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Discrete Optimization

Scheduling uniform parallel machines subject to a secondary resource to minimize the number of tardy jobs

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Abstract

This research investigates the problem of scheduling jobs on a set of parallel machines where the speed of the machines depends on the allocation of a secondary resource. The secondary resource is fixed in quantity and is to be allocated to the machines at the start of the schedule. The scheduling objective is to minimize the number of tardy jobs. Two versions of the problem are analyzed. The first version assumes that the jobs are pre-assigned to the machines, while the second one takes into consideration the task of assigning jobs to the machines. The paper proposes an Integer Programming formulation to solve the first case and a set of heuristics for the second.

Keywords: Scheduling; Parallel machines; Dual resource constrained scheduling; Number of tardy jobs

1. Introduction

Global competition and meeting customer requirements continue to challenge the traditional way of doing things, demanding more from manufacturers, who must use their capabilities in the most effective possible way. However, the methods researched and used in production planning and control systems often over-simplify the representation of the production environment in order to reach optimal solutions fast. Over-simplifying the representation of the environment sacrifices the ability of the system to reach very good or even optimal solutions for the true underlying problems. Simplifications often eliminate from the model characteristics that account for the flexibility of the system. Production planning systems that utilize the flexibility of the system to their advantage will be better positioned to meet customer needs (Jensen, 2000). Labor is the most commonly available flexible resource (FR) in production systems (for example in assembly cells). Labor flexibility is obtained by training workers to perform multiple functions across multiple machines (workcenters), and then designing workcenters that can accommodate various levels of labor, which leads to a change in the effective capacity of the machines (workcenters).

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Daniels et al. (1996) describe a scheduling problem that considers job scheduling in parallel machines with a flexible resource, called the parallel machine flexible resource scheduling (PMFRS) problem. In the PMFRS problem jobs are pre-assigned to machines. The goal is to sequence the jobs in each machine and to assign the FR across machines, such that makespan is minimized. Daniels et al. (1996) developed an integer programming formulation for both the static case, where the assignment of the FR does not change during the schedule; and a dynamic case, where the distribution of workers varies dynamically during the planning horizon. They present solution strategies and experimental results. Olafsson and Shi (2000) also addressed the PMFRS problem, providing a new formulation and a new heuristical solution methodology called *nested partitions,* which combine sampling of the feasible region with search heuristics.

Daniels et al. (1999) study the unassigned PMFRS (UPMFRS) problem, where jobs are not pre-assigned to machines and therefore the problem includes making decisions both on the assignment of jobs and the FR to the machines, in such a way that makespan is minimized. They propose two heuristics and compare them under a variety of experimental conditions, concluding that the tabu-search approach proves to be more effective in terms of quality and cost. Ruiz-Torres and Centeno (in press) obtain a lower bound for the UPMFRS problem when all jobs share the same *modes* (see the definition of *modes* below). They propose new heuristics that combine resource allocation with list scheduling and bin-packing approaches, and demonstrate that their heuristics outperform those in Daniels et al. (1999) under most experimental combinations.

Based on the formulations used in Daniels et al. (1999) and Ruiz-Torres and Centeno (in press), the UPMFRS problem is tightly related to the uniform parallel machine problem. In the uniform parallel machine problem jobs have a baseline process time and machines have independent processing speeds. The time to process a job depends on this speed and as in Daniels et al. (1999) and Ruiz-Torres and Centeno (in press) the processing speed on a machine is a function of the assignment of the FRs. Therefore once the flexible resources have been assigned, the problem is the same as the uniform parallel machine problem. Research in uniform parallel machines with due date objectives is scarce (Guinet, 1995) as most researchers focus in makespan related problems (Liao and Lin, 2003; Koulamas and Kypasis, 2004).

The research by Daniels et al. (1996, 1999), Olafsson and Shi (2000) and Ruiz-Torres and Centeno (in press), demonstrate the significant benefits that can be gained by modeling labor flexibility when the objective is minimizing makespan. Others have demonstrated similar benefits when considering two or more resources in the scheduling process. For example, Kellerer and Strusevich (2003) analyze a problem where parallel machines are dedicated to a job set (for example a family of products), similar to the PMFRS, and where some jobs require additional renewable resources, although this has no effect on processing speed. In this case, the double constraint effect is only in place as a requirement to production for that specific job. Research by Jensen (2000) is also of interest since it considers a variety of parallel workcenters and investigates the impact of labor flexibility on flowtime, mean tardiness, and root mean square tardiness, concluding that controlling labor assignment has a significant impact on these measures.

In this paper, we consider both the PMFRS and UPMFRS problems with the objective of minimizing the number of tardy jobs, which minimizes, as a consequence, the percentage of tardy jobs. Measures that track the percentage of tardy jobs are important due to their relation to customer satisfaction, and therefore are commonly used in practice. Scheduling research related to the minimization of late jobs is relatively limited, particularly for multiple (parallel) machines settings. Ho and Chang (1995) propose and analyze the performance of several heuristics derived from the optimal single machine algorithm from Moore (1968). Lin and Jeng (2004) addressed the case of batch scheduling in parallel machines with the double objective of minimizing the maximum lateness and the number of tardy jobs. They propose a dynamic programming approach and some heuristics to solve the problem. Finally, M'Hallah and Bulfin (2005) developed a branch and bound algorithm to optimally minimize the weighted and un-weighted number of tardy jobs for the identical and unrelated parallel machine cases.

This paper presents a straightforward integer programming formulation for the PMFRS problem and some heuristical approaches to address the UPMFRS version. In the latter case, the objective of the paper is to understand the performance of the various scheduling approaches under a variety of experimental conditions related to the size and complexity of the problem. The next sections