Computers & Industrial Engineering 98 (2016) 360–372

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

A stable reactive approach in dynamic flexible flow shop scheduling with unexpected disruptions: A case study

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ARTICLE INFO

Article history:
Received 28 April 2015
Received in revised form 17 May 2016
Accepted 18 June 2016
Available online 18 June 2016

Keywords:
Flexible flow shop
Disruption
Stability
Resistance to change
Reactive approach
VNS

ABSTRACT

In industrial environments, scheduling systems often operate under dynamic and stochastic circumstances. In these conditions, it is inevitable to encounter some disruptions which are inherently stochastic or totally unexpected events. These disruptions may cause the initial schedule to become infeasible and non-optimal. So, appropriate revisions and rescheduling methods are needed to overcome the unfavorable subsequent of these disruptions. In this paper, we address a dynamic flexible flow shop (FFS) environment considering unexpected arrival of new jobs into the process as disruptions. A novel reactive model is proposed based on a classical objective function (total weighted tardiness) and two new surrogate measures, stability and resistance to change. In fact the proposed model is presented to generate a stable reschedule against of any possible occurrences of mentioned disruption. Due to the computational complexity, a variable neighborhood search (VNS) algorithm is implemented to solve the problem. To show the performance of the reactive approach, a case study in petrochemical industry is studied. Computational experiments and comparisons of the proposed algorithm with three dispatching rule and an efficient rescheduling approach show the efficiency of the presented reactive approach to reschedule the jobs.

1. Introduction

Production planning is a decision making process in which limited resources such as material, machinery, tools and equipment, and operators are allocated to different jobs in order to achieve specific objectives. Most of the researches on this subject assume that the scheduling environment is a static environment in which no unexpected event occurs during the execution of the schedule. However, the real production environments are dynamic, and numerous random or unexpected events such as machine failure, uncertain processing times, arrival of a new job, and cancellation of jobs may occur. Therefore, the subject of scheduling under uncertain conditions has been greatly focused on in recent years. In fact, the occurrence of disruptions and unexpected events in scheduling problems makes the obtaining of stable solutions more valuable than the finding of optimal solutions that ignore these disruptions. In these environments, the best schedule is the one with high systematic performance and low deviation from the initial schedule after disruptions. To overcome stochastic disruptions, three fundamental methods have been employed including the reactive, proactive and proactive-reactive approaches (Aytug, Lawley, McKay, Mohan, & Uzsoy, 2005; Vidal, 2004).

The *proactive approach* predicts the occurrence of unexpected events, and takes them into consideration in formulating the initial schedule. This approach is in fact pursuing a schedule that considers the effects of future disruptions by using the performance measures trying to reduce their negative influences. In this approach, for the establishment of a schedule, in addition to classical criteria such as makespan and tardiness, performance measures such as robustness and stability are also considered. Based on the literature, some researchers considered *stability* and *robustness* to face the stochastic disruptions in scheduling problem as proactive measures. To produce robust and stable solutions, the value of uncertain parameters should be determined. But, since the exact values of these parameters are not specified from the start, these proactive measures have discrepancies with their true values, and they may not show the true performance of the system.

Conversely, the *reactive approach* does not consider the issue of uncertainty in determining the initial schedule; but modifies the schedule providing the necessary reactions when an unanticipated event occurs. In the reactive method, there is no predetermined schedule which considers the uncertainties. Decisions are taken locally and these decisions change during the implementation of a necessary rescheduling. Therefore, the reactive approach is

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http://dx.doi.org/10.1016/j.cie.2016.06.018
0360-8352/

seeking ways through which it can react to the disruptions in the best possible manner. This reaction can be in the form of modification and improvement of the initial schedule or the formulation of a totally-new schedule. The "*dispatching rule*" is a reactive method by which the jobs are scheduled based on a predetermined criterion. This method can find an acceptable solution within a short time, and therefore is considered as a significant method for dynamic scheduling problems. *Rescheduling process* is another reactive approach where initial schedules are revised to adapt to the new situation caused by a disruption. Most of the existing research in the literature produced a new schedule after a disruption just based on shop efficiency like tardiness (Adibi, Zandieh, & Amiri, 2010; Chryssolouris & Subramanian, 2001). Indeed, it may generate a new schedule completely different from the initial one. For example, some remaining jobs in the initial schedule which have not begun processing at the time of rescheduling may be accelerated or delayed. It has a serious influence on other system activities planned based on the initial schedule, and cause to instability in the shop system (Rangsaritratsamee, Ferrell, & Kurtz, 2004). Thus, both the efficiency and stability measures should be considered (Shen & Yao, 2015).

The *proactive-reactive* method is a two-step approach. In the first step, an initial schedule is proactively presented. Then, when a disruption occurs during the implementation of this schedule, the reactive step adopts a new sequence to counter this unexpected event (O'Donovan, Uzsoy, & McKay, 1999).

In this paper, a flexible flow shop system with unexpected arrival of new jobs is considered. To determine an initial schedule, some jobs are available in the shop from the beginning and the information regarding these jobs (e.g. processing time and due date) is known. However, in addition to the initially-set jobs, new jobs which we have no prior information about, unexpectedly come into the shop. In fact, the arrival of a new job which is not expected at the beginning of planning constitutes a disruption in the system. We first generate an initial schedule by using a deterministic mathematical model for the initial jobs in the beginning of horizon planning. Then, it is possible that new and unexpected jobs gradually come into the shop, for which there is no prior planning. In this case, an approach is presented to appropriately react this unexpected disruption, and to determine the new sequence in this dynamic system. So we proposed a new bi-criteria reactive approach to overcome their weaknesses. Both of efficiency and stability measures are considered in our proposed method. We also, innovatively introduce an important concept in dynamic scheduling problem called "RTC". This parameter has been ignored in the literature of scheduling problems with unexpected disruptions. RTC considers the effects of the frequency of rescheduling in the system. In fact, when a disruption occurs, the internal system factors (e.g. operators) may show resistance against any change and rescheduling in the previous program. The effect of this problem should be interpreted to generate a new schedule (see Section 3.2). The main contributions of this paper are as follow:

- A flexible flow shop (FFS) scheduling problem with unexpected arrival of new totally unpredicted jobs into the process is considered.
- An appropriate reactive method to create a stable schedule to deal with the unexpected disruptions is proposed in dynamic scheduling systems.
- An innovative concept called the "resistance to change" factor (RTC) in the scheduling problem is introduced to show the real processing times after any disruption and rescheduling.
- A variable neighborhood search (VNS) algorithm is implemented to solve mentioned problem for a case study in petrochemical industry is considered.

2. Literature review

One of the most important scheduling schemes with many applications in real industries is the FFS scheduling. A "FFS" which is also called a hybrid flow shop (HFS), includes a series of production stages; and at each of these stages, there are one or several identical machines that work in parallel. Also, all the jobs are processed with the same order at different stages. An extensive review of published papers on HFS scheduling problems is presented by Ribas, Leisten, and Framinan (2010). To deal with the stochastic events in scheduling problems an appropriate approach should be adopted.

Deblaere, Demeulemeester, and Herroelen (2011) presented a reactive scheduling approach in the multi-mode RCPSP. Nie, Gao, Li, and Shao (2013) proposed a heuristic as a reactive approach to rescheduling of the jobs in the dynamic production system. Gao et al. (2015) proposed a two-stage artificial bee colony algorithm for scheduling and re-scheduling with arrival of new job(s) in flexible job shop scheduling problems. They proposed three re-scheduling strategies as reactive methods.

Lodree, Jang, and Klein (2004) proposed a new dispatching rule for minimizing the number of jobs with tardiness. Branke and Mattfeld (2005) presented a dynamic FFS for the minimization of tardiness. Jayamohan and Rajendran (2000) presented a set of new dispatching rules for the minimization of different performance measures such as the average, maximum and variance of tardiness in dynamic environments. Kianfar, Fatemi Ghomi, and Karimi (2009) introduced four dispatching rules for the minimization of the sum of tardiness and rejection costs. Kianfar, Fatemi Ghomi, and Oroojlooy Jadid (2012) also presented a new dispatching rule for the FFS system in a dynamic non-deterministic environment.

Leon, Wu, and Storer (1994) studied robustness in a job shop environment. Their goal was to establish a primary robust schedule. By using the right-shift rescheduling (reaction) policy approach, they developed a forward offline scheduling to achieve high performance for a system subjected to machine failure. In their model, breakdowns constitute machine failures. They assumed that the times of failures and breakdown repairs are known. In their paper, makespan is considered as a shop performance measure. The authors proposed a slack time based on robustness criteria to analyze the effects of machine failures and processing time changes.

Wu, Storer, and Chang (1993) considered the increase of stability in the single-machine rescheduling problem with machine failures. They rescheduled the jobs in response to machine failure so that minimum makespan was achieved along with high scheduling stability. Rangsaritratsamee et al. (2004) proposed a rescheduling method based on the local search genetic algorithm to solve the problem of job shop scheduling, considering the fact that jobs arrived dynamically. Their proposed algorithm considers the effectiveness of the schedule by preserving the makespan, and also considers the tardiness, stability and robustness by minimizing the deviations of job start times.

Jensen (2003) generated robust schedules in a job shop environment with respect to machine breakdowns so that the makespan performance criterion is accounted. The author defined two neighborhood-based robustness measures. The first measure is the average makespan of the given schedule's neighbors. So, the scheduled neighborhood is considered as all schedules that can be achieved through the pair displacement of two consecutive jobs on a machine. The second robustness measure is an upper limit of the first measure. Jensen's idea is based on the principle that the robust optimal solution is found in the wider regions of the distribution function, while the non-robust and fragile optimal