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A hybrid algorithm based on a new neighborhood structure evaluation method for job shop scheduling problem

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ABSTRACT

Job shop scheduling problem (JSP) which is widespread in the real-world production system is one of the most general and important problems in various scheduling problems. Nowadays, the effective method for JSP is a hot topic in research area of manufacturing system. JSP is a typical NP-hard combinatorial optimization problem and has a broad engineering application background. Due to the large and complicated solution space and process constraints, JSP is very difficult to find an optimal solution within a reasonable time even for small instances. In this paper, a hybrid particle swarm optimization algorithm (PSO) based on variable neighborhood search (VNS) has been proposed to solve this problem. In order to overcome the blind selection of neighborhood structures during the hybrid algorithm design, a new neighborhood structure evaluation method based on logistic model has been developed to guide the neighborhood structures selection. This method is utilized to evaluate the performance of different neighborhood structures. Then the neighborhood structures which have good performance are selected as the main neighborhood structures in VNS. Finally, a set of benchmark instances have been conducted to evaluate the performance of proposed hybrid algorithm and the comparisons among some other state-of-art reported algorithms are also presented. The experimental results show that the proposed hybrid algorithm has achieved good improvement on the optimization of JSP, which also verifies the effectiveness and efficiency of the proposed neighborhood structure evaluation method.

1. Introduction

There are various types of scheduling problems in manufacturing systems. Effective scheduling methods can improve the performance of manufacturing system well. Therefore, many researchers focus on proposing effective methods for different scheduling problems. Nowadays, it is a hot topic in research area of manufacturing system. Job shop scheduling problem (JSP) which is widespread in the real-world production system is one of the most general and important problems in various scheduling problems (Park, Choi, & Kim, 2003). In JSP, there are n jobs must be processed through m machines. All the operations of every job are processed in a pre-determined processing sequence. Each operation has a specified machine with the specified processing time. The aim of JSP is to determine the operations' processing sequence on each machine and the start time of each operation by optimizing one or more objectives, such as makespan, due date and so on. Comparing with other scheduling types, its main feature is that all the jobs contain different process plans. JSP had been proved to be the NP-hard problem (Garey, Johnson, & Sethi, 1976). Due to the large and complicated solution space and process constraints, JSP is very difficult to find an optimal solution within a reasonable time even for small instances. For example, the optimal solution of the well-known JSP benchmark problem FT10 had not been found until a quarter of century after the problem was proposed originally (Adams, Egon, & Zawack, 1988).

Because of the representativeness and complexity of JSP, a lot of researchers have put their efforts on improving effective optimization methods for it. JSP was primarily handled by Branch & Bound method, some heuristic procedures based on priority rules and shifting bottleneck method. These methods are called as the exact methods. Their main disadvantage is that they cannot solve the large scale problems (the total number of operations is more than 200). So, during the past decades, most researchers turn their focus to the approximation methods, including numerous meta-heuristic algorithms which have been used in JSP extensively. These algorithms could be divided into two categories, population based

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algorithms and local search algorithms. The most popular and latest population based algorithms include genetic algorithm (GA), artificial bee colony algorithm (ABC), particle swarm optimization (PSO), biogeography-based optimization (BBO), teaching learning based optimization algorithm (TLBO) and so on. The most popular local search algorithms include tabu search (TS), neighborhood search, variable neighborhood search (VNS) and so on. Asadzadeh and Zamanifar (2010) proposed an agent-based parallel GA for JSP. Yusof, Khalid, Hui, Yusof, and Othman (2011) proposed a hybrid parallel micro GA to solve the JSP. Sels, Craeymeersch, and Vanhoucke (2011) presented a hybrid single and dual population GA for JSP. Zhang, Song, and Wu (2013) proposed a novel ABC for solving JSP with total weighted tardiness criterion. In this algorithm, a tree search algorithm was devised to enhance the exploitation capability of ABC. Wang and Duan (2014) designed a hybrid BBO algorithm for JSP. This method combined the chaos theory and "searching around the optimum" strategy with the basic BBO. Nasad, Modarres, and Seyedhoseini (2015) presented a self-adaptive PSO for the lot sizing JSP. This algorithm was self-controller about its working parameters. Baykasoglu, Hamzadayi, and Kose (2014) designed a new TLBO algorithm for JSP. Based on the above survey, we find that the main advantage of the population based algorithms is their powerful global searching ability because of their multiple points searching process. However, also because of this feature, their local searching ability is not good. So, some researchers paid their attentions on the local search algorithms for JSP. Lei and Guo (2015) proposed a neighborhood search method for the dual-resource constrained interval JSP with environmental objective. Peng, Lu, and Cheng (2015) proposed a TS/path relinking algorithm for the JSP. These algorithms are very powerful for their local searching ability. But, because of the single point searching process, their global searching ability is not very good. Based on the above analysis of population-based algorithms and local search algorithms, we find that every algorithm contains its own advantages and disadvantages. The hybrid algorithm which combines them together becomes more and more popular for JSP. Compared with local search using single-point search method, population based algorithms have the characteristics of multi-point parallel, sharing the current and historical information and faster global convergence speed. Since this reason, the combination employ of population based algorithm and effective local search algorithm is an inevitable trend.

In recent years, more and more researchers paid their attentions on designing hybrid algorithm for JSP. Goncalves, Mendes, and Resende (2005) utilized GA, schedule generation procedure and local search procedure for JSP. Zhang, Li, Rao, and Li (2005) developed an effective combination of GA and simulated annealing (SA) to solve the JSP. Zhang, Rao, and Li (2008) proposed a hybrid GA based on a local search heuristic for the JSP. Zhang, Li, Rao, and Guan (2008) developed the heuristics search approach combining SA and TS strategy to provide a robust and efficient methodology for the JSP. Ge, Sun, Liang, and Qian (2008) proposed a computationally effective algorithm of combining PSO with artificial immune system (AIS) for solving the minimum makespan problem of JSP. Gao, Zhang, Zhang, and Li (2011) designed an efficient hybrid evolutionary algorithm (memetic algorithm), with a novel local search to solve the JSP. Eswaramurthy and Tamilarasi (2009) hybridized TS with ant colony optimization for solving JSP. Zuo, Wang, and Tan (2012) proposed an artificial immune system (AIS) and TS based hybrid strategy for JSP. Ren and Wang (2012) proposed a hybrid GA based on a new algorithm presented for finding the critical path from schedule and a local search operator. Nasiri and Kianfar (2012) proposed a hybrid algorithm which combined global equilibrium search, path relinking and TS to solve the JSP. Ponsich and Coello (2013) hybridized differential evolution and TS for solving JSP.

Based on the above survey, this paper also proposes an effective hybrid algorithm for solving JSP. In this method, PSO which is one of the most efficient population-based algorithms is employed for the global searching process and VNS which is one of the most efficient local search algorithms is designed for the local searching process. PSO, proposed by Kennedy and Eberhart (1995), is a population based algorithm inspired by the behavior of bird flock. Due to its simple principle and good optimization ability (Vassiliadis & Dounias, 2009), PSO has attracted more and more attentions both in continuous optimization and combinatorial optimization problems (Schutte, Reinbolt, Fregly, Haftka, & George, 2004; Wang, Huang, Zhou, & Pang, 2003). Recently, many researchers proposed hybrid algorithms based on PSO and local search method to deal with different optimization problems, such as PSO-Tabu search (Gao, Peng, Zhou, & Li, 2006), PSO-SA (Niknam, Amiri, Olamaei, & Arefi, 2009) and so on. Some hybrid PSO algorithms are also proposed to deal with JSP (Pongchairerks and Kachitvichyanukul, 2009; Sha & Hsu, 2006; Xia & Wu, 2006). VNS, proposed by Mladenovic and Hansen (1997), has quickly gained widespread successful utilization in many domains, such asly graphs (Caporossi & Hansen, 2000), traveling salesman problem (Felipe, Ortuno, & Tirado, 2009) and vehicle routing problem (Kuo & Wang, 2012). The research and application of VNS also have increased gradually in the shop scheduling problem (Bagheri & Zandieh, 2011; Mehmet & Aydin, 2006; Yazdani, Amiri, & Zandieh, 2010). VNS was firstly applied on JSP by Mehmet and Aydin (2006). The crossover operator and mutation operator of GA were utilized as two neighborhood structures in this VNS, which used the single-point search method. Although the optimal solution could be obtained by multiple trials, the efficiency of the algorithm was not so good. VNS contains two inherent limitations. One is how to select and design efficient neighborhood structures, which impact the performance of VNS greatly. The neighborhood structures design has to base on the features of different problems. For example, in this paper, we need to base on the features of JSP to design effective neighborhood structures. How to evaluate the performance of different neighborhood structures is also another problem. To solve this, this paper proposes a new neighborhood structure evaluation method based on logistic model. The other limitation is that VNS often traps into the local optimum because of its single point searching process. Some researchers use the multiple trials to overcome this problem. In this paper, we combine it with PSO to deal with this. The PSO is used to provide different searching points for VNS.

Almost all of these hybrid algorithms focused on the improvement of local search procedure. As we all known, neighborhood structure plays the very important role in local search. Preferable solutions for JSP benchmark could been found after a good neighborhood structure proposed every time. However, most existing hybrid algorithms select the neighborhood structures randomly in the local search procedure and just combine the neighborhood structures with the original algorithm directly. To overcome this blind selection of neighborhood structures, a new neighborhood structure evaluation method based on logistic model has been developed in this paper to guide the neighborhood structures selection process. This method is utilized to evaluate the performance of different neighborhood structures. Then the neighborhood structures which have good performance are selected as the main neighborhood structures in VNS. Based on this neighborhood structure evaluation method, a hybrid PSO algorithm based on VNS (HPV) has been proposed to solving JSP in this paper.

The reminder of this paper is organized as follows: Section 2 is the problem formulation of JSP. Section 3 elaborates the proposed hybrid algorithm. The neighborhood structure evaluation method based on logistic model is given in Section 4. Experiments are illustrated in Section 5 to evaluate the performance of the proposed