Computers & Industrial Engineering 61 (2011) 920–929

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

A two-stage heuristic for single machine capacitated lot-sizing and scheduling with sequence-dependent setup costs ☆

Ik-Soo Shim, Hyeok-Chol Kim, Hyoung-Ho Doh, Dong-Ho Lee *

Department of Industrial Engineering, Hanyang University, Seoul, Republic of Korea

ARTICLE INFO

Article history:
Received 21 July 2010
Received in revised form 16 February 2011
Accepted 2 June 2011
Available online 13 June 2011

Keywords:
Capacitated lot-sizing and scheduling
Sequence-dependent setup costs
Heuristics

ABSTRACT

This paper considers a single machine capacitated lot-sizing and scheduling problem. The problem is to determine the lot sizes and the sequence of lots while satisfying the demand requirements and the machine capacity in each period of a planning horizon. In particular, we consider sequence-dependent setup costs that depend on the type of the lot just completed and on the lot to be processed. The setup state preservation, i.e., the setup state at the end of a period is carried over to the next period, is also considered. The objective is to minimize the sum of setup and inventory holding costs over the planning horizon. Due to the complexity of the problem, we suggest a two-stage heuristic in which an initial solution is obtained and then it is improved using a backward and forward improvement method that incorporates various priority rules to select the items to be moved. Computational tests were done on randomly generated test instances and the results show that the two-stage heuristic outperforms the best existing algorithm significantly. Also, the heuristics with better priority rule combinations were used to solve case instances and much improvement is reported over the conventional method as well as the best existing algorithm.

1. Introduction

Lot-sizing and scheduling is to determine the lot sizes and the sequence of lots while satisfying the demand requirements over a planning horizon under certain objective functions. Many researchers and practitioners have been focusing on the problem due to its wide applications, especially to the process industry such as petroleum, steel, paper, and impacts on various system performances. However, most lot-sizing and scheduling problems are known to be very difficult to solve optimally due to their inherent combinatorial complexity.

According to Drexl and Kimms (1997), lot-sizing and scheduling problems can be classified into several types. The most representatives are: (a) discrete lot-sizing and scheduling problem (DLSP); (b) proportional lot-sizing and scheduling problem (PLSP); and (c) capacitated lot-sizing and scheduling problem (CLSP). First, the DLSP assumes that at most one item can be produced in each period, i.e., all-or-nothing. Therefore, the length of a period in DLSP is generally much smaller than those in PLSP and CLSP, i.e., macro periods are divided into micro periods. See Fleischmann (1990) for an exact branch and bound algorithm for the DLSP. Second, the PLSP is the problem under the assumption that at most one setup may occur in a period, and hence at most two items can be produced in a period. Finally, the CLSP is a general case that several items can be produced in a period, i.e., a large bucket problem. See Drexl and Kimms (1997), Karimi, Fatemi Ghomi, and Wilson (2003) and Quadt and Kuhn (2008) for relevant literatures on the CLSP and its extensions.

This study was originally motivated from a production planning problem occurred in a paper manufacturing system that produces various corrugated cardboards according to raw material types and production methods after collecting waste papers. Since the system is a type of the process industry, the entire system can be regarded as a single machine. Also, the setup costs are dependent on the sequence of lots. Based on these observations, we define the problem as the single machine capacitated lot-sizing and scheduling problem (CLSP) with sequence-dependent setup costs. After reviewing previous research on the problem, we find that the best existing heuristic can be improved with more sophisticated improvement methods.

The CLSP is the problem of determining the lot sizes and the sequence of lots while satisfying the demand requirements and the machine capacity in each period of a given planning horizon. In general, the CLSP is known to be NP-hard (Bitran & Yanasse, 1982; Florian, Lenstra, & Rinnooy Kan, 1980). Also, Maes, McClain, and van Wassenhove (1991) reported that even finding a feasible solution for the problem with setup times is NP-complete. As an extension of the ordinary problem, the sequence-dependent setup costs are additionally considered that depend on the type of the lot just completed and on the lot to be processed. Also, we consider the setup

☆ This manuscript was processed by Area Editor T.C. Edwin Cheng.

* Corresponding author. Tel.: +82 2 2220 0475; fax: +82 2 2297 0475.
E-mail address: leman@hanyang.ac.kr (D.-H. Lee).

0360-8352/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cie.2011.06.002

state preservation in which the setup state for the last item on some period (pre-period) is carried over to the first item of the next period. See Gopalakrishnan, Ding, Bourjolly, and Mohan (2001) for the reduction in total cost through the setup state preservation.

Various studies have been done on lot-sizing and scheduling with sequence-dependent setups. (See Zhu and Wilhelm (2006) and Jans and Degraeve (2008) for literature review on lot-sizing and scheduling with sequence-dependent setups). Dilts and Ramsing (1989) consider the uncapacitated lot-sizing and scheduling problem with sequence-dependent setup costs, and Dobson (1992) suggest a heuristic algorithm for the static lot-sizing problem with a constant demand per period and sequence-dependent setup costs/times. Fleischmann (1994) consider the DLSP with sequence-dependent setup costs in which at most one item can be produced in each period. Haase (1996) considers the CLSP with sequence-dependent setup costs on a single machine and suggested a heuristic while considering the setup state preservation, and showed that the heuristic outperforms the previous one of Fleischmann (1994). Later, Fleischmann and Meyr (1997) suggest a heuristic algorithm after dividing macro periods into micro periods for the CLSP with sequence-dependent setup costs, but it could not outperform the algorithm of Haase (1996). To cope with more complex system configurations, Kang, Kavindra, and Thomas (1999), Clark and Clark (2000), and Marinelli, Nenni, and Sforza (2007) considered parallel machines and Sikora (1996) and Sikora, Chhajed, and Shaw (1996) flow shops. Also, some articles consider the sequence-dependent setup times and costs. See Meyr (2000), Gupta and Magnusson (2005), Almada-Lobo, Klabjan, Carravilla, and Oliveira (2007), Kovacs, Brown, and Tarim (2009) and Almada-Lobo and James (2010) for examples.

As stated earlier, this study considers the single machine CLSP with sequence-dependent setup costs while preserving the setup state between two consecutive time periods. In fact, the problem considered here is the same as that of Haase (1996). To improve the best existing algorithm of Haase (1996), we suggest a two-stage heuristic in which an initial solution is obtained and then it is improved using a backward and forward improvement method with various priority rules to select the items to be moved among periods. Computational experiments were done on a number of test instances and the results are reported. In particular, the heuristics with better priority rule combinations were tested on the case data obtained from a paper manufacturing system and a significant amount of improvement is reported.

This paper is organized as follows. In the next section, the problem is briefly described. The two-stage heuristic is explained in Section 3, and the computational results are reported in Section 4. Finally, conclusions and further research directions are discussed in Section 5.

2. Problem description

The CLSP considered in this paper can be briefly explained as follows. For given demands over a planning horizon, the problem is to determine the lot sizes and the sequence of lots on a single machine for the objective of minimizing the sum of sequence-dependent setup and inventory holding costs. As stated earlier, we consider the setup stage preservation in which the setup states can be preserved between two consecutive periods. Other constraints are: (a) inventory balance constraints; and (b) capacity constraints; and (c) logical constraints, e.g., an item can be produced in a period only if the machine is setup for the item at the beginning of the period.

It is assumed that all problem data, such as demands, cost values, processing times, capacity, etc., are deterministic and given in advance. Besides this, other assumptions made are: (a) setup times are sequence-independent and hence can be added to the corresponding processing times; (b) inventory holding costs are computed based on the end-of-period inventory; and (c) backlogging is not allowed. In particular, we assume that setup times are sequence-independent due to the characteristic of the paper manufacturing system, i.e., setup times for the cleaning process are not highly dependent on the sequence of lots. Therefore, this study focuses on the CLSP with sequence-dependent setup costs. The mathematical formulation of the problem, adopted from Haase (1996), is given in Appendix A. For a clear description, see Haase (1996).

The optimal solutions can be obtained by solving the mixed integer programming model of Haase (1996) directly using a commercial software package. However, this is not practical due to prohibitive computational requirement. Recall that the CLSP without sequence-dependent setup costs has been proved to be NP-hard (Florian et al., 1980). Also, the sequencing problems with sequence-dependent setups are well-known to be NP-hard (Monma & Potts, 1989; Coleman, 1992).

3. Solution algorithm

In this section, we explain the two-stage heuristic in which an initial solution is obtained at the first stage and then it is improved using a backward and forward improvement method. Fig. 1 shows an overall description.

3.1. Preprocessing

Before presenting the algorithms, we explain the preprocessing step to modify the current demands if there is an initial inventory. In other words, the current demands must be modified before the algorithms are applied since the initial inventory can be used to satisfy the demands over some initial periods of the planning horizon. Let d_{it} denote demand of item i in period t, where $i = 1, 2, \ldots N$ and $t = 1, 2, \ldots T$.

The details of the preprocessing step (from the first to the last period) are given below. In the description, d'_{it} denotes the modified demand of item i in period t. (Initially, set $d'_{it} = d_{it}$ for all i and t).

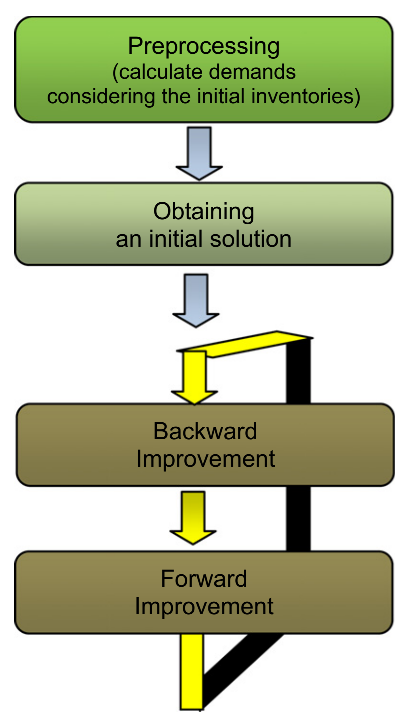

Fig. 1. Two-stage heuristic: overview.