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A proactive approach to solve integrated production scheduling and maintenance planning problem in flow shops

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ABSTRACT

This paper deals with the integration of production scheduling and maintenance planning in order to optimize the bi-objective of quality robustness and solution robustness for flow shops with failure uncertainty. First, a proactive model is proposed to formulate the problem mathematically. Then, Monte Carlo sampling method is adopted to obtain the objective value for feasible solutions and a surrogate measure is proposed to approximate the objective function efficiently. Based on the sampling method and surrogate measure, a two-loop algorithm is devised to optimize the sequence of jobs, positions of preventive maintenances and idle times simultaneously. Computational results indicate that solution robustness and stability of quality robustness can be significantly improved using our algorithm compared with the solutions obtained by the traditional way.

1. Introduction

Although many researchers have discussed the production scheduling problems, classical scheduling articles assume that machines are always available for processing jobs at all times during the scheduling horizon. However, machines may be unavailable for different reasons in realistic practice, such as unexpected breakdowns or preventive maintenances (PMs). The production scheduling and maintenance activities are interrelate since both of them occupy the machine's capacity, where production depletes the machine's reliability and maintenance restores its reliability. Production scheduling and PM planning should be taken into the integrated optimization model into consideration to balance the utilization and availability of the resource (Wang & Liu, 2014).

There are two classes of research when maintenance part is introduced into the production scheduling problems. For the first class, researchers ignore the unexpected breakdowns and only focus on the capacity of machine; conversely, the second class considers the impact of unexpected breakdowns and performs corrective maintenance (CM) when breakdown occurs.

In the first class, researchers assume that PMs are performed periodically to keep machines in a good condition and a high reliability. Thus, the random breakdowns can be ignored, which results in the deterministic problems. And, the traditional regular objectives, e.g., the makespan, the total flow time, the tardiness, etc., are considered. Since the machine is unavailable to process jobs when PMs are performed, the impact of unavailability of machine on the production needs to be analyzed to search the optimal jobs' sequence.

In the second class, researchers assume that there are unexpected random breakdowns during the execution of scheduling plan. Considering the impact of uncertainty, this kind of problem belongs to the stochastic programming problem, which is completely different from the first class. Since the existence of random variables, the expectation of performance is usually considered in the related articles. Besides, the schedule robustness is also subscribed by many experienced schedulers when some uncertainties are considered. Herroelen and Leus (2005) divided schedule robustness into two groups: solution robustness and quality robustness. They defined solution robustness as the insensitivity of the activity start times to variations in the input data, and quality robustness as the insensitivity of schedule performance (such as project makespan or cost) with respect to disruptions.

In this paper, the coordination between production scheduling and entire maintenance policy is investigated to provide an integrated decision system for the operators in flow shops. To the best of our knowledge, this is the first endeavour to establish a proactive joint model for flow shops with stochastic failure uncertainty to integrate the production scheduling and maintenance policy, including the PMs and CMs, in order to optimize the bi-objective of quality robustness and solution robustness.

The main contributions of this paper are as follows:

- A flow shop scheduling problem subject to the degenerate machines

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with the consideration of robustness is studied.
- A proactive model and a two-loop algorithm are proposed to deal with the uncertainty caused by the unexpected disruptions.
- An efficient and effective surrogate measure based on the analysis of propagation of breakdown's impact is devised to approximate the objective function, which can reduce the computation time of algorithm dramatically.

2. Literature review

Since Johnson's remarkable paper on flow shop scheduling problems (FSPs) was published in 1954, FSPs have attracted a lot of attention from researchers and practitioners. Considering the problem's *NP-complete* nature, exact algorithms such as dynamic algorithm and branch & bound can only be used to solve small-sized problems. Thus, many researchers focus on the development of constructive heuristics or meta-heuristics. In recent years, different kinds of meta-heuristics have been developed to solve large-sized traditional problems, such as Deng and Gu (2012), Wang and Liu (2013), and Kheirandish, Tavakkoli-Moghaddam, and Karimi-Nasab (2015).

Deterministic scheduling problems with non-availability intervals have received considerable attention since the beginning of the 1990s. For the scheduling problems with unavailability constraints, two cases of consideration can be found in literature: (i) the intervals are fixed and known in advance, and (ii) the intervals are flexible and can be scheduled by the operator. For the first case, comprehensive reviews about different kinds of machine systems are provided by Sanlaville and Schmidt (1998), Schmidt (2000), and Ma, Chu, and Zuo (2010). For the research on flow shops, Lee (1997), Cheng and Wang (2000), Breit (2004, 2006), Hadda, Dridi, and Hajri-Gabouj (2010), and Hadda (2012) focused on the two-machine systems; Aggoune(2004), Aggoune and Portmann (2006), Choi, Lee, Leung, and Pinedo (2010), and Shoaardebili and Fattahi (2015) studied multi-machine flow shops. For the second case, no related review paper can be found in this area. The corresponding problem for flow shops can be found in Aggoune (2004), Kubzin and Strusevich (2005, 2006), Allaoui, Lamouri, Artiba, and Aghezzaf (2008), Vahedi-Nouri, Fattahi, and Ramezanian (2013), Vahedi-Nouri, Fattahi, Tavakkoli-Moghaddam, and Ramezanian (2014), Gara-Ali and Espinouse (2014), and Hadda (2015).

When the deterioration of machine is considered, some researchers only consider the expectation of regular objectives, e.g., $E(C_{max})$, which is the expectation of makespan. Cassady and Kutanoglu (2003), Sortrakul, Nachtmann, and Cassady (2005) and Wang and Liu (2014) investigated the integrated model that simultaneously determines production scheduling and PMs planning for optimizing the expectation of regular objectives. Ruiz, García-Díaz, and Maroto (2007), Jabbarizadeh, Zandieh, and Talebi (2009) and Naderi, Zandieh, and Aminnayeri (2011) implicitly considered three different preventive maintenance polices and proposed a simple criterion to schedule preventive maintenance operations to the production sequence.

When the unexpected disruption is considered, some researchers consider the system's robustness. Leon, Wu, and Storer (1994), O'Donovan, Uzsoy, and McKay (1999), Goren and Sabuncuoglu (2008) and Al-Hinai and ElMekkawy (2011) considered the robustness measure in the scheduling problems with random breakdowns. They stated that idle times in the initial schedule can improve the robustness of system. Briskorn, Leung, and Pinedo (2011) also considered the same idea and analyzed the allocation of idle times in a single machine environment. Rahmani, Heydari, Makui, and Zandieh (2013) considered the arrival of new unpredicted jobs and devised a two step procedure in which an initial solution is generated in the first step and a corresponding solution is obtained by an appropriate reactive method to deal with this unexpected event in the second step. Rahmani and Ramezanian (2016) developed a variable neighbourhood search (VNS) algorithm to solve the problem of a dynamic flexible flow shop environment considering the arrival of new unpredicted jobs. Rahmani and Heydari (2014) proposed an initial robust solution which is more insensitive against the fluctuations of uncertain processing times and then developed a reactive approach determining the best modified sequence after any unexpected disruption based on the classical objective and performance. The above articles did not consider the machine's deterioration effect and preventive maintenances (PMs). When the machine's deterioration effect is considered, Weibull probability distribution is commonly assumed to be the failure function of machine. Cui, Lu, and Pan (2014) and Lu, Cui, and Han (2015) assumed that the machine failure is governed by this kind of distribution and investigated the robustness problem for a single machine system to integrate the production scheduling and maintenance policy.

The remainder of this paper is organized as follows. In Section 3, we describe the problem in detail. In Section 4, methods of evaluating the feasible solutions are proposed. In Section 5, a two-loop algorithm is devised according to the division of decision variables. Computational experiments are then given in Section 6 to demonstrate the effectiveness of algorithm we proposed, followed by the conclusions and discussions in Section 7.

3. Problem description and modelling

The following notations are used to formulate the problem.

Indices:

i	index of jobs
j	index of machines
[k]	index of the position in each machine

Sets:

J	set of jobs; $J = \{J_1, J_2, \ldots, J_n\}$
M	set of machines; $M = \{M_1, M_2, \ldots, M_m\}$
O_i	set of operations of J_i; $O_i = \{O_{i1}, O_{i2}, \ldots, O_{ij}, \ldots, O_{im}\}$, O_{ij} is the operation of J_i in M_j

Parameters:

n	number of jobs
m	number of machines
p_{ij}	processing time of O_{ij}
t_{pj}	preventive maintenance time of machine M_j
t_{rj}	corrective maintenance time of machine M_j
β_j	shape parameter of failure function of machine M_j
θ_j	scale parameter of failure function of machine M_j

3.1. Problem assumptions and formulation

A set of jobs J is supposed to be processed on a set of machines M for minimizing the objective of makespan in flow shops. Every job J_i ($J_i \in J$) consists a sequence of m operations $\{O_{i1}, O_{i2}, \ldots, O_{im}\}$ and requires a fixed processing time p_{ij} on machine M_j. Each machine can only process one job and each job can only be processed by one machine at a time. All jobs are available at the beginning of scheduling horizon. The buffer capacity between any two machines is unlimited, i.e., no block exists. The jobs' sequences in different machines are the same, i.e., permutation flow shop is considered here.

Suppose the machines used to process jobs are subject to failure, and the time to failure for the machines are run-based and governed by Weibull probability distributions. $(t_{pj}, t_{rj}, \beta_j, \theta_j)$ is the set of parameters of the Weibull function for machine M_j. Furthermore, we assume $\beta_j > 1$, which means the machine degenerates over time. Since unexpected failures usually cause the instability of the system and quality loss of product, it is practical to perform PMs on machines throughout the production horizon to improve the machines' condition and reduce the risk of unexpected machines' failures. We assume that the PM action restores machine to the "as good as new" condition, i.e., the machine's age becomes zero after PM. Since the unexpected machine's failures