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Modeling and scheduling a flexible manufacturing cell with parallel processing capability

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ABSTRACT

Traditionally, machine tools are able to process at most one operation on one part at a time provided they have only a single spindle and a single turret. Yet, with the advent of Turn-Mill machining centers carrying multiple spindles and turrets, parallel processing and multitask metal-cutting becomes possible. This paper deals with scheduling of a flexible manufacturing cell with parallel processing capability. This problem is first formulated as a mixed integer linear programming model. Using this model, small instances are solved for optimality. Then, to solve large instances, five metaheuristics are developed based on the proposed encoding scheme, operators and local search. Test cases are used to evaluate and compare the algorithms as well as the mathematical model.

Introduction

In recent days, with the advent of the newly developed Turn-Mill machining centers, multi-tasking for subtractive flexible manufacturing systems is now a reality. These machining centers which are primarily lathes equipped with multiple spindles and turrets are capable of performing different types of turning and milling processing. Traditionally, machine tools used to have single spindles and turrets; they would normally either have milling or turning capability. A machine tool includes two main components, part holding device (spindles) and tool unit (turrets) [1]. As a result, a machine tool can process at most one part at a time (since it has only one part holding device). Furthermore, a machine can perform at most one operation at a time on the part loaded in its spindle (since normally it would have only one tooling unit/turret). Yet, in advanced flexible manufacturing systems, we have been having a new breed of Turn-Mill machining centers that would have multiple spindles [2,3] and multiple turrets [4]. Fig. 1 shows a realistic example of such machining centers with two spindles and three turrets. According to the literature, it is apparent that this new concept is even conducive to enable and enhance the focused/reconfigurable manufacturing systems further [5–7].

The main repercussions that such multitasking machine tools entail are that the assumption of sequential processing does not hold anymore. In other words, the assumption of having one operation at a time has now been violated and parallel processing of one or two work-pieces is achievable (see Fig. 2) [9]. A machine tool can carry out more than one operation at a time or/and process more than one part at a time. More precisely, a machine tool can perform different operations using each of its turrets on a part loaded on one of its spindles. Or, it can process different operations on different parts loaded on different spindles [1].

Fig. 2 shows an example of a machine tool with two spindles and two turrets. In this case, this machine can perform at most two different operations and also can process at most two different parts. In Fig. 2(a), two parts are held and a distinct operation is being processed on each one. In Fig. 2(b), one part is held and two operations are being processed.

Although manufacturing shops are constantly moving toward more advanced flexible manufacturing systems with advanced machinery enabling multitasking, a dearth of the literature only does consider the subject and development of the needed enablers for such new capability. Yip-Hoi and Dutta [11] propose a genetic algorithm to sequence operations in parallel processing. Chiu et al. [12] consider a very restricted problem of operation sequencing with parallel processing. They assume a shop with only one part to be produced and that at any time at most two operations can be processed. They first propose a mixed integer programming model which is nonlinear; hence, optimality cannot be claimed. They, then, develop another genetic algorithm for this problem.

Norman and Bean [13] study scheduling operations on parallel machine tools, the same problem as [11]. To formulate the

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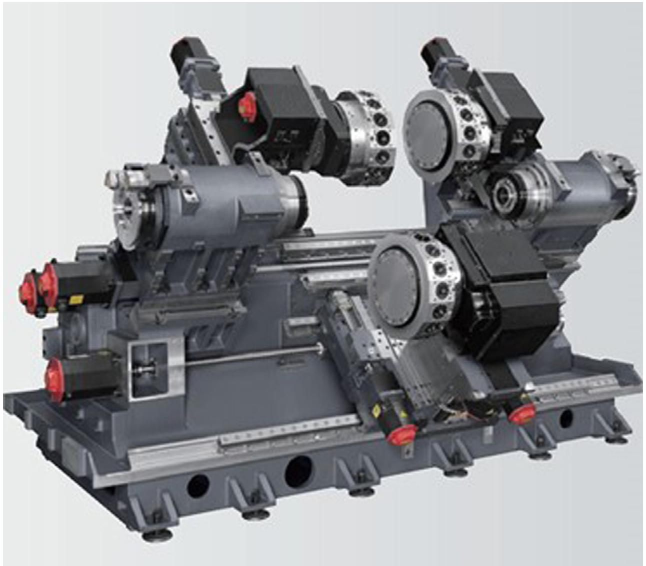

Fig. 1. A real example of a machine with multiple spindles and turrets [8].

problem, they assume that assignment of parts to spindles and assignment of turrets to operations are known in advance. Therefore, the mathematical model only sequence operations according to the given assignments. They also develop three priority dispatching rules as well as a genetic algorithm. The algorithms are numerically compared with that by Yip-Hoi and Dutta [11].

This paper deals with a manufacturing cell with a set of machines each of which has multiple spindles and multiple turrets. It is believed that studying this problem will add value to both theory and practice. The problem is important for industries. Due to today's highly competitive markets, companies intend to cut down on lead times and costs, increase productivity and deliver products to market quicker. Multitasking attends to these challenges by carrying out a variety of operations and processing at the same time. Hence, there is an increasing trend among the machine tool vendors for incorporating the technology and offering a variety of those mill-turn machining centers, and more customer base reaching out to implementing it.

A novel mathematical model has been formulated for the problem at hand; there has been no attempt in the literature to formulate this problem yet. Through the mathematical modeling, it was possible to explicitly formulate and formally fully define the problem, as well as to solve the small and mid-range problem instances exact for optimality. The model is supposed to be a mixed integer linear programming model. The decision variables determine the sequence and schedule of operations so as to minimize makespan (the measure of productivity). This model enables us to optimally solve only limited-size problems using advanced mathematical programming tools due to the combinatorial nature of the problem and its NP-completeness.

Firstly, the encoding scheme of this problem has been presented. For this scheme, some novel mechanisms such as neighborhood search operators, local search, etc. have been developed. Secondly, five different algorithms based on these mechanisms have been designed and implemented. The proposed algorithms include genetic algorithm, simulated annealing, iterated greedy algorithm, iterated local search and artificial immune algorithm. A suitable encoding scheme has been creatively tailored for the problem at hand. Each of these algorithms has its own structure and mechanics; the different operators for the exploited five metaheuristics are being utilized. The purpose is to evaluate which structure is more effective for this problem.

The rest of this paper is organized as follows. The second section formally defines and mathematically formulates the problem. The third section proposes the developed algorithms. The fourth section evaluates the proposed model and algorithms for performance. The last section finally concludes the paper.

Problem definition and formulation

In this section, we describe in detail the problem of scheduling jobs for such advanced multitasking/parallel-processing flexible manufacturing systems. A numerical example to better illustrate the problem is provided. Finally, the developed mixed integer linear programming model is presented.

For the problem at hand, there are a set of n jobs to be scheduled. Each job j consists of n_j operations with precedence relations amongst its operations. Traditionally, it is assumed that precedence relations are purely sequential (also sometimes described informally as linear); that is, each operation has one predecessor and one successor. In this work, arbitrary relations among operations are also considered; that is, an operation can have more than one predecessor and might be successor for more than one operation forming a network-like structure known as precedence relations graph (see example shown in Fig. 3). In the example, operation 4 can be started only after completing both operations 1 and 2.

There are a set of m machines. Machines are flexible; i.e., machines can perform different types of processing; their turrets can hold different types of tools which could be either milling or turning ones, in case of Mill-Turn Machining Centers. Traditionally, it is assumed that each machine has only one single spindle and one single turret. As a result, a machine can process at most one part at a time (since it has only one spindle). Furthermore, a machine can process at most part loaded to its spindle (due to having only one turret); i.e., one operation. In this work, however,

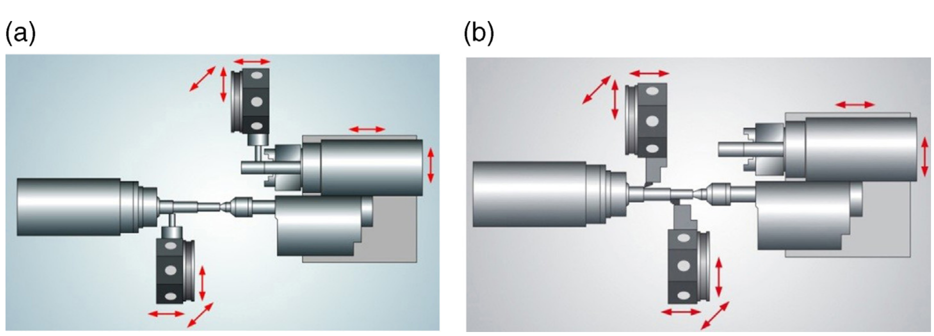

Fig. 2. An example of a machine tool with two spindles and two turrets [10].