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Simultaneous scheduling of machines and transport robots in flexible job shop environment using hybrid metaheuristics based on clustered holonic multiagent model

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ABSTRACT

In real manufacturing environments, the control of some elements in systems based on robotic cells, such as transport robots has some difficulties when planning operations dynamically. The Flexible Job Shop scheduling Problem with Transportation times and Many Robots (FJSPT–MR) is a generalization of the classical Job Shop scheduling Problem (JSP) where a set of jobs have to be processed on a set of alternative machines and additionally have to be transported between them by several transport robots. Hence, the FJSPT–MR is more computationally difficult than the JSP presenting two NP-hard problems simultaneously: the flexible job shop scheduling problem and the robot routing problem. This paper proposes hybrid metaheuristics based on clustered holonic multiagent model for the FJSPT–MR. Firstly, a scheduler agent applies a Neighborhood-based Genetic Algorithm (NGA) for a global exploration of the search space. Secondly, a set of cluster agents uses a tabu search technique to guide the research in promising regions. Computational results are presented using three sets of benchmark literature instances. New upper bounds are found, showing the effectiveness of the presented approach.

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1. Introduction

Scheduling is a field of investigation which has known a significant growth these last years. The scheduling problems appear in all the economic areas, from computer engineering to industrial production and manufacturing. The Job Shop scheduling Problem (JSP), which is among the hardest combinatorial optimization problems (Sonmez & Baykasoglu, 1998), is a branch of the industrial production scheduling problems. The JSP is known as one of the most popular research topics in the literature due to its potential to dramatically decrease costs and increase throughput (Jones & Rabelo, 1998). The Flexible Job Shop scheduling Problem with Transportation times and Many Robots (FJSPT–MR) is a generalization of the classical JSP where a set of jobs have to be processed on a set of alternative machines and additionally have to be transported between them by several transport robots. Hence, the FJSPT–MR is more computationally difficult than the JSP presenting two additional difficulties caused by a set of jobs to be processed on a set of alternative machines and to be transported between them by many robots. In the FJSPT–MR, we have to consider two NP-hard problems simultaneously: the flexible job-shop scheduling problem (Garey, Johnson, & Sethi, 1976) and the robot routing problem, which is similar to the pickup and delivery problem (Lenstra & Kan, 1981).

For the literature of the Flexible Job Shop scheduling Problem with Transportation times and Many Robots, most of the researchers have considered the machine and robot scheduling as two independent problems. Therefore, only few researchers have emphasized the importance of simultaneous scheduling of jobs and several robots.

To solve this problem, mathematical formulations are used to find optimal solutions for this problem, but the complexity of some large instances allowed to increase the processing time for some important solutions. Raman, Talbot, and Rachamadgu (1986) proposed a mixed integer programming formulation for this problem, and they assumed that the robot always returns to the load/unload station after transferring a load, which reduces the flexibility of the robot and influences the overall schedule length. An integer programming model is formulated by Bilge and Ulusoy (1995) for the machine and robot scheduling problems with a set of time

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window constraints. According to the authors, the resulting model is intractable in practice, because of its nonlinearity and its size. Caumond, Lacomme, Moukrim, and Tchernev (2009) adapted a mathematical formulation for a shop scheduling problem with one transporter robot. This formulation differed from the published works because it considered the maximum number of jobs authorized in the system, the upstream and downstream storage capacities and the robot loaded/unloaded movements.

Moreover, heuristic and metaheuristic methods offered new opportunity to find solutions for this problem in a reasonable time but they did not guaranteed the optimality. Pundit and Palekar (1990) implemented a Branch and Bound procedure for a simultaneous scheduling of machines and resources handling in a Job shop environment. But, they did not take into consideration the violation of precedence relations between the different machines operations belonging to the same job. An iterative heuristic is used by Bilge and Ulusoy (1995) based on the decomposition of the master problem into two sub-problems, allowing a simultaneous resolution of this scheduling problem with time windows. Blazewicz, Domschke, and Pesch (1996) elaborated a study on the conventional and new solutions for the job shop scheduling problem, where they detailed the different proposed techniques for this problem, from the exact methods using the brand and bound algorithm, to the approximation algorithms such as the priority rules, the shifting bottleneck heuristic, the opportunistic scheduling and the local search techniques. Ulusoy, Erifolu, and Bilge (1997) adapted a genetic algorithm for this scheduling problem in a flexible manufacturing system, and where they used a chromosome representation composed by two parts, the operation task sequencing and the transport resource assignment. Anwar and Nagi (1998) treated the simultaneous machine and robot scheduling problem using a forward propagation heuristic, and where they supposed that the robot movements between cells are considered as additional machines. A local search algorithm is proposed by Hurink and Knust (2002, 2005) for the job shop scheduling problem with a single robot, where they supposed that the robot movements can be considered as a generalization of the traveling salesman problem with time windows, and additional precedence constraints must be respected. The used local search is based on a neighborhood structure inspired from (Mastrolilli & Gambardella, 2000) to make the search process more effective. Abdelmaguid, Nassef, Kamal, and Hassan (2004) addressed the problem of simultaneous scheduling of machines and identical robots in flexible manufacturing systems, by developing a hybrid approach composed by a genetic algorithm and a heuristic. The genetic algorithm is used for the jobs scheduling problem and the robot assignment is made by the heuristic algorithm. A hybrid multi-objective genetic algorithm is proposed by Reddy and Rao (2006) to solve this combined problem, and considered three minimization objectives, which are the makespan, mean flow time and mean tardiness. Lacomme, Larabi, and Tchernev (2007) studied the job shop scheduling problem with several transport robots, where they used a local search algorithm based on a neighborhood generated by permutation of two operations or by assigning another robot to a transport operation. Deroussi, Gourgand, and Tchernev (2008) addressed the simultaneous scheduling problem of machines and robots in flexible manufacturing systems, by proposing new solution representation based on robots rather than machines. Each solution is evaluated using a discrete event approach. An efficient neighboring system is then implemented into three different metaheuristics: iterated local search, simulated annealing and their hybridisation. A differential evolution algorithm is developed by Babu, Jerald, Haq, Luxmi, and Vigneswaralu (2010) for the machines and two robots scheduling problem, this algorithm is inspired by (Storn & Price, 1995) which was proposed for the chebyshev polynomial fitting problem. Deroussi and Norre (2010) considered the flexible Job shop scheduling problem with transport robots, where each operation can be realized by a subset of machines and adding the transport movement after each machine operation. To solve this problem, an iterative local search algorithm is proposed based on classical exchange, insertion and perturbation moves. Then a simulated annealing schema is used for the acceptance criterion. Subbaiah, Rao, and Rao (2009) treated simultaneously the machines and two identical AGVs scheduling problem in an FMS in order to minimize the makespan and the average lag. To solve this problem, a sheep flock heredity algorithm of Hyunchul and Byungchul (2001) was proposed based on basic notions of genetic algorithms. Kumar, Janardhana, and Rao (2011) addressed simultaneous scheduling of both machines and material handling system with alternative machines for the makespan minimization objective. They proposed a machine selection heuristic and a vehicle assignment heuristic which are incorporated in the differential evolution approach to assign the tasks, to appropriate machine and vehicle, and to minimize cycle time. A hybrid metaheuristic approach is proposed by Zhang, Manier, and Manier (2012) for the flexible Job Shop problem with transport constraints and bounded processing times. This hybrid approach is composed by a genetic algorithm to solve the assignment problem of operations to machines, and then a tabu search procedure is used to find new improved scheduling solutions. Lacomme, Larabi, and Tchernev (2013) solved the machines and robots simultaneous scheduling problem in flexible manufacturing systems, by adapting a memetic algorithm using a genetic coding containing two parts: a resource selection part for machine operations and a sequencing part for transport operations. Nageswararao, Narayanarao, and Ranagajanardhana (2014) developed a Binary Particle Swarm Vehicle Heuristic Algorithm (BPSVHA) for simultaneous Scheduling of machines and AGVs adopting the robust factor function and minimization of mean tardiness. This hybrid algorithm is based on two techniques, the particle swarm algorithm is used for the machine scheduling problem and the heuristic is integrated for the vehicle assignment problem. Zhang, Manier, and Manier (2014) considered the job shop scheduling problem with transport robots and bounded processing times. A modified shifting bottleneck procedure is used coupled with a heuristic for assigning and sequencing transportation tasks iteratively. Poppenborg and Knust (2015) proposed a tabu search algorithm for the resource constrained project scheduling problem with transfer times. Solutions are represented by resource flows extending the disjunctive graph model for shop scheduling problems. Neighborhoods are defined by parallel and serial modifications rerouting or reversing flow on certain arcs.

Furthermore, a newly maturing area of the distributed artificial intelligence are used, providing some effective mechanisms for the management of such dynamic operations in manufacturing environments, such as the multi agent systems. Braga, Rossetti, Reis, and Oliveira (2008) treated the machines and robots scheduling problem in flexible manufacturing systems. They proposed a distributed model based on cooperative agents, composed by five agents: an order-agent, a store-agent, a set of machine-agents and a set of robot-agents, using negotiation between them in order to obtain a best scheduling solution for this problem. Komma, Jain, and Mehta (2011) formulated the machines and robots scheduling problem in flexible manufacturing systems as a multi-agent system, allowing to realize an Agent-Based Shop Floor Simulator (ABSFSim). This simulator is composed by eight agents classified into three categories: The first category containing agents with a single instance such as the part-generator-agent, the arrival-queue-agent and departure-agent. A second category taking agents with multiple instances and a long lifetime such as the machine-agent, the robot-agent, the node-agent and segment-agent. And for the third category, it contained agents with multiple instances

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