Computers & Industrial Engineering 56 (2009) 1223–1231

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

Criteria selection and analysis for single machine dynamic on-line scheduling with multiple objectives and sequence-dependent setups

Adeline T.H. Ang [a,*], Appa Iyer Sivakumar [a], Chao Qi [b]

[a] Systems and Engineering Management Division, School of Mechanical and Production Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore
[b] Singapore-MIT Alliance, Nanyang Technological University, N3.2-01-36, 65 Nanyang Drive, Singapore 637460, Singapore

ARTICLE INFO

Article history:
Received 13 November 2007
Received in revised form 24 June 2008
Accepted 14 July 2008
Available online 31 July 2008

Keywords:
Dynamic scheduling
Multiobjectives
Sequence-dependent setup
Single machine

ABSTRACT

Fertile opportunities exist for research involving dynamic and stochastic scheduling with multiple conflicting objectives and sequence-dependent setups as little has been reported in the literature to date. This research focuses on understanding and identifying the criteria that could be combined into a single rule using the linear weighted aggregation approach to consider the contradicting needs of cycle time and delivery accuracy. Eight dispatching criteria are compared and evaluated using discrete event simulation. In most studies, the basic concept is to combine different dispatching criterion that performs the best in each objective into a single rule but this may be insufficient. Simulation results show that it is necessary to take into account not only the criterion's strength in optimizing a performance objective but also the degree of trade-off it has on the other conflicting performance objectives of interest. A correlation analysis of the objectives used is also presented.

1. Introduction

In a continually evolving, market driven, and competitive environment, semiconductor manufacturers are placing more emphasis on market responsiveness to outdo competitors by reducing cycle time and improving delivery accuracy, while narrowing the cycle time and delivery accuracy distribution to achieve greater repeatability. Effective production planning and scheduling is one of the key aspects to achieving a predictable and repeatable manufacturing performance.

Semiconductor manufacturing is probably one of the most complex systems in terms of equipment, manufacturing routes, and system dependency, and this poses great challenges for production planning and scheduling, as reported in Sivakumar (2001). Review papers by Allahverdi, Gupta, and Aldowaisan (1999), Yang and Liao (1999), and Zhu and Wilhelm (2006) have also shown that few papers have considered the combined aspects of scheduling (i) of a stochastic nature, (ii) with sequence-dependent setups, and (iii) multiobjectives. Sequence-Dependent Setup (SDS) times imply that the setup times depend on both the part that has been processed and the next part to be processed (Gupta, 1982).

Stochastic scheduling problems involving SDS are strongly nondeterministic polynomial-time hard (NP-hard) (Baker, 1974). As such, heuristics via a linear combination of criteria with relative weights are used to address the multiobjective aspect of this study. Although it is theoretically possible to consider as many criteria in a combined, weighted manner, it is not computationally practical to search for a large set of optimized or desired weights for on-line applications that require decisions to be made with near-real-time responsiveness. Hence, in most studies, the basic concept is to identify and combine the least number of different dispatching criteria that each has different strength in addressing the objective(s) of interest, such as the Shortest Processing Time (SPT) dispatching criterion with good cycle time performance, and Critical Ratio (CR) dispatching criterion with good on-time delivery performance, into a single rule.

Scheduling problems involving SDS and multiobjectives are still not well understood in terms of how commonly used setup conscious rules and conventional dispatching rules perform, before and after they are combined, and how the selection of a criterion that is aimed at optimizing a specific performance objective will affect the overall performance of the weighted rule. Hence, this study will evaluate and analyze the performances of eight commonly used dispatching criteria individually, then select the prospective criteria and study them in a combined form (using weighted aggregation) using a dynamic and stochastic serial (i.e. single lot processing) ion implanter machine with SDS.

The main objective is to identify the criterion to be combined to consider the contradicting needs of cycle time (i.e. average cycle time, *avgCT*, and standard deviation of cycle time, *sdCT*) and deliv-

* Corresponding author. Tel.: +65 91507881.
E-mail addresses: adelath@pmail.ntu.edu.sg (A.T.H. Ang), msiva@ntu.edu.sg (A.I. Sivakumar), qichao@ntu.edu.sg (C. Qi).

0360-8352/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cie.2008.07.018

ery accuracy (i.e. average tardiness, *avgTARD*, and standard deviation of tardiness, *sdTARD*). In the process of doing so, this study will also highlight the importance of taking into account not only the criterion/rule's strength, but also its trade-off (i.e. degree at which a criterion optimizes a performance objective at the expense of other performance objectives) in the rule selection.

The remainder of this paper is organized as follows. Related works are briefly reviewed in the next section. Single criterion dispatching rules are evaluated and analyzed following the problem formulation in Section 3. The prospective criteria are combined and analyzed in Section 4. Lastly, Section 5 summarizes the key findings of this paper and discusses future research directions.

2. Related works

Dynamic scheduling is often known as on-line or real-time scheduling (Sabuncuoglu & Karabuk, 1999). Dynamic scheduling strategies do not create schedules. Instead, decentralized production control methods dispatch jobs when necessary and uses dispatching rules or other heuristics to sort or prioritize jobs waiting for processing at a machine based on information available at each decision points (Vieira, Herrmann, & Lin, 2003).

The study of Sequence-Dependent Setup (SDS) times is relevant to virtually all machine configurations (e.g. single machine, parallel machine, flow shop, and job shop) and numerous industrial applications (e.g. metal casting (Yuan, Khoo, Spedding, Bainbridge, & Taplin, 2004), Textiles/Garment Maker (Joines, Sutton, Thoney, King, & Hodgson, 2003), semiconductor (Sivakumar & Gupta, 2006)). Even though numerous researchers have studied SDS, no solution approach is widely recognized as providing a superior capability to resolve problems for each class of machine configurations (Zhu & Wilhelm, 2006). Despite so, most existing methods for scheduling with SDS are heuristics (e.g. genetic algorithms, simulated annealing, tabu search, dispatching rules, discrete event simulation) mainly because applying conventional search and optimization methods (e.g. branch and bound, dynamic programming, mixed-integer programming) for intractable NP-hard problems are generally intensive in computation time and therefore less favored for near-real-time applications.

The Apparent Tardiness Cost with Setups (ATCS) heuristic (Lee, Bhaskaran, & Pinedo, 1997) is developed to minimize total weighted tardiness for a one-machine problem with SDS. Lee et al. (1997) mentioned that the ATCS heuristics could be applied to stochastic problems where jobs have different release dates by computing the involved parameters (taking into account all jobs including those still to be released) every time the machine is free to select the next job. Despite so, the ATCS heuristic is unable to address multiobjectives on its own and is harder to apply in a weighted aggregation manner than other simple dispatching rules.

Dabbas, Chen, Fowler, and Shunk (2001) developed a scheduling approach that combines multiple dispatching criteria into a single rule, with the objective of simultaneously optimizing multiple performance measures. The results (using a Mini-Fab and a full-scale real factory model) show significant improvement over the use of a single dispatching criterion. However, no sequence-dependent setup was addressed.

Lin, Wang, and Kuo (2005) developed a parameterized dispatching rule for semiconductor Logic IC sort operations using response surface methodology to select the weights for the weighted aggregation of the normalized lot's attributes. Multiple performance measures are combined into a single performance value using desirability function and the geometric mean method. Results suggest that the dispatching rules significantly affect the combined performance value for all scenarios at 95% confidence level.

Wang, Chen, and Lin (2005) developed a hybrid knowledge discovery model, using a combination of (i) decision tree (off-line rule learning module) to determine an appropriate dispatching rule given a specific performance measure and system status, and (ii) a back-propagation neural network (on-line prediction module) to predict precisely the performance of the selected rule of a semiconductor final testing factory. The dispatching rules considered in this study include earliest-due-date (EDD), first-come-first-served (FCFS), and a practical dispatching heuristic that takes setup reduction into consideration.

Sivakumar and Gupta (2006) address the scheduling of a complex job shop with SDS in semiconductor back-end using linear weighted aggregation of criterion (i.e. due date priority, relative cost factor of a setup, and cycle time priority) and applies auto simulation model generation approach for on-line application to minimize average cycle time and average tardiness, and to maximize machine utilization.

Despite the relevance of the studies reviewed above, scheduling problems involving sequence-dependent setups (SDS) are generally not well understood in terms of how and which commonly used setup conscious rules and conventional dispatching rules should be selected for used in a combined dispatching criteria approach, how the rules perform before and after they are combined with respect to multiple conflicting objectives, and how the degree of optimizing a performance objective at the expense of other performance objectives will affect the overall performance of the weighted rule. In fact, stochastic scheduling with multiobjectives and SDS is highlighted as a potential area for future research in a review paper by Zhu and Wilhelm (2006). This suggests that much more remains to be done.

3. Criterion selection and analysis

In order to identify the criteria to be combined in a weighted aggregation approach to address multiple conflicting objectives, this section will evaluate eight dispatching rules to understand each of their performances in not only the objective it is designed to optimize, but also its effect on the other conflicting objectives considered in this study. The measures related to the performance objectives considered in this study are the mean of (i) average cycle time (*avgCT*), (ii) standard deviation of cycle time (*sdCT*), (iii) average tardiness (*avgTARD*), and (iv) standard deviation of tardiness (*sdTARD*).

This study involves scheduling a dynamic and stochastic serial (i.e. single lot processing) ion implanter machine with SDS. The notations and abbreviations used in this paper are listed in Table 1 and the assumptions considered are:

- Operators, handlers, and hardware are not explicitly modeled.
- No yield losses are considered.
- No rework is modeled.
- No preemption is allowed.
- No machine breakdowns are modeled.
- All lots hold equal weights.

3.1. Dispatching criteria

The dispatching criteria considered in this study are summarized in Table 2.

3.2. Computational experiments

In this study, three lot types (namely *T1*, *T2*, and *T3*) are considered and released to the machine in proportional amounts to pro-