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An improved shuffled complex evolution algorithm with sequence mapping mechanism for job shop scheduling problems

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ABSTRACT

The job shop problem is an important part of scheduling in the manufacturing industry. A new intelligent algorithm named Shuffled Complex Evolution (SCE) algorithm is proposed in this paper with the aim of getting the minimized makespan. The sequence mapping mechanism is used to change the variables in the continuous domain to discrete variables in the combinational optimization problem; the sequence, which is based on job permutation, is adopted for encoding mechanism and sequence insertion mechanism for decoding. While considering that the basic SCE algorithm has the drawbacks of poor solution and lower rate of convergence, a new strategy is used to change the individual's evolution in the basic SCE algorithm. The strategy makes the new individual closer to best individual in the current population. The improved SCE algorithm (ISCE) was used to solve the typical job shop problems and the results show that the improved algorithm is effective to the job shop scheduling.

1. Introduction

The job shop scheduling problem (JSP) is one of the most difficult combinatorial optimization problems which can be described as: There are n jobs to be processed through m machines. Each job must pass through each machine once and once only. Each job should be processed through the machines in a particular order, and there are no precedence constraints among operations of different jobs. Each machine can process only one job at a time, and it cannot be interrupted. Furthermore, the processing time is fixed and known. The objective of the JSP is to find a schedule to minimize the makespan, namely, the process time which is required to finish all jobs. JSP is a NP-hard problem (Cook, 1971), so it can not be exactly solved in a reasonable computation time. Many approximate methods have been developed in the recent years to solve JSP. At present, the method for the job shop scheduling mainly includes two kinds, one of which is exact methods and the other is meta-heuristic algorithm. The exact methods such as linear programming, enumeration, branch and bound are usually used to solve the small-scale scheduling. Recently, a lot of meta-heuristics methods are proposed for the optimization of job shop scheduling problems, these methods can find the optimum in reasonable amount of time and make up for the shortcomings of reaching the optimum in the exact method. Now the methods are used for job shop scheduling problems mainly include tabu search (Meeran & Morshed, 2012), simulated annealing (Elmi, Solimanpur, Topaloglu, & Elmi, 2011), genetic algorithm (Wang, 2003), shuffled frog leaping (Cai & Li, 2010), artificial neural networks (Wang & Qi-di, 2007) and particle swarm optimization (PSO) (Zhang, Sun, Ouyang, & Zhang, 2009; ZHANG, WANG, XU, & JIE, 2012). There are many better features shown when these methods are used for solving high dimensional and complex problems. However, for the job shop scheduling, many of these methods usually trap into local solution and could not get the global optimum, so the research on the job shop scheduling is still an important issue in the field of production scheduling.

Due to the general limitation of exact enumeration methods which can not solve the large scale classical JSSP (Allahverdi, Ng, Cheng, & Kovalyov, 2008; Jain & Meeran, 1999; Mati, Dauzère-Pérès, & Lahlou, 2011), many more recent papers that have developed innovative techniques such as hybrid meta-heuristics (Bilyk, Mönch, & Almeder, 2014; Bożejko, Uchroński, & Wodecki, 2010; Kuo & Cheng, 2013), TPA (team process algorithm) (Li & Chen, 2011), TS/PR (tabu search/path relinking) (Peng, Lü, & Cheng, 2015), PSO with VNS (Tavakkoli-Moghaddam, Azarkish, & Sadeghnejad-Barkousaraie, 2011; Zhao, Tang, Wang, & Jonrinaldi, 2014; Zhao, Tang, Wang, Wang, & Jonrinaldi, 2013), BFA (bacterial foraging algorithm) (Zhao, Jiang, Zhang, & Wang, 2014),

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GRASP × ELS approach (Chassaing et al., 2014). It was not surprise with the new techniques emphasis substantial progress was made and in the short time period from 2012–2015, which shall be called as the boom period for the new algorithms to JSSP, some of the most innovating algorithms were formulated.

The job shop problem (JSP) is among the hardest combinatorial problems (Johnson & Garey, 1979). Not only is it complicated, but it is one of the worst NP-complete class members. A large body of literature discusses JSP with meta-heuristic algorithm has been considered in single machine, parallel machine, flow shop and job shop environment. Lin et al. (2010) proposes a new hybrid swarm intelligence algorithm consisting of particle swarm optimization, simulated annealing technique and multi-type individual enhancement scheme to solve the job-shop scheduling problem and prove his algorithm has more robust and efficient than the existing algorithms. The Distributed and Flexible Job-shop Scheduling problem (DFJS) considers the scheduling of distributed manufacturing environments, where jobs are processed by a system of several Flexible Manufacturing Units (FMUs). De Giovanni and Pezzella (2010) extend the gene encoding to include information on job assignment and proposes an Improved Genetic Algorithm to solve the Distributed and Flexible Job-shop Scheduling problem. Wei-ling and Jing (2013) consider the job-shop problem with release dates and due dates, with the objective of minimizing the total weighted tardiness. They combine differential evolution algorithm with the improved critical path algorithm on a disjunctive graph model and presents a hybrid DE (HDE) to solve this kind of problem. Xing, Chen, Wang, Zhao, and Xiong (2010) provides an effective integration between Ant Colony Optimization (ACO) model and knowledge model and proposes a Knowledge-Based Ant Colony Optimization (KBACO) algorithm for the Flexible Job Shop Scheduling Problem (FJSSP). Zhang, Manier, and Manier (2014) consider job shop scheduling problems with transportation constraints and bounded processing times. They use a modified disjunctive graph to represent the whole characteristics and constraints of such considered problems. Compared with classical disjunctive graph, it contains not only processing nodes, but also transportation and storage nodes. The traditional scheduling models consider performance indicators such as processing time, cost and quality as optimization objectives. Salido et al. (2013) study and analyze three important objectives: energy-efficiency, robustness and makespan, and focus the attention in a job-shop scheduling problem where machines can work at different speeds. It can be observed that there exits a clear relationship between robustness and energy-efficiency and a clear trade-off between robustness/energy efficiency and makespan. Adibi, Zandieh, and Amiri (2010) study the dynamic job shop scheduling that considers random job arrivals and machine breakdowns. Considering an event driven policy rescheduling, is triggered in response to dynamic events by variable neighborhood search (VNS) and proposed a new dynamic local search method which is compared with some common dispatching rules that have widely used in the literature for dynamic job shop scheduling problem. Due to the discrete solution spaces of scheduling optimization problems, Sha and Lin (2010) modify the particle position representation, particle movement, and particle velocity of the original PSO algorithm and proposes a multi-objective PSO for solving the job shop problem. Zhang and Wu (2010) propose a hybrid simulated annealing algorithm based on a novel immune mechanism for the job shop scheduling problem with the objective of minimizing total weighted tardiness. The bottleneck jobs existing in each scheduling instance generally constitute the key factors in the attempt to improve the quality of final schedules so that the sequencing of these jobs needs more intensive optimization. Wong, Puan, Low, and Wong (2010) presents an improved bee colony optimization algorithm with Big Valley landscape exploitation (BCBV) as a biologically inspired algorithm to solve the job shop problem. The BCBV algorithm mimics the bee foraging behavior where information of newly discovered food source is communicated via waggle dances. Lei (2010) proposes a random key genetic algorithm (RKGA) for solving the fuzzy job shop scheduling problem with availability constraints which objective is to find a schedule to maximize the minimum agreement index subject to periodic maintenance, non-resemble jobs and fuzzy due-date. Hwang and Choi (2007) propose a workflow-based dynamic scheduling framework, in which a workflow management system (WfMS) serves as a dynamic job-shop scheduler and have developed an algorithm for embedding a discrete-event simulation mechanism into a WfMS, and have implemented a prototype job-shop scheduler. Tavakkoli-Moghaddam et al. (2011) proposes a new multi-objective Pareto archive particle swarm optimization (PSO) algorithm combined with genetic operators as variable neighborhood search (VNS) and presents a new mathematical model for a bi-objective job shop scheduling problem with sequence-dependent setup times and ready times that minimizes the weighted mean flow time and total penalties of tardiness and earliness. Wang and Tang (2011) propose an improved adaptive genetic algorithm (IAGA) for solving the job shop scheduling problem which was Inspired from hormone modulation mechanism, and then the adaptive crossover probability and adaptive mutation probability are designed. Renna (2010) concerns the job shop scheduling problem in cellular manufacturing systems; the schedule is created by a pheromone-based approach. Her proposed approach is carried out by a Multi-agent Architecture and it is compared with a coordination approach proposed in literature used as a benchmark. Liu, Sun, Yan, and Kang (2011) proposes an adaptive annealing genetic algorithm to deal with the job-shop planning and scheduling problem for the single-piece, small-batch, custom production mode. Kachitvichyanukul and Sitthitham (2011) propose a two-stage genetic algorithm (2S-GA) for multi-objective Job shop scheduling problems with three criteria: Minimize makespan, Minimize total weighted earliness, and Minimize total weighted tardiness. Inspired by the decision making capability of bee swarms in the nature, Banharnsakun, Sirinaovakul, and Achalakul (2012) proposes an effective scheduling method based on Best-so-far Artificial Bee Colony (Best-so-far ABC) which biases the solution direction toward the Best-so-far solution rather a neighboring solution and then use the method for solving the job shop problem. Seo and Kim (2010) propose an ant colony optimization algorithm with parameterized search space is developed for job shop problem. The problem is modeled as a disjunctive graph where arcs connect only pairs of operations related rather than all operations are connected in pairs to mitigate the increase of the spatial complexity. Thürer, Godinho Filho, and Stevenson (2013) use the controlled order release in the job shop problem with finite storage space and finds out that the best results are achieved by the workload control order release (WLCOR) rule.

SCE algorithm is a relatively new intelligent optimization method based on population, this algorithm combines shuffled method and make each individual's information shared in the space, so it has the ability of powerful global searching and can avoid being trapped into the local solution. Now the SCE algorithm has been used for solving various problems in many fields (Barakat & Altoubat, 2009; Li, Cheng, Zeng, & Lin, 2011; Tang, Li, & Fan, 2010). Job shop scheduling is a typical combinatorial optimization problem, and there have been also many researches shown the advantages of heuristics algorithm on the job shop scheduling. At present, there are very few researches in the job shop scheduling based SCE algorithm, so in this paper we use the SCE algorithm to get the makespan in the job shop scheduling problem. Because the basic SCE algorithm has the drawbacks of lower convergence rate and poor solution, an improved SCE algorithm (ISCE) is