Available online at www.sciencedirect.com
ScienceDirect
European Journal of Operational Research 187 (2008) 1171–1183
EUROPEAN JOURNAL OF OPERATIONAL RESEARCH
www.elsevier.com/locate/ejor

Single-job lot streaming in $m-1$ two-stage hybrid flowshops

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Received 27 December 2005; accepted 8 June 2006
Available online 3 November 2006

Abstract

This paper studies the single-job lot streaming problem in a two-stage hybrid flowshop that has m identical machines at the first stage and one machine at the second stage, to minimise the makespan. A setup time is considered before processing each sublot on a machine. For the problem with the number of sublots given, we prove that it is optimal to use a rotation method for allocating and sequencing the sublots on the machines. With such allocation and sequencing, the sublot sizes are then optimised using linear programming. We then consider the problem with equal sublot sizes and develop an efficient solution to determining the optimal number of sublots. Finally optimal and heuristic solution methods for the general problem are proposed and the worst-case performance of the equal-sublot solution is analysed. Computational results are also reported demonstrating the close-to-optimal performances of the heuristic methods in different problem settings.

Keywords: Scheduling; Hybrid flowshop; Setup times; Optimal solution; Heuristics

1. Introduction

Lot streaming is the process of splitting a production lot (a job) into sublots and scheduling those sublots as separate jobs in production. It combines lot sizing and scheduling decisions that were traditionally made separately. While it can shorten the production lead time, lot streaming also presents additional complexity.

In this paper, we consider the problem of lot streaming a single job in a two-stage hybrid flowshop (HFS) with m identical machines at the first stage and a single machine at the second stage. We call such a production system $m-1$ HFS. The total size of the job is U units, all available at time zero. The job can be split into sublots. It is not necessary for the sizes of the sublots to be equal or to be integers, but they must not be smaller than a lower bound, $x_0 \geqslant 0$. A sublot will be treated as an independent entity during the production in the system. Each sublot requires processing on any one of the machines at the first stage and then on the machine at the second stage. The processing times of a sublot at the two stages are proportional to the size of the sublot. The unit processing times on the stage-1 and stage-2 machines are $p^{(1)}$ and $p^{(2)}$, respectively. Each machine

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0377-2217/$ - see front matter
doi:10.1016/j.ejor.2006.06.066

can process at most one sublot at a time. Each sublot can be processed on at most one machine at any time. Before the processing of each sublot on a machine, a setup time is required for loading the sublot onto the machine. The setup times on the machines of stages 1 and 2 are $s^{(1)}$ and $s^{(2)}$, respectively, which are independent of the processing sequence and the sizes of the sublots. The problem is to determine the number and the sizes of the sublots and the schedule of processing them on the machines to minimise the makespan (the completion time of the entire job).

Lot streaming in HFS is very useful as many practical production systems can be considered as HFS. However, lot-streaming in HFS has received very limited research attention. Tsubone et al. (1996) studied the lot-streaming problem in a two-stage HFS with one machine in the first stage and several process lines in the second stage. They investigated the impact of lot size, sequencing rules and scheduling scenarios on production makespan, capacity utilization and work-in-process inventory, using simulation. Zhang et al. (2003) studied the integer version of the $m-1$ HFS lot streaming problem. They solved special cases of the equal-sublot version of the problem, in which one of the stages was obviously a bottleneck. The general problem was formulated as a mixed integer linear programming (MILP) model and solved using two heuristics. Both heuristics enumerated the number of sublots, and for each given number of sublots, allocated the sublots as evenly as possible to stage-1 machines. The sublot sizes were then determined by making them as equal as possible in one heuristic, and by using a smaller MILP model in the other. In this paper, we study the continuous version of the problem and provide efficient optimal solutions to both the problem with given number of sublots and all the cases of the equal-sublot problem. The continuous version does not restrict the sublot sizes to be integers. This is practical in situations where the product is of continuous type (e.g., those in process industries) and where an order consists of a large quantity of small items such as DVDs.

Most other previous work on lot streaming considers general flowshops with only one machine at each stage. Potts and Van Wassenhove (1992) presented a general model and reviewed algorithms and complexity for lot streaming problems as well as for integrated scheduling and batching problems in various machine shops including flowshop. An overview of basic models and algorithms for flowshop lot streaming problems was given by Trietsch and Baker (1993). Many studies restricted to one job (Baker and Pyke, 1990; Glass and Potts, 1998), flowshop with only two or three machines (Potts and Baker, 1989; Vickson and Alfredsson, 1992; Williams et al., 1997), or problem with both restrictions (Glass et al., 1994; Sen et al., 1998). In these studies, the number of sublots for a job was taken as a given parameter and setup times were not considered.

In the few studies that considered setup times (Cetinkaya, 1994; Baker, 1995; Vickson, 1995; Chen and Steiner, 1996, 1998), a setup time was assumed only at the beginning of each job as a whole. In some practical systems, however, a setup time is needed for each sublot. Take the wire-bonding process in integrated circuit (IC) packaging as an example. Each sublot of ICs on lead frames is held in a magazine. Before the machine starts processing a sublot, a setup time is required for properly loading the magazine onto the machine, no matter how many ICs it contains. Truscott (1985) allowed setup times for each sublot in his model. A heuristic algorithm was given to schedule the setup, processing and transport operations, considering equal sublot size for a given number of sublots. For a comprehensive survey of scheduling research with setup times or setup costs, please refer to Allahverdi et al. (in press).

The problem studied here includes the decision on the number of sublots and considers the setup times for each sublot. In the rest of this paper, we first focus on the problem with given number of sublots (Section 2). We use a rotation method for sublot allocation and sequencing and prove its optimality. A linear programming model is then presented to optimize sublot sizes. Section 3 gives very efficient solutions to the problem with equal sublots. Section 4 proposes optimal and heuristic solution methods for the general problem. The worst-case performance of the heuristic solutions is analysed. The heuristic methods are also tested computationally in different problem settings. Section 5 concludes the paper.

2. The problem with the number of sublots given

Given the number of sublots l, into which the job is to be split, we need to determine the allocation and sequencing of the sublots on the machines as well as the sizes of the sublots. To solve the problem efficiently, we first decide the sublot allocation and sequencing and then determine the sublot sizes.