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A Hybrid of Variable Neighbor Search and Fuzzy Logic for the permutation flowshop scheduling problem with predictive maintenance

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Abstract

This study focuses on permutation flowshop scheduling problem (PFSP) under availability constraints with makespan and maintenance cost optimization criteria. Machines unavailabilities are due to predictive maintenance interventions scheduled based on Prognostics and Health Management (PHM) results. Hence, we deal with the post prognostic decision making in order to improve system safety and avoid downtime and inopportune maintenance spending. For this reason, we propose a new interpretation of PHM outputs to define machines degradations corresponding to each job. Moreover, to take into account the several sources of uncertainty in the prognosis process, we choose to model PHM outputs using fuzzy logic. Motivated by the computational complexity of the problem, Variable Neighborhood Search (VNS) methods are developed including well designed local search procedures. Computational experiments carried out on well known benchmark sets for permutation flowshop show that the proposed algorithms seems to be efficient and effective.

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Keywords:
Permutation Flowshop Scheduling Problem (PFSP); predictive maintenance; Prognostic and Health Management (PHM); Variable Neighborhood Search (VNS); fuzzy logic.

1. Introduction

As one of the most important tasks carried out in manufacturing industry, production scheduling has received considerable attention and been extensively studied in the last decades. To match the real life industrial settings and respect today's highly competitive environment, numerous realistic constraints have been incorporated into scheduling problems. Since production is not a standalone activity, this scheduling must take into account equipments unavailabil-

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ity due to breakdowns or maintenance operations. In this field, interactions between production and maintenance has been attractive to researchers in order to balance resource availability and avoid conflictual situations. This problem is known in the literature as *"production scheduling with availability constraints"*[1].

Many researchers have made great attempts to investigate this problem where various maintenance policies have been thoroughly studied. So far, there is a considerable amount of literature on the scheduling problem integrating deterministic preventive maintenance, also called time based maintenance, where periods of unavailability are known and fixed in advance (deterministic unavailability). Ma *et al.* (2010) provided a detailed review on this topic where works were featured with different production configurations and under various criteria using different optimization methods[2]. However, for deterministic preventive maintenance, two main drifts can be observed. The first occurs when the maintenance frequency is very high, which induces an excessive cost due to useless interventions. The second occurs when the interval between two successive maintenance interventions is very long, consequently failures cannot be avoided resulting in system shutdown.

To reduce maintenance costs noticeably while increasing equipments reliability and availability, a more efficient maintenance strategy has emerged, called predictive maintenance. This policy proposes to maintain system only when necessary based on Prognostic and Health Management (PHM) outputs[3]. PHM is recognized to be a key feature for industrials in order to make maintenance decision aiming to reduce inopportune spending. In brief, the production system health state is continuously observed by analyzing signals collected from embedded sensors. After that, the current state is inferred and the future progression of failure is predicted in order to estimate the time before failure known as the *Remaining Useful Life (RUL)*[4]. The process forecasting the time of the failure and identification of the system RUL is called *prognostics*. Relatively few works have been proposed in this field. Pan *et al.* (2012)[5] proposed an integrated prognostics-based-scheduling model incorporating both production scheduling and predictive maintenance planning for a single machine with the objective of minimizing the maximum tardiness. Kovacs *et al.* (2011)[6] investigated the problem of optimizing the scheduling of maintenance actions using a Mixed Integer Programming (MIP) to minimize the total production loss. The case of parallel machines was studied by Herr *et al.* (2014)[7] where authors used PHM results and developed many heuristics to set the platform in order to reach a given demand as long as possible. Considering a multi-stack fuel cell system, the same problem was studied by Chretien *et al.* (2015)[8], where RULs were used to maximize the global useful life of the system under service constraint. Convex optimization was used to cope with the scale of the whole production horizon.

In this work, we deal with flowshop which is a common layout in production shops of wide engineering and theoretical background[9]. To the best of authors' knowledge, there is a unique study on flowshop scheduling problem with predictive maintenance proposed by Varnier and Zerhouni (2012)[10]. Authors developed a MIP model to optimally solve this scheduling problem with the objective of minimizing the makespan and maintenance delays. However, the defined MIP allows to solve only small instances and is not able to compute the optimal solution for instances with an important number of jobs and machines. To deal with larger instances, we propose a heuristic method based on Variable Neighborhood Search (VNS)[11]. Moreover, in all previous studies, a unique RUL value (expressed in unit of time) was predicted and used as a threshold to perform predictive maintenance interventions regardless of tasks being processed and without taking into account the variable operating conditions of machines. Since various production jobs are carried out, this assumption is not always realistic. Hence, we propose in this study a new interpretation of PHM results. We assume that machines are continuously monitored and a PHM module provides, due to various deterioration levels, the corresponding RUL and degradation value for each machine when processing each kind of job. On the other hand, since the prognosis process lays on failure prediction, the PHM outputs cannot be considered as deterministic or certain data. Thus, RULs and degradation values cannot be specified precisely or accurately due to the error of prediction techniques. For this reason, we choose to model them using Fuzzy Logic[12]. In this context, we develop a hybrid of VNS and fuzzy logic to solve the permutation flow shop scheduling problem with predictive maintenance.

The remaining content of the paper is organized as follows. In section 2, we present the scheduling problem. Section 3 is devoted to describe the proposed VNS algorithms. Finally, section 4 compares and analyses the performances of the newly designed algorithms. A general conclusion of the work and the perspectives considered are given in the last section.