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Multi-objective distributed reentrant permutation flow shop scheduling

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Abstract: *The distributed reentrant permutation flow shop (DRPFS) is acombination of the re-entrant flow shop problem and distributed scheduling. The DRPFS is an -hard problem, consisting of two subproblems: (1) assigning a set of jobs to a set of available factories and (2) determining the operation sequence of jobs in each factory. The applications of flow shop in industries indicate that the machine setup time to process a job may depend on previously processed jobs. Particularly, in DRPFS, the effect of sequence-dependent setup time is intensified due to its re-entrant characteristic. This paper presents a survey on different re-entrant flow shop scheduling algorithms.*

Introduction-The reentrant flow shop (RFS) scheduling is a special case of flow shop scheduling, where jobs revisit each machine in the same order. The RFS is commonly used in high-tech industries, such as semiconductor wafer fabrication [1].

The general RFS scheduling problem is at least as complex as the flow shop scheduling and has been categorized as -hard. The re-entrant characteristic adds another perspective in determining the optimal job sequence, where avoiding bottlenecks in the production line is critical as their effects are magnified with the increase in the number of reentrants. Most past studies on the RFS scheduling problem typically focus on a single production line. However, the necessities of multiple facilities are growing to achieve higher productivity and reduce production cost while managing the risks associated with the production shutdown in asingle factory [2].In recent literature, Rifai, Nguyen, Dawal (2016)[3] extended the concept of RFS by considering multiple facilities. The extended concept is called the distributed reentrant permutation flow shop (DRPFS) scheduling. This new concept combines RFS with the distributed permutation flow shop (DPFS),where there are factories that are capable of processing all jobs. The DPFS scheduling is more complex than the standard permutation flow shop problem[4]. Therefore, the DRPFS is also considered an -hard problem and is difficult to obtain optimal solutions even for small instance sizes. The problems encountered in the DRPFS scheduling can be decomposed into two intertwined subproblems: deciding the production allocation in each factory and determining its optimum schedule.

These factors should be simultaneously examined to optimize

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the DRPFS scheduling. Although such a concept has been extensively studied in the literature, there is still a lack of attention given to the development of reentrant and distributed flow shop scheduling models with sequence-dependent setup time. To fill the gap, in this study, we consider the sequence-dependent setup time for the DRPFS that has not been covered by previous studies. Setup operations include cleaning, fixing, or releasing parts to machines, changing tools, and adjustments to machines (Pan, Gao, Li, Gao, 2017). They are non-productive operations performed on machines to prepare them for the next products. Setup operations often depend on the job that a machine has just processed, and the job comes after it. The significance of considering sequence-dependent setup time is that it mimics the real condition in some manufacturing lines for certain products, i.e., paint industry (Ruiz St ?utzle, 2008).

Particularly, in the re-entrant setting, the necessities to consider sequence-dependent setup time are much more significant than in standard flow shop, because the total setup times are multiplied based on the number of reentrants.The formal description of the DRPFS scheduling problem follows that of Rifai et al. (2016) with consideration of sequence-dependent setup time. An instance of DRPFS is composed of a set of job to be processed by a set of machines with reentrant characteristic, where the jobs visit each machine more than once, indicated as a number of layers. After completing a layer, the jobs return to the first machine and go through all machines again, thus completing the second layer, and so on. The jobs are allocated to a set of factories, where each factory has the same machine configurations. Each job also has the same operation sequence, and true to the flow shop configuration, the operation is always processed by the machine Therefore, each job can be allocated to any factory.

Related Works- The RFS scheduling has recently received more attention as it is viewed as a solution for the scheduling problem in high-tech industries. It is extensively applied for the fabrication of electronic parts, such as semiconductor manufacturing enterprises, printed circuit boards, and thin film transistor liquid Multi-objective distributed reentrant permutation flow shop scheduling 3 crystal display panels [5]. It also has other applications in the coating and printing processes in the tinplate printing industry (Qian, Li, Hu, 2017).

The process is described in three operations: surface treatment, printing, and drying, in which the products visit each stage twice for printing in both sides. Characterized by expensive equipment and reentrant flows, the RFS problems require more attention than the classical flow shop scheduling. The nature of reentrant flows, which allows the repeated process of the same job in the same machine, often causes conflicts among jobs when those with higher layers overlap other jobs at the same workstations. Therefore, the prohibition of job overtaking should be properly defined.Depending on the number of machines used in each stage, the RFS can be categorized into two cases: the classical RFS with one machine at each stage and the reentrant hybrid flow shop (RHFS) that utilizes parallel machines in all or some stations. Various studies have successfully addressed the RHFS in a single-objective environment (Chamnanlor, Sethanan, Gen, Chien, 2017; Zhou, Hu, Zhong, 2018) and in multi-objective cases (Ying, Lin, Wan, 2014; Cho Jeong, 2017). Despite its effectiveness in tackling real world problems and increasing the flexibility of the manufacturing line, the RHFS still assumes that all machines are placed in the same/nearby location.

Meanwhile, there is a growing concern that manufacturers may employ more than one factory or production centers, which are often independent to one another. In this case, the optimum production planning concerns the scheduling in each factory and the production allocation. Within this condition, the RFS is not sufficient to be applied because it only concerns a single manufacturing line. The problem concerning the production allocation and scheduling of multiple factories is manifested in the distributed manufacturing scheduling. In recent times, the distributed manufacturing has been addressed extensively and proposed to solve the key issue in the modern manufacturing wherelarge companies have several production centers. The more specific case of distributed manufacturing scheduling is the DPFS, or the distributed variants of permutation flow shop scheduling.

Naderi and Ruiz (2010) defined the DPFS as a system consisting of identical factories, each one with the same machine flow shop, with uniform processing time between factories. Due to its complexity, recent studies that have dealt with the DPFS preferred to develop meta heuristics, such as the greedy randomized adaptive search procedure with biased-randomized semi heuristic (Gonzalez-Neira, Ferone, Hatami, Juan, 2017), collaborative optimization algorithm (Chen, Wang, Peng, 2019), improved artificial bee colony (Li, Bai, Duan, 5 Sang, Han, Zheng, 2019), iterated greedy methods (Ruiz, Pan, Naderi, 2019), and cooperative co evolution algorithm (Zheng, Wang, Wang, 2020).

Regarding the problem concerned, some studies presented the distributed hybrid flow shop scheduling (Ying Lin, 2018; Lei Wang, 2019; Cai, Zhou, Lei, 2020). This environment extends the multi-factory setting of DPFS with the rule of a hybrid flow shop where there may be multiprocessor in each stage. Rifai et al. (2016) addressed both issues of RFS and distributed manufacturingby combining the RFS with the DPFS, called DRPFS scheduling. The modelwas developed to solve the multi-objective problem, with the minimization of the makespan, cost, and tardiness as the selected objective functions. Themodel was built under the assumption that only the maximum number of factories is regulated. Therefore, three interrelated decisions need to be taken number of factories to be used, production allocation of selected factories, andsequence of jobs assigned to each factory.Despite the enormous number of studies addressing reentrant and distributed flow shop scheduling, most studies seldom consider the incorporation of the non-uniform and sequence-dependent setup times.

Meanwhile, thesequence-dependent setup time is more prevalent in real industrial applications because the setup operations are not only often required between jobs, but they are also strongly dependent on the immediately preceding processon the same machine (Naderi, Zandieh, Fatemi Ghomi, 2009). Thus, thegenerated schedule should be equipped with more effective and economicalsequences (Naderi, Ghomi, Aminnayeri, Zandieh, 2011). Hekmatfar, FatemiGhomi, Karimi (2011) were the first to add the sequence-dependent setup timefor the RFS scheduling problem. In the DPFS scheduling, Duan, Li, Yang, Liu, Wang (2017) added machine blocking and job sequence-dependent setup timeconstraints. Shao, Pi, Shao (2019) presented a model with consideration ofno-wait and sequence-dependent setup times for multi-objective DPFS.3

Conclusion-The consideration of sequence-dependent setup time in the reentrant settingis critical as the bad sequence of job processing is severely penalized through a significantly longer setup time. Consecutively, it will affect the longer makespanand higher tardiness. Besides makespan and tardiness, the total cost attributedto the use of distributed scheduling is also considered as an objective. Becausethe costs have trade-off effects with the makespan and tardiness, the DRPFS is presented as a multi-objective problem. In the future, the current model can be extended to cover the RHFS withparallel machine. Thus, it has three decisions to be optimized: (1) job assignment to available factories, (2) determining the operation sequence of jobs ineach factory, and (3) allocation of jobs to the parallel machine at each stage. Tosolve such complex problem, the development of an effective exact algorithmand the other approximation algorithms needs further exploration. Anotherextension that can be pursued is assessing the applicability of the proposedalgorithm for different types of distributed scheduling, such as distributedmixed blocking flow-shop scheduling problem and distributed vehicle routingproblems in prefabricated systems. Because the heuristics of the large neighbourhood search may be problem dependent, new destroy and repair methodsshould be investigated for further applications.

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