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Unrelated parallel machine scheduling with dedicated machines and common deadline ☆

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A B S T R A C T

This paper addresses a scheduling problem in the manufacturing of Polyvinyl Chloride pipes. There are two main attributes of PVC pipes: diameter and color. Each attribute has a corresponding attribute setup time and usually has several different levels. Each extruder produces different PVC pipe products based on the diameters as large, middle and small. The alternatives exist between these extruders, where the large and the middle type extruders can be used to produce the PVC pipes with the other diameters; the small type extruders can be used to produce the PVC pipes with middle diameters but cannot produce those with large diameters. The processing times are longer in all of the alternatives among different types of extruders. The objective is to minimize the total completion time for the unrelated parallel machine problem.

Three dedicated machine heuristics are proposed herein for the problem and have been evaluated by comparing with the current scheduling method used in the case plant. The computational results show that the proposed constructive heuristics outperform the current scheduling method with significant improvements and can be used to solve large-size problems in reasonable computational times.

1. Introduction

In this paper we address a real-life scheduling problem in the manufacturing of Polyvinyl Chloride pipes (hereafter referred to as PVC pipes). PVC pipes are the most widely produced plastic piping material. The production process of PVC pipes includes the main machine extruder and some peripheral equipment, which can produce different kinds of PVC pipe products (see Fig. 1). There are two main attributes of PVC pipes: diameter and color. Each attribute has a corresponding attribute setup time and usually has several different levels (see Fig. 2). The PVC pipe products with the same levels of both attributes are always grouped into a single job, which is the basic unit on the scheduling operation. Because there is at least one different level of the attribute between two adjacent jobs, it is necessary to make a setup adjustment whenever there is a switch to a different job. If the levels of diameter are different (e.g., 200 mm and 150 mm) between two adjacent jobs, there is a major attribute setup time taking 8 h to adjust the level of diameter on the extruder. If the extruder is adjusted for different levels of color (e.g., yellow and gray) between two adjacent jobs, a minor attribute setup time of 2 h is required. If both the levels of diameter and color are different, the setup time will be ten (8 + 2) hours between two adjacent jobs.

PVC pipe production is a typical make-to-stock environment. Whenever a job is finished, it is immediately forwarded to warehouse in order to replenish the inventory. The production quantity of a job is determined by the inventory level. Because the length of a production cycle is fixed at 7 days in the case plant, the production quantity of each PVC pipe product depends on the difference between the current level and the fixed safety level of inventory. There are eleven extruders in the considered PVC pipe plant; each produces different PVC pipe products based on the large (diameter $\geqslant$ 200 mm), middle (diameter $\geqslant$ 80 mm but <200 mm) and small (diameter < 80 mm) diameters of pipes. For convenience, we will refer to the three types of extruders for producing large, middle and small diameters of pipes as large (L), middle (M) and small (S) type of extruders, respectively. If there is sufficient inventory for a particular PVC pipe product, the dedicated extruder for this product may or not produce in the production cycle. But, alternatives exist between the extruders, i.e., the large and middle type extruders can be used to produce the PVC pipes with the other diameters; the small type extruders can be used to produce the

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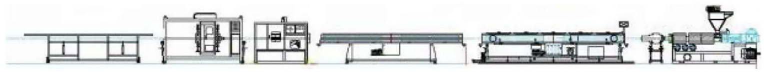

Fig. 1. Production flow line of PVC pipe plant.

Fig. 2. PVC pipe products with a variety of diameters and colors.

PVC pipes with middle diameter but cannot produce with large diameter. The processing times are longer in all of the alternatives. If a job is not carried out on its own dedicated extruder but on the same type of extruder, the increasing rate of processing time has been measured about 1.25 on average by the scheduler in the plant. Further, if a job is carried out on a different type extruder, the processing time of the job will be longer with an increasing rate of 1.75 on average. This is because the adjustments of diameters among the different type extruders are more time-consuming than the adjustment within the same type. Moreover, there are certain PVC pipe products with special specifications which have to be produced only on their own dedicated extruders without alternatives. To sum up, there must be one or more jobs corresponding to each one of the dedicated machines, since the production is scheduled once a week – 7 days (or 168 h) is a common deadline. The completion times for all the jobs processed on the extruders cannot exceed the common deadline. The purpose of PVC pipe production is not only to replenish the insufficient inventory as soon as possible, but also to fully utilize the costly equipment. Therefore, we choose the total completion time (i.e., sum of completion times of jobs) as the objective function to be minimized.

In this paper, we will propose effective scheduling methods to fit the requirements of the PVC pipe plant; and the proposed heuristics will be compared with the current scheduling method used in the plant to evaluate its effectiveness and efficiency.

2. Literature review

Parallel machine scheduling has received great attention in recent years. Most of the literature on parallel machine scheduling focuses on the identical parallel machine environment and the objective of minimizing the makespan. Rabadi, Moraga, and Al-Salem (2006) addressed a non-preemptive unrelated parallel machine scheduling problem with sequence-dependent setup times to minimize the makespan. They proposed a meta-heuristic called the Meta-RaPS, which was evaluated by comparing its solutions to the solutions of an existing heuristic called the Partitioning Heuristic introduced by Al-Salem (2004) for the same problem. Balasubramanian, Fowler, Keha, and Pfund (2009) considered a bi-criteria scheduling problem on identical parallel machines, proposing an iterative SPT–LPT–SPT heuristic and a bi-criteria genetic algorithm. Both the approaches were designed to exploit the problem structure and generate a set of non-dominated solutions. The heuristic and the genetic algorithm were compared with a time-indexed integer programming formulation for small and large instances. Results indicated that both the heuristic and the genetic algorithm provided high solution quality and were computationally efficient. Mosheiov (2001) dealt with a scheduling problem of flow time minimization with a learning effect on parallel identical machines and showed that this problem has a polynomial time solution. Chang, Damodaran, and Melouk (2004) presented a scheduling problem with identical parallel batch-processing machines, and proposed a simulated annealing approach to minimize the makespan for the problem.

Lots of reviews of scheduling have considered parallel machine scheduling problems, for example, Mokotoff (2001) and Allahverdi, Ng, Cheng, and Kovalyov (2008). Especially, Li and Yang (2009) surveyed the non-identical parallel machine scheduling problems with minimizing total (or mean) weighted (unweighted) completion times. Chen and Powell (1999) considered scheduling problems on identical, uniform, or unrelated parallel machines, and proposed a decomposition approach for solving these problems. They applied this decomposition approach to two particular problems: the total weighted completion time problem and the weighted number of tardy jobs problem. The computational results indicated that the decomposition approach is capable of solving large problems. Weng, Lu, and Ren (2001) addressed the problem of scheduling a set of independent jobs on unrelated parallel machines with job sequence-dependent setup times so as to minimize a weighted mean completion time. They proposed seven heuristic algorithms and tested them by simulation. Their computational results indicated that heuristic algorithm 7 is clearly the best for all cases.

There are many studies discussing the industrial applications of non-identical parallel machine in the scheduling literature. Kim, Kim, Jang, and Chen (2002) proposed an unrelated parallel machine scheduling problem with sequence-dependent setup times in compound semiconductor manufacturing. They developed a simulated annealing (SA) meta-heuristic in their research to determine a scheduling policy so as to minimize total tardiness. Chuang, Liao, and Chao (2010) considered a parallel machine scheduling problem in the manufacturing of anodic electro-etching aluminum foil. The problem was to schedule jobs on the high and medium voltage equipment, each having several pieces in parallel, with setup times to minimize the total completion time. Chen (2006) proposed an unrelated parallel machine scheduling problem with process restrictions and setups to minimize maximum tardiness in die casting environment. A setup for dies was incurred if the type of the job scheduled was different from the previous one on that machine. An efficient heuristic based on guided search, record-to-record travel, and tabu lists was presented for the problem.

According to the related literature given above, though there exists some information about the unrelated parallel machine problem with sequence-dependent setup times to minimize total (or mean) weighted completion time, such as Chen and Powell (1999) and Weng, Lu, and Ren (2001), yet their methods cannot directly deal with the problem that has the restrictions of dedicated machines. Therefore, we need to develop heuristics that can solve directly the problem for large-size instances.