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Scheduling of multi-component products in a two-stage flexible flow shop

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ABSTRACT

In this research, the problem of scheduling and sequencing of two-stage assembly-type flexible flow shop with dedicated assembly lines, which produce different products according to requested demand during the planning horizon with the aim of minimizing maximum completion time of products is investigated. The first stage consists of several parallel machines in site I with different speeds in processing components and one machine in site II, and the second stage consists of two dedicated assembly lines. Each product requires several kinds of components with different sizes. Each component has its own structure which leading to difference processing times to assemble. Products composed of only single-process components are assigned to the first assembly line and products composed of at least a two-process component are assigned to the second assembly line. Components are placed on the related dedicated assembly line in the second phase after being completed on the assigned machines in the first phase and final products will be produced by assembling the components. The main contribution of our work is development of a new mathematical model in flexible flow shop scheduling problem and presentation of a new methodology for solving the proposed model. Flexible flow shop problems being an NP-hard problem, therefore we proposed a hybrid meta-heuristic method as a combination of simulated annealing (SA) and imperialist competitive algorithms (ICA). We implement our obtained algorithm and the ones obtained by the LINGO9 software package. Various parameters and operators of the proposed Meta-heuristic algorithm are discussed and calibrated by means of Taguchi statistical technique.

1. Introduction

A hybrid flow shop scheduling problem (HFS), as described by Linn and Zhang [1], is to optimize processing of a set of n jobs in a series of m production stages, each of which has multiple machines operating in parallel and at least one stage must have more than one machine to differ from traditional flow shop environment. HFS scheduling problem with different settings and special cases has been extensively studied in the literature, such as two-stage hybrid flow shop (e.g., [2,3]), no-wait or blocking hybrid flow shop (e.g., [4]), HFS problems with sequence-dependent setup times (e.g., [5]), HFS problems with availability constraints (e.g., [6]), and HFS problems with precedence constraints (e.g., [7]).

But there are two other special kinds of two-stage HFS scheduling problem, namely (1): two-stage HFS scheduling problem with dedicated machines at stage 2 where different jobs require processing in the first stage, and then depending on the specifications of the jobs, they are processed on a dedicated machine in stage two, and (2): two-stage assembly-type HFS scheduling problems in which each product composes of several components. When all of the components are processed at the first stage, a machine at the second stage, namely the assembly machine, assembles the components to produce final product.

These two kinds of problems are common in real-world situations and can be used in many manufacturing environment such as: label sticker manufacturing [8], furniture assembly, and pottery production [9], another example can be found in the process industry where multiple servers (machines) are available at each stage [10]. For further review on the industries where the hybrid flow shop organization is found, see Riane et al. [11].

This paper considers a combination of these two special kinds of HFS scheduling problem, that is, a two-stage assembly-type hybrid flow shop scheduling problem with dedicated assembly lines which produces different multi-component products according to requested demand during the planning horizon with the aim of minimizing maximum completion time of products. The first stage consists of several parallel machines in site 1 with different speed in processing components and one machine in site

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2, and the second stage consists of two dedicated assembly lines which the products are assigned to one of them depending on their specifications.

The rest of the paper is organized as follows. Section 2 gives the literature review of hybrid flow shop scheduling. Section 3 is the problem description and mathematical model. Section 4 introduces the proposed hybrid algorithm. Taguchi design of experiments to set parameters of ICA–SA algorithm is explained in Section 5. Section 6 presents the computational results which compares the results achieved by proposed hybrid algorithm with those achieved by LINGO9 software. Finally, Section 7 is devoted to conclusions and future works.

2. Literature review

2.1. Assembly-type hybrid flow shop scheduling

Johnson [12] first introduced the flow shop scheduling model and proposed a solution algorithm to minimize the makespan in a two-machine environment. As a generalization of Johnson's two-machine flow shop, the three-machine assembly flow shop problem motivated by the manufacture of fire engines was studied by Lee et al. [13]. They studied a two-stage problem with two machines at the first stage and a single machine at the second stage. In their model, each product was assembled from two types of parts. Each machine at the first stage processed one type of parts, and the machine at the second stage assembled the two types of parts into products. They showed that the general version of this problem was strongly NP-complete and then discussed a few polynomial solvable cases. They also suggested a branch and bound solution scheme and three heuristics to find approximate solutions to the general problem. For the same problem, Hariri and Potts [14] proposed a branch and-bound algorithm to solve it. Fattahi et al. [15] studied a HFS scheduling problem with assembly operations at stage two. In their considered problem, a number of products of the same kind were produced. Each product was assembled using a set of several parts. At first, the parts were produced in a hybrid flow shop and then they were assembled in an assembly stage to produce products. They showed that the problem was strongly NP-hard. So in order to solve it, a hierarchical branch and bound algorithm was presented. Also, some lower and upper bounds were developed to increase the efficiency of the proposed algorithm.

In all of the problems mentioned above, the scheduling objective was to minimize the makespan. The following researches have considered the weighted sum of completion times as the scheduling measure.

Yokoyama [16] studied a two-stage production system where the first stage was a single machine to produce parts and the second stage was a single assembly machine. The machine on the first stage could process all kinds of parts. All the operations were partitioned into blocks and in each block the parts of the same kind were processed successively. Different kinds of components were assembled into finished products in the second stage. He proposed a solution procedure using pseudo-dynamic programming to obtain a near-optimal schedule and developed a lower bound to evaluate the accuracy of the near-optimal schedule. The model was extended by Yokoyama and Santos [17] to a three-stage flow shop. In the model, all the parts for each product were processed on the first-stage machine, and then processed on the second-stage machine. The parts were assembled at the third (assembly) stage to make products. They proposed a solution procedure using a branch and bound method to obtain the optimal and near-optimal schedules. Yokoyama [18] generalized the work into flow shop with several stages where each stage consisted of a single machine. Solution procedures using pseudo-dynamic programming and a branch and bound method were proposed.

Yan et al. [19] presented a study on the two-stage assembly flow shop scheduling problem for minimizing the weighed sum of maximum makespan, earliness, and lateness. There were m machines at the first stage, each of which produced a component of a job. A single machine at the second stage assembled the m components together to complete the job. A novel model for solving the scheduling problem was built to optimize the maximum makespan, earliness, and lateness simultaneously. Two optimal operation sequences of jobs were determined and verified. As the problem was known to be NP-hard, a hybrid variable neighborhood search-electromagnetism-like mechanism (VNS-EM) algorithm was proposed for its handling. Xiong et al. [20] considered a hybrid assembly-differentiation flow shop scheduling problem (HADFSP), in which there were three production stages, including components manufacturing, assembly, and differentiation. In their problem, all the components of a job were processed on different machines at the first stage. Subsequently, they were assembled together on a common single machine at the second stage. At the third stage, each job of a particular type was processed on a dedicated machine. The objective was to find a job schedule to minimize total flow time (TFT). At first, a mixed integer programming (MIP) model was formulated and then because of the NP-hardness of the problem, two fast heuristics (SPT-based heuristic and NEH-based heuristic) and three hybrid meta-heuristics (HGA-VNS, HDDE-VNS, and HEDA-VNS) were developed for solving medium- and large-size problems. Shoaardebili and Fattahi [21] studied a three-stage assembly flow shop scheduling problem with machine availability constraints. Two objectives of minimizing total weighted completion times (flow time) and minimizing sum of weighted tardiness and earliness were simultaneously considered. The problem was generalization of three-machine flow shop scheduling problem and two-stage assembly flow shop scheduling problem. Since these problems were known to be NP-hard, the considered problem was also strongly NP-hard. Therefore, two multi-objective meta-heuristics were presented to efficiently solve this problem in a reasonable amount of time.

2.2. Hybrid flow shop scheduling with dedicated machines

Riane et al. [11] considered the two-stage HFS scheduling problem with two dedicated machines in the second stage with the aim of minimization of makespan. They demonstrated that the problem was strongly NP-complete, and developed three heuristic methods running in polynomial time and one dynamic programming algorithm running in exponential time. Besbes et al. [22] considered the two-stage flow shop problem with parallel dedicated machines and developed two approximate methods. The first approximate method was based on the Johnson's and FIFO rules. The second one was a genetic algorithm based approach. Wang and Liu [23] studied a two-stage HFS problem with dedicated machines in which there were one machine M_0 on the first stage and m dedicated machines M_k, $k \in \{[1,\ldots,m\}$ on the second stage. There was a set $J = \{J_1 J_2,\ldots J_n\}$ of jobs to be scheduled. The jobs belonged to m disjoint types T_k, $k \in \{1,\ldots,m\}$. Each job consisted of a sequence of two operations. The first operation of all jobs must be performed on M_0. The second operation must be processed on M_k if the job was type T_k ($k \in \{1,\ldots,m]$). The objective was to minimize the makespan. To solve the problem, a heuristic method based on branch and bound (B&B) algorithm and two meta-heuristic methods, that is, simulated annealing and tabu search were proposed. Hadda et al. [24] considered the same problem and introduced a branch and bound algorithm to solve it. They used an elimination rule to enhance the algorithm's performances. Abbas et al. [25] considered a two stages robotic flow shop problem, which was a scheduling problem in a robotic cell with dedicated machines at the first stage and a common machine at the second stage. There were two types of jobs.