CMS scheduling problem considering material handling and routing flexibility

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Abstract Cell manufacturing as an application of group technology increases the flexibility and efficiency of the production. Cell scheduling problem, one of the subjects in cell manufacturing, has not been widely studied by researchers compared with other problems in cell manufacturing. In spite of great importance of material handling in cell scheduling, it has not been paid enough attention by researches. In this paper, a new mathematical model for cell scheduling problem considering material handling time and routing flexibility is proposed. The proposed model belongs to the mixed-integer nonlinear programs (MINLP). A linearization procedure is proposed to convert the MINLP to an integer program (IP) in order to develop more powerful optimization tools. Furthermore, a simulated annealing-based heuristic is developed to solve the large-size problems.

Keywords Cell manufacturing · Routing flexibility · Material handling · Simulated annealing

1 Introduction

In the recent decades, production systems have changed over due to the increase of competition in markets. In the past, production volume and finished costs of goods were the two major determinant competitive factors; thus, the tendency to use flowshop production systems was pervasive among the companies. Nowadays, other factors such as variety in products and swift response to the market’s demand are of higher importance. Consequently, production systems with higher level of flexibility have been developed and applied by both practitioners and academics. Job shop can be considered as a clear-cut example of such systems.

The aforementioned changes along with the development of new businesses have created a novel environment for manufacturing and competing in markets. In such an environment, reducing production costs and make-span, increasing flexibility, and precipitating reactions to the market’s needs are turning into the critical competitive advantages of companies. In the 1970s, through highly competitive atmosphere among the companies in the US, a few modern management concepts such as just in time (JIT) and group technology (GT) came into existence. Cell manufacturing system (CMS) is considered as an application of GT, in which the whole machines are divided into a number of distinctive groups according to the similarities in processing the assigned parts. The groups are called cells. The set of parts processed in each cell is called a part family. Cell formation, cell layout, production planning, and cell scheduling are the major issues in CMS (Solimanpur et al. [25]). Unlike the cell formation problems, cell scheduling has not been widely studied by researchers. Moreover, in spite of the great importance of material handling issue, it has not been considered in the most of cell scheduling problems.

As Nomden and Van der Zee [19], routing flexibility provides the possibility to choose from among a number of machines to execute an operation. We consider routing flexibility in terms of alternative machines available for a product family. On the other hand, there will be alternative production routes per product family. This issue can increase the flexibility of a manufacturing system; however, it can increase the complexity of the problem.
In the current research, a new mathematical model for a cell scheduling problem is proposed. The main contributions of the proposed model are explained as follows:

- There are some papers that have considered routing flexibility in cellular manufacturing problem such as Koon [14]. To the best of our knowledge, this issue has not been directly integrated with CMS scheduling problem while it may have great influence on the sequencing of the jobs.

- Material handling time is also one of the subjects, which is undermined in the literature of CMS scheduling. In the proposed model, the time is determined based on the characteristics of the part and position of the machines.

- A number of the researches in this sphere assume that all the operations of a part family on a particular machine have to be done consecutively and without any interruption [16, 25]. This assumption leads to minimizing the total setup times and may be interpreted as a proper policy for minimizing the makespan. This assumption reduces the solution space and as a result can decrease the computational time. However, it is clear that in many cases, consecutively, performing operations of a part family is not optimal and may impede the solving algorithm from finding the global optimum. In the given model, a machine can process the parts without any restriction on the sequence considering the setup times. This approach extends the applicability of the proposed model to the job shop environment scheduling.

The complexity of scheduling problems and the nonlinearity of the models hinder the applicability of the regular optimization tools. Therefore, we alleviate this problem by converting the nonlinear model into a linear one in order to implement more efficient optimization tools. Finally, a simulated annealing (SA) based heuristic is proposed in order to tackle the large-size instances of the problem.

This paper is organized as follows: a literature review of CMS scheduling is presented in Section 2. In Section 3, the problem description and the mathematical model are given. The linearization process is demonstrated in Section 4, and we introduce the proposed SA-based heuristic in Section 5. Section 6 gives the computational results. In Section 7, conclusions and further research ideas are given.

2 Literature review

Generally, a significant portion of the literature in CMS is devoted to the flowline-based cellular manufacturing. In this sphere, it is assumed that all the parts follow a similar sequence of processes; however, there may be some missing operations on some machines. Since the proposed model in this paper can be considered as a submodel in cell scheduling, we directly go through the corresponding literature.

There are a few researches focusing on the minimization of tardiness of jobs in cell scheduling problem. Parthasarathy and Rajendran [20] study the problem of scheduling in flowshop and flowline-based manufacturing cell (or simply, a cell) with the objective of minimizing mean tardiness of jobs. A heuristic algorithm, based on the SA technique, is developed. The proposed SA algorithm with two schemes is evaluated against the existing heuristics that seek to minimize mean tardiness of jobs. The results of the computational evaluation reveal that the SA algorithm with two schemes performs better than the existing rival heuristics. Rajendran and Ziegler [22] study the addressed problem with the objective of minimizing the sum of weighted flowtime and weighted tardiness of jobs. Initially, heuristic preference relations are developed considering lower bounds on the completion times, operation due dates, and weights for holding and tardiness of jobs; then, a heuristic algorithm is proposed making use of the heuristic preference relations. Two more heuristic algorithms are developed, implementing an improvement scheme on the solution given by the first heuristic algorithm.

There are a number of successive researches on the scheduling of part families and jobs within each family in a flowline or flowshop (all jobs available at time zero, different job availability times known a priori) manufacturing cell with sequence-dependent family setup times. Schaller et al. [23] study the addressed problem. The objective is to minimize the makespan while processing parts (jobs) in each family together. França et al. [6] study the problem in a flowshop manufacturing cell. Two evolutionary algorithms including a genetic and a memetic algorithm with local search are proposed and empirically evaluated as to their effectiveness in finding optimal permutation schedules. Hendizadeh et al. [9] present various tabu search (TS)-based meta-heuristics for the problem to minimize makespan. Concepts of elitism and the acceptance of worse moves inspired from simulated annealing are considered in the proposed meta-heuristics to improve intensification and diversification. The effectiveness and efficiency of the proposed heuristics are compared against the best rival meta-heuristic and heuristic algorithms. Lin et al. [16] declare that almost all published studies in this regard focus on using permutation schedules to deal with flowline manufacturing cell scheduling problem with sequence-dependent family setup times. To explore the potential effectiveness of treating this argument using nonpermutation schedules, three prominent types of meta-heuristics including SA, genetic algorithm (GA), and TS are proposed and empirically evaluated. The experimental results demonstrate that the improvement made by nonpermutation schedules over permutation schedules for the due date-based performance criteria were significantly better than that for the completion-time-based criteria. Bouabda et al. [2] address the permutation flowline manufacturing cell with sequence-dependent family setup time problem with the objective to minimize the