) are planned to best meet forecasted or confirmed demand.

Furthermore, the paper producer generally aims to set the production sequence from lighter weight to heavier weight paper. To face this complexity, plant managers often fix a cycle time t in which the different papers are produced in a specific and stable order. Hence, one of the objectives of the current study is to evaluate the impact of considering fixed cycle time on production costs and planning.

The problem addressed in this paper is the production planning of n paper products on a capacitated paper machine within a horizon of T periods. For each period, capacity is limited and demand is deterministic (historic demand database). Demand must be satisfied without backlogs. The paper machine stops producing only for planned maintenance. This problem is known in the literature as a capacitated lot sizing problem with a particularity that the setup costs are sequence dependent and a predetermined production sequence must be maintained.

*Corresponding author.
E-mail address: hanen.bouchriha@yahoo.fr (H. Bouchriha).

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The aim of this contribution is to define the optimum cycle time and lot sizes to produce for each planning period minimizing the sum of the fixed setup costs, the variable production costs and the inventory costs for the entire planning horizon while respecting demand and capacity constraints for each period. Validation of the proposed methodology is pursued studying the case of a Canadian paper producer. Its historical delivery database serves as demand for the experimentation. The impact of planning under a cyclic approach is also addressed.

Let us proceed as follows. In Section 2, we first present the literature review related to the problem. Section 3 will then formally introduce the models describing the approach proposed to solve our real case problem. In the following section we give some experimental results obtained by testing our models on real data obtained from our partner so that we can evaluate their current practises. Section 5 provides concluding remarks.

2. Literature review

In the literature this multi-item, multi-period, dynamic demand and finite capacity problem is known as the capacitated lot sizing problem (CLSP). The CLSP has been extensively treated in the literature because of its complexity. However, few works consider lot sizing problem with sequence-dependent setup cost and time.

The following literature review section will be divided in two parts. First, we present works dealing with CLSP, and second we detail how authors model sequence-dependent setup time and cost in lot sizing problems.

2.1. CLSP problem

Florian et al. (1980) showed that in the case of only one product, the CLSP is NP hard. Trigeiro et al. (1989) proved that in the case of several products and when setup time are considered, even the feasibility of the problem is NP hard, that is, it is difficult to find a feasible solution. Moreover, if setup continues from one period to another (setup carryover) the problem becomes even more complex (Gopalakrishnan et al., 2001).

The most common methods used to solve CLSP are as follows:

2.1.1. Exact methods

Barany et al. (1984) and Eppen and Martin (1987) solved the problem by using mixed linear programming. However, mixed linear programs are not used to solve real size planning problems because their standard formulation requires very long resolution times. Eppen and Martin (1987) were able to solve problems of up to 200 products and 10 periods using a variable redefinition technique to reformulate the problem. Then the problem was modeled as a shortest-path problem (dynamic programming), and auxiliary variables were added to provide an integer programming formulation.

2.1.2. Heuristic methods

Because of the complexity of the problem, heuristics are the most common approaches. Mainly, two types of heuristics are used to solve this problem.

2.1.2.1. Mathematical programming-based heuristics. Lagrangian relaxation-based heuristics have been developed (Thizy and Wassenhove, 1985; Trigeiro et al., 1989; Lozano et al., 1991; Diaby et al., 1992; Anderson and Cheah, 1993), as well as branch and bound (Gelders et al., 1986) and column generation-based methods (Dzielinski and Gomory, 1965; Lasdon and Terjung, 1971; Salomon et al., 1993).

2.1.2.2. Rule-based heuristics. The majority of rule-based heuristics used the "period-by-period" approach. These heuristics can be found in Eisenhut (1975), Lambrecht and Vanderveken (1979), Dixon and Silver (1981), Dogramaci et al. (1981), Günther (1987), and Maes and Van Wassenhove (1988). These approaches define lot sizes by considering one period at a time in order to cover the entire planning horizon. The definition of batches is done by satisfying cost minimizing criteria. For a given period, the future demand of products is produced if there is enough capacity and just until it is no longer possible to achieve additional cost savings.

2.2. Lot sizing problem with sequence dependent set-up

If setup costs are sequence dependent, the calculation of setup costs requires the definition of the sequence under which products will be produced in all periods. This implies simultaneous sequencing and lot sizing. This problem is known as lot sizing