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Simulation analysis of lot streaming in job shops with transportation queue disciplines

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ABSTRACT

In this paper we study a multi-product lot streaming problem in a stochastic job shop with equal and discrete sublots. The problem involves splitting order quantities of different products into different number of equal sublots (NES) and analyzing the effects of sublot-related transportation queue disciplines (TRQD) for different performance measures. Our simulation results show that some combination of TRQD and NES alternatives are appropriate for some performance measures. We also propose a simple heuristic to determine the NES of each product type to further improve the values of performance measures.

1. Introduction and background

The term "lot streaming" (LS) denotes techniques of splitting given jobs, each consisting of identical items, into sublots to allow their overlapping processing on successive machines in a multi-stage production system in order to improve the system performance [2,3]. The benefits of LS are reduction in makespan, average work-in-process inventory, space requirements and material handling capacity requirements [10]. Reiter [11] is the first researcher who used the LS concept to develop a planning system for the job shops to get smaller processing times for the lots. Also, the first linear programming model for the LS problems is developed by Trietsch and Baker [13].

Jobs are processed in different orders on workstations of conventional job shop systems. By optimizing the sequence of jobs on each machine, the system performance can be improved. If there are m workstations and n jobs, unfortunately there will be $(n!)^m$ sequencing alternatives. So it is hard enough to solve this type of problem within practical time limits. Traditional scheduling problems assume fixed lot sizes, however in LS problems in addition to sequencing problem sublot sizes are also decision variables. Moreover number of setups and inter stage trips may increase due to the increment in split lots [5] and this unavoidably causes job shops to get more crowded, and eventually increases the waiting times in queues. The setups on each machine can be reduced by giving priority to the parts of the same type. However, the number of trips and the waiting times of sublots in transporter queue unavoidably increase due to LS. Consequently TRQDs become important at this point. Nevertheless, by using appropriate queue disciplines, the performance measures may be improved.

We consider a multi-product, multi-stage LS problem in job shops with equal and discrete sublot sizes and transportation activities. Seven TRQDs are used to analyze the effects of queue disciplines on five different performance measures.

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In the following, we briefly summarize LS components related to our problem. For a comprehensive review about LS problems and a classification including all components such as number of machines, production type, sublot type, sublot size, idling/no-idling cases, intermingling/non-intermingling schedules, and setup/production/transportation operations with various objective functions, see Chang and Chiu [6]. They also point out future research directions for the LS studies.

Job shop scheduling problems are hard enough to solve even without LS. Since the problem size also expands as the sublot type changes from equal to consistent and consistent to variable, equal sublot type is assumed in this study.

In case of equal sublots, the sublot sizes are fixed for each product, as in Eq. (1):

$$s_{ijk} = s_i = q_i/n_i \qquad i = 1, \ldots, P \qquad j = 1, \ldots, n_i \qquad k = 1, \ldots, m, \tag{1}$$

where, i denotes products, j sublots and k machines. q_i and n_i represent the production lot size and the number of sublots for product i, respectively.

The divisibility of the sublots in our problem is selected to be discrete, i.e., the sublot size is integer. In addition, sublot availability, i.e., a sublot can be transferred to the next machine if and only if the whole sublot is completed on the current machine, is considered. The last component is the idling case. The idling case allows idle times between sublots on the same stage.

A number of studies deal with LS problems in job shops. However, none of these studies considers the effects of TRQDs on performance measures. There are two stochastic [8,12] and four deterministic studies [4,5,7,9] related to LS problems in job shops.

Jacobs and Bragg [8] study the equal sized sublots for a 10-product, 10-machine stochastic job shop LS problem and use the term 'repetitive lots' instead of LS. Their problem also includes the queuing disciplines and aims to minimize the flow time. They use simulation to compare the results of repetitive lots, queue disciplines and traditional methods. However, they did not try to optimize the equal sublot sizes; they just investigated the benefits of LS in job shops.

Another study that investigates the effects of LS is by Smunt et al. [12]. They consider LS problems in stochastic flowshops and job shops. The performance measures, i.e., the mean flow time and the standard deviation of flow time, are evaluated by applying various LS policies. They use simulation to obtain the results for different levels of setup and processing time variability, processing utilization and job size.

Jeong et al. [9] study a deterministic LS problem in job shops and consider the before-arrival family setups and the sublot sizes. They define four sublot types: minimum batch size, required batch size, full batch size, and equal batch size. First, they try to find the sublot sizes, and then improve the schedule by using simple splitting and forward interchange methods.

Dauzere-Peres and Laserre [7] study another deterministic LS problem in job shops. They propose an iterative procedure which first solves the LS problem with fixed number of consistent sublots and then schedules these sublots on the machines. The procedure ends when predetermined number of iterations reached. They obtain discrete sublot sizes by rounding up the continuous sublot sizes. They compare their results with the lower bounds.

Two very recent studies are by Chan et al. [4,5]. In [4] they combine LS and assembly job shop scheduling problem for the first time. They extend LS applicability to both machining and assembly. They propose an efficient algorithm using genetic algorithms and simple dispatching rules. Their experiment results suggest that MST (Min Slack Time) decision rule with equal sublots surpasses variable sublots in terms of two performance measures, i.e. the minimum cost obtained in most of the test problems, and the average cost obtained over all test problems. However, their model considers only the lateness and inventory penalties that may not be practical enough to simulate the real manufacturing shop floor. In [5] they propose a new approach using genetic algorithms to determine LS conditions in a job shop scheduling problem. They solve two subproblems simultaneously. The first problem is the LS problem and the second one is the job shop scheduling problem which is handled after the LS conditions have been determined. They apply their approach to a number of test problems and their results show that their proposed model works well with different objective measures and good solutions can be obtained with reasonable computational effort.

In the next section we define our problem and present a simulation study to analyze the effects of different TRQD on LS problems in stochastic job shops. Section 3 discusses computational results. Then we propose a simple search procedure to improve the performance measures. Finally our conclusions and further research directions are outlined.

2. Problem definition

In this paper we study a similar problem described in [8]. There are 10 different machines and 10 different product types in the job shop environment. Each product's weekly demand is randomly generated from a uniform distribution. The routes of the products on the machines are assigned randomly. The number of operations, machine assignments, setup, load–unload, trip and processing times are determined for the products.

The average number of operations is five per product with a range of four to six operations. The machine assignments approximate a random-routed job shop with all machines equally likely being assigned as the first, last or any operation on the routing. Each machine is assigned exactly five operations, with no machine assigned twice on any product's routing.

All sublots waiting for processing at a machine are ranked by first-in-first-out (FIFO) rule. However, in order to reduce the number of setups, the sublots of the same product type are processed one after the other on a machine, if any sublot of the same type is present in that machine's queue.