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A hybrid method for flowshops scheduling with condition-based maintenance constraint and machines breakdown

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ABSTRACT

One of the most important assumptions in production scheduling is that the machines are permanently available without any breakdown. In the real world of scheduling, machines can be made unavailable due to various reasons such as preventive maintenance and unpredicted breakdown. In this paper, we explore flowshop configuration under the assumption of condition-based maintenance to minimize expected makespan. Furthermore, we consider a condition-based maintenance (CBM) strategy which could be used in most industrial settings. The proposed algorithm is designed for non-resumable flowshop state where the processing of jobs after preventive maintenance is restarted from the beginning. We propose a hybrid algorithm based on genetic algorithm and simulated annealing. Additionally, we conduct an extensive parameter calibration with the utilization of Taguchi method and select the optimal levels of the algorithm's performance influential factors. The preliminary results indicate that the proposed method provides significantly better results compared with other high performing algorithms in the literature.

1. Introduction

Scheduling, as a decision-making process, plays an important role in most manufacturing and production planning. It tackles the allocation of resources to operations throughout specified time periods and there are normally different objectives to be optimized. One of the most important scheduling problems is called flowshop. In a typical flowshop there are different processing jobs on a set of sequential machines, each job has to be processed on all machines and the processing roads of all jobs are the same; that is the operations of any job are processed in the same order. Along with the definition of the flowshop, the number of operations for each job is equal to the number of machines and no two machines are able to perform the same operation.

One of the primary assumptions with most of the traditional scheduling of flowshop problems is that all machines are available throughout the scheduling period. Nevertheless, a machine can be unavailable due to unexpected breakdowns or scheduled preventive maintenance during the planning horizon, in the real world of scheduling.

Maintenance activities and production are always in disagreement. Maintenance activities bring the production to a halt and delay it until the production sequence leads to an increase in the probability of machines failure and level of degradation. During the scheduling, it is usually assumed that the machine is available during the planning horizon but this simple assumption may not hold for many real-world applications. Recently, condition-based maintenance (CBM) policies are growing in popularity in industrial environments. Many of these policies apply to decrease the cost of maintenance activities which are the largest part of any operational budget, so CBM is extensively used in production environment.

The processing models of jobs are divided into two main categories in flowshops with unavailability constraint of machines: "resumable" and "non-resumable". For the first one, when the maintenance period interrupts the processing of a job, the operations can continue with no penalty until the maintenance is completed. However, there is a penalty for the non-resumable case and the whole processing operations on the unavailable machine need to be restarted (Lee, 1997).

Johnson's work motivated others to attempt to solve the flowshop problems with more than two machines. Subsequent work includes Campbell, Dudek, and Smith (1970) and Dannenbring (1977) heuristics in flowshops. Nawaz, Enscore, and Ham (1983) provided a high performance heuristic called NEH which tackles the other heuristics. Ruiz and Maroto (2005) showed that NEH heuristic provides better solutions with respect to other heuristics. There are also more interesting meta-heuristic methods to solve the flowshop problems (e.g. Rajendran & Ziegler, 2004; Reeves, 1995; Ruiz, Morato, & Alcazar, 2006; Taillard, 1990). The other types of problems are when the machine is unavailable during the planning horizon.

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The problem with some periods of preventive maintenance on two machines in resumable case was considered by Blazewicz (2001) where the problem is proved to be NP-hard in the strong sense. Liao and Chen (2003) considered a machine scheduling problem with cyclic maintenance, where the machine is supposed to be brought to a halt from time to time for maintenance in a constant time during the scheduling period. They provided a mixed binary integer programming model to find the optimal solution and also an effective heuristic was introduced to find the near-optimal solution to large-scale problems. Alcaide, Rodriguez-Gonzalez, and Sicilia (2002) investigated stochastic scheduling models with several machines to complete the operations where breakdowns are enabled. Their method converts breakdowns scheduling problems into a finite sequence of without-breakdowns problems. The length of the available periods and repair times are considered randomly. Lee and Lin (2001) took into account a single machine scheduling where maintenance and repair are allowed. They assumed that processing time is deterministic while machine breakdown is random. This problem was studied in both cases, resumable and non-resumable, with objective functions such as expected makespan, total expected completion time, maximum expected lateness, and expected maximum lateness. Allaoui and Artiba (2004) tackled the hybrid flowshop scheduling problem with maintenance constraints with different objective functions based on flow time, due date, setup, cleaning and transportation times. Allaoui, Lamouri, Artiba, and Aghezzaf (2008) studied the simultaneous scheduling of n jobs and the preventive maintenance in a two-machine flowshop with the objective of makespan and non-resumable case. They assumed that one of the two machines may be repaired during the first T periods of scheduling. Yang, Hsu, and Kuo (2008) surveyed two-machine flowshop scheduling problem with a separate maintenance constraint and proposed a heuristic algorithm to solve the problem. The objective was to find the job schedule such that the makespan was minimized. Ruiz, Garcia-Diaz, and Marato (2007) considered two most popular preventive maintenance policies used to maximize the availability or to maintain a minimum reliability during the planning horizon. The results for six adaptations of existing heuristic and metaheuristic methods showed that PACO and GA provided very effective solutions for minimization of makespan. Chen (2009) addressed a machine scheduling problem with periodic maintenance. He focused studies on several maintenance periods where each maintenance period was scheduled after a periodic time interval. The objective function was minimizing the number of tardy jobs subject to periodic maintenance and non-resumable jobs. Effective heuristic and branch-and-bound algorithms were proposed to find near-optimal and optimal schedules for the problem. Gholami, Zandieh, and Alem-Tabriz (2008) explored the hybrid flowshop scheduling problems with sequence-dependent setup times and maintenance actions constraints for machines. A genetic algorithm was used to find production sequence and simulation to obtain expected makespan. Safari, Sadjadi, and Shahanaghi (xxxx) considered flowshop problem where machines suffer from degradation due to shocks and they considered two thresholds to apply maintenance polices. They provided a hybrid meta-heuristic based on the combination of the simulated annealing and the tabu search algorithms to tackle the NP-hardness of the problem. Overall, seven adaptations of the existing meta-heuristic and the heuristic methods were evaluated and they showed that the proposed meta-heuristic has a good performance with respect to other existing methods.

This paper deals with a practical and stochastic flowshop problem in which the scheduling of jobs is performed under the maintenance constraints called condition-based maintenance (CBM) in which a condition of each machine is monitored at equidistant time intervals. If the variable indicating the condition is more than a preventive maintenance threshold, an instantaneous preventive maintenance action is executed and condition variables take on its initial value. The machines can fail more than once within an inspection interval. The number of breakdowns in each inspection period has a Poisson distribution function and when a breakdown takes place, immediately the repair is performed. Our scheduling environment model is general in nature which could be employed in series workshop such as automobile, chemical and textile manufacturing systems. This paper deals with algorithmic complexity (flowshops problem is NP-hard) and problem complexity (the stochastic nature of problem); heuristic approach (genetic algorithm-simulated annealing (SA-GA)) and simulation (simulator) are applied, respectively, and finally a combination of them is employed to solve the problem. Parameters tuning the proposed GA–SA and the effects of different factors on problem are evaluated using Taguchi method. This paper is organized as follows. We first state the necessary notations and problem assumption in Section 3. Section 4 is devoted to solution procedure and the results are discussed in Section 5. Finally, concluding remarks are given at the end in order to summarize the contribution of the paper.

2. Condition-based maintenance and problem assumption

2.1. Condition-based maintenance

There are many reasons that interrupt a production process, such as failures, power shortage, and degradation. Degradation is one of the primary reasons for production failure and if no maintenance activities are done, this degradation process will result in a machine breakdown. Obviously, any breakdown in machines' operations may result in a decrease in production and subsequently reduce the profitability. Maintenance activities after and before breakdown are called corrective maintenance (CM) and preventive maintenance (PM), respectively (Nakagawa, 2007). The most important advantage of PM is to return a machine in good condition and to decrease the risk of unexpected breakdowns. PM activities are generally divided into time-based maintenance (Vaurio, 1997) (TBM) and condition-based maintenance (CBM). TBM usually suffers from a most important problem which sets periodic intervals to perform PM apart from the health state of the physical quality. The rapid development of modern technology requires products with better quality and higher reliability which lead us to have higher PM expenditures. Therefore, PM has become one of the major expenses for many industrial companies which could change the strategy to use CBM (Legat, Zaludova, Cervenka, & Jurca, 1996). CBM maintenance polices are derived from the gathered information through condition monitoring. The main effort of CBM is to avoid unnecessary maintenance tasks by taking maintenance actions just in case of detecting any evidence of abnormal performances in physical quality. A CBM programme, if precisely done and efficiently employed, can significantly decline the maintenance cost by decreasing the number of needless scheduled PM activities. On the other hand, excessive maintenance can virtually eliminate downtime caused by equipment failure and the corresponding cost of maintenance will increase which could result in a decrease of profitability. Therefore, it is clear that a cost-effective CBM strategy in a production system is necessary (Biroloni, 2004; Castanier, Grall, & Bérenguer, 2005; Grall, Berenguer, & Dieulle, 2002; Legat et al., 1996; Wang, 2007).

At the start of equidistant time intervals of length T_I, a machine is inspected and the condition of the machine in period i at time t (which origins at start of period) is shown by a variable, $X_{i,t.}$ where breakdown time has a nonhomogenous Poisson process with the failure rate of $\lambda\,(X_{i,t})$. The failure can occur any time and the degradation value, $Y_{i,t}$, occurs over a period independently and randomly