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Operation assignment and capacity allocation problem in automated manufacturing systems

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Abstract

We address an operation assignment and capacity allocation problem that arises in semiconductor industries and flexible manufacturing systems. We assume the automated machines have scarce time and tool magazine capacities and the tools are available in limited quantities. The aim is to select a subset of operations with maximum total weight. We show that the problem is NP-hard in the strong sense, develop two heuristics and a Tabu Search procedure. The results of our computational tests have revealed that our Tabu Search procedure produces near optimal solutions very quickly.

Keywords: Operation assignment; Capacity allocation; Tabu Search

1. Introduction

In this study, we consider an operation assignment and tool magazine and time capacity allocation problem arising in many automated manufacturing systems. A set of operations with corresponding weights is given. The weight of an operation may represent the profit brought or the assignment cost when it is negative. The operations are ready to be processed by a set of parallel Computer Numerically Controlled (CNC) machines. The amount of inventory for each operation, which can be interpreted as the demand or maximum production quantity, is known. There are limitations on the number of tools of each type available in the system due to the economic restrictions. The number of tool slots on the tool magazine of the machines, and the capacity of machines in terms of time units are other constraining factors. We consider the tactical level problem of selecting operations and assigning them together with their required tools to parallel machines so as to maximize the total weight of selected operations, hence the total profit.

The main motivation of the problem stems from the applications in the semiconductor industries and the flexible manufacturing systems. Semiconductor manufacturing companies are often faced with the time capacity allocation and tool investment decisions due to their capital intensive nature. Managing the

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limited time capacity with the limited number of tools is important for the effective operation of those industries.

The Flexible Manufacturing Systems (FMSs) are often faced with the tool magazine capacity allocation problem due to the limited tool slots on the tool magazine of the CNC machines and expensive tools that are available in limited quantities. Managing the limited tool magazine capacity with scarce tool resources is crucial for the effective operation of the FMSs.

There are several studies in the literature that consider capacity allocation problem. The capacity allocation problem without tooling decisions is addressed in Toktay and Uzsoy (1998), Akçalı, Üngör, and Uzsoy (2005) Çatay, Erengüç, and Vakharia (2005). Toktay and Uzsoy (1998) assume that the machines of limited time capacity can accommodate a limited number of operations, and the operations can be assigned to more than one machine. Their problem is to find an assignment of operations to the machines so as to maximize total assigned work. They show that the problem is strongly NP-hard and propose a number of heuristic algorithms. Akçalı et al. (2005) extend this study to the environment where the machines are eligible to process a specified subset of the operations. They propose a number of heuristic algorithms and settle their worst-case complexities. Çatay et al. (2005) study the capacity allocation problem with machine duplications. They propose a Lagrangean based lower bound and a heuristic algorithm to their cost minimization problem. In another study, Çatay, Erengüç, and Vakharia (2003) consider an allocation problem where they decide on the number of the tools. They propose a Lagrangean relaxation based heuristic algorithm to find efficient tool procurement plans.

Several studies in the FMS literature have considered the operation assignment and tool allocation decisions simultaneously. D'Alfonso and Ventura (1995) and Ventura, Chen, and Leonard (1988) assume some tools use more than one slot of the tool magazine. D'Alfonso and Ventura (1995) aim to minimize the number of visits between the CNC machines. Ventura et al. (1988) study the minimum makespan problem. Sarin and Chen (1987) address the machine utilization maximization and cost minimization problems under lower limits on the utilization levels. Berrada and Stecke (1986) impose time capacities not only for each individual machine and but also for the overall system. Kim, Lee, Lim, and Choi (2003) consider the problem of minimizing total tool purchase costs subject to the constraint that all operations should be completed at a given date. They propose several heuristic procedures and test their performances via simulation. Swarnkar and Tiwari (2004) study system balancing and throughput maximization problems, in assigning the operations of the selected jobs. They integrate Tabu Search and Simulated Annealing procedures.

Recently, Bilgin and Azizoğlu (2006) study the operation assignment and capacity and tool allocation model for operation splitting allowed case. They propose several heuristic procedures and test their performances relative to the optimal solutions and Linear Programming based upper bounds. This paper extends analysis of the model proposed by Bilgin and Azizoğlu (2006) to no operation splitting allowed case. To the best of our knowledge, there is no reported study that addresses our problem.

The rest of the paper is organized as follows. In Section 2, the problem is defined and the mixed integer linear programming model is presented. The heuristic procedures and the details of our Tabu Search procedure are given in Sections 3 and 4 respectively. Section 5 reports results from computational experiment and Section 6 concludes the paper.

2. Problem definition

Consider n operations that are ready to be processed by a set of m parallel CNC machines. An operation can be processed on only one machine and when operation i is assigned to machine j, the whole job should be finished, i.e., no operation splitting is allowed. We let w_i be the weight of operation i ($i = 1,\ldots,n$) which may represent the profit brought or the assignment cost when it is negative. W_i is the amount of inventory of operation i on hand. C_j is the time capacity of machine j. W_i and C_j are measured in same units, say in the minutes. All machines are flexible in the sense that they function according to the loaded tools. Machine j has a tool magazine capacity of s_j tool slots. There are t tool types in the system. Due to the technological restrictions and/or budget limitations, a maximum of r_k tools of type k ($k = 1,\ldots,t$) are available. To process operation i, a set of tools $l(i)$ should be available on the tool magazine(s) of the associated machine(s).