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An efficient heuristic for a two-stage assembly scheduling problem with batch setup times to minimize makespan

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ABSTRACT

This paper considers a two-stage assembly scheduling problem of N products with setup times to minimize the makespan. In this problem, there is a machining machine which produces components in the first stage. When the required components are available, a single assembly machine can assemble these components into products in the second stage. A setup time is needed whenever the machining machine starts processing components, or the item of component is switched on the machine. The problem is formulated as a mixed integer programming model, and several properties for finding optimal solutions are developed. Moreover, an efficient heuristic based on these optimal properties is proposed. A lower bound is derived to evaluate the performance of the proposed heuristic. Computational results show that the proposed heuristic can obtain a near optimal solution in almost zero time and the average percentage deviation is only 0.478.

1. Introduction

The two-stage assembly scheduling, a common problem in the real-life production system, contains two main operations: machining and assembly. There are many practical examples in real-life industries, such as personal computer manufacturing (Potts, Sevast'janov, Strusevich, Van Wassenhove, & Zwaneveld, 1995) and gears of motor assembly industry, etc. In this paper we address a two-stage assembly scheduling problem originated from a motor factory. The case factory produces various components in the first stage, and assembles the components into products according to the purchase orders of clients in the second stage.

The motor factory produces and assembles various kinds of motors, such as blender motor, elevator motor, lathe motor, starter motor, and mechanical fan motor. In general, a motor is composed of two parts: stator and rotor. This research focuses on the gear assembly in the manufacturing of rotors. The functions of a gear are changing direction, speeding up, increasing torque, and transmitting power. Every kind of gears has its own function. The production strategy of the case factory is to produce all kinds of gears. Motors are assembled in the case factory according to the client's demand. A setup time will be incurred whenever a machine starts producing gears, or whenever the item of gear must be switched on the machine. The production flow line of motor factory is depicted in Fig. 1.

The objectives of this research are to find the optimal properties of the two-stage assembly scheduling, and to develop an effective and efficient scheduling method based on the optimal properties in order to fit the requirements of the schedulers in the case factory. Furthermore, the proposed scheduling method can be expected to be practically applied in the real-life production systems in the future.

2. Literature review

We briefly review the related research about the two-stage assembly scheduling problems with and without setup times.

2.1. Two-stage assembly scheduling problem with setup times

The two-stage assembly scheduling problem with setup times has received great attention in recent years because the setup times often exist in the real-life production systems. Cheng and Wang (1999) considered minimizing the makespan in a two-stage assembly scheduling problem of N products, where each product consists of a unique component and a common component. There was a single machining machine in the first stage

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and an assembly machine in the second stage. The common components were produced in batches, and setup time was needed between each batch. A proof was given by them to demonstrate that the problem is NP-complete, and they presented optimal properties and polynomial solvable cases in the problem. For the same problem, Lin and Cheng (2002) gave proofs for the strong NP-complete of the problem, and developed a polynomial- or pseudo-polynomial-time algorithm for the problem. Yokoyama (2004) studied a two-stage assembly scheduling problem of the single batch problem with the objective of minimizing mean completion time. He developed a heuristic using pseudo-dynamic programming to obtain a near-optimal schedule, and used a tight lower bound to evaluate the performance of his heuristic. Afterward, Yokoyama (2008) extended the model by considering more than one machine in the first stage and proposed a procedure to minimize the same objective function. Allahverdi and Al-Anzi (2006) dealt with a two-stage assembly scheduling problem of N products with setup times. They developed the evolutionary heuristics including a particle swarm optimization (PSO) and a taboo search (TS) to solve the problem. Later, Al-Anzi and Allahverdi (2007) considered the same model with the objective of minimizing maximum lateness. Hatami, Ebrahimnejad, Tavakkoli-Moghaddam, and Maboudian (2010) presented a three-stage assembly flow shop scheduling problem with bi-objective, namely the mean flow time and maximum tardiness. They considered a middle stage between the production and assembly stages, called transportation stage, in which components and subassemblies were collected and transferred from the production stage to assembly stage. They proposed a simulated annealing (SA) and a taboo search (TS) to solve the problem. Tian, Liu, Yuan, and Wang (2013) developed a discrete particle swarm optimization (DPSO) for a two-stage assembly scheduling problem of the N products with minimizing the weighted sum of makespan and mean completion time, where the setup time was treated as separate from processing time. In the first stage, there were one or more machining machines. When all components of each product were available, a single assembly machine completed the product in the second stage. The results showed that DPSO is an effective and efficient for the assembly scheduling problem. Mozdgir, Fatemi Ghomi, Jolai, and Navaei (2013) addressed a two-stage assembly flow shop problem with multiple non-identical assembly machines in stage two to minimize weighted sum of makespan and mean completion time. Sequence dependent setup times were considered for the first stage. After extending a mathematical mixed-integer linear programming model to solve the problem, they used GAMS software. A hybrid VNS heuristic, which is a combination of the variable neighborhood search (VNS) algorithm and a novel heuristic, was developed and its solutions were compared with solutions obtained by GAMS. Computational experiments revealed that the hybrid VNS heuristic performed much better than GAMS with respect to the percentage errors and run times. Navaei, Fatemi Ghomi, Jolai, and Mozdgir (2014) addressed a two-stage assembly flow-shop scheduling problem with non-identical assembly machines at the second stage to minimize a sum of holding and delay costs, and sequence dependent setup times were considered for both stages. They developed four hybrid meta-heuristics to solve the addressed problem. A simulated annealing algorithm (SA) and an imperialist competitive algorithm (ICA) were presented to find a sequence of jobs at the first stage and a heuristic (HEU) and again the SA for assigning addressed jobs to assembly machines in stage two; therefore, these hybrid meta-heuristics were SA+HEU, ICA+HEU, SA+SA and ICA+SA. Computational results showed that ICA+HEU outperformed all other algorithms; however, the run time of SA+HEU was the shortest among the algorithms.

2.2. Two-stage assembly scheduling problem without setup times

There have been many literature related to the two-stage assembly scheduling problem without setup times. Kusiak (1989) was probably the first author who introduced the two-stage assembly scheduling problem with the objective of minimizing the makespan. Four types of products, named single product, N products, single batch, and N batchs, were defined respectively. He developed two optimal algorithms to solve the single product and N product scheduling problems. Lee, Cheng, and Lin (1993) considered minimizing the makespan in a two-stage hybrid assembly scheduling problem of N products. Two parallel machines produced components, which were assembled into products on a single machine. They proved that the problem is strongly NP-complete, and proposed a branch and bound scheme as well as three heuristics employed to solve the problem. Seidgar, Kiani, Abedi, and Fazlollahtabar (2014) considered a two-stage assembly flow shop problem where m parallel machines are in the first stage and an assembly machine is in the second stage. The objective was to minimize the weighted sum of makespan and mean completion time for n available jobs. They employed an imperialist competitive algorithm (ICA) as the solution approach. They compared the proposed ICA with an existed cloud theory-based simulated annealing algorithm (CSA). The computational results clarified that ICA performs better than CSA in quality of solutions. Hariri and Potts (1997) developed a branch and bound algorithm for a two-stage hybrid assembly scheduling problem of N products so as to minimize the makespan. In the first stage, there were one or more machining machines. When all components of each product were available, a single assembly machine completed the product in the second stage. A two-stage hybrid assembly scheduling problem of N products was addressed by He, Babayan, and Kusiak (2001). There were multiple identical machines in the first stage. Then, a single assembly machine assembled components into products in the second stage. Three heuristics were developed to minimize the makespan for his model. Later, He and Babayan (2002) formulated a two-stage hybrid assembly scheduling problem of N products with the objective of minimizing makespan. There was a single machining machine in the first stage and multiple identical assembly machines in the second stage. They built up four heuristic algorithms, and developed a lower bound to evaluate the performance of the heuristic algorithms. For the same problem, Liao and Liao (2007) presented an ant colony optimization (ACO) algorithm to solve the problem, and developed a branch and bound procedure to evaluate the performance of the algorithm. Yan, Wan, and Xiong (2014) dealt with a two-stage assembly flow shop scheduling problem for minimizing the weighed sum of maximum makespan, earliness and lateness. They proposed a hybrid variable neighborhood search – electromagnetism-like mechanism (VNS-EM) algorithm to solve the problem. In the VNS-EM, VNS algorithm was embedded in each iteration of EM in order to search beyond local optimum for a global optimum. Computational results showed that the proposed hybrid VNS-EM algorithm outperforms the EM and VNS algorithms in both average value and standard deviation. Sung and Kim (2009) developed a branch and bound algorithm by using the solution properties to solve the two-stage multiple-machine assembly scheduling problem. Moreover, the objective of the problem they considered was the sum of completion times.

3. Problem definition

In this paper, a two-stage assembly scheduling problem of N products is presented. The objective of the problem is to minimize