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A branch population genetic algorithm for dual-resource constrained job shop scheduling problem

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ABSTRACT

The manufacturing systems constrained by both machines and heterogeneous workers are referred to as Dual Resource Constrained (DRC) systems. DRC scheduling problem has attracted more and more attention in recent years. In order to address the Dual Resource Constrained Job Shop Scheduling Problem (DRCJSP) to minimize the *makespan* and *cost*, a meta-heuristic algorithm named Branch Population Genetic Algorithm (BPGA) is proposed in this paper. The proposed algorithm is a genetic algorithm (GA) based scheduling approach, and it introduces the branch population to accumulate and transfer evolutionary experience of parent chromosomes via pheromone. The branch population can strengthen the population diversity and accelerate convergence. Additionally, several mechanisms are applied to optimize the performance of BPGA. The elite evolutionary operator is utilized to optimize search ability by laying particular emphasis on the evolution of the elite population. The roulette selection operator based on sector segmentation is proposed to decrease the computational complexity and avoid the algorithm prematurity. The scheduling strategy based on compressed time window is proposed to improve the global scheduling performance. In our research, BPGA shows convergence to the Pareto front according to the Markov chain theory. Numerical experiments with randomly generated examples and case studies are analyzed to evaluate the performance of the proposed algorithm. Computational experiments show BPGA can provide the promising results for the DRCJSP.

1. Introduction

Since the early 1960s, the Job-shop Scheduling Problem (JSP) has been well known as one of the most important NP-hard combinatorial optimization problems. Many researchers have developed numerous scheduling approaches for machine-constrained manufacturing systems, but they neglected important constraints of available workers.

In recent years, the business environment has become increasingly uncertain and dynamic. As a result, trends in the manufacturing industry have revealed an increasing reliance on the agility and flexibility. Products are characterized by more mixes, smaller lot sizes, and shorter cycle times. To accommodate these requirements, unique inherent characteristics in different types of machines and human resources must be considered for quick responses to market demands.

This type of system, where both machines and workers represent potential capacity constraints, is referred to as the Dual Resource Constrained Job-shop Scheduling Problem (DRCJSP) (Xu, Xu, & Xie, 2011). In reality, jobs cannot be processed if workers, machines, or both of them are not available. Thus, DRCJSP has gained more and more attention in recent years.

In a Dual Resource Constrained (DRC) system, the number of workers is typically less than the number of available machines. In order to obtain a feasible scheduling scheme with the optimal performance criteria, workers need to be cross-trained and transferred among different machines according to their respective skills. The scheduling process of DRCJSP consists of two routing sub-problems: job scheduling and resource dispatch. This makes DRCJSP more difficult than JSP. Moreover, DRCJSP presents a number of additional technical challenges. One research highlight focuses on interactions between the job dispatching and the worker assignment due to un-fully staffed machines. It is important to study how these worker assignments affect and are affected by job dispatching rules. E.g. "when" rule and "where" rule (Kher, 2000), "Push/Pull" rule (Salum & Araz, 2009) and "who" rule

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(Berman & Larson, 2004; Bokhorst, Slomp, & Gaalman, 2004). Another research highlight focuses on the improved utilization based on unique characteristics of workers, as this direction allows more accurate depictions of real manufacturing situations. Some previous works had been researched to address the effect of different characteristic levels among individual workers, such as cross-trained staffing levels (Kim & Nembhard, 2010), worker allocation (Lobo, Wilson, Thoney, Hodgson, & King, 2014), worker fatigue and recovery (Jaber & Neumann, 2010), learning and forgetting levels (Givi, Jaber, & Neumann, 2015). This research allows better reflection of the real manufacturing process and makes DRC more valuable and relevant to current industry technologies.

Traditionally, DRCJSP has been solved using analysis and simulation approaches (Treleven & Elvers, 1985). However, it is difficult to accurately model details of DRC system using analytical approach. In addition, the efficiency of simulation approach is undesirable because of its iterative nature which may lead to high computational costs. Consequently, there is an observed move toward the use of meta-heuristic methods, which can quickly find a near optimal solution.

A practical meta-heuristic algorithm called Branch Population Genetic Algorithm (BPGA) is proposed in this paper. BPGA is not only a hybrid of Genetic Algorithm (GA) and the Ant Colony Optimization (ACO) algorithm based on the characteristics of multi-constraint and flexible process of DRCJSP. The algorithm introduces an idea of accumulating and transferring evolutionary experience via pheromone of ACO. The proposed algorithm can guarantee the excellent global search performance with its parallel evolution mechanism on multi population. The branch chromosomes population will not only strengthen the population diversity, but also speed up the convergence of the inheritance of the survival experience. Additionally, several mechanisms are utilized to optimize the performance of BPGA. These mechanisms include but not limited to the elite evolutionary operator; roulette wheel selection operator based on sector segmentation; scheduling strategy based on compressed time window.

This paper is organized into six main sections. The introduction is presented in Section 1. Section 2 is literature reviews. Section 3 describes the mathematical model of the double-objective DRCJSP problem. The details of the BPGA are explained in Section 4, and then the convergence of the proposed algorithm is analyzed by applying the Markov chain theory. Section 5 is composed of verification experiments, comparative experiments, and NSGAII (Deb, Pratap, Agrawal, & Meyarivan, 2002). Finally, Conclusion is in Section 6.

2. Literature review

Over the past fifty years, numerous researches about DRCJSP have been proposed after the pioneering work from Nelson (1967).

The problem becomes more and more complicated as factors, such as various human and job characteristics, are considered. Consequently, there is an observed move toward finding an optimum solution or presenting a general solution using meta-heuristic approaches. For example: GA, Simulated Annealing algorithm (SA).

2.1. Genetic algorithm

GA is a parallel searching approach via the natural selection mechanism for solving optimization problems. The idea of GA, which is proposed by Holland (1975), is to evolve a chromosome population of candidate solutions using several operators. These operators, such as selection, crossover and mutation, are inspired by the natural genetic variation and selection. Thus, GA can obtain the best individual, which reflects the global optimal solution after evolving many generations. GA has two major differences compared to other heuristic algorithms. They are the population evolution mechanism and the evolutionary operators. The efficiency of GA is improved by the population evolution mechanism due to the distributed search in the solution space. Evolutionary operators are used to simplify the algorithm by considering gene as an evolutionary unit. During the population evolution, the individual chromosome is evolved randomly, and the whole population represents the gradual optimization and the continuous approximation to the optimal solution without considering constraints of the specific problem.

Numerous researches about solving JSP were proposed, such as chromosomes coding approaches, evolutionary operators, algorithm structure, and hybrid search strategy (Cheng, Gen, & Tsujimura, 1996, 1999; Yamada & Nakano, 1997). Nowadays, the trend moves toward improving applications of GA and meta-heuristic algorithm to solve the expand JSP.

Manikas and Chang (2009) proposed the permute GA and GA imbedding heuristic rule respectively for multi-objective JSP. The hybrid PSO-GA algorithm was proposed by Liu, Hu, Hu, and Wang (2015) and Yu, Zhang, Chen, and Zhang (2015) to solve high dimensional JSP. Their methods could achieve not only a better solution quality, but also a faster convergence with a reasonable computation time. Vilcot and Billaut (2008) proposed an elite preserve GA which generated initial population based on Tabu search. Pezzella, Morganti, and Ciaschetti (2008) solved FJSP with the composite heuristic strategy. Ishikawa, Kubota, and Horio (2015) also proposed a hierarchical multi-space competitive distributed genetic algorithm to solve FJSP. His research could efficiently find an optimal solution with a low computational cost by increasing the number of individuals in the solution space. A solution space related multi-objective genetic algorithm based on the ELECTRE method (Rohaninejad, Kheirkhah, Fattahi, & Vahedi-Nouri, 2015) was presented by Rohaninejad. After that, Rohaninejad, Sahraeian, and Nouri (2016) proposed a hybrid meta-heuristic based on a combination of Genetic algorithm and particle swarm optimization algorithm to solve a particular integrated lotsizing FJSP. Regarding to the comparison computational results, the hybrid algorithm surpasses the other algorithms in the closeness of solutions to Pareto optimal front and diversity criteria. Kurdi (2015) presented a hybrid island model genetic algorithm (HIMGA) with naturally inspired self-adaptation phase strategy, which is capable of striking a better balance between diversification and intensification. In order to improve the effectiveness of the HIMGA, Kurdi (2016) proposed a new naturally inspired evolution model and migration selection mechanism that are capable of improving the search diversification and delaying the premature convergence.

Through the above researches, the inherent drawbacks of GA, such as worse local searching ability and premature convergence, can be improved via imbedding some local searching mechanism.

2.2. Ant colony optimization algorithm

ACO is a constructed meta-heuristic algorithm based on swarm intelligence proposed by Dorigo (1992). The algorithm created artificial ants to solve problems by simulating the natural foraging behavior of actual ant colony on three principal characteristics: (1) each ant communicates with others indirectly by releasing pheromone on passing routes; (2) pheromone of shorter paths accumulates faster compared to longer paths; (3) ants prefer routes with a higher pheromone level. After the initial work of utilizing ACO to solve Travel Salesman Problem (TSP), numerous scholars had paid more attention to improving the robustness and searching ability of ACO, and proposed many improved ACOs, such as Ant-Q algorithm (Gambardella & Dorigo, 1995), MMAS