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Multi-level genetic algorithm for the resource-constrained re-entrant scheduling problem in the flow shop

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ABSTRACT

The re-entrant flow shop scheduling problem (RFSP) is regarded as a NP-hard problem and attracted the attention of both researchers and industry. Current approach attempts to minimize the makespan of RFSP without considering the interdependency between the resource constraints and the re-entrant probability. This paper proposed Multi-level genetic algorithm (GA) by including the co-related re-entrant possibility and production mode in multi-level chromosome encoding. Repair operator is incorporated in the Multi-level genetic algorithm so as to revise the infeasible solution by resolving the resource conflict. With the objective of minimizing the makespan, Multi-level genetic algorithm (GA) is proposed and ANOVA is used to fine tune the parameter setting of GA. The experiment shows that the proposed approach is more effective to find the near-optimal schedule than the simulated annealing algorithm for both small-size problem and large-size problem.

1. Introduction

In this paper, a multi-level genetic algorithm is proposed to minimize the makespan for the re-entrant flow shop scheduling problem (RFSP) with dual resource constraints. In the re-entrant flow shop, routes of all jobs are identical, while some jobs will visit certain machines more than once at different stages of processing. The number of the re-entrant jobs and the re-entrant frequency may increase or decrease based on the manufacturing or repair process of different products. Each workstation consists of several machines and operators, which is regarded as resource constraints.

A typical example of the re-entrant manufacturing system is the semi-conductor manufacturing process, especially wafer fabrication line. In the semiconductor line, chemical material is added to the silicon wafers layer by layer where the wafer needs to repeatedly go through the clean rooms, depending on the manufacturing procedure of the wafer. Another example is the maintenances industry where repair parts will iteratively go through typical operations such as inspection, blasting, welding, grinding, fitting, coating, and packing. Moreover, depending on the repairing technology and product specification, the required production capacity and time would be different. Therefore, an extensive study on re-entrant flow shop is essential for balancing the production efficiency and product quality.

According to Tseng and Chen (2009), a mode is the combination of different resources and/or levels of resource requirements with a specified duration. For many scheduling problems, machines and skilled labor requirements vary at different workstations. The selection of the execution mode will directly influence the production duration and product quality. Therefore, it is critical to determine the execution mode for each task. Take the electro-coating as an example, sophisticated machines such as high pressure sprayer have high performance but consume more paint and less prone to rework, while skilled worker may use less paint but more time for the same job and has a higher chance of rework. Hence, different modes of production (i.e. machine or man) will affect rework probability. Therefore, effective scheduling of high cost labor and machine can provide a higher payoff for enterprises.

The re-entrant flow shop scheduling problem considered here is based on a maintenance company that offers repair, modification and upgrading services for a wide range of machinery from marine, electrical to mechanical. The repair parts include huge parts such as buckets, fuel nozzles, power nozzles, shroud, and rotors. Approximately 95% of repair parts of this company need to go through the blasting, heat treating, welding, alloying, grinding, and inspection procedures. If parts fail in the inspection process or new faults are found, the repair parts need to be returned to the previous workstations and reworked. As long as rework happens, the due dates of the re-entrant jobs are becoming tighter. Moreover, as the repairing execution mode is optional, the

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Nomenclature

N	the set of all jobs
n	the number of jobs
i,j	job index
r	re-entrant job index
R	the set of resource
k	the amount of resource consumption
m	machine index
M_i	the set of machines to process job i
E_m	the set of jobs that might be processed on machine m
B	the set of pairs of jobs between which there is precedence relationship, when job i must precedence job j
p_{im}	processing time of job i in machine m
t_i	the stating time of job i
C_{max}	the completion time of the last job

Decision variables

$x_{im}=1$	if operation of job i is assigned to machine m; 0, otherwise
$y_{ijm}=1$	if operation of job i and j are assigned to the same machine m; 0, otherwise
$z_{ijm}=1$	if operation of job i immediately precedes on machine m
$r_{imk}=1$	if operation of job i is conducted on machine m with k resource consumption

corresponding technology and standard will differ. Thus the machine time and required operators will vary. The re-entrant probability and the number of re-entrant jobs will change accordingly. Take the power nozzles repairing procedure as an example. According to different repairing technologies, a power nozzle part can be repaired in a complicated mode which goes through 40 steps. Under this mode, a typical piece of power nozzle will cost 400 units of worker time, 120 units of machine time with 9% of rework possibility. Or when the job is urgent, the same piece of power nozzle can be done by applying the compact mode that only goes through 13 steps, consuming 215 units of worker time, 420 units of machine time with as high as 15% of chance to be reworked. No matter it is the original job or the re-entrant job, the differences of the execution modes are the processing time at some particular stages and the consumption of the machine and manpower resources. Some of the parts do not need to pass all the machines. Similar phenomena can be found from the coating procedure. High pressure sprayers have good performance but consume more paint and less prone to be reworked, while skilled worker may use less paint but more time for the same job and has a higher chance of rework. Therefore, the choice of execution mode can affect the overall makespan.

Prior to the problem formulation and proposed method, we will review the related literature in Section 2. Section 3 will formulate the problem and Section 4 elaborates the multi-level encoding genetic algorithm with various operators setting. In Section 5, we describe the experiment and analyze the corresponding results. In Section 6, the main explanation of the experimental results is further discussed and finally Section 7 summarizes the paper and draws conclusions based on our experimental results.

2. Literature review

Graves et al. (1983)maybe the first work that systematically mentioned the RFSP term which represents the scheduling problems happened in the shop area with a sequence of operations are processed by machines. Based on the re-entrant characteristics, some jobs would visit certain machines more than once before completion but with the same routing. When each machine processes the set of all jobs in the same order, this problem evolves into the re-entrant permutation flow shop scheduling problem (RPFSP), which is the special case of RFSP.

However this problem was only studied rigorously since 2000 with the demanding manufacturing requirement from the semiconductor industries or integrated circuit fabrication or thin film transistor liquid crystal display process. Exact method, heuristic and meta-heuristic methods all have been proposed for solving the re-entrant flow shop scheduling problem. However, the comprehensive analysis of this problem is not done till the review paper of Lin and Lee (2010) which classifies the re-entrant problems and analyzes the optimization methods of re-entrant manufacturing scheduling.

Mostly exact methods formulate the re-entrant flow shop scheduling problem as the integer programming problem and simulate the efficiency of the new proposed approaches. However, the computational complexity is high as long run time is used to narrow down the space within the constraints. The referenced work can be found from many studies(Chen and Pan, 2006; Choi and Kim, 2007; Demirkol and Uzsoy, 2000; Haitham and Ruml, 2006; Jiang and Tang, 2008; Kaihara et al., 2010; Nielsen, 2004; Odrey et al., 2001; Pan and Chen, 2003; Park et al., 2000; Scholz-Reiter et al., 2010; Yang et al., 2008).

Heuristic techniques such as dispatching rules and constructive heuristics have also been applied to the re-entrant flow shop scheduling problem. The dispatching rules are applied in the semiconductor industries by testing various experiments for the simulation models (Cigolini et al., 1999; El-Khouly et al., 2009; Perkins and Kumar, 1995). Though these heuristic methods produce good quality solutions, they are not extensively used during the period of 2000–2007 as the running time are often large and increase rapidly with size of the problem.

Meta-heuristic, especially genetic algorithm (GA), evolved to be the new trend for the re-entrant flow shop scheduling problem. GA gets the edges over other techniques in the area of large-scale complexity like the very large scale integrated (VLSI) circuit manufacturing or repairing industries which are highly re-entrant, and involves hundreds of machines, restrictions and processing steps. Therefore, (Chen et al., 2008a; Hwang and Sun, 1998; Lee and Lin, 2010; Liu, 2010; Rau and Cho, 2009) used GA to solve the re-entrant problem and mainly focus their objectives on minimizing the makespan. Another meta-heuristic method such as tabu search has been used. In the hybridized tabu search (HTS) model of Chen et al. (2008b), the proposed HTS is compared with pure tabu search and NEH (Nawaz et al., 1983) to find out the optimal makespan for various problem sizes. While in the interactive models of Alfieri (2009), a neighborhood search is started with non-dominated and dominated initial solutions, then weighted function is used to evaluate the best solution that becomes the seed for the successive tabu search iteration. The results are compared with composite priority rule in terms of maximum tardiness and total delay which is weighted by the customer priority.

Among all these papers, it is obvious that exact methods and meta-heuristics are the main used tools because efficient and economic computational method is required for solving this