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A bounded dynamic programming solution to the batching problem in mixed-model just-in-time manufacturing systems

Mesut Yavuz[a], Suleyman Tufekci[b,*]

[a]Research and Engineering Education Facility, University of Florida, Shalimar, FL 32579, USA
[b]Department of Industrial and Systems Engineering, University of Florida, Gainesville, FL 32611, USA

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Abstract

The batch production smoothing problem (BPSP) aims at finding appropriate batch sizes for a variety of products and sequencing the batches in such a way that their appearances are uniformly dispersed over the planning horizon. Extending the previous research work on the BPSP, this paper introduces a bounded dynamic programming (BDP) approach. Computational experiments prove that the BDP approach reduces the computational time needed to solve the problem significantly and allows larger-size problems to be solved within practical times.

Keywords: Mixed-model production; Production smoothing; Just-in-time; (Bounded) dynamic programming

1. Introduction

Mixed-model production systems enable manufacturers meet demand for a variety of products in an efficient way. The demand for each product is too low to use dedicated manufacturing lines or facilities, therefore a versatile facility is used to produce many similar but not identical products. Planning and scheduling such a mixed-model system is an important challenge that has gathered significant interest since 1960s, starting with balancing and sequencing mixed-model assembly lines (Thomopoulos, 1967, 1970; Macaskill, 1972; Dar-el and Cother, 1975; Chakravarty and Shtub, 1985; Dar-el and Rabinovitch, 1988). We address the operation of these systems under the just-in-time (JIT) philosophy.

JIT manufacturing is based on the employment of a pull system on the shop floor, and the entire system is controlled by a schedule of the final level of operations. The schedule of the final operation determines the demand and schedule of the immediate upstream operation. Application of the pull system at every stage of the shop floor implies that the final schedule determines the demand pattern for all the operations. In the literature the problem of scheduling the final level, such that demand for the other operations are stabilized, is known as the *production smoothing problem* (PSP).

Ideally, production smoothing aims at reducing batch sizes and creating a leveled one-piece-flow of products, parts and materials through the entire system. This ideal flow requires the end products to

*Corresponding author. Tel.: +1 352 392 1464x2022; fax: +1 352 392 3537.
E-mail addresses: yavuzm@ufl.edu (M. Yavuz), tufekci@ise.ufl.edu (S. Tufekci).

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be dispersed over the final schedule, as uniformly as possible. For a given end product, this goal is achieved if its cumulative production amount at any time is proportional to time elapsed since the beginning of the planning horizon. In Fig. 1, the straight line demonstrates this *ideal schedule* concept for a given product. The actual production amount, on the other hand, increases at times devoted to that product and remains constant at times when some other products are produced. The deviation of an actual schedule from the ideal schedule is demonstrated by the gap between the lines in the figure. The PSP aims at minimizing this gap.

The PSP has gathered significant interest in the last two decades. In Miltenburg's (1989) seminal paper, the problem is formulated as an integer nonlinear programming problem where the objective function measures the total squared deviation between the actual and ideal schedules, for each product at each stage in the sequence. Several heuristic and exact solution methods for the problem are available in the literature (Miltenburg, 1989; Miltenburg et al., 1990; Kubiak and Sethi, 1991; Ding and Cheng, 1993; McMullen, 1998, 2001a–c; McMullen and Frazier, 2000; McMullen et al., 2000; McMullen and Tarasewich, 2005). The most efficient exact method known so far is Kubiak and Sethi's (1991) transformation to assignment problem. In all these papers the problem has been studied for synchronized assembly lines only, where each product takes exactly one unit of processing time on every station and setup times are ignored.

A variant of the PSP is batch PSP (BPSP). The seminal work addressing the BPSP is due to Yavuz and Tufekci (2004). The authors analyze mixed-model JIT production systems, where a single machine is critical in the system. The single machine can either be the final level of the production system, or a bottleneck operation that all the products go through. In contrast to the former literature on the PSP considering synchronized assembly lines, the authors generalize processing times to be arbitrary non-zero numbers and also allow setup times, which were previously ignored, to take arbitrary non-zero values. The total available time is limited, such that the ideal one-piece-flow (manufacturing the end products in quantities of one) is infeasible. Therefore, any feasible production plan should collect several copies of products into batches and decrease the amount of productive time devoted to setups. In order to create an easily implementable system and also make use of the well-established literature on the PSP, the authors develop a two-phase solution method to the problem. The first phase determines batch sizes and number of batches for the products and the second phase finds a sequence for these batches. We refer to these phases as *batching problem* (BP) and *sequencing problem* (SP), respectively. The key to this two-phase solution approach is a *takt-time*, which is obtained by dividing the total available time into the total number of batches to be produced. Every product, no matter if it is produced in a batch of one or multiple number of products, is

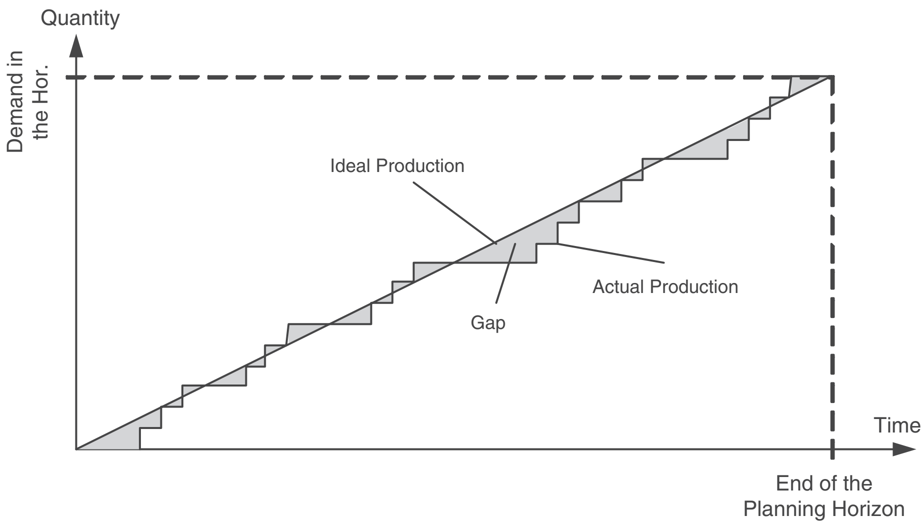

Fig. 1. Ideal and actual schedules.