Journal of Manufacturing Systems 30 (2011) 28–40

Contents lists available at ScienceDirect

Journal of Manufacturing Systems

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

Technical paper

Analysis of dynamic due-date assignment models in a flexible manufacturing system

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ARTICLE INFO

Article history:
Received 5 August 2010
Received in revised form 9 January 2011
Accepted 22 February 2011
Available online 14 April 2011

Keywords:
Flexible manufacturing system
Due-date assignment models
Routing flexibility
Sequencing flexibility
Part sequencing rules
Simulation
Metamodels

ABSTRACT

This paper investigates the effects of dynamic due-date assignment models (DDDAMs), routing flexibility levels (RFLs), sequencing flexibility levels (SFLs) and part sequencing rules (PSRs) on the performance of a flexible manufacturing system (FMS) for the situation wherein part types to be produced in the system arrive continuously in a random manner. The existing DDDAMs considered are dynamic processing plus waiting time and dynamic total work content. A new model known as dynamically estimated flow allowance (DEFA) has also been developed and investigated. The routing flexibility of the system and the sequencing flexibility of parts are both set at three levels. A discrete-event simulation model of the FMS is used as a test-bed for experimentation. The performance measures evaluated are mean flow time, mean tardiness, percentage of tardy parts and mean flow allowance. The statistical analysis of the simulation results reveals that there are significant interactions among DDDAMs, RFLs, SFLs and PSRs for all the performance measures. The proposed DEFA model provides the minimum percentage of tardy parts in all the experiments. Regression-based metamodels have been developed using the simulation results. The metamodels are found to provide a good prediction of the performance of the FMS within the domain of their definition.

1. Introduction

With the globalization of manufacturing, there has been a renewed interest in the competitiveness of the manufacturing sector throughout the world. There is an increasing trend towards higher product variety, smaller lot sizes and shorter lead times in the market place. In this environment, manufacturing companies are forced to implement systems that can provide flexibility and efficiency [1]. Emergence of flexible manufacturing systems is an important development in this direction. MacCarthy and Liu [2] state that a flexible manufacturing system (FMS) is a production system in which groups of numerically controlled or computer numerically controlled machine tools and an automated Material Handling System (MHS) work together under computer control. Stecke [3] identifies four hierarchical levels of decision problems in FMSs, i.e. design, planning, scheduling and control. Scheduling decision problems of FMSs continue to attract the interest of both the academic and industrial sectors [4]. This can be attributed to the fact that these problems have fundamental implications on the overall performance of the system. Proper scheduling procedures are essential for the efficient utilization of the expensive resources in FMSs such as machines and MHS and for improving the responsiveness of the system in meeting the changing customer needs. Smith [5] and Lee et al. [6] provide a review of simulation-based research on manufacturing system design and operation problems. Hwang and Kim [7], Merchawi and ElMaraghy [8], Son et al. [9], Sinreich and Shnits [10], and Um et al. [11] adopt simulation for scheduling FMSs.

Flexibility is defined as the ability of a system to respond effectively to changes in volume requirements, product-mix requirements, machine status and processing capabilities. The flexibility of an FMS is dependent upon its components, capabilities, interconnections and mode of operation and control. Browne et al. [12] describe eight types of flexibility as follows: machine flexibility, process flexibility, product flexibility, routing flexibility, volume flexibility, expansion flexibility, operation flexibility and production flexibility. Sethi and Sethi [13] and Vokurka and O'Leary-Kelly [14] provide additional types of flexibility. Routing flexibility can be regarded as the main contributor to the flexibility of an FMS. It is the ability of a system to provide multiple alternate routes to produce a set of parts economically and efficiently. Sequencing flexibility exists when alternate feasible sequences can be used to process the operations of a part.

Due-date is the date by which an order or a part is required to be delivered to the customer. Due-dates can be set either exter-

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0278-6125/$ – see front matter
doi:10.1016/j.jmsy.2011.02.005

nally by the customer or internally by the scheduling system. When due-dates are externally set, the scheduling system is charged with appropriate prioritization and synchronization to provide timely flow of operations. Internally set due-dates usually reflect current system congestion levels, manufacturing system capacity and work content of parts. In either case, tight due-dates and on-time completion of parts are challenges to the scheduler. This can be met through better scheduling and due-date management at the operational level [15,16]. Due-date performance can be assessed using measures such as mean tardiness and percentage of tardy parts.

Due-date assignment process consists of making an estimate of flow time for a part and then setting the due-date on the basis of this estimate. In this research study, due-date assignment is done using the proposed model known as dynamically estimated flow allowance (DEFA) and two existing dynamic assignment models such as dynamic processing plus waiting time (DPPW) and dynamic total work content (DTWK). The objective of this research is to investigate the effects of dynamic due-date assignment models (DDDAMs), routing flexibility levels (RFLs), sequencing flexibility levels (SFLs) and part sequencing rules (PSRs) on the performance of an FMS for the situation wherein part types to be produced in the system arrive continuously in a random manner. Simulation experiments are conducted for two Cases. The simulation results for Case 1 (Base Case) are analyzed to determine the effect of DDDAMs, RFLs, SFLs and PSRs on the system performance. Based on the analysis of results for Case 2, regression-based metamodels are developed and validated. Metamodels are supplementary models used to predict the performance of the FMS within the range of the experimental factors. To the best of our knowledge, this is the first study on FMS scheduling with DDDAMs. The analysis of the performance of an FMS under different DDDAMs, RFLs, and SFLs together with the scheduling policies is a significant contribution of the research work presented in this paper.

The rest of the paper is organized as follows. Section 2 deals with the review of the relevant literature. Section 3 provides the salient aspects of the development of the simulation model. This section includes the modelling aspects of the DDDAMs, routing flexibility and sequencing flexibility. Section 4 describes the details of the simulation experiments. Section 5 provides the analysis of the simulation results. Section 6 presents conclusions.

2. Literature review

Early research studies in the area of due-date assignment in dynamic job shops have focused on static due-date setting methods based on number of operations in a job, constant allowance, allowance proportional to total work content (TWK), total work content plus a constant slack [17,18]. Ragatz and Mabert [19] provide a conceptual model of due-date management in job shops. Recent research concentrates on determining due-dates based on dynamically changing shop conditions. DDDAMs consider shop status in terms of congestion of machines to establish flow allowances to arriving jobs. Vig and Dooley [20] use multiple regression analysis to estimate the job flow time on various job, shop and job's route information. Using a simulation study, Chang [21] presents a method to identify factors that have significant effects on completion times of jobs in a job shop. Enns [22] proposes a forecasting model for flow time estimation using dynamic shop load information. Cheng and Jiang [23] propose a dynamic total work content method to provide a more accurate estimation of job flow time. The due-date allowance factor is determined on the basis of the feedback information about the job shop status at the time a job arrives at the shop.

In order to improve the performance of the TWK method, Sha and Liu [24] present a model that incorporates a data mining tool for mining the knowledge of job scheduling in a dynamic job shop. Ozturk et al. [25] use data mining approach for lead time estimation in make-to-order manufacturing. Alpay and Yuzugullu [26] propose a regression-based DDDAM using job-related and shop-related factors in a dynamic job shop. Sha and Hsu [27] develop an artificial neural network-based DDDAM combined with simulation and statistical analysis for due-date assignment in wafer fabrication. Baykasoğlu et al. [28] propose two approaches for due-date assignment in a job shop environment. The approaches are based on smoothing methods for estimating waiting times of jobs at machines. Kuo et al. [29] adopt theory of constraints approach for due-date assignment in a wafer fabrication factory.

In the literature on FMS, researchers have used TWK method for due-date assignment [30–33]. In TWK method, due-dates of parts are assigned according to their total amount of work. The same degree of flow allowance is given to all parts with the allowance being proportional to the total amount of work. Thus, TWK method is a static method that does not take current system status data into consideration when assigning due-dates. Hence, there is a need for research focused on the analysis of dynamic due-date assignment methods on FMS performance. The present paper deals with a simulation-based experimental study in this direction.

3. Development of simulation model

A discrete-event simulation model has been developed to investigate the effects of DDDAMs under different RFLs, SFLs and PSRs on the performance of the chosen FMS. The various aspects involved in the development of the simulation model are described as follows.

3.1. Physical configuration

A typical FMS is considered for investigation in the present study. The FMS consists of six different (non-identical) machines with local input and output buffers, two automatic guided vehicles (AGVs) as the MHS for part transportation and a load/unload station as shown in Fig. 1.

3.2. Part data

The FMS processes ten different part types. Orders for part types to be produced arrive at the system randomly. The interarrival time of orders follows an exponential distribution with a mean of 14 min. An order for production can belong to any one of the ten part types with the same likelihood. Each part type requires a set of operations to be performed. The number of operations for a part type is uniformly distributed between 4 and 6. The system is capable of performing 15 types of operations. The operation types are numbered O_1, O_2, ..., O_{15}. For a part type, the operation type of an operation is uniformly distributed between 1 and 15. For example, the following is the data generated for part type 1: number of operations: 5; operation types: O_8–O_{10}–O_1–O_7–O_{11}. The processing time of an operation on the primary machine is uniformly distributed between 10 and 20 min.

3.3. Modelling routing flexibility

The machines in the system perform fifteen different operations. An operation can be performed on alternative machines depending upon the level of routing flexibility present in the system. The routing flexibility levels (RFLs) have been modelled as a variable. RFL = 0 (denoted as RFL0 in the present study) means that there is exactly one machine known as primary machine available in the system for processing an operation on a part. That is, there are no alternatives. RFL = 1 (denoted as RFL1) implies that for each operation, there