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Technical Paper

Improvement of constructive heuristics using variable neighbourhood descent for scheduling a flow shop with sequence dependent setup time

Rajesh Vanchipura[a], R. Sridharan[b,*], A. Subash Babu[c]

[a] Department of Mechanical Engineering, Govt. Engineering College Thrissur, Thrissur 680009, Kerala, India
[b] Department of Mechanical Engineering, National Institute of Technology Calicut, Calicut 673601, Kerala, India
[c] Department of Mechanical Engineering, Indian Institute of Technology, Bombay, Powai, Mumbai 400076, Maharashtra, India

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ABSTRACT

This paper deals with the problem of scheduling a flow shop operating in a sequence dependent setup time environment. The objective is to determine the sequence that minimises the makespan. Two efficient neighbourhood search-based heuristics have been developed and tested using 960 problems, and the results obtained reveal their usefulness. The algorithms make use of two existing constructive heuristics. A neighbourhood search known as variable neighbourhood descent is used to improve the two constructive heuristics. Experimentation is carried out on the 96 groups of problems with 10 problem instances in each group. Performance analysis is carried out using the relative performance improvement of each heuristic. The analysis shows a consistently better performance of the neighbourhood-based improvement heuristics. A paired comparison test is used for validating the superiority of the proposed heuristics. The statistical analysis reveals that the performance of the neighbourhood-based heuristics is very much dependent on the initial constructive heuristics used.

1. Introduction

Manufacturing companies are under constant pressure to reduce costs and shorten manufacturing lead times. Reductions in manufacturing lead time can generate numerous benefits including lower inventory levels, improved quality, lower costs, and lesser forecasting error. A common way of managing lead time is by using effective scheduling procedures. There are a variety of scheduling procedures depending upon various types of manufacturing systems [1–6]. Manufacturing systems can be identified with different shop floor configurations, such as flow shop, job shop, open shop etc. The present study addresses the problem of scheduling in a flow shop, wherein multiple jobs are processed. Besides the processing time being different from job to job, the setup time is also different as it is dependent on the sequence in which the jobs are processed. Many real world scheduling problems encounter with environments wherein the setup time is sequence dependent. Allahverdi et al. [7] and Eren [8] highlight the relevance of sequence dependent setup times in printing industry, where the machine cleaning depends on the colour of the current and immediately following orders; textile industry applications, where setup for weaving and dying operations depends on the job sequence; container and bottle industry, where the settings change depending on the sizes and shapes of the containers; and in chemical compounds manufacturing, where the extent of the cleaning depends on both the chemical most recently processed and the chemical about to be processed. Similar situations arise in pharmaceutical, food processing, metal processing, paper manufacturing, and many other industries. In these situations, sequence dependent setup time plays a major role and must be considered explicitly when modelling the problem. The trend in manufacturing towards production of batches or unit production to satisfy demand and avoid inventory has made more relevant the scheduling problem with sequence dependent setup times. This paper relates to research carried out for developing suitable algorithms in order to minimise the makespan which in many ways influences the lead time.

The motivation of the present study is to apply variable neighbourhood descent (VND) method to improve the solutions obtained from two constructive heuristics. The first constructive heuristic is NEHRB heuristic (Nawaz, Enscore, and Ham heuristic modified by Rios-Mercado and Bard) [9] and the second constructive heuristic is Fictitious Job Setup Ranking Algorithm (FJSRA) [10]. The VND method known as the best improvement local search is a steepest descent heuristic [11]. The proposed algorithms NEHRB-VND and FJSRA-VND are developed by enhancing the capabilities of NEHRB

* Corresponding author. Tel.: +91 9495788136; fax: +91 495 2287250.
E-mail addresses: rajeshvanchipura@gmail.com (R. Vanchipura), sreedhar@nitc.ac.in (R. Sridharan), subash@me.iitb.ac.in (A.S. Babu).

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and FJSRA, respectively by integrating with them the power of VND. Thus, the objectives of the present study are as follows.

- To develop VND-based neighbourhood heuristics for SDST flow shop scheduling problem.
- To investigate the dependence of VND-based neighbourhood heuristics on the initial constructive heuristics.
- To provide guidelines for applying the proposed VND-based heuristics on any given real life problem instance.

The proposed heuristics show a variation in performance with respect to the setup time level. Paired comparison test is used to determine the statistically superior heuristic. Further, the statistical analysis also helps to understand the dependence of the neighbourhood-based algorithms over the initial constructive algorithm used. The development and analysis of the improvement heuristics (NEHRB-VND and FJSRA-VND) form the major contributions of this research work.

The rest of the paper is organised as follows. Section 2 describes the research background and Section 3 presents the problem description. Section 4 explains the proposed algorithms. Section 5 deals with the details of the experimentation carried out using the proposed heuristics. Section 6 presents results and analyses. Section 7 provides conclusions.

2. Research background

Many researchers have considered sequence dependent set up time for scheduling different shop floor configurations in manufacturing. In this context, the work of Tanaka and Araki [12], Sabouni and Logendran [13] and Xi [14] drew the attention of the authors of this paper. There are also other works such as those reported in [15–20] from which it can be realised that sequence dependent setup time environments are not limited to production and manufacturing situations, but it can be observed in various service and information processing systems also.

As rightly observed by Vahedi-Nouri et al. [21] and Khalili and Tavakkoli-Moghaddam [22], the flow shop scheduling problem is one of the most thoroughly studied area among scheduling problems. Researchers have investigated different variations of the flow shop scheduling problem [23]. However, its sequence dependent setup time (SDST) version is relatively less explored by researchers. This is due to the complexity of the SDST flow shop scheduling problems, which have been proved as NP complete problems [24]. Metaheuristics are more suitable to complex scheduling problems of this category. There are a wide variety of metaheuristics that can be applied to SDST flow shop scheduling problem such as imperialist competitive algorithm [25], simulated annealing algorithm [26,27], immune algorithm [28], recurrent neural network [29] and firefly-inspired algorithm [30]. Parthasarathy and Rajendran [31] develop a simulated annealing algorithm to minimise mean weighted tardiness for a flow shop with sequence dependent setup times. Ruiz et al. [32] propose a heuristic based on genetic algorithms. Gajpal et al. [33] present an ant colony optimisation algorithm for flow shop scheduling with sequence dependent setups for the makespan objective. Apart from these metaheuristics, there are a few research works that have reported local-search and greedy heuristics. Ruiz and Stutzle [34] present two simple local search-based iterated greedy algorithms. Tseng et al. [35] develop a penalty-based heuristic algorithm and compare their heuristic with an existing index heuristic algorithm. Rajendran and Ziegler [36] propose two heuristics for the SDST flow shop scheduling problem with a combination of two objectives namely, weighted flow time and weighted tardiness.

There are variations of the SDST flow shop such as flexible flow shop with SDST, no wait flow shop with SDST, which also find application of such intelligent metaheuristics. Ruiz and Marato [37] present a heuristic based on genetic algorithm for hybrid flow shop scheduling with SDST. Logendran et al. [38] develop three tabu-search based algorithms for the same problem. Zandieh and Gholami [39] present an immune algorithm for hybrid SDST flow shop with machines that suffer from stochastic breakdowns. A water flow-like approach is used by Pargar and Zandieh [40] in their study to minimise the weighted sum of makespan and total tardiness for the hybrid SDST flow shop. Varmazyar and Salmasi [41] present several metaheuristic algorithms based on tabu search and imperialistic competitive algorithm for SDST flow shop scheduling problem with the objective of minimising the number of tardy jobs. Wang et al. [42] use a simulated annealing approach for a hybrid SDST flow shop with the objective of minimising makespan.

Due to the inherent complexity of the SDST flow shop scheduling problem, development of constructive algorithms poses a challenging task for researchers and practitioners. In the literature, there are two well performing deterministic constructive algorithms. The first algorithm, NEHRB heuristic proposed by Rios-Mercado and Bard [9] is an extension of the well known constructive algorithm namely, NEH heuristic for general flow shop developed by Nawaz, Enscore, and Ham [43]. NEHRB heuristic is based on the principle that scheduling jobs with higher processing times earlier can result in a better schedule that minimises the makespan. The second algorithm, Fictitious Job Setup Ranking Algorithm (FJSRA) [10] uses sequence dependent setup time information for constructing the sequence.

Hansen and Mladenović [11] discuss about the relevance of variable neighbourhood search metaheuristic for solving combinatorial and global optimisation problems. The basic idea of this approach is systematic change of neighbourhood within a local search. This approach has been used for solving shop scheduling problems by Blazewicz et al. [44] Zobolas et al. [45], Roshanaei et al. [46], Lei and Wang [47], Driessel and Mönch [48], Almeder and Hartl [49], Chen et al. [50], and Seeanner et al. [51]. However, there have been a few attempts to apply the variable neighbourhood approach for solving scheduling problems with sequence dependent setup times. Bagheri and Zandieh [17] use a variable neighbourhood approach for solving flexible job shop scheduling problems involving sequence dependent setup time. Variable neighbourhood descent (VND) is a type of variable neighbourhood search method where the different neighbourhoods are obtained in a deterministic way. It is a steepest descent heuristic which is also known as the best improvement local search [11]. VND approach finds application in various optimisation problems [52,53]. To the best knowledge of the authors, the present research is the first work on the application of VND approach for solving SDST flow shop scheduling problem.

3. The problem on hand

The present study considers a flow shop, wherein the values of the setup times are sequence dependent. The problem involves scheduling a set of n jobs which are available for processing on m machines. The setup time of a job j, on a machine is dependent on job k processed just prior to job j on the machine. The objective is to determine the schedule that minimises the makespan. This problem is denoted as $F|s_{ijk}, prmu|C_{\max}$, where the first field describes the machine environment (F stands for an m-machine flow shop), the second field provides details of processing characteristics and constraints (s_{ijk} stands for sequence dependent setup time and $prmu$ means that the order or permutation in which the jobs go through the first machine is maintained throughout the