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Scheduling optimization of a stochastic flexible job-shop system with time-varying machine failure rate

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ABSTRACT

Due to environmental circumstances encountered in manufacturing processes, operating machines need to be maintained preventively, so as to ensure satisfactory operating condition. This paper investigates a scheduling problem in a flexible job-shop system with maintenance considerations where each operation can be processed by a machine out of a set of capable machines, and so, jobs may have alternative routes. Machine failure rates are assumed to be time-varying. This is a real assumption comes from a fact in realistic environments, where failure rate of a machine is variable when environmental situations like shop temperature, shop light, shop humidity or even worker skill change significantly. Moreover, in order to more close the addressed problem into the situations encountered in real world, the processing times and due dates are considered to be stochastic parameters. A mixed integer linear programming (MILP) model is constructed for addressed problem with the objective of number of tardy jobs and a minimum total availability constraint. Then a simulation-optimization framework based on a simulated annealing (SA) optimizer and Monte Carlo (MC) simulator is presented to solve the problem.

1. Introduction

Production and maintenance scheduling are important problems in the field of operations research in which scheduling term deals with finding the appropriate assignment and sequence of production and maintenance activities in order to optimize especial objective(s). Both problems have been handled separately in most of manufacturing literature. Maintenance planning is usually generated in maintenance systems, like computerized maintenance management systems (CMMS) regardless of detailed schedule of production activates. However, this assumption is not reasonable in real life manufacturing due to interactions encountered between production and maintenance. For example, drilling machine is one of the most important devices in the printed circuit board (PCB) manufacturing that should stop to change the micro-drill after a fixed period of processing time. It is not uncommon to observe in practice that some machines are waiting maintenance service while there are jobs waiting to be processed by these machines. Hence, simultaneous scheduling of the received jobs and the maintenance activities has become a common practice in many companies. The preventive maintenance (PM) actions help to keep production tools in good operating conditions (they increase the availability of a system) and allow decreasing the costs by avoiding unexpected failures [8]. For many years the relationship between production and maintenance has been considered as a conflict in management decisions while this conflict may result in an unsatisfied demand if the production and maintenance services do not respect the requirements of each other [9]. Therefore it is necessary to collaborate the production scheduling and the maintenance services in order to maximize system productivity and improve the manufacturing efficiency.

This paper is organized as follows. Related literature is reviewed in Section 2. Time-Varying machine failure rates will be discussed in Section 3. In Section 4, the addressed problem is defined and formulated mathematically. Section 5 describes a simulation-optimization solution approach. An illustrative example and some computational experiments are presented in Section 6. Finally, Section 7 concludes the paper.

2. Review of related literature

In today's manufacturing industries, scheduling play an important role in maximizing customer service level in a supply chain. Job-shop scheduling problem (JSSP) as a major branch of production scheduling is one of the most popular optimization problems in both academic and practical context. In a JSSP, there are n different jobs with pre-known and fixed routings has to be processed on m machines. Many researchers have investigated this problem under different assumptions and environments. Flexibility and maintenance considerations are among popular assumptions of JSSP treated in

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literature during recent years. In the sequel, we will review related works on flexibility and maintenance scheduling in detail.

2.1. Flexible job-shop problem

Flexible job-shop problem (FJSP) is a generalization of the traditional job-shop scheduling problem (JSSP) where one operation can be processed on one machine out of a set of capable machines. Therefore, it is very close to the real manufacturing situation. Because of the additional assignment decisions of operations to the machines, FJSP is at least as complex as the JSSP and therefore belongs to the class of NP-hard problems. This problem can be decomposed into two sub-problems: (i) routing sub-problem, in which each operation is assigned to a machine out of a set of capable machines and (ii) sequencing sub-problem, in which a sequence of the assigned operations is delineated on all machines in order to gain a feasible schedule optimizing special objectives [53].

The FJSP was first introduced by Brucker and Schlie [12] where a polynomial algorithm was suggested to solve the routing and sequencing sub-problems in a case of problem with two jobs and makespan objective. Afterwards, Brandimarte [13] suggested a hierarchical approach to minimize makespan in FJSP. Using two-level Tabu Search (TS) algorithm, he solved the problem based on the decomposition of FJSP to a routing and a job shop scheduling sub-problems. This algorithm resolved the sub-problems separately and iteratively. Another TS based algorithm has been devised by Hurink et al. [26] for solving a special case of FJSP. In their work, initial solutions are calculated using a heuristic based on reduced the neighborhood size and beam search method. They altered routing and sequencing decisions simultaneously to reach reasonable solutions. Moreover, Dauzere-Peres and Paulli [20] proposed an extended class of disjunctive graph for modeling the flexibility issue in FJSP. To solve the problem, a TS algorithm as an integrated approach was introduced where moving an operation is carried out by re-assigning it to another machine or re-sequencing it on the same machine. Mastrolilli and Gambardella [39] improved the approach presented by Dauzere-Peres and Paulli [20] by proposing a local search and two other neighborhood functions based on computation time and solution quality. Besides, Norman and Bean [45] considered a FJSP with ready times, sequence dependent setups, machine downtime and scarce tools. To minimize total tardiness objective, they developed a genetic algorithm based on random key representation, elitist reproduction, Bernoulli crossover, and immigration mutation. Baykasoğlu [7] suggested a linguistic for representing the FJSP data, and proposed dispatching rules for the sequencing of operations and a simulated annealing meta-heuristic for solving overall problem. Choi and Choi [18] devised a mixed integer model for FJSP with sequence-dependent setups in various manufacturing environments and in project scheduling, and devised a local search with time reduction property. Besides, Kacem et al. [28] proposed an integrated approach by localization to decide on routing component, and three dispatching rules to make decision on sequencing one. In order to enhance the solution quality, an advanced genetic manipulation was applied. Kim et al. [29] proposed a new approach based on an artificial intelligent technique, called symbiotic evolutionary algorithm, in order to address joint process planning and scheduling with makespan and mean flow time minimization. A flexible job shop problem with recirculation was studied by Ho and Tay [25], and a cultural algorithm was designed to obtain minimal makespan. Gao et al. [24] suggested a hybrid genetic algorithm and variable neighborhood descent search to minimize three objectives: makespan, maximal machine workload and min total workload. The "global search ability" of genetic algorithm and "the local search ability" of variable neighborhood descent have been exploited to reach the best solution of FJSP. In another study, Pezzella et al. [46] designed a GA integrating different strategies for generating the initial population, selecting the individuals for reproduction and reproducing new individuals. Moreover, Chen et al. [16] considered a real-life weapons production factory as a case of FJSP with parallel machines and reentrant process, and a combined algorithm based on two modules: the machine selection module (MSM) and the operation scheduling module (OSM), has been established. Xing et al. [55] proposed a hybrid algorithm integrating ant colony optimization algorithm (ACO) and knowledge model to cope with FJSP to find minimum makespan. In their approach, knowledge model learns some available knowledge from the ACO and then existing knowledge is employed to guide the current search of ACO. The algorithm parameters were calibrated dynamically in terms of optimization performance. A joint job-shop planning and scheduling problem was considered by Liu et al. [36] for the single-piece, small-batch, custom production mode. Then an adaptive annealing genetic algorithm (AAGA) was devised by changing the mutation probability adaptively to shorten the entire optimization process and improve the convergence speed of the traditional GA. Besides, Chan et al. [14] introduced a resource-constrained FJSP with multiple identical machines and developed a GA-based approach to obtain minimum machine idle cost (MIC) objective. Chan et al. [15] presented a real life FJSP considering a flexible multi-product, parallel machine, setup time. To minimize makespan measure, a GA-based job-shop scheduler which is better than existing sequencing rules was presented. Bagheri et al. [6] proposed an integrated approach based on artificial immune algorithm combining several initial solution methods, multiple individual selection strategies and different mutation operators, to solve a FJSP with makespan objective. Zhang et al. [57] devised a GA to achieve an effective solution of makespan oriented FJSP through combining Global Selection and Local Selection as initialization stage, employing an improved chromosome representation, and applying different strategies for crossover and mutation operators.

SA is a frequently used metaheuristic algorithm for addressing FJSP. Shivasankaran et al. [52] proposed a new hybrid non-dominated sorting simulated annealing algorithm to solve a multi-objective FJSP. A flexible job shop scheduling problem with overlapping was also considered by Fattahi et al. [23] where a mixed integer linear programming model was constructed and a SA was devised to evaluate the validity of the proposed SA algorithm. In another work, Shahsavari-Pour and Ghasemishabankareh [51] suggested a new hybrid genetic algorithm and simulated annealing entitled NHGASA for solving FJSP. Moreover, Dalfard and Mohammadi [19] analyzed a FJSP with parallel machines and maintenance operations, and then developed an optimization model and two meta-heuristic algorithms, a genetic algorithm and a simulated annealing algorithm for solving their problem. In another study presented by Raich et al. [47], a SA based approach was designed for solving job-shop scheduling problem to obtain an optimal or a near optimal solution and compared the SA results with heuristic techniques like SPT and LPT.

To our knowledge, FJSP with stochastic parameters has attracted very little attentions. Mahdavi et al. [40] developed a decision support system for addressing a stochastic FJSP manufacturing system. Three cases in both deterministic and stochastic modes were investigated where the applicability and efficiency of proposed framework was proved. In another work, Al-Turki et al. [5] considered a FJSP with setup time, batch processing, and uncertain data. To make the optimal number of machines at each center and the optimal batch sizes, various dispatching rules have been evaluated. The most common random parameters encountered in real manufacturing processes are usually processing times and due dates. Hence, in this paper, we also consider these parameters to be uncertain with general types of distribution behavior in a FJSP.

2.2. Joint production and maintenance scheduling

As mentioned earlier, the basic studies in production scheduling with the maintenance activities were presented based on "machine