Computers & Operations Research 40 (2013) 1207–1223

Contents lists available at SciVerse ScienceDirect

Computers & Operations Research

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

Dynamic parts scheduling in multiple job shop cells considering intercell moves and flexible routes ☆

Dongni Li [a,*], Yan Wang [a], Guangxue Xiao [a], Jiafu Tang [b]

[a] Beijing Lab of Intelligent Information Technology, School of Computer Science, Beijing Institute of Technology, Beijing 100081, China
[b] National Key Laboratory of Process Industry Automation, Northeastern University, Shenyang, Liaoning 110004, China

ARTICLE INFO

Available online 27 December 2012

Keywords:
Part scheduling
Intercell move
Flexible route
Multi-agent system
Pheromone

ABSTRACT

Aiming at the problem of scheduling with flexible processing routes and exceptional parts that need to visit machines located in multiple job shop cells, a pheromone based approach (PBA) using multi-agent is presented in this paper, in which various types of pheromone inspired by ant colony optimization (ACO) are adopted as the basis of negotiation among agents. By removing redundant routes and constructing coalition agents, communication cost and negotiation complexity are reduced, and more importantly, the global performance of scheduling is improved. The performance of the PBA is evaluated via experiments with respect to the mean flow time, maximum completion time, mean tardiness, ratio of tardy parts, and ratio of intercell moves. Computational results show that compared with various heuristics, the PBA has significant advantages with respect to the performance measures considered in this paper.

1. Introduction

The issues in cellular manufacturing system (CMS) can be broadly divided into two branches [1,2], i.e. cell design which includes cell formation and cell layout, and cell operation which deals with planning and scheduling in CMS. Of these issues, the scheduling problem plays an important role in implementing an effective CMS. Nevertheless, this area has not been attempted widely in the literature as compared to the cell design problem. The objective of scheduling in cells is to identify a sequence of parts in part families that optimizes some measures of effectiveness, such as makespan, total weighted flow time, total weighted tardiness, etc. There are two types with regarding cell layout, i.e. flow-line layout and job shop layout. Accordingly, the scheduling problem in CMS is attempted in flow-line layout and job shop layout, respectively.

Most of the researchers addressed this problem in a flow-line manufacturing cell. Baker considered the problem in a two-machine flow-line cell, and time lags or sequence-independent setup times were considered [3]. Wemmerlov and Vakharia developed two heuristic procedures for part family scheduling in a flow-line manufacturing cell with three or more machines, and both procedures were extensions of flow shop scheduling to include a family sequence [4]. Skorin-Kapov and Vakharia developed six tabu search heuristic procedures [5], and Sridhar and Rajendran developed a genetic algorithm for scheduling of parts in a flow-line manufacturing cell for the objective of minimizing makespan [6]. Logendran et al. and Schaller investigated and compared the performance of several combined heuristics for scheduling parts within a part family in a flow-line cell [7,8]. Reddy and Narendran proposed a heuristic for scheduling parts considering sequence-dependent setup times to improve the use of machines within a flowline cell [9]. Logendran et al. developed a LN-PT method to minimize the makespan in a flexible flow shop with regard to single setup and multiple setups on machines [10]. Logendran et al. developed a tabu search algorithm to solve the sequence-dependent group scheduling problem in flexible flow shops [11]. Gupta and Schaller proposed a branch-and-bound algorithm capable of solving the moderate sized problems with independent setup times in a flow-line manufacturing cell [12]. Hendizadeh et al. proposed a tabu search meta-heuristic to minimize the makespan in the presence of sequence-dependent family setup times [13]. Venkataramanaiah developed a simulated annealing-based algorithm considering three objectives as minimizing weighted sum of makespan, total flow time, idle time [14]. Zandieh et al. proposed three meta-heuristics based on tabu search, simulated annealing, and genetic algorithm, and applied them to the group scheduling problem considering sequence dependent setup times [15]. Karimi et al. proposed a multi-phase genetic algorithm to optimize the makespan and total weighted tardiness in flexible flow shop [16]. Ying et al. considered permutation and non-permutation

☆ Supported by National Defense Basic Scientific Research (A0920110023) and Natural Science Foundation of Beijing (4122069).

* Corresponding author. Tel.: +86 186 1819 4058.
E-mail addresses: ldn@bit.edu.cn (D. Li), wyamy815@gmail.com (Y. Wang), xiaoguangxue@gmail.com (G. Xiao), jftang@mail.neu.edu.cn (J. Tang).

0305-0548/$ - see front matter Crown Copyright © 2012 Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.cor.2012.11.024

schedules for the flowline manufacturing cell with sequence dependent family setups [17]. Lin et al. proposed three meta-heuristics based on tabu search, simulated annealing, and genetic algorithm for scheduling a non-permutation flowline manufacturing cell in the presence of sequence dependent family setup times [18]. Zandieh and Karimi proposed an adaptive multi-population genetic algorithm to solve the multi-objective group scheduling problem in hybrid flexible flowshop with sequence-dependent setup times by minimizing total weighted tardiness and maximum completion time simultaneously [19]. Salmasi et al. used a mathematical programming model for minimizing the total flow time to solve the flow shop group scheduling problem [20].

A few researchers addressed this scheduling problem in a job-shop manufacturing cell. Mahmood et al. developed dynamic scheduling heuristics to stress good due date performance while reducing overall setup time in a job shop cell [21]. Tsai and Li presented a due-date oriented scheduling heuristic algorithm for a job-shop CMS based on capacity constraint resource [22]. Naumann and Gu applied fuzzy logic to real-time part dispatching in cells [23]. Bo et al. considered the scheduling problem in CMS under fuzzy constraint based on group technology [24]. Gou et al. developed a Lagrange relaxation based approach to solve the problem in job shop cells in CMS [25]. Kesen et al. proposed a genetic algorithm based heuristic for scheduling of virtual manufacturing cells [26].

The above researches assumed that all parts in a part family are processed in one cell and there is no intercell move. Ideally, all machines required for producing a part can be allocated to a cell. However, this is hard to achieve in practice because parts processed in different cells may all require a particular machine [27]. Although the difficulty can be resolved by purchasing additional machines, it may not be economical to achieve such a cell independence. Thus, it is not unusual to transport parts between two or more cells. The parts required processing on machines in two or more cells are termed exceptional parts in this paper. Such a movement of exceptional part is usually called intercell move. The interaction between cells caused by the existence of exceptional parts disrupts the CM philosophy of creating independent cells, but it is essential for enterprises to reduce production cost. So there is a need to study scheduling in the context of multiple cells [28]. There has been relatively little research on the scheduling problem considering multiple cells and intercell moves.

Some researchers considered this problem in the context of multiple flow-line cells with intercell moves. Yang and Liao proposed a branch-and-bound approach to solve the problem [29]. They assumed that a CMS consists of two cells and each part cannot have more than one operation in each cell, however, a CMS usually contains multiple cells and each part might have more than one operation in a cell. Solimanpur et al. developed a heuristic to solve the problem and evaluated its performance by comparing to LN-PT method [30]. They assumed that the intercell moves cannot happen until the destination cells have completed processing all the parts originally assigned to them, however, intercell moves may occur at anytime in practice. Tavakkoli-Moghaddam et al. proposed a scatter search algorithm in the context of multi-criteria considering makespan, intracellular movement, tardiness, and sequence dependent setup costs simultaneously [31]. They considered the problem as consisting of two distinct subproblems, i.e. intracell scheduling which determines the sequence of parts within cells and intercell scheduling which determines the sequence of cells.

Actually, each part may have a different required sequencing of operations. A few researchers addressed this problem in the context of multiple job shop cells with intercell moves. Tang et al. proposed a non-linear programming model and developed a meta-heuristic based on scatter search to solve the problem [1]. Based on the problem model presented by Tang et al., Elmi et al. proposed an integer linear programming model and developed a simulated annealing based approach to solve the problem in which parts are allowed to visit machines more than once in the non-consecutive manner [2].

However, it was assumed in the above researches that the intercell routes are known and fixed. Actually, it is more often in real production environment that a given operation can be performed by more than one machine due to the overlapping capabilities of machines, which was defined as 'flexible routing' by Lin and Solberg [32]. Though flexible routes are common in practice, they have not been attempted in the intercell scheduling problems.

Therefore, this paper addresses the problem of intercell parts scheduling with flexible routes. To our limited knowledge, this is the first paper considering flexible routes and intercell moves simultaneously.

The approaches working on routing flexibility can be categorized into four types with respect to their solution strategy, i.e. heuristic rules, soft computing approaches, multi-agent systems, and the combination of the above approaches.

Heuristic rules: Heuristic rules have been shown to be efficient by several studies for dynamic scheduling with flexible routing. In these methods, the priority of each operation is calculated using the current state of the production environment. Based on the priority index, an operation from a specified set of operations is chosen to route or sequence next. Tunali selected machines by 11 heuristic rules and sequenced parts by the first-in-first-out (FIFO) rule [33]. Subramaniam et al. investigated three machine selection rules in a dynamic job shop [34]: lowest average cost (LAC), least average process time (LAP), and least aggregate cost and process time (LACP). Under each rule, queues were sequenced by four dispatching rules: random, FIFO, earliest due-date (EDD), and shortest processing time (SPT). Tuncel selected suitable route by heuristic rules for parts with flexible routings [35].

Soft computing approaches: Soft computing approaches feature largely in non-precise, non-deterministic, and near optimal. Jawahar et al. [36], Morad and Zalzala [37], and Candido et al. [38] used genetic algorithms to make scheduling decisions. By reasonably hybridizing particle swarm optimization and simulated annealing, Xia and Wu developed a hybrid approach for the multi-objective flexible job-shop scheduling problem [39]. Zhang et al. used combination of a particle swarm optimization algorithm and a tabu search algorithm to solve the multi-objective flexible job-shop scheduling problem with several conflicting and incommensurable objectives [40].

Multi-agent system (*MAS*): MAS approaches have the advantages of accomplishing real-time planning and scheduling with great flexibility and robustness. A multi-agent system achieves its flexibility, robustness, and responsiveness through coordination among agents in the system. Lin and Solberg presented an integrated shop floor control and simulation system based on autonomous agents to explore routing flexibility [41]. The agents negotiated with each other to allocate jobs based on negotiation protocols and built-in price adjustment algorithms. MacChiaroli and Riemma reported an iterative auction-based model (ABM) for dynamic manufacturing scheduling [42]. Agents in the model achieve a schedule based on an iterative bidding process. Wang and Usher modeled both jobs and machines as agents which negotiated with each other using the contract-net protocol [43]. Siwamogsatham and Saygin presented an iterative auction-based algorithm for real-time scheduling of flexible manufacturing systems with alternate routings [44]. A multi-agent scheduling system was developed for solution in a flexible job shop problem considering dynamic events in Rajabinasab and Mansour [45]. They proposed a pheromone based approach for coordination among agents.