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A knowledge-based evolutionary proactive scheduling approach in the presence of machine breakdown and deterioration effect

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ABSTRACT

This paper considers proactive scheduling in response to stochastic machine breakdown under deteriorating production environments, where the actual processing time of a job gets longer along with machine's usage and age. It is assumed that a job's processing time is controllable by allocating extra resources and the machine breakdown can be described using a given probability distribution. If a machine breaks down, it needs to be repaired and is no longer available during the repair. To absorb the repair duration, the subsequent unfinished jobs are compressed as much as possible to match up the baseline schedule. This work aims to find the optimal baseline sequence and the resource allocation strategy to minimize the operational cost consisting of the total completion time cost and the resource consumption cost of the baseline schedule, and the rescheduling cost consisting of the match-up time cost and additional resource cost. To this end, an efficient multi-objective evolutionary algorithm based on elitist non-dominated sorting is proposed, in which a support vector regression (SVR) surrogate model is built to replace the time-consuming simulations in evaluating the rescheduling cost, which represents the solution robustness of the baseline schedule. In addition, a priori domain knowledge is embedded in population initialization and offspring generation to further enhance the performance of the algorithm. Comparative results and statistical analysis show that the proposed algorithm is effective in finding non-dominated tradeoff solutions between operational cost and robustness in the presence of machine breakdown and deterioration effect.

1. Introduction

As one of the most crucial functions in a manufacturing system, production/machine scheduling determines the allocation of limited resources, such as machines, operators and tools, to a set of competing jobs or operations on a short term (daily or weekly) basis, in order to optimize one or several objectives with respect to a job's completion time [1]. Production scheduling returns a baseline schedule which specifies the time/machine/operation assignments. The main purpose is to pursue the optimality or near-optimality of the baseline schedule under ideal environmental conditions. However, in practice, the assumption of ideal environmental condition does not hold due to the intrinsic uncertainties in real world. In the presence of such uncertainties, the baseline schedule quickly becomes infeasible as jobs scheduled in the time interval of machine breakdown could not be processed as planned, and therefore, appropriate reactions are needed to partially or completely reschedule the unfinished jobs. From the practitioner's point of view, it is important to make sure that the revised schedule deviates as little as possible from the baseline schedule and maintains satisfactory performance.

To handle such uncertainties, the robustness of the baseline schedule has been widely studied in the literature [2]. Generally speaking, there are two types of robustness: quality robustness and solution robustness. Quality robustness means that the performance of the realized schedule is relatively insensitive to machine breakdown, and does not degrade significantly in the presence of uncertainties. By contrast, solution robustness is also referred to as stability [3,4], which means that the realized schedule stays in consistence with the baseline schedule as much as possible after disruptions. The importance of solution robustness can be illustrated in three aspects [5]. First, facilitated by powerful Internet technologies, companies frequently share their production schedules with their raw material suppliers. It is expected that suppliers make just-in-time delivery of material following the baseline schedule. Second, the baseline schedule serves as a performance indicator for management and shop-floor operators. Third, the baseline schedule provides visibility into the near future, allowing the quotation of competitive delivery dates for customers.

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Once machine breakdown occurs, repairing of the machine will be undertaken immediately, resulting in an unavailability time interval during which no production can be carried out. A widely adopted approach to reducing the impact of machine breakdown, known as the proactive scheduling, is to generate a predictive schedule that is robust against anticipated disruptions that may occur during execution of the schedule [2–4]. After disruption happens, the realized schedule can match up with the baseline schedule as soon as possible using additional resource cost. Therefore, this paper adopts the proactive scheduling approach and aims to find the optimal processing sequence and a resource allocation strategy so as to minimize the operational cost of the baseline schedule and the rescheduling cost in response to machine breakdown, which is in essence the solution robustness. Here, we assume that machine breakdown can be described using a probability distribution. It is further assumed that the operational cost is measured by the sum of total completion time cost and resource cost of the baseline schedule, and the rescheduling cost consists of the match-up time cost and additional resource cost. To minimize the above objectives, a multi-objective evolutionary algorithm based on non-dominated sorting has been proposed. To enhance the computational efficiency, support vector regression based surrogate models have been employed to reduce the extra computation time needed for assessing the solution robustness. In addition, a priori domain knowledge, here the structural property of the predictive schedule is embedded into the evolutionary algorithm to help improve the search efficiency.

The remainder of this paper is organized as follows. In Section 2, a review of relevant literature is provided. Section 3 formulates the proactive scheduling problem considered in this work. A knowledge-based multi-objective evolutionary algorithm is presented in Section 4 to solve the proposed proactive scheduling problem. In Section 5, comparative studies are conducted to verify the effectiveness of the proposed algorithm. Finally Section 6 concludes this paper and suggests a few future research directions.

2. Literature review

In scheduling literature, proactive scheduling approaches to handling uncertainties aim to prepare a baseline schedule which can be easily adjusted within little performance degradation [2–4]. Aytug et al. [6] review existing literature on scheduling in the presence of unforeseen disruptions and robust scheduling approaches focusing on predictive schedules that minimize the effect of disruptions. Sabuncuoglu and Goren [7] summarize existing robustness and stability measures for proactive scheduling and endeavor to understand the philosophy of proactive and reactive approaches by analyzing the major issues in a scheduling process under uncertainties and studying how different policies are generated for handling these issues.

The buffering approach is the most frequently used proactive approach to minimizing the impact of stochastic disruptions, through which idle times are inserted into the predictive schedules [8–10]. It is first proposed by Mehta and Uzsoy [8] for a job-shop scheduling problem. They present a proactive scheduling approach so as to absorb the impacts of breakdowns. By jointly deciding the location and amount of additional idle time along with the proactive schedule, a revised schedule can be obtained with simple adjustments and little performance degradation under certain conditions. After that, studies on accommodating disruptions through inserting idle times into the baseline schedule have been reported by many researchers. Leus and Herroelen [9] consider inserting idle times on a single machine to maximize solution stability under uncertainties. They show that the horizon of the predictive schedule is not propagated with small changes caused by uncertainty in processing time. Yang and Geunes [10] consider a scheduling problem aiming to create a predictive schedule with uncertain arrival of future jobs. The amount and positions of additional idle time are determined for the predictive schedule to minimize the sum of tardiness cost, disruption cost and wasted idle time cost. Goren and Sabuncuoglu [4] consider scheduling problems with processing time variability and machine breakdowns. A proactive scheduling approach that requires inserting idle times is taken so as to minimize two robustness and three stability measures being defined.

In the above reviewed literature, the buffering approach has been widely adopted [2,8,11–13], and has been examined as an efficient proactive approach to generating a robust baseline schedule with fixed processing times. However, inserting idle times will degrade the performance of the baseline schedule and if no disruption occurs, the inserted idle time becomes useless and the limited capacity of production resources is wasted. By assuming that the job processing time can be compressed with certain extra resource cost [14], several researchers consider absorbing disruptions by extensively compressing a set of jobs in the schedule to catch up with the baseline schedule at a certain point. For example, Akturk et al. [15] study a scheduling problem on non-identical parallel machines with disruptions, where the processing time of each job is controllable at a certain manufacturing cost. They generate reactive schedules to catch up with the baseline schedule as soon as possible in response to disruptions with a slight increase in manufacturing cost. Gurel et al. [16] consider anticipative scheduling problems on non-identical parallel machines with disruptions and controllable processing times. Distributions of uncertain events and flexibilities of jobs are considered for making the anticipative schedule, and a match-up strategy is used to catch up with the predictive schedule at some certain point with compression of processing times for the remaining jobs. Al-Hinai and ElMekkawy [17] address flexible job shop scheduling problems with random machine breakdowns to find robust and stable solutions. Several bi-objective measures along with the robustness and stability of the predictive schedule are investigated.

Deterioration effect widely exists in realistic production environments [18–23], and has been extensively studied in rescheduling problem with disruptions [24–26], where the actual processing time of a job becomes longer if the job starts processing later. However, not much work has considered generating a proactive schedule without idle time in response to machine breakdown under deteriorating production environments. Controllability of job's processing time enables us to use non-buffering proactive approaches so that the disruption can be absorbed at the price of additional resource cost. Taking deterioration effect into account makes the formulation of the problem more realistic but unfortunately also more difficult to solve.

Consequently, this work aims to solve proactive scheduling problems in the presence of machine breakdown and deterioration effect. The objective is to find an optimal processing sequence and a resource allocation strategy for the baseline schedule to simultaneously minimize the initial operational cost and rescheduling cost (i.e., solution robustness) in response to machine breakdown. In order to solve this challenging proactive scheduling problem, a knowledge-based multi-objective evolutionary algorithm is proposed to reduce the computational cost resulting from simulation-based robustness evaluation and to enhance the search capability of the algorithm.

3. Problem formulation

Assume that there is a set of n jobs $\{J_1, J_2, \ldots, J_n\}$ to be processed without interruption on a common machine. All jobs are available for processing at time zero. Each job J_j has a normal processing time $\bar{p}_j$. The processing times of jobs may be subject to change due to deterioration of the machine's performance with increase of machine's usage and age. In other words, the actual processing time of a job becomes longer if the job starts processing later. The strategy of controlling the processing times of jobs by allocating extra resource with corresponding resource consumption cost is adopted to improve the scheduling performance, assuming that the actual processing time of