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The "Dual-Ants Colony": A novel hybrid approach for the flexible job shop scheduling problem with preventive maintenance

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ABSTRACT

Due to their importance in the fields of both manufacturing industries and operations research, production scheduling and maintenance planning have received considerable attention both in academia and in industry. This paper investigates the Flexible Job Shop Scheduling Problem (FJSSP) with machine unavailability constraints due to Preventive Maintenance (PM) activities, under the objective of minimizing the makespan. We propose two new formulations: the first one in the form of a Mixed Integer Nonlinear Program (MINLP) and the second corresponding to a bi-level disjunctive/conjunctive graph. To deal with this variant FJSSP with PMs (FJSSP/PM), we develop the "Dual-Ants Colony" (DAC), a novel hybrid Ant Colony Optimization (ACO) approach with dynamic history, based on an ants system with dual activities. This optimization provides an effective integration of a local search and a set of dispatching rules. Three regular performance measures are also implemented. To show the efficiency of the DAC algorithm, computational experiments are carried out on a large range of well-known benchmarks from the literature and others newly generated. We address first the classical JSSP case, then the flexible FJSSP for partial flexibility. Finally, we study the case with preventive maintenance based on well-chosen PM periods. Obtained results demonstrate the viability and performance of the proposed approach, especially for the FJSSP/PM.

1. Introduction

Good coordination of logistics activities on the shop floor is strongly required at all levels of manufacturing and has become an important decision (Dabia, Talbi, van Woensel, & De Kok, 2013; Harjunkoski et al., 2014; Pinedo, 2008; Pratap, Nayak, Cheikhrouhou, & Tiwari, 2015). Furthermore, the quality and maintenance of manufacturing systems are closely related functions of any organization (Alrabghi & Tiwari, 2015; Froger, Gendreau, Mendoza, Pinson, & Rousseau, 2016; Meng & Pian, 2016, chap. 8).

From both the theoretical and the practical points of view, the Job Shop Scheduling Problem (JSSP) represents one of the most common scheduling models existing in industry applications (Beasley, 1990; Jain & Meeran, 1999; Jamili, 2016; Udomsakdigool & Kachitvichyanukul, 2008). Generally, in the classical JSSP, a set of independent jobs (each one having its own processing order) has to be processed through a set of several machines; the aim is to determine a sequence of operations on each machine, subject to precedence constraints, in order to optimize one or multiple objectives. A central assumption is that every operation has to be processed on one predetermined machine. The actual relevance to a modern production environment that assumes a more flexible set-up is problematic. In practice, there is often more than one machine that is able to process a particular manufacturing operation. As an extension and generalization of the classical JSSP, the FJSSP is equally known to be NP-hard, and is challenging due to expanding machine tool capabilities and increased product variety (Billaut, Moukrim, & Sanlaville, 2008; Shahsavari-Pour & Ghasemishabankareh, 2013; Sobeyko & Mönch, 2016; Trentesaux et al., 2013). In this case – prior to the sequencing of operations – an assignment to machines is necessary.

Moreover, in most real-life industrial settings, machines may be unavailable due to unforeseen breakdowns (stochastic unavailability) or due to their need for scheduled PM activities, where the

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corresponding unavailability periods are known in advance (deterministic unavailability). Generally, PMs are planned for time intervals of the planning horizon, to restore the reliability of a machine before it breaks down, in order to maintain the equipment as well as the shop and provide better overall availability. It should be noted that in some systems maintenance can only be done if all the production lines are stopped. In other management policies, maintenance and production are planned jointly. However, it is important to integrate production decisions into developing optimal PM policies (Aggoune, 2002; Mollahassani-pour, Abdollahi, & Rashidinejad, 2014; Xiao, Song, Chen, & Coit, 2016). Some authors assume that all machines must be maintained simultaneously, while others study the relaxed version where machines are not restricted to be maintained at the same time.

The manufacturing setting studied in this paper is a generalized variant of the FJSSP, considering machines' unavailability constraints due to PM activities (FJSSP/PM). We adopt a joint 'mainte nance/production' planning policy to enhance the effectiveness of a global organization on a shop floor. Our purpose is to simultaneously sequence jobs and schedule maintenance activities to optimize the makespan. In the present study, a formulation as an MINLP and a bi-level disjunctive/conjunctive graph are proposed. For the resolution, we develop a novel hybrid ACO approach with dynamic history, based on an ants system with dual activities, and which provides an effective integration of a local search and a set of dispatching rules. The approach incorporates numerous dispatching rules in order to study different management policies. Integrated local search deals with the introduction of intelligent mutations operators to improve the solutions generated after every cycle of the resolution algorithm. Three regular performance measures are also applied. To validate the proposed algorithm, several sets of problem instances have been considered and various computational experiments are performed.

The remainder of this paper is organized as follows. A brief literature review is presented in Section 2. After a statement of the studied problem in Section 3, we present in Section 4 the implemented assumptions and notation as well as all details of the new adapted mathematical formulation. The bi-level disjunctive/conjunctive graph and the framework of the proposed resolution approach are described in Section 5. Section 6 deals with a comparative study of the performed computational results. Finally, the last section is devoted to the conclusion and some directions for future research.

2. Related works

Extensively in the literature, scheduling problems have been discussed under the assumption that machines are continuously available. Current trends are towards integrating practical constraints in traditional scheduling models. One of these constraints that has attracted researchers during the last decade is the unavailability of machines. Much of the research in this area is focused on PMs and considerable research has been devoted to the Job Shop environments. A polynomial algorithm for the non-preemptive JSSP with two jobs is proposed in Aggoune (2002). This algorithm is used to develop a heuristic for solving the general case with multiple jobs. The work of Harrath (2003) also contributes to the joint scheduling of production and maintenance, as does that of Naderi, Khalili, and Tavakkoli-Moghaddam (2009) for realistic variations of the JSSP. Ma, Chu, and Zuo (2010) present a survey summarizing the complexity results of exact and approximation algorithms on a set of deterministic scheduling problems with PMs. The studies focus on single machine, parallel machines, Flow Shop, Open Shop and Job Shop environments, subject to numerous criteria. In the same year, Mati (2010) aimed at minimizing the makespan in a non-preemptive JSSP with limited availability of machines. To represent schedules, the disjunctive graph model is used and the concept of blocks is generalized to include the unavailability periods of machines. A taboo thresholding heuristic with a new block-based neighbourhood function is developed to solve the problem. The fuzzy JSSP with availability constraints is investigated in Lei (2010). The author proposes a random key genetic algorithm, in which a novel random key representation, a new decoding strategy incorporating maintenance operation, and discrete crossover are used. The objective is to find a schedule that maximizes the minimum agreement index subject to periodic maintenance, non-resumable[1] jobs and fuzzy due-date. Based on dynamic programming and on short-term optimization, a dynamic opportunistic PM model for the multi-component systems under a changing Job Shop schedule is proposed in Zhou, Lu, and Xi (2012). In Li and Pan (2013), the JSSP with fuzzy processing time is probed. The flexible maintenance activities under both resumable and nonresumable situations are also considered to make the problem more realistic. For resolution, a hybrid chemical-reaction optimization algorithm is proposed, in which each solution is represented by a chemical molecule. Recently, Fnaiech, Fitouri, Varnier, Fnaiech, and Zerhouni (2015) presented a new heuristic method for solving the joint Job Shop scheduling of production and maintenance.

The FJSSP with machine availability constraints is studied in Gao, Gen, and Sun (2006), and in Zribi, El Kamel, and Borne (2008). In the former paper, the non-fixed unavailability periods are tackled using a hybrid genetic algorithm. The latter paper considers the fixed case and proposes a hierarchical approach that first solves the assignment problem using a heuristic based on dispatching rules, a local search algorithm is introduced to improve this assignment solution, and then a genetic algorithm is carried out to solve the sequencing problem. The same problem is also considered in Wang and Yu (2010), where each machine is subject to PM during the planning period and the starting times of maintenance are to be flexible in a time window or fixed in advance. A filtered beam search based heuristic algorithm is proposed. In the same year, the paper by Moradi, Fatemi Ghomi, and Zandieh (2010) deals with the FJSSP with PMs under makespan minimization. This study applies an enforceable and easily extendable PM policy, and an effective learnable genetic architecture is carried out, integrating FJSSP and PM. For the multi-objective FJSSP with PMs, Moradi, Fatemi Ghomi, and Zandieh (2011) attempt to simultaneously minimize the makespan for the production part and the system unavailability for the maintenance part. The study in Dalfard and Mohammadi (2012) focuses on the multi-objective FJSSP with parallel machines and maintenance cost. A new mathematical modelling was developed. Two meta-heuristic algorithms, a hybrid genetic algorithm and a simulated annealing algorithm, were applied. Another study on the multi-objective optimization case figures in Li and Pan (2012). This paper proposes an effective discrete chemical-reaction optimization algorithm for solving the FJSSP problems with maintenance activity constraints. Three minimization objectives are considered simultaneously: the makespan, the total workload of machines and the workload of the critical machine. In the same direction, an efficient heuristic algorithm is developed in Ziaee (2014), where a critical machine corresponds to the most loaded machine. A novel discrete artificial bee colony algorithm for solving the same problem is presented by Li, Pan, and Tasgetiren (2014), where the performance criteria considered are also the makespan, the total workload of machines and the workload of the critical machine. More recently, attention has been directed towards using simulation for improving and optimizing

[1] Nonresumable means that a job must be reprocessed fully after maintenance if its processing is interrupted by the maintenance activity on a machine. Resumable means that if a job cannot be finished before a maintenance activity, it can continue the processing once the maintenance activity is finished.