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Real-time order flowtime estimation methods for two-stage hybrid flowshops

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ABSTRACT

In this study, we consider a problem of estimating order flowtimes in two-stage hybrid flowshops, where orders arrive dynamically and various scheduling schemes can be used. To solve the problem, we devise several order flowtime estimation methods, and each method is specific to the scheduling scheme used in the shop. Whenever an order arrives, the flowtime of the order is estimated by using one of the proposed methods. In the methods, we consider not only the current workload but also the expected workload in the near future, the volume of which mainly depends on the scheduling scheme. To evaluate the performance of the proposed methods, we obtained the actual flowtimes of orders from simulation runs, and compared them with the estimated flowtimes of the orders. The results of a series of computational experiments show the superior performance of the proposed methods over the several existing methods.

1. Introduction

As customer satisfaction becomes one of the most prominent goals of many companies, the problems inherent to order promising or available-to-promise (ATP) are becoming increasingly more important. In particular, if a company produces make-to-order products, delivering orders on time is regarded as an essential capability that the company must possess. However, on-time delivery is difficult to achieve in today's dynamic business environment. Even if two orders have the same number of products with the same type and due-date, the flowtimes of these orders can vary because of different inventory status, scheduling schemes, and so on. In this paper, we propose real-time methods for estimating order flowtimes in hybrid flowshops, where orders arrive dynamically and the various scheduling rules can be used. Here, the *flowtime* of an order is the time interval between the arrival and the completion of the order; this interval is also called the *flow allowance* in many due-date assignment studies.

Order flowtime estimation, order promising, ATP, and due-date assignment have been popular issues that many researchers have been focusing on. Several survey studies have already been conducted in this regard. Recently, Framinan and Leisten [1] classified the order promising approach into six categories, according to the combinations of integration of its three constituent decisions: i.e., order selection, due-date assignment, and order scheduling. Keskinocak and Tayur [2] thoroughly summarized several topics relevant to due-date management: e.g., scheduling policies, off-line vs. on-line models, service constraints, and so on. Kaminsky and Hochbaum [3] primarily reviewed analytical approaches including queuing models, which are largely limited to simple models such as static, common due-dates, and single or parallel machine shops. For earlier reviews on the related fields, we refer to Gordon et al. [4] and Cheng and Gupta [5].

Although a significant number of existing studies on order promising problems exists, several practical limitations remain in those studies. First, many studies consider a very simple machine system. Particularly in cases of analytical approaches, most of them consider only a single machine model. Second, many existing studies ignore the dynamic characteristics of order arrivals, and they assume that the jobs to be produced are given. However, in practice, it is common that orders arrive in the system dynamically. Third, in previous studies, the scheduling schemes of the systems have mostly been a naive dispatching rule, e.g., FIFO (First In First Out), and this is especially common if the system involves complex processes. In this study, these limitations are overcome toward a more practical flowtime estimation.

Note that, in this study, we focus on estimating the flowtimes of orders. Many previous studies on due-date assignment or order promising problems consider the estimation of flowtimes as a pre-step to assign or quote due-dates. Basically, they consider total work (TWK), jobs in queue (JIQ), or jobs in bottleneck (JIBQ)

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for estimating flowtimes or flow allowances [5]. While TWK only considers the workload of a job itself, the inventory workload is taken into account in JIQ and JIBQ. Unlike these methods, Lawrence [6] estimates the flowtime of an order using the actual flowtimes of the latest completed orders. Recently, the same decision problem was addressed by Lee [7], whose proposed methods were devised for long hybrid flowshops and were mainly focused on the inventory workload at the bottleneck stage. In the later section, these methods are compared with the proposed methods.

The contribution of this study is that we develop methods which can estimate the flowtimes of orders more accurately than the existing methods under practical environments. Furthermore, four dispatching rules are incorporated in the proposed methods, which, to the best of our knowledge, is the largest number of scheduling schemes considered in this field. The rest of this paper is structured as follows: Section 2 presents a detailed description of the considered problem. In Section 3, the proposed methods are introduced. Using the proposed methods, we conducted a series of computational experiments, the results of which are presented in Section 4. Finally, we conclude the paper with some discussions and the future directions for this study.

2. Problem description

In this study, we consider two-stage hybrid flowshops with dynamic order arrival. The hybrid flowshop consists of two stages that are connected serially and each stage has its own operation for each product type. Each operation can be handled by one of the parallel machines at the stage. A product is completed after processed at stages 1 and 2 sequentially. In this study, we assume that parallel machines in the same stage have the same capabilities; hence, each stage can be referred to as an identical parallel machine system. Although the two-stage is the simplest layout of hybrid flowshops, the scheduling problem of the two-stage hybrid flowshop is well known to be NP-complete [8]. Due to its difficulty, in the earlier studies on this area, case-oriented studies were mainly performed, such as Tsubone et al. [9] and Kim et al. [10]. Nevertheless, two-stage hybrid flowshops have received much attention because of their applications, which can be easily noticed in recent survey papers [11,12]. Even very recent studies on hybrid flowshop scheduling problems continue to consider two-stage layouts [13–15].

In the considered shop, orders arrive dynamically, which means we have no information about a certain order prior to its arrival. When orders arrive, they contain information regarding which and how many products should be produced until what time. Once an order arrives in the system, it is released as multiple lots into the first stage. In this study, a lot is regarded as the minimum production unit so that the processing time of one lot of each product type is provided. The released lots immediately become part of the inventory at stage 1, if no machine is available. All the waiting lots at each stage are sequenced according to a pre-specified dispatching rule. In this study, we could use several different dispatching rules; however, only one rule is selected and used at both stages during the single production run. We assume that a lot cannot be interrupted by another lot, once a machine starts processing it; the inventory buffer size in front of the machines at each stage is infinite; and no machine failures occur.

In this study, we estimate the flowtime of each order at the time the order arrives. We anticipate how the order will flow through the two-stage hybrid flowshop using the proposed estimation methods, in which the current workload, future orders, and the dispatching rule used in the system are mainly considered.

3. Proposed methods

In the considered system, not only FIFO but also EDD (Earliest Due-Date), SLACK, and SPT (Shortest Processing Time) can be used as the scheduling scheme; hence, an appropriate flowtime estimation method for each scheduling scheme is necessary. In this study, we devise different flowtime estimation methods for different scheduling schemes. However, they analyze the flowtime of an order in the same manner. Fig. 1 shows the schematic breakdown of an order flowtime. The flowtime can be decomposed into two parts: flowtimes caused by processing the order itself, and workloads with higher priorities than that of the order. Workloads with higher priorities could come from the current inventory and from future orders, and those workloads should be processed prior to the order just arrived. The proposed estimation methods use different logics in obtaining the flowtimes caused by processing these workloads with higher priorities, depending on which dispatching rule is used in the shop.

In the proposed methods, we employ list scheduling procedures to achieve more accurate estimation results. In each method, we select the stage with the higher inventory level as the target stage to which a list scheduling procedure is applied in order to construct a virtual schedule. Applying a list scheduling procedure to a stage is similar to solving a parallel machine scheduling problem using a dispatching rule, which can be done in a very short time.

3.1. Notation and formula

We devise equations to obtain the flowtimes of orders in the proposed methods. The notations used in the flowtime estimation formula are as follows:

i	index of order
k	index of stage
δ	index of dispatching rule
a_{ik}	arrival time point of order i at stage k in the shop
p_{ik}	processing time of a lot from order i at stage k
Λ_{ik}	set of orders waiting at stage k when order i arrives in the shop
$LS_k^\delta(\Omega)$	function that returns the completion time of the virtual schedule which is constructed by list scheduling on order set Ω at stage k under dispatching rule δ
w_{ik}^δ	partial flowtime of order i through stage k incurred by the current workload under rule δ, which can be obtained by $LS_1^\delta(\{i\}\cap\Lambda_{i1})-a_{i1}$, if $k=1$; $LS_2^\delta(\{i\}\cap\Lambda_{i1}\cap\Lambda_{i2})-a_{i1}$, o/w
$\hat{f}_{ik}^\delta$	estimated partial flowtime of order i through stage k expected to be incurred by future orders under dispatching rule δ
$\hat{r}_{i2}^\delta$	estimated ready time point of order i at stage 2 under dispatching rule δ

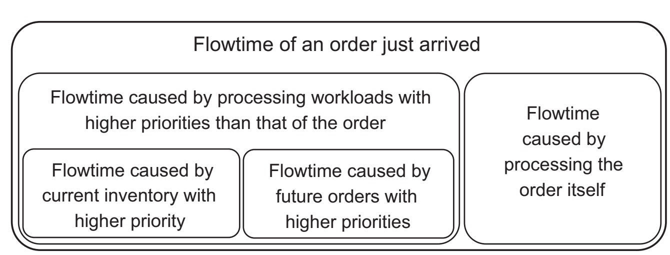

Fig. 1. Schematic breakdown of an order flowtime.