Applied Soft Computing 40 (2016) 319–330

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

Two meta-heuristic algorithms for flexible flow shop scheduling problem with robotic transportation and release time

Seyedeh Sarah Zabihzadeh, Javad Rezaeian*

Department of Industrial Engineering, Faculty of Engineering, Mazandaran University of Science and Technology, P.O. Box 734, Babol, Iran

ARTICLE INFO

Article history:
Received 17 April 2014
Received in revised form 5 June 2015
Accepted 1 November 2015
Available online 27 November 2015

Keywords:
Flexible flow shop
Unrelated parallel machine
Robotic transportation
Eligible machine
Ant Colony Optimization
Genetic algorithm

ABSTRACT

In this research, flexible flow shop scheduling with unrelated parallel machines at each stage are considered. The number of stages and machines vary at each stage and each machine can process specific operations. In other words, machines have eligibility and parts have different release times. In addition, the blocking restriction is considered for the problem. Parts should pass each stage and process on only one machine at each stage. In the proposed problem, transportation of parts, loading and unloading parts are done by robots and the objective function is finding an optimal sequence of processing parts and robots movements to minimize the makespan and finding the closest number to the optimal number of robots. The main contribution of this study is to present the mixed integer linear programming model for the problem which considers release times for parts in scheduling area, loading and unloading times of parts which transferred by robots. New methodologies are investigated for solving the proposed model. Ant Colony Optimization (ACO) with double pheromone and genetic algorithm (GA) are proposed. Finally, two meta-heuristic algorithms are compared to each other, computational results show that the GA performs better than ACO and the near optimal numbers of robots are determined.

1. Introduction

Due to the development of science and industry, the manufacturing sector tries to use automatic devices in processing, transportation, inspection and so on; they try to minimize production cost and makespan. Therefore, they need to design a plan to meet these goals. In many manufacture and assembly parts, many operations perform on parts, and machines placed in series. In many of these cases, these operations have to be done on all parts in the same processing sequence. Therefore, all parts should have the same path for processing. These sequences of machines are referred as flow shop (FS). Machines can be placed in parallel at each stage to facilitate the processing of parts and reduction of processing time; and parts have to be processed at each stage only on one of the machines, and these sequences of machines are referred as flexible flow shop (FFS). In fact, all machines may have not the ability to perform all activities. Therefore, unrelated parallel machine can be used at each stage. Unrelated machines may perform the same operations, but they generally require different processing times for the same operations. Inspection of resources can be performed by one or more robots in some automated manufacturing system. Cells involving robots for inspecting resources are termed as robotic cells (RCs).

In this study, flexible flow shop is considered with unrelated parallel machines. Unloading, transferring and loading parts are performed by robots; and the objective of the problem is finding an optimal sequence of processing parts and robots movement for minimizing the makespan and finding the closest number to the optimal number of robots.

There are several researches that studied multiple part-type production cells with transportation constraints. Gupta [1] proved that the two stage hybrid flow shop scheduling problem is NP-hard in a strong sense even if there is only one machine on first stage and two machines on the second stage. Kalczynski and Kamburowski [2] presented that a two-machine flow shop with release times and objective of minimizing the makespan is strongly NP-hard. They also presented a new heuristic with short worst-case running time. Engin et al. [3] studied the hybrid flow shop scheduling with multiprocessor task (HFSMT) problem for minimizing the makespan. They showed these kinds of problems are NP-hard and developed an efficient genetic algorithm to solve the problem. Marichelvam et al. [4] studied the multistage hybrid flow shop (HFS) scheduling problem and proved these kinds of problems are NP-hard. They developed cuckoo search (CS) meta-heuristic algorithm to minimize the makespan. They used the data from a leading furniture manufacturing company. Pan and Huang [5]

* Corresponding author. Tel.: +98 9111571257.
E-mail address: j_Rezaeian@ustmb.ac.ir (J. Rezaeian).

http://dx.doi.org/10.1016/j.asoc.2015.11.008
1568-4946/

considered no-wait job shop scheduling problems and the objective is minimizing the total completion time. They showed the problem is NP-hard and used a hybrid genetic algorithm to solve the problem. Knust [6] solved a special case of hybrid flow shop problem with automatic transportation, and showed that different samples with single transportation source are NP-hard. Soukhal et al. [7] investigated two machines flow shop scheduling problems with transportation. They proved that the mentioned problem with additional constraints, such as blocking, is also strongly NP-hard.

Cheng et al. [8] considered the three-machine permutation flow shop scheduling problem with release times where the objective is to minimize makespan. The branch and bound algorithm proposed and combined an adaptive branching rule with a fuzzy search strategy to narrow the search tree and lead the search to an optimal solution as early as possible. Kashyrskikh et al. [9] considered the two-machine flow shop sequencing problem with arbitrary release times of jobs and the minimum makespan criterion. They showed this problem is NP-hard and studied the performance and running times. Behnamian and Fatemi Ghomi [10] developed a PSO–SA hybrid meta-heuristic for a new comprehensive regression model to time-series forecasting.

Sangsawang et al. [11] studied the two-stage reentrant flexible flow shop (RFFS) with blocking constraint. The objective is minimizing the makespan. The hybridization of GA (HGA: hybrid genetic algorithm) with adaptive auto-tuning based on fuzzy logic controller and the hybridization of PSO (HPSO: hybrid particle swarm optimization) with Cauchy distribution were developed to solve the problem. Moslehi and Khorasanian [12] considered blocking flow shop scheduling problem to optimize the total completion time criterion. They presented two mixed binary integer programming models, one of them is based on the departure times of jobs from machines, and the other is based on the idle and blocking times of jobs. Guanlong et al. [13] proposed a discrete artificial bee colony algorithm for solving the blocking flow shop scheduling problem with total flow time criterion. Wang et al. [14] suggested a hybrid modified global-best harmony search (hmgHS) algorithm for solving the blocking permutation flow shop scheduling problem with the makespan criterion. Wang et al. [15] proposed a novel hybrid discrete differential evolution (HDDE) algorithm for solving blocking flow shop scheduling problems to minimize makespan and developed the efficiency of the whole algorithm. Grabowski and Pempera [16] developed a fast tabu search algorithm to minimize makespan in a flow shop problem with blocking. Pan et al. [17] presented a novel discrete differential evolution (DDE) algorithm for solving the no-wait flow shop scheduling problems with makespan and maximum tardiness criteria.

Hurink and Knust [18] studied flow shop scheduling with transportation times and a single transportation source. Moreover, they assumed an unlimited buffer space between the machines and negligible empty moving times. Soukhal and Martineau [19] considered flow shop robotic cell scheduling problem with multiple parts and a single robot. They assumed that there are no buffers between the machines and proposed an integer linear programming model and a genetic algorithm to solve the problem. Carlier et al. [20] studied the same problem and presented several lower bounds and also proposed an exact branch and bound algorithm. Additionally, they proposed a two-phase genetic algorithm to solve the same problem in which the first phase solves blocking flow shop scheduling problem and the second phase determines the sequence of robot moves.

Kharbeche et al. [21] proposed an exact branch and bound algorithm for the flow shop robotic cell scheduling problem where a single robot is considered. In addition they proposed a genetic algorithm to solve the large scale problems in shorter time. Moreover, Geismar et al. [22] considered robotic cells with parallel machines and multiple dual gripper robots. In contrast, they asserted that the assignment of processing stages to robots can have a significant effect on the potential throughput of a cell.

Agnetis [23] and Agnetis and Pacciarelli [24] investigated the complexity of a no-wait flow shop problem in which one robot is used to move the parts from a machine to the next, as well as between the machines and the input/output devices.

Lawler et al. [25] considered different scheduling problems of manufacturing systems and provided a survey for the investigated algorithms. Inna et al. [26] considered the problem with robotic cells with input and output machine buffers. The machines and buffers are served by one single gripper robot. The objective was to find a cyclic sequence of robot moves that minimizes the long-run average time to produce a part or, equivalently, maximizes throughput.

Dawande et al. [27] focused on cyclic production and provided a survey on robotic cell scheduling problem. Batur et al. [28] considered the scheduling problem in two-machine robotic cells producing multiple parts. They proposed a two-stage heuristic to optimize the cycle time. Geismer et al. [29] considered the cyclic flow shop robotic cells with parallel machines and constant travel time. Geismer et al. [30] also considered the same problem with more robots. Elmi and Topaloglu [31] considered hybrid flow shop problem with robotic cells.

Ruiz and Vazquez-Rodriguez [32] stated that the properties of graph representation in hybrid flow shop scheduling problem, implied by critical block theory can be used to speed up the search procedure.

Low et al. [33] considered hybrid flow shop scheduling problem and consist unrelated alternative machines on the first stage and one machine on second stage. Kurz and Askin [34] considered flexible flow lines with sequence-dependent setup times. They also developed a random key genetic algorithm to effectively solve the problem. Hekmatfar et al. [35] considered a two-stage reentrant hybrid flow shop scheduling problem. The first stage is a reentrant shop which all jobs have the same routing over the machines of the shop and the same sequence is traversed several times to complete different levels of the jobs and in stage two, there is a station with m_2 identical parallel machines. The objective function is to minimize the makespan of the system. A new hybrid genetic algorithm (HGA) is proposed for solving the problem.

Researchers tend to consider more complex problems which exist in industrial environments and research on practical samples. Therefore, other constraints are considered. Nikzad and Rezaeian [36] considered two-stage scheduling problem in which the first stage consists 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, and the objective function is minimizing makespan. They developed a new mathematical model for the problem and solved the problem with a hybrid meta-heuristic method as a combination of simulated annealing (SA) and imperialist competitive algorithms (ICA). Abdollahpour and Rezaeian [37] investigated flow shop scheduling problem with intermediate buffer and permutation. Minimization of makespan is considered as the objective function. The problem solved with a hybrid artificial immune system and artificial immune system (AIS-IG). Li et al. [38] considered a three-stage flexible flow shop scheduling problem, where the jobs have the group constraint at the second stage and the three stages consist of unrelated parallel machines. The performance of 10 algorithms are compared in this study.

Yang [39] considered a two-stage hybrid flow shop scheduling with dedicated machines at stage one and two machines in this stage and one machine in stage two. Yang empirically evaluated the heuristics, including an optimal algorithm for a special case. Lei [40] studied flow shop scheduling problem with two agents and its feasibility model is considered, in which the goal is to minimize