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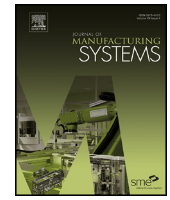

Technical paper

Robust and stable flow shop scheduling with unexpected arrivals of new jobs and uncertain processing times

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ABSTRACT

In real scheduling problems, some disruptions and unexpected events may occur. These disruptions cause the initial schedule to quickly become infeasible and non-optimal. In this situation, an appropriate rescheduling method should be used. In this paper, a new approach has been proposed to achieve stable and robust schedule despite uncertain processing times and unexpected arrivals of new jobs. This approach is a proactive–reactive method which uses a two-step procedure. In the first step an initial robust solution is produced proactively against uncertain processing times using robust optimization approach. This initial robust solution is more insensitive against the fluctuations of processing times in future. In the next step, when an unexpected disruption occurs, an appropriate reactive method is adopted to deal with this unexpected event. In fact, in the second step, the reactive approach determines the best modified sequence after any unexpected disruption based on the classical objective and performance measures. The robustness measure is implemented in the reactive approach to increase the performance of the real schedule after disruption. Computational results indicate that this method produces better solutions in comparison with four classical heuristic approaches according to effectiveness and performance of solutions.

1. Introduction

Scheduling in production systems concludes the proper coordination of activities in order to increase productivity and reduce operational costs. In the stochastic and dynamic manufacturing environments, scheduling solutions based on the classical objectives such as makespan will not be sufficient. Ouelhadj and Petrovic [1] provided a comprehensive survey on dynamic scheduling in manufacturing systems. In fact, because of random disruptions that may occur in the system, additional criteria that have capability to counter stochastic disruptions should be considered. To maintain system performance effective, rescheduling is often used to counteract the effects of random disruptions. There are some disruptions may occur in the real-world production systems such as:

- Machine breakdowns
- Receiving a new job
- Cancellation of orders
- Change in delivery times
- Uncertain processing times
- Uncertain due dates
- Equipment overhaul
- Addition or removal of operations

In practical production environments, the scheduling process starts with determining an initial schedule. Then, when a disruption arises, the initial schedule should be revised in order to keep its feasibility and performance quality. The type of scheduling that is actually carried out in shops is known as *real schedule*. As it is clear, real schedule can be different from the initial schedule. This difference depends on the level of failure and disruption and also the changes of the setting. In the literature, there are two policies to achieve a high level of system performance for the real schedule after occurring of any disruption. These strategies are entitled *reactive scheduling* and *proactive scheduling*.

The "*reactive approach*" does not consider the uncertainty when an initial schedule is determined. However, when a random event occurs, it modifies the initial schedule and performs the necessary reaction to obtain better result. In the reactive method, there is no predetermined schedule which considers the uncertainty. Decisions are taken locally and these decisions change during the implementation a necessary rescheduling. Therefore, the reactive approach is seeking ways through which it can react to the disruptions in the best possible manner. This reaction can be in the

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form of modification and improvement of the initial schedule or the formulation of a totally-new schedule.

On the other hand, the "*proactive approach*" considers the stochastic and unexpected events to create the initial schedule. In this approach, in addition to classical criteria such as makespan and tardiness, performance measures such as robustness and stability is also considered to establish a schedule. Optimization of stability is concerned with the deviation of the modified schedule relative to the initial schedule. Optimization of robustness is concerned with the different in terms of objective function (performance criteria) between initial and modified schedules. However, proactive scheduling considers the future failures and disruptions. It is actually seeking a schedule which also considers the effects of future failures and disruptions together with the performance criteria. An integrated proactive–reactive approach can also be considered to generate better and practical results [2].

In this paper, a two-step proactive–reactive method is presented for two-machine flow shop scheduling to achieve a more stable and robust solution. In the first step, it is attempted to generate an initially robust schedule by using robust optimization approach. The initial robust schedule handles the uncertain processing times. In the second step, when a random disruption occurs (which is the arrival of an unexpected new job), an appropriate reaction is adopted to determine the best modified schedule.

The rest of the paper has been organized as follows. In Section 2, the technical literature has been reviewed. In Section 3 a brief description of robust optimization approach has been presented. The foundation of the proposed two-step approach of the paper has been presented in Section 4. In the first step, a robust model of two-machine flow shop problem has been presented and solved and in the second step, the appropriate reactive approach has been described. The computational results and relevant comparisons have been presented in Section 5 and finally, the conclusions and future studies have been discussed in the last section.

2. Literature review

In this paper, a two-machine flow shop system is studied in which the processing times are uncertain. However, in addition to the set of initial jobs, new jobs which we have no prior information about, unexpectedly come into the shop with a dynamic state. In fact, the arrival of a new job which is not expected at the beginning of planning horizon constitutes a disruption in the system.

To deal with the uncertain processing time, some researchers are considered a specific random distribution for it. They solved the problem by defining their anticipated values in the objective functions and using the stochastic optimization approach [3,4]. Some other researchers used the robust optimization approach so that the performance of the presented schedule could be improved. They formulated the fluctuations of uncertain processing times with regards to all the possible future scenarios. Daniels and Kouvelis [5], Kouvelis et al. [6], Mulvey et al. [7] and Rossi [8] presented a proactive scheduling method that deals with the future fluctuations of uncertain parameters using the robust optimization approach.

In the stochastic and dynamic manufacturing environments, due to the possible occurrence of random disruptions, it is not sufficient to just establish initial schedules that minimize classical objective functions like makespan. In these cases, the proper response to random events is particularly important and influence productivity of systems. In deterministic production environments without any random disruptions, the two-machine flow shop problem will be easily solved by the Johnson algorithm [9]. However, with uncertain processing times and the probability of machine breakdowns, there will be machine non-availability intervals ($w > 1$), this algorithm does not work optimally in these conditions. Braun et al. [10] investigated the circumstances in which the Johnson algorithm could operate optimally despite the existence of machine non-availability intervals. They also showed that this problem will be NP-hard even if there is only one non-availability interval ($w = 1$).

Considering the disruptions and unexpected events in the system, the researchers either used iteration based simulation methods [11] or they attempted to develop robust and stable schedules to handle these disruptions. Leon et al. [12] studied the issue of robustness in the job shop environment and tried to develop a method to generate a robust initial schedule. They developed an offline pre-schedule to achieve high performance for the system in the case of machine failures. For the analysis of the effects of machine failures and changes of the processing time, the authors proposed a slack-time based robustness measure.

Lawrence and Sewell [13] studied the performance of the simple dispatching heuristics against the algorithmic solution techniques in a job shop environment with uncertain processing times. Kochhar et al. [14] considered the dispatching heuristic methods for flexible flow line scheduling. Sabuncuoglu and Karabuk [15] showed that the dispatching rules for interruptions are more robust compared to the optimum search algorithms for offline schedules. Wu et al. [16] considered the increasing of stability measure in the single-machine rescheduling problem with machine breakdowns. They rescheduled the jobs in response to machine failures so that the minimum makespan can achieve a high scheduling stability.

Rangsaritratsamee et al. [17] proposed a rescheduling method based on the local search genetic algorithm to solve the job shop scheduling problem with considering the dynamic jobs arrivals. They presented an algorithm that simultaneously considers the efficiency with the preservation of makespan, tardiness and stability and the robustness by minimizing the deviation of the job startup time. Jensen [18] generated robust schedules in a job shop environment with respect to machine breakdowns to minimize makespan as a performance criterion. He presented two neighborhood-based robustness measures. The first measure is the average makespan of the given schedule's neighbors. The scheduled neighborhood is considered as the all schedules that can be achieved through the pair displacement of two consecutive jobs on a machine. The second robustness measure is estimation (upper limit) of the first measure. Jensen's idea is based on this principle that the robust optimal solution is found in the wider regions of the distribution (objective) function, while the non-robust and fragile optimal solutions are located on the narrow peaks of the distribution function.

Sotskov et al. [19,20] presented some approaches based on interval processing times for the evaluation of robustness and stability in a single-machine environment. Lambrechts et al. [21] developed a tabu search algorithm that uses a free slack-based objective function to generate robust reactive–proactive schedules with considering uncertain renewable resource availabilities. Bouyahia et al. [22] proposed an approach for the robustness design of a pre-scheduling which assumes that the number of jobs to be processed on parallel machines is a random variable. Their approach minimizes the total weighted flow time as an objective function. Goren and Sabuncuoglu [23] investigated the problem of robust and stable scheduling with random failures in a single machine environment. They presented two surrogate measures for robustness and stability and used the tabu search algorithm to solve the problem. Al-Hinai and ElMekkawy [24] tried to produce proactive robust and stable solutions for the flexible job shop scheduling problem with random failures. They presented a new procedure that combines the approach of insertion of non-idle time and a hybrid genetic algorithm proposed by Al-Hinai and ElMekkawy [25]. Ghezail et al. [26] proposed a qualitative graphical approach for responding to the disruptions in the flow shop problem. Their graphical approach