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A variable neighborhood search metaheuristic for cellular manufacturing with multitask machine tools

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Abstract

Traditionally in metal cutting, it is assumed that a machine tool can process at most one operation at a time since machine tools have one spindle and one turret. Yet, with advent of machine tools with multiple spindles and multiple turrets, this assumption does not hold anymore. This paper deals with the integrated problem of process planning and production scheduling for a parallel processing manufacturing cells with multitasking machines. A novel Variable Neighborhood Search (VND) metaheuristic is proposed to solve the problem. This algorithm employs novel operators that cover mechanisms to combine and improve, replace and shake plans and individuals of the VNS population-based search.

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1. Introduction

Process planning is the link between product design and manufacturing. A process plan simply outlines the recipe required to fabricate a certain part or product; higher level process planning is concerned primarily with determination of the manufacturing resources, operations and routes required to produce a part. Lower level process planning on the other hand performs the detailed planning functions for each sub-operation of the different operations of a certain job. Production scheduling on the other hand is the operational-level planning functions of production planning and control typical cycle. It schedules different jobs on the different machines for a certain shop taking into account factors such as transportation of parts/jobs between the different machine tools, and objectives which are usually time-related such as makespan and maximum completion times. In this paper, integrated high-level process planning and production scheduling are being combined and performed for a particular specific type of advanced manufacturing shops.

In a manufacturing system, several parts with their unique process plan are usually produced. Moreover, there is a set of processing machines to carry out operations. A machine tool includes two main components, part holding devices (or spindles) and tool units (or turrets) [4]. In advanced parallel processing flexible manufacturing systems, we assume multi-task machines. That is, machines can perform different operation types given the fact that their turret can hold different tools.

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 part holding device). Furthermore, a machine can carry out at most one operation at a time on the part loaded in its spindle (since only one tool unit/turret is usually all a machine tool possesses). Yet, in advanced multitask flexible manufacturing systems, manufacturers encounter the advent of new generation of machines with multiple spindles and multiple turrets. Figure 1 shows a realistic example of such machine tool with two spindles and three turrets.

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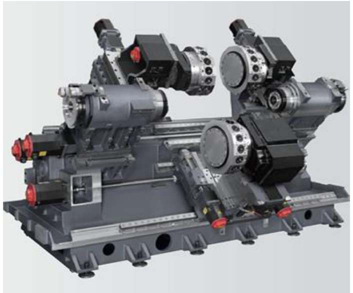

Figure 1. A real example of a machine with multiple spindles and turrets [5].

The first implication of having such machine tools is that the assumption of sequential processing does not hold anymore. In other words, the assumption of one operation at a time is violated and parallel processing during each time slot is achievable. A machine can execute more than one operation at a time or/and process more than one part at a time. More precisely, a machine can process different operations on the different parts loaded to its different spindles using each of its different available turrets [4].

Although manufacturing shops are increasingly moving towards more flexible systems with advanced machines which enable parallel processing, papers commonly fail to consider parallel processing. Yip-Hoi and Dutta [1] propose a genetic algorithm to sequence operations in parallel processing. Chiu *et al.* [2] consider a very restricted problem of operation sequencing with parallel processing. They assume a shop with only one part to produce and any time at most only two operations can be processed. They first propose a mixed integer programming model which is unfortunately nonlinear. They, then, develop another genetic algorithm for this problem. Norman and Bean [3] study scheduling operations on parallel machine tools, the same problem as [1]. To formulate the problem, they assume that assignment of parts to spindle and assignment of turret to process each operation are known in advance. Therefore, the mathematical model only sequence operations according to given assignments. They also develop three priority dispatching rules as well as a genetic algorithm. The algorithms are numerically compared with genetic algorithm proposed by Yip-Hoi and Dutta [1].

This paper deals with a manufacturing cell with a set of machines each of which has multiple spindles and multiple turrets. To effectively solve such a hard problem, we propose a novel powerful algorithm. We are proposing a novel Variable Neighborhood Search algorithm (VNS). This term is referred to all local search based approaches that are centered on the principle of systematically exploring more than one type of neighborhood structure during the search. Yet, this paper proposes a population-based VNS. In this case, VNS is hybridized and strengthened using the exploration capacity of population based evolutionary algorithms. Moreover, it is equipped with several novel operators to cope with this problem.

The rest of this paper is organized as follows. Section 2 formally defines the problem. Section 3 proposes a novel population-based variable neighborhood search algorithm. Section 4 evaluates the proposed algorithms for performance. Section 5 finally concludes the paper.

2. Problem definition

The problem under consideration can be described as follows. There are a set of n jobs to process. Each job j consists of n_j operations with a set of precedence relationships prescribed. Traditionally, it is assumed that precedence relations can be expressed in a straightforward sequential manner; that is, each operation has one predecessor and one successor- see Figure 2 for an example precedence relationships diagram of a job with 5 operations. We can also have other forms of precedence relationships of higher complexity, where the relationships can take more arbitrary network-like form; that is, an operation can have more than one predecessor and successor– see example precedence relationship diagram in Figure 3. In this example, operation 4 can be started only after completing both operations 1 and 2.

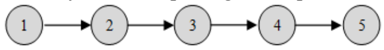

Figure 2. An example for straightforward sequential precedence relations

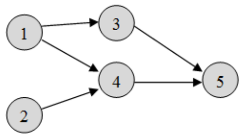

Figure 3. An example for network-like precedence relations.

There are a set of m machines. Machines are flexible; that is, machines can perform different operation types since their turrets can hold different tools- still and live. 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 one operation at a time on the part loaded in its spindle since traditionally a machine is assumed to only carry one turret). We assume that each machine i consists of $s_i \geq 1$ spindles and $t_i \geq 1$ turrets, (usually $t_i > s_i$). Therefore, s_i different jobs can be held at a time on this machine. For each turret, one operation type can be processed at a time. If we assign two or more turrets to a spindle, we can process two or more operations on the same job at a time.

At most one part can be loaded in each spindle at a time. By each turret, we can process one operation on each part and each part can be loaded at most in one spindle at a time. Not all spindles are eligible to hold all different parts. Moreover, each turret cannot process all different operations. Each part has its own processing route and precedence relations among its operations. Additionally, we assume machines (spindles and turrets) are continuously available. Preemption is not allowed, that is, when processing of an operation starts, it cannot be interrupted before its completion. A job can be loaded into at most one spindle at a time. Not every job can be loaded into every spindle. Not every turret may be accessible to every spindle. Each turret can process a set of different operations by change of its tools. Before starting any operation, to load the corresponding part in a spindle, some setup must be done. The scheduling problem deals with three decisions in flexible manufacturing systems with parallel processing and multi-task machines.

1- Assignment of jobs to eligible spindles for each of its