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Hybrid genetic algorithms for minimizing makespan in dynamic job shop scheduling problem ☆

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ABSTRACT

Job shop scheduling has been the focus of a substantial amount of research over the last decade and most of these approaches are formulated and designed to address the static job shop scheduling problem. Dynamic events such as random job arrivals, machine breakdowns and changes in processing time, which are inevitable occurrences in production environment, are ignored in static job shop scheduling problem. As dynamic job shop scheduling problem is known NP-hard combinatorial optimization, this paper introduces efficient hybrid Genetic Algorithm (GA) methodologies for minimizing makespan in this kind of problem. Various benchmark problems including the number of jobs, the number of machines, and different dynamic events are generated and detailed numerical experiments are carried out to evaluate the performance of proposed methodologies. The numerical results indicate that the proposed methods produce superior solutions for well-known benchmark problems compared to those reported in the literature.

1. Introduction

Effective production is very important in today's competitive environment. Companies are under pressure to shorten their lead times and meet customer requirements to maintain customer satisfaction. Production planning and scheduling plays a crucial role in increasing the efficiency of the plants. Scheduling is a decision making process that concerns the allocation of limited resources among competing tasks over time with the goal of optimizing one or more objectives (Pinedo, 2008). Proper scheduling leads to increased efficiency and capacity utilization, reduced time required to complete tasks, and consequently, increased profitability for the organization (Vinod & Sridharan, 2008).

Most scheduling problems are defined as complex combinatorial optimization problems. Job shop scheduling is a branch of production scheduling, which is among the most challenging combinatorial optimization problems (Motaghedi-larijani, Sabri-laghaie, & Heydar, 2010). The job shop scheduling (JSS) problem involves determining a schedule for jobs that have pre-specified operation sequences in a multi-machine environment (Fattahi, Mehrabad, & Jolai, 2007). A JSS problem generally refers to a static scheduling problem in the job shop, where a set of different jobs are processed on a series of machines. Each job has some operations that must be processed in a certain technical sequence and each operation has a predetermined processing time. The main goal of a JSS problem is to find a schedule to process all jobs in a manner that optimizes given performance objectives (Zhou, Nee, & Lee, 2009). The general JSS problem is strongly Non-deterministic Polynomial-time hard (NP-hard). The JSS problem shifts to a new kind of problem that is known as a dynamic job shop scheduling (DJSS) problem when real time events such as random job arrivals, machine breakdowns and changes in processing times occur (Adibi, Zandieh, & Amiri, 2010). DJSS is also NP-hard combinatorial optimization problem. In the scheduling literature, most publications focus on static scheduling problems and seldom take into account dynamic factors. However in real life, scheduling problems that naturally include dynamic events are more complex than the job scheduling problem (JSP).

Although there are several research papers in the literature which address these problems, there is potential for developing fast and effective solutions. The main contribution of this paper is to develop different hybrid GA approaches for dynamic job shop scheduling problems to obtain efficient solutions in terms of solution quality and computational efficiency. Firstly, we develop a new KK (Kundakcı & Kulak) heuristic and it is combined with GA for dynamic job shop scheduling problems including new job

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arrivals, machine breakdowns and changes in the processing time. Moreover, well-known dispatching rules are integrated with GA to obtain outstanding initial population. In addition, various benchmark problems including the number of jobs, the number of machines, and different dynamic events are generated and presented in the paper to evaluate the performances of the proposed methodologies. Finally, we provide a numerical evaluation, which demonstrates the superiority of the hybrid GA approaches over conventional GA and tabu search (TS) algorithms.

This study is organized as follows: In the second section, a comprehensive literature review of dynamic job shop scheduling is given and then, a mathematical model of the problem is presented. Next, efficient heuristic solution procedures are proposed. Experiments are conducted to demonstrate the effectiveness of the proposed methods and detailed numerical results are presented in the fifth section. Finally, results of the experiments are discussed and suggestions for future research are offered.

2. Literature review

The job shop scheduling problem is well-known to be one of the hardest combinatorial optimization problems. JSS problems have captured the interest of many researchers. Although there has been considerable interest in JSS problems, several research papers have been published that consider dynamic factors. Dynamic job shop scheduling problems are also combinatorial in nature and known to be NP-hard. In the literature, various heuristic methods have been proposed to obtain a near optimum solution. The first study in dynamic job shop scheduling was published by Holloway and Nelson in 1974. They developed a multi-pass heuristic scheduling procedure for job shop scheduling problems with due dates and variable processing times. Another study that used the same method for the scheduling of a job shop with job due dates, intermittent job arrivals, and statistical processing times was conducted by Nelson et al. in 1977.

Other heuristic methods have also been proposed for dynamic job shop scheduling problems. Muhlemann, Lockett, and Farn (1982) used heuristics in the form of dispatching disciplines for the dynamic scheduling problem that includes new job arrivals and uncertainty like errors in estimating process times and machine breakdowns. Their experiments indicated that more frequent revisions are needed to obtain better scheduling performance. Chang (1997) developed a new approach to provide real-time estimates of queuing times for the remaining operations of jobs in the dynamic job shop and incorporated this estimated queuing time information into existing scheduling heuristics to improve their performance.

Another paper that considers dispatching rules in dynamic job shop scheduling problems is from Rajendran and Holthaus (1999). They presented a comparative study on the performance of dispatching rules in dynamic flow shops, job shops and flow shops, and job shops with missing operations and they observed that the performance of dispatching rules is being influenced by the routing of jobs and shop floor configurations. Dominic, Kaliyamoorthy, and Kumar (2004) proposed an efficient method for dynamic job shop scheduling by combining different dispatching rules and simulated the dynamic model of a job shop under various rules and performance measures. Vinod and Sridharan (2008) presented a simulation-based experimental study of dispatching rules for scheduling a dynamic job shop in which the setup times are sequence dependent and experiment results indicated that setup-oriented rules provide better performance than ordinary rules. Lu and Romanowski (2013) proposed multicontextual dispatching rules for job shops with dynamic job arrival. They examined 11 basic dispatching rules and 33 composite rules made with multi-contextual functions that describe machine idle time and job waiting time. Sharma and Jain (2014) assessed the performance of nine dispatching rules in dynamic job shop from makespan, mean flow time, maximum flow time, mean tardiness, maximum tardiness, number of tardy jobs, total setups and mean setup time performance measures viewpoint. Results indicated that shortest setup time rule provides the best performance for mean flow time and number of tardy jobs measures.

In the literature, different authors propose reactive scheduling policies for dynamic job shop problems. Sabuncuoğlu and Bayız (2000) studied the reactive scheduling problems in a stochastic manufacturing environment and tested several scheduling policies under machine breakdown in a classical job shop system. Kutanoğlu and Sabuncuoğlu (2001) developed reactive scheduling policies against unexpected machine failures in dynamic job shop problems. Suwa and Sandoh (2007) proposed a new when-to-schedule policy in reactive scheduling and demonstrated the effectiveness of the proposed policy by applying it to job shop problems with machine breakdown. Nie, Gao, Li, and Shao (2013) proposed a heuristic to implement the reactive scheduling of the jobs in the dynamic production environment. They also proposed an approach based on gene expression programming (GEP) to construct efficient scheduling rules for dynamic job shop scheduling.

Genetic Algorithm (GA) has frequently been used for dynamic job shop scheduling problems. Qi, Burns, and Harrison (2000) used parallel multi-population GA to meet the dynamic nature of the job-shop scheduling. They compared the results of the proposed GA with dispatching rules and proved that the proposed GA successfully improved the solution. Rangsaritratsamee, Ferrell, and Kurz (2004) proposed a methodology for dynamic job shop scheduling that simultaneously addresses efficiency and stability though a multi-objective approach. Their methodology uses periodic rescheduling in which a multi-criteria objective function is used as the fitness function of a GA to generate the schedules at each rescheduling point. They tested the methodology on a simulated job shop to determine the impact of the key parameters on the performance measures. Fattahi and Fallahi (2010) developed a meta-heuristic algorithm based on a GA for dynamic scheduling in a flexible job shop and considered two objectives to balance efficiency and stability in the schedules. Kapanoglu and Alikalfa (2011) proposed a GA based learning system for constructing interval-based, state-dependent priority rules for each interval of queue lengths in dynamic job shops and their proposed approach considerably outperformed the priority rules for most of the problems.

Meta-heuristic methods based on local search are also used in dynamic job shop scheduling problems. Liu, Ong, and Ng (2005) proposed Tabu Search for solving the static shop scheduling problem for a number of dynamic shop scheduling benchmark problems and analyzed the characteristics of the dynamic shop scheduling problem when machine breakdowns and new job arrivals occur. Hosseinabadi, Siar, Shamshirband, Shojafar, and Nasir (2014) developed a new method called TIME_GELS that uses the gravitational emulation local search algorithm (GELS) for solving the multi-objective flexible dynamic job-shop scheduling problem. Also evolutionary algorithms are prosed for dynamic job shop scheduling problems. Hao and Lin (2010) focused on a job shop rescheduling problem in dynamic environment which considers random job arrivals and machine breakdowns and proposed an interactive adaptive-weight evolutionary algorithm. Hao and Gen (2011) formulated a multi-objective job shop rescheduling problem to improve the practical application of rescheduling. They designed an evolutionary algorithm in which a random key-based representation and interactive adaptive-weight fitness assignment are embedded.

Furthermore, hybrid methods are proposed to solve dynamic job shop scheduling problems. Li and Chen (2009) analyzed the