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A quantitative approach for scheduling activities to reduce set-up in multiple machine lines

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Abstract

The importance of ensuring short set-up times in manufacturing has been well-documented in the literature over the past years. However, this body of work largely addresses situations involving a single machine with no specific worker-related issues. In practice, there exist multiple machines or workstations that form a machine line, and that need set-up operations to be performed by multiple workers. The existing literature does not provide adequate methodologies for set-up reduction in such cases. This paper describes a quantitative modeling and algorithmic approach for scheduling activities or tasks in order to minimize the set-up time in such situations, also taking into account relevant secondary objectives such as balancing the workload amongst the workers, concentrating slack toward the end of the set-up process, and minimizing the movement costs of the workers performing the different set-up tasks. Three real-life examples are used to demonstrate the efficacy of the proposed approach.

Keywords: Scheduling and sequencing; Set-up times; Set-up reduction; Mixed-integer programming; Cutting planes; Network flows

1. Introduction

Customer requirements have changed drastically over the past few decades: customers want lower costs, higher quality, better delivery performance, more product features, and customized products (Ayres and Butcher, 1993; Baker, 2000; Coble and Bohn, 1997; Lewis, 2002; Ohm, 2000). In order to meet this wide range of customer requirements, flexibility is becoming more and more important in all areas of industry from a strategic perspective (Bateman et al., 1999; Olhager, 1993). Upton (1995) states that companies are increasingly focusing on flexibility as a competitive advantage.

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Slack (1991) defines four types of flexibility related to manufacturing, which respectively arise in the contexts of product, mix, volume, and delivery. We refer to McIntosh et al. (2001) for an in-depth discussion on these types of flexibility and their relationship to change-over performance. It is clear though that flexibility is very strongly linked with lot sizes. Indeed, the smaller the lot size that can be produced in an economical fashion, the easier it is to react to changes in market demand. Hay (1989) states that reducing lot sizes brings a company closer to producing products as often as needed, a key element of just-in-time manufacturing and more contemporary lean manufacturing approaches, as acknowledged by Hong and Hayya (1992).

One of the key enablers for improving flexibility is to enhance change-over performance (McIntosh et al., 2001). Nowadays, most machines and machine lines in manufacturing plants are "shared resources." Hence, the same machines are used to produce different product types, or different product variants within a given product family, with a set-up involved when production is switched from one product type to another.

Since customers demand shorter response times and more customized products, Baker (2000) also concludes that set-up reduction is needed to reduce the minimum economical batch quantities. According to Nasri and Paknejad (1992), small lot sizes are impossible to achieve unless machine set-up times are drastically reduced. Habchi and Labrune (1995) demonstrate this in a job shop production setting using simulation techniques. In a field study conducted in ATO (assemble-to-order) and MTO (make-to-order) environments, it is shown that reduced set-ups justify smaller lot sizes (Handfield, 1993). The general sense that having short set-up times is an important prerequisite for flexible manufacturing systems has been acknowledged by several researchers (e.g., Edstrom and Olhager, 1987; Kim and Arinze, 1992; Olhager, 1993; Diaby, 2000), particularly in the context of enhancing the mix flexibility (Olhager, 1993). Bateman et al. (1999) have developed a method using stochastic equations for measuring mix flexibility based on the duration of the different possible set-ups and their occurrence. In this research, they provide very clear evidence that the shorter the set-up times, the greater the mix flexibility.

Traditionally, the time needed for this intermediate set-up has always been considered as a given necessary evil (Hahn et al., 1988; Narasimhan and Melnyck, 1990), and the focus has been to sequence and schedule jobs within a product-run so as to minimize the total change-over cost or time (Allahverdi et al., in press). Since the publication of Shingo (1985), however, there has been a shift in thinking with the recognition that set-up times can indeed be controlled and thereby reduced drastically. As a result, nowadays set-up times are no longer considered as fixed (Freeland et al., 1990; Johansen and McGuire, 1986; Narasimhan and Melnyck, 1990; Olhager and Rapp, 1991).

Reducing downtimes due to set-ups results in additional available time for production, which can be used in two different ways: to effectively boost capacity to be able to produce more – which impacts volume flexibility, or to produce a greater range of products without increasing the total set-up, i.e., produce smaller batches with an accompanying increase in the set-up frequency – which improves the mix flexibility (Spence and Porteus, 1987).

One way of reducing the downtime of a machine is to perform fewer time-consuming set-ups. This can be achieved by optimizing planning schedules (e.g., grouping production orders of the same product, and determining an optimal scheduling sequence for the different product types). Although there exists an extensive list of publications that cover these approaches, such as Bateman et al. (1999), Kim and Bobrowski (1994), O'Brien (1999), Selen and Heuts (1990), Bamea and Sipper (1993), Hashiba and Chang (1991), Maimon et al. (1993), and Bhaskar and Narendran (1996), it is debatable if this, by itself, is the best solution for the problem. The optimized schedule is often-times not comformable with customer due-dates, and this can lead to unnecessary storage and customer dissatisfaction. Hence, it is more beneficial to attack the root cause and reduce the time needed for a set-up.

A fundamental method to reduce set-up times, the SMED method, was proposed by Shingo (1985). While other publications offer alternative approaches to set-up reduction, these are mainly variants of Shingo's SMED method (Moxham and Greatbanks, 2001), with the possible exception of McIntosh et al. (2001), which presents a substantial extension to this method. These existing approaches focus on situations where the set-up of a single machine is performed by one operator. The set-up of multi-machine production lines where multiple persons are involved is not explicitly covered. In this situation set-up activities need to be performed on different machines or workstations of the line by different persons. Van Goubergen and Van Landeghem (2001) have proposed an iterative approach for set-up reduction of such multi-stage manufacturing lines.