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Two-stage multiprocessor flow shop scheduling with deteriorating maintenance in cleaner production

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ABSTRACT

Cleaner production has become popular since the global warming problem resulted from most industrial activities. This study proposes an environment of two-stage multiprocessor flow shop scheduling, which allows multiple identical parallel machines in each station, thus enhancing efficiency and resulting in cleaner production. The considerable research interest in the topic of parallel machines suggests that these machines may be highly efficient and effective. Appropriately scheduling deteriorating maintenance activity on parallel machines is necessary to prevent excessive energy consumption and minimize makespan, which is necessary for clean production. Improved processes in the development and use of deteriorating maintenance procedures lead to improved efficiency. Computational results indicate that the proposed method outperforms ant colony optimization and particle swarm optimization with respect to the effectiveness and robustness of clean production. Saving energy can prevent excessive waste. This study demonstrated that the scheduling problem on parallel machines with deteriorating maintenance activity can be solved efficiently in an environment-friendly and economical manner.

1. Introduction

Production scheduling in cleaner production, that is critical to production activity, offers benefit to coherent process jobs on machine when maximizing effectiveness (He et al., 2015). Apart from production scheduling, scheduling problems include other critical applications that appreciably affect operating efficiency in practical situations. A flow shop with multiprocessors (FSMP) provides multiple identical parallel machines at each station to increase capacity and reduce costs. Flow shop processing involves constant sequences of initial, standard, steady and nonpermutable production that are common in real-world situations. However, the deterioration of machines affects efficiency and quality of production; for example, the accumulation of dust on machine parts leads to increased temperature, the wearing of parts, and improper manual operation. Mosheiov (2001) was the first to demonstrated the deterioration concept. Wang and Cheng (2007) considered learning and deterioration outcomes in a single-machine environment and investigated the flow shop scheduling problem by using polynomial solutions to minimize the total completion time, weighted total completion time, and tardiness. Chang et al. (2009) obtained two lower bounds for the learning or aging effect to solve an n-job single-machine scheduling with a common due date. The proposed method minimized earliness and tardiness and computational test results demonstrated the efficiency of the method. Increasing attention has focused on developing clean production techniques and thus protecting the environment (Zhang and Chiong, 2016; Liu et al., 2014; Shrouf et al., 2014; Mukund Nilakantan et al., 2015; Liu et al., 2015). The FSMP can save energy and lower manufacturing costs by reducing the completion time and inventory in industrial environments (Sproedt et al., 2015).

Besides, heuristic algorithms have replaced enumeration owing to their rapid search abilities, and are widely applied to solve large scale or complex problems like flow shop with multiprocessors scheduling. The main heuristic algorithms include ant colony optimization (ACO), genetic algorithm (GA), tabu search (TS) and simulated annealing (SA), and all obtain time-efficient near-optimal solutions. He et al. (2015) demonstrated that the environmental load resulting from energy consumption during machine tool systems is broadly recognized. Improving scheduling saves energy, selects other machine tools, and reduces the idle energy consumption. He et al. (2015) proposed an energy-saving

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optimization method involving machine tool selection and a series of machining operations for flexible job shops. The method sought to reduce the energy consumption of machining operations, and the scheduling was aimed at reducing the unused power consumption of machine tools. Furthermore, a mathematical model based on mixed integer programming was used to reduce power consumption by minimizing the makespan. The proposed method estimated on the basis of two conditions, different power optimization procedures, and the makespan. Results indicated that the proposed method can help achieve energy savings for a flexible machining job shop. The current study investigated how to approach the deteriorating maintenance activity of parallel machines to promote clean production.

The novelty of this study is considering the deterioration and maintenance constraints in clean production situation. The more well-scheduled deterioration and maintenance, the more benefit enterprises earn. To verify the deterioration and ensure the effective operation of production equipment, companies create effective and efficient production environments, which maximize corporate benefits from production activities. Zhao and Tang (2010) considered a single machine with a job contingency and investigated the deterioration scheduling problem by using a polynomial time algorithm. Their objective was to minimize the makespan. Computational results indicated that their method was reliable and effective for solving the scheduling problem. Yang and Yang (2010a) also proposed a polynomial method for solving a single machine scheduling problem involving deterioration effects and deteriorating maintenance. The objective was to minimize the makespan and determine the optimal maintenance position. Test results indicated that the method had high capacity. Yang and Yang (2010b) developed a polynomial method for solving a single-machine scheduling problem involving a position-dependent aging effect and variable maintenance duration. The results revealed that the method effectively minimized the makespan and identified the optimal maintenance position. Yang (2010) proposed a polynomial time algorithm to solve a single-machine scheduling problem involving deterioration effects and deteriorating maintenance. The objective was to search for the best start time-dependent learning effect of machines, and minimize makespan, and total absolute deviation of completion times. Computational results showed that the proposed approach had high effectiveness and efficiency. Yang et al. (2010) proposed a polynomial time algorithm for solving a single-machine due-window assignment and scheduling problem with job-dependent aging effects and deteriorating maintenance. The objective was to search for the best maintenance point under due-window constraints and minimize the costs of earliness, tardiness, and the due-window. Computational results revealed that the proposed method solved the problem efficiently.

Zhao and Tang (2012) investigated two-machine flow shop scheduling problems with deteriorating jobs and chain precedence constraints. They considered two types of precedence constraints. Under one type constraint, a predecessor should have been completed on the same machine before its successor starts on a machine. Under the second type, a successor cannot start on any machine before its predecessor has been completed on all machines. Experimental results showed that the problem with the first type precedence constraints was polynomially solvable, and that the problem with the second type of precedence constraints was NP-hard. Sicilia et al. (2013) developed a mathematical model for studying the optimal replenishment policy for an economic order quantity system by considering deteriorated items. The aim of this study was to minimize the inventory average total cost per unit time. Computational results confirmed the efficiency of the approach. This study considered deteriorations that reduced the efficiency of machines and increments of defectives in practical situations under machine maintenance constraints. Ribas et al. (2013) proposed a two-variable neighborhood search (VNS) method for solving the blocking flow shop problem; they used serial VNS, which involves PW/PWE2, for generating the initial solution. Computational results indicated that the proposed algorithm was very competitive.

By applying the deteriorating maintenance constraint to clean production, the current study attempted to minimize makespan costs. A cluster particle swarm optimization algorithm (CPSO) is proposed for solving two-stage multiprocessor flow shop scheduling problems and thus minimizing makespan costs. Ant colony optimization (ACO) and particle swarm optimization (PSO) were compared with the proposed optimization to obtain superior solutions for the attempted problems and aid enterprises to increase profits and lower overhead costs. This study compared the proposed solution with two previously reported solutions that yielded comparable improvements. Lian (2010) obtained average relative error rates of −28.20% and 60.25% for the local and global combine particle swarm optimization algorithm against particle swarm optimization and genetic algorithms, respectively. Zhang et al. (2010) presented an I-ATTPSO algorithm with an average effectiveness improvement rate of −14% in small-scale problem and 55% for a large-scale problem. Liu et al. (2011) obtained an average relative error rates of 0.65% for the PSO-EDA_PI algorithm against other algorithms. Zhao et al. (2014) found the average relative error rate of the logistic dynamic particle swarm optimization algorithm, which they proposed, against other algorithms to be approximately 1.19−2.39%.

The remainder of the paper is organized as follows: In Section 2, the FSMP is formulated. In Section 3, the basic algorithms are introduced briefly. Then, the framework of CPSO for solving the FSMP is proposed in Section 4. The influence of parameter setting is investigated based on design of experiment testing in Section 4, and computational results and comparisons are provided as well. Finally, we end the paper with some conclusions in Section 5.

2. Problem definition

The two-stage flow shop problem provides multiple identical parallel machines in each station to increase capacity and reduce costs in cleaner production. All jobs can choose one machine in every station and begin process from the first station. After the last job completed in second stage, all jobs are completed.

The scope and constraints of this study are demonstrated as follows:

1. Number of jobs, machines and stages are known.
2. Processing time of each job on each machine is known and constant.
3. Each machine in each stage can only process one job simultaneously.
4. The sequence through which jobs pass through machines may differ with the sequence of machine receiving job.
5. Jobs cannot be preempted.
6. There is no permutation, or machine breakdown.
7. The job ready time is 0.

The problem examined in this study can be defined as: $F_2(P_1,P_2)|ma, p_{ij} = \overline{p}_{ij} + u_{ij}|C_{\max}$, where n jobs with P_{ij} processing time are processed in a $F_2(P_1,P_2)$ two-stage parallel flow shop environment comprising P_1 machines in the first stage, P_2 machines in the second stage, ma for deterioration and deteriorating maintenance. $p_{ij} = \overline{p}_{ij} + u_{ij}$ represents the P_{ij} processing time, which is summation of original processing time, regardless of deterioration