Available online at www.sciencedirect.com
ScienceDirect
Computers & Industrial Engineering 52 (2007) 210–228
computers & industrial engineering
www.elsevier.com/locate/dsw

Late work minimization in a small flexible manufacturing system

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Received 6 June 2006; received in revised form 11 October 2006; accepted 12 December 2006
Available online 24 January 2007

Abstract

The paper concerns a small flexible manufacturing system consisting of three CNC machines: a lathe machine, milling machine and measurement center and a single robot, located at the Poznań University of Technology. A short description of the production environment, which can be modeled as the extended job shop system with open shop sections within particular jobs, is followed by the proposition of a branch and bound method. It optimizes production plans within a single shift in order to minimize the late work, i.e. the amount of work executed after a given due date. Based on results of computational experiments, conclusions are formulated on the efficiency of the B&B algorithm and on the behavior of FMS under consideration.

Keywords: Late work criterion; Shop scheduling; Flexible manufacturing system; Branch and bound algorithm

1. Introduction

Flexible manufacturing systems (cf. e.g. Ciriani & Leachman, 1993; Kusiak, 1988; Pesch, 1994; Pinedo & Chao, 1999; Stecke & Suri, 1985) are a very important application field for scheduling theory (cf. e.g. Błażewicz, Ecker, Pesch, Schmidt, & Węglarz, 2001; Brucker, 1998; Chen, Potts, & Woeginger, 1998; Leung, 2004), which supports solving various problems arising in a production environment from designing a system to managing it efficiently. Most scheduling cases concerning FMSs are computationally hard, since industrial systems usually consist of many specialized machines as well as additional tools and they work under numerous constraints. From the point of view of computational complexity, in general, scheduling problems on more than two specialized machines are NP-hard (cf. e.g. Garey, Johnson, & Sethi, 1976). Similarly, even if a basic scheduling case can be solved in polynomial time taking into account additional parameters, such as release times or weights, makes it intractable (cf. e.g. Lenstra, Rinnooy Kan, & Brucker, 1977). Even evaluating the quality of solutions obtained is a difficult task. Estimating the system performance requires taking into account different points of view, which are usually in conflict, representing interests of system owners as well as its customers.

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0360-8352/$ - see front matter
doi:10.1016/j.cie.2006.12.004

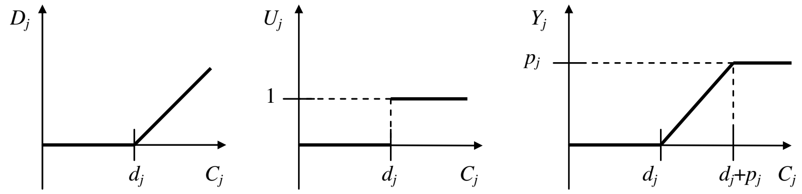

Fig. 1. Tardiness (D_j), the number of late jobs (U_j) and late work parameter (Y_j) for job J_j, with processing time p_j and due date d_j, with regard to its completion time C_j.

The late work objective function (Błażewicz, 1984; Sterna, 2006a) is one of scheduling criteria, which has not been considered in the FMS environment so far. It estimates the quality of a solution with regard to the size of late parts of particular activities, i.e. it takes into account the amount of late work not the quantity of the delay. Hence, minimizing the value of the late work criterion is equivalent to minimizing the total number of tardy units of particular activities executed in the system. This criterion combines the idea of two performance measures: the total tardiness and the number of late jobs (cf. Fig. 1). Similarly as tardiness, late work increases with a job delay, but when the job becomes totally late, the penalty remains on the certain level (determined by the job processing time) as for the number of late jobs parameter.

The criteria based on late work have been investigated only for classical scheduling models such as: single machine environment (Hariri, Potts, & Van Wassenhove, 1995; Hochbaum & Shamir, 1990; Kethley & Alidaee, 2002; Kovalyov, Potts, & Van Wasenhove, 1994; Leung, Yu, & Wei, 1994; Potts & Van Wassenhove, 1991a, 1991b), parallel identical and uniform machines environments (Błażewicz, 1984; Błażewicz & Finke, 1987) and, more recently for shop systems (Błażewicz, Pesch, Sterna, & Werner, 2000, 2004a, 2004b, 2005a, 2005b, 2005c, 2007; Sterna, 2000, in press). These studies were motivated by interesting applications, which arise in control systems (Błażewicz, 1984) and agriculture (Błażewicz, Pesch, Sterna, & Werner, 2004b; Potts & Van Wassenhove, 1991a). However, late work criterion can be also very useful in analyzing FMSs (Sterna, 2000, 2006b), since it models the viewpoints of a customer as well as an owner of a system. Customers are interested in minimizing parts of their orders which are not finished on time. System owners are also interested in minimizing this factor, for it reflects the quality of service in their FMS. Additionally, the late work criterion can be useful in production optimization. Modern industrial systems are usually managed in a hierarchical way: first, a long-term production plan is determined, then, a short-term schedule is constructed for a certain time horizon (e.g. for a month, a day or a shift). Activities or parts of activities which could not be sequenced within a given interval (modeled as late work) have to be scheduled in the incoming one, together with orders newly appearing in a system, making the planning process more difficult.

The paper concerns a scheduling tool for a production optimization in a small flexible manufacturing system, located at the Poznań University of Technology, which minimizes late work within a single shift. FMS consists of three CNC machines and a single robot. Due to numerous parameters and constraints describing the system, optimizing a schedule in a long time horizon can be supported efficiently only by heuristic methods. However, when a short time horizon is considered, it is possible to relax the formal model and to apply exact approaches such as a branch and bound one (B&B). Since the system analyzed can be modeled as the job shop with additional flexibility, the branch and bound method, proposed for it, incorporates the ideas developed for B&Bs solving this classical scheduling case (cf. e.g. Błażewicz, Domschke, & Pesch, 1996; Brucker, Jurisch, & Sievers, 1994).

Section 2 presents an overview of the flexible manufacturing system and it is followed by the problem formulation given in Section 3. Section 4 provides a general framework of a branch and bound method proposed, incorporating a list scheduling approach to calculate upper bound of the criterion value. Section 5 summarizes results of computational experiments. The paper is concluded in Section 6.

2. Description of the flexible manufacturing system

The flexible manufacturing system considered in the paper (cf. also Błażewicz, Pawlak, Sterna, Walter, & Zawirski, 1999; Sterna, 2000) is a small production unit located at the Poznań University of Technology