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A branch and bound algorithm for hybrid flow shop scheduling problem with setup time and assembly operations

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ABSTRACT

A hybrid flow shop scheduling problem (HFSP) with assembly operations is studied in this paper. In the considered problem, a number of products of the same kind are produced. Each product is assembled using a set of several parts. At first, the parts are produced in a hybrid flow shop and then they are assembled in an assembly stage to produce products. The considered objective is to minimize the completion time of all products (makespan). This problem has been proved strongly NP-hard, so in order to solve it, a hierarchical branch and bound algorithm is presented. Also, some lower and upper bounds are developed to increase the efficiency of the proposed algorithm. The numerical experiments are used to evaluate the performance of the proposed algorithm.

1. Introduction

One of the most important tasks in service and manufacturing systems is how to schedule arriving jobs to satisfy some criteria. Finding the best schedule can be very easy or very difficult, depending on the shop environment, the process constraints and the performance indicator [1]. In a scheduling problem with assembly operations, usually there is a preassembly stage followed by an assembly stage. When the preassembly stage is a machining stage, the parts are processed independently and then, they are assembled into product in the assembly stage. Although scheduling for the parts machining and planning for the assembly operations have been independently studied [2], this may not lead ideal results for the total production system. Hence considering these two stages simultaneously in scheduling problems has received an increasing attention of researchers recently [3].

In this paper, a hybrid flow shop scheduling problem (HFSP) with assembly operations is studied. At first the parts are fabricated in a two stage hybrid flow shop and then, they are assembled into products in the assembly stage. The hybrid flow shop is a generalization of the classical flow shop in which there are parallel machines for some operations [4–7]. In this system, generally a set of n jobs must be processed in a series of m stages and it has the following characteristics [8,9]:

- The number of processing stages (m) is at least 2.
- Each stage k has $M^{(k)}$ machines in parallel ($M^{(k)} \geqslant 1$ for all stages and $M^{(k)} > 1$ for at least one stage).

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- All n jobs are processed following the same production flow: stage 1, stage 2, ..., stage m. A job might skip any number of stages provided it but it is processed in at least one of them.
- Each job j requires a processing time P_{jk} on stage k.

Generally, HFSP comprises three sub-problems: Batching, loading, and sequencing. Batching occurs only if setup costs or times are not negligible and several jobs of the same product type have to be produced. In this case, it might be advantageous to batch multiple jobs of the same product type and produce them with just a single setup in the beginning [10]. The loading sub-problem refers to the allocation of operations to machines. After calculating batch-sizes, the loading sub-problem is used to assign the batches to the machines. Finally the sequencing sub-problem is used to sequence the assigned jobs to a machine. This problem is well-known as NP-hard. Gupta showed that HFSP restricted to two processing stages, one stage contains two machines and the other one a single machine, is NP-hard [8]. So, it is obvious that the considered problem in this paper with a more complex structure than HFSP is strongly NP-hard.

There are two major types of studies in which both machining operations and assembly operations are treated: type I in which more complex models are built and priorities dispatching rules or heuristic methods are presented. Type II in which simpler models are considered and strict solution methods or theory associated with them is proposed [11].

The first study in assembly-type flow-shop scheduling problem was done by Lee et al. in 1993. They studied a two stage assembly flow-shop scheduling problem with makespan objective function. They considered a simple problem in which each product is assembled from two types of parts. The first component of each product must be processed on the first machine and the second component is processed on the second machine. Finally the third machine assembles the two parts into a product [12]. Potts et al. [13] extend the problem to the case of multiple fabrication machines in which there are m machines and one machine at the first and second stages, respectively. Hariri and Potts [14] also studied the same problem as [13] and proposed a branch and bound algorithm. Cheng and Wang [15] consider minimizing the makespan in the two-machine flow-shop scheduling with a special structure and develop several properties of an optimal solution and obtain optimal schedules for some special cases. In their model, the first machine produces two types of parts, unique components and common components. The second machine assembles the components into the products. Sung and John [16] studied a 2-stage assembly scheduling problem subject to component available time constraint with the objective function of makespan minimization. In their problem there are n jobs (products), each product consists of two components. One of the two components is outsourced subject to job-dependent lead time and the other, is fabricated by a single machine.

In all of the above studies, the considered problem is an assembly type flow shop which has only one fabrication stage and there is a specified processor machine for each kind of the parts. But in this study there are two series stages with parallel machines for the fabrication and there is no constraint to assign any part to any machine in each stage.

Yokoyama [17] studied a hybrid scheduling for the production system including parts machining and assembly operations. In his study several products of different kinds are ordered to be produced and parts for the products are manufactured in a flow shop and each product is produced by hierarchical assembly operations from the parts. The parts are assembled into the first sub-assembly, and several other parts and the first sub-assembly are assembled into the second sub-assembly. These assembly operations are continued until the last sub-assembly that is the final product is obtained. Sun et al. [18] studied 3-machine, assembly-type flow shop scheduling problem. They proposed a series of heuristic algorithms based on the basic idea of Johnson's algorithm and Gupta's idea. Yokoyama and Santos [2] considered flow-shop scheduling problem with assembly operations. In their models, several products of different kinds are ordered and the parts are manufactured. Each part of the products are processed on machine M_1 (the first stage) and then processed on machine M_2 (the second stage). Each product is joined with the parts by one assembly operation on assembly stage M_A (the third stage).

Allahverdi and Al-Anzi [3] studied a two-stage assembly scheduling problem where there are m machines on the first stage and an assembly machine at the second stage. In their model the setup times are treated as separate from the processing times. They presented a dominance relation and proposed three heuristics that are a hybrid tabu search, a self-adaptive differential evolution (SDE), and a new self-adaptive differential evolution (NSDE). Al-Anzi and Allahverdi [19] also considered the same problem as [3] where setup times are ignored. They proposed some heuristics based on tabu search (Tabu), particle swarm optimization (PSO), and self-adaptive differential evolution (SDE) along with the earliest due date (EDD) and Johnson (JNS) heuristics to solve the problem. Computational experiments reveal that both PSO and SDE are much superior to tabu. Moreover, it is statistically shown that PSO performs better than SDE.

The considered problem of the studies that mentioned in two last paragraphs is parallel machines with assembly operations or flow shop with assembly operations and none of them considers the fabrication stage as HFS problem. Literature review shows that, no study considers assembly scheduling problem with HFS for the machining. Also only a few studies consider setup times between the jobs in the assembly production system.

Allahverdi et al. [20] have done a review of scheduling research involving setup considerations. For a separable setup, two problem types exist. In the first type, setup depends only on the job to be processed; hence it is called as sequence-independent. In the second, setup depends on both the job to be processed and the immediately preceding job; hence it is called as sequence-dependent. Furthermore, treating setup time separately from processing time allows operations to be performed simultaneously and hence improves performance. This concept is inherent in recent production management philosophies and techniques such as just-in-time (JIT), optimized production technology (OPT), group technology (GT), cellular manufacturing (CM), and time-based competition [20].