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Operation-based flowtime estimation in a dynamic job shop☆

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Abstract

In the scheduling literature, estimation of job flowtimes has been an important issue since the late 1960s. The previous studies focus on the problem in the context of due date assignment and develop methods using aggregate information in the estimation process. In this study, we propose a new flowtime estimation method that utilizes the detailed job, shop and route information for operations of jobs as well as the machine imbalance information. This type of information is now available in computer-integrated manufacturing systems. The performance of the proposed method is measured by computer simulation under various experimental conditions. It is compared with the existing flowtime estimation methods for a wide variety of performance measures. The results indicate that the proposed method outperforms all the other flowtime estimation methods. Moreover, it is quite robust to changing shop conditions (i.e., machine breakdowns, arrival rate and processing time variations, etc.). A comprehensive bibliography is also provided in the paper.

Keywords: Flowtime estimation; Due date assignment; Simulation; Scheduling

1. Introduction

In the job shop scheduling literature, estimation of job flowtimes has always been an important issue since the late 1960s. Because the flowtime estimation is used to assign order due dates, the problem has been mostly studied within the context of due date assignment. In several previous studies [1,2], the term due date assignment has been often used to describe the problem. However, beyond the objective of due date setting, accurate flowtime estimates are also needed for better management of the shop floor control activities, such as order review/release, evaluation of the shop performance, identification of jobs that requires expediting, lead-time comparisons, etc. All these application areas make the problem as important as other shop floor control activities (i.e., scheduling).

The research problem studied in this paper is the estimation of the jobs' time spent in the system from their arrival until the completion of all processing activities. The difficulty of the problem stems from the dynamic and stochastic nature of the job shop environments (i.e., arrival of hot jobs, sudden machine breakdowns and variations in machining conditions, etc.) that precludes accurate predictions.

The existing studies in the literature examine the problem by identifying the key information sources required in flowtime estimation. The results indicate that job- and shop-related information are the key elements in the estimation process. Researchers (e.g. [3]) used these information sources in aggregate terms by ignoring the benefits of using more detailed shop and route congestion information in the flowtime estimation. Other important findings which motivated our study to develop a new flowtime estimation method are as follows.

First, previous studies indicate that total load on the route of an arriving job provides valuable information in flowtime estimation [3–7]. We also expect that the distribution of the work load on the machines is as important as the total load itself. The load information of the machines nearer

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to the beginning of the route of the job would affect the flowtime of that job more than the load of the machine closer to the end of its route, because the system state can be considerably different when the job arrives at these machines for its later operations. Thus, splitting the route information in terms of operations of the job can improve the quality of the flowtime estimation. Second, previous research also indicate that consideration of total load of the jobs elsewhere in the shop (i.e. the jobs which are not currently at the machines on the route of the arriving job, but will visit them later for processing) is also important [8]. This is because these jobs will eventually bring additional workloads to the route of the arriving job. Hence, both timing and distribution of these so called "other jobs" should also be taken into account in the estimation process.

Third, as shown by several researchers, dispatching rules affect the performance of the flowtime estimation methods [3,9–14]. For example, Ragatz and Mabert [3] use different flowtime estimation models for different dispatching rules. Finally, it is observed that the performance of the flowtime estimation methods are significantly affected by the load balance in the shop (e.g., [5]).

In this study, we develop a new method by using these four observations outlined above. Specifically, the proposed method estimates flowtimes by employing the detailed job, shop and route information for each operation of a job as well as considering the machine imbalance and dispatching rule information. Results indicate that it is quite effective in using these information sources to achieve better system performance.

The rest of this paper is organized as follows. In Section 2, we present a literature survey. In Section 3, basic structure and characteristics of the proposed method are described. The key components of the model are also discussed using an illustrative example. In Section 4, we define the experimental design and give the details of the simulation model. Computational requirements of the proposed study are discussed in Section 5. Results of the simulation experiments and statistical tests are presented in Section 6. Finally, the concluding remarks are made and further research directions are outlined in Section 7.

2. Review of the literature

Due date assignment is one of the main application areas of flowtime estimation. As it is frequently observed in the literature, most research efforts directed towards flowtime estimation are within the context of due date assignment [4,12,15]. Hence, we will also review the due date assignment literature to the extent that it deals with flowtime estimation in production systems.

There are basically two flowtime estimation approaches in the literature: analytical approach and simulation approach. Cheng and Gupta [10] present an extensive survey of both of these approaches for the due date assignment problem. They also provide a framework for the scheduling problems in the due date assignment process. There are advantages and disadvantages associated with each approach. The analytical approach offers an exact way of determining mean and variances of flow time estimates. However, the dynamic and stochastic nature of production systems makes it difficult to develop realistic analytical models. On the other hand, simulation approach does not always produce reliable estimates. Moreover, a great number of computer runs may also be needed in the latter case to obtain the accurate and precise estimates. Since these two areas are complimentary in nature, the literature has been developed in both directions. Our primary focus in this paper is on the simulation methodology. Thus, we next discuss the simulation related research in detail. For the analytical studies, the reader can refer to the following research papers: Miyazaki [14], Enns [13,16,17] Cheng [18,19], Shanthikumar and Buzacott [20], Buzacott and Shanthikumar [21], Shanthikumar and Sumita [22], and Lawrence [23]. The recent trend in analytical studies is to determine flowtime prediction errors and distribution functions so that leadtime estimates can be derived (Enns [24] and Lawrence [23]).

The first simulation-based study in this area is conducted by Conway [11] who compares four flowtime estimation methods: total work content (TWK), number of operations (NOP), constant (CON), random (RDM). The results of this study indicate that the methods which utilize the job information perform better than the others. Conway also observes the relationship between due date assignment methods and dispatching rules. Later, Eilon and Chowdhury [4] use shop congestion information in estimating flowtimes. In this work, TWK is compared with three other methods: jobs in queue (JIQ), delay in queue (DIQ) and modified total work content (MTWK). Results indicate that JIQ, which employs the shop congestion information, outperforms other methods.

In another study, Weeks [25] proposes a method which combines both the job and shop information. This method performs very well for the performance metrics such as mean lateness, mean earliness, and number of tardy jobs. The results also indicate that flowtime estimation is affected by the structural complexity of the shop more than the size of the system. Later, Bertrand [5] proposes a new method of flowtime estimation which exploits time-phased workload information of the shop. Two factors are used in analyzing the performance of the method: minimum allowance for waiting (SL) and capacity loading limit (CLL). His results indicate that time-phased workload and capacity information significantly decrease variance of the lateness.

Ragatz and Mabert [3] compare eight different methods: TWK, NOP, TWK-NOP, JIQ, WIQ (similar to JIQ except that the total processing times of jobs on the route is used instead of the number of them), WEEK's method, JIS (similar to JIQ except that the number of jobs at the system is used instead of the number of jobs on the route), and response mapping rule (RMR). Among them, RMR utilizes