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Job shop scheduling with alternative process plans

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Abstract

Successful implementation of automated manufacturing systems highly depends on effective utilization of resources. Efficient scheduling algorithms for alternative process plans may increase the throughput rate and guarantee a reasonable return on investment. This paper investigates an optimization methodology for scheduling jobs in a just-in-time environment. We consider the non-preemptive case where each job consists of a distinct number of operations to be processed in a specified order. Each operation has to be processed on one of a set of resources (e.g. machines) with possibly different efficiency and hence processing time. The objective is to minimize the sum of the weighted quadratic tardiness of the jobs. We obtain a fast near-optimal algorithm with guaranteed bounds for the distance to the optimum by using Lagrangian relaxation and show that just one relaxation suffices. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Job shop scheduling; Alternative process plans; Lagrangian relaxation

1. Introduction

Scheduling in a just-in-time environment is considered one of the most important resource planning issues in a production system with varying products and small lots. Increasing computer support in industrial practice will enable the flexibilization of production towards alternative machines. But even small-sized problems need time-consuming enumeration to find the optimum, moreover if there exist alternative process plans. It is unlikely that a polynomial time algorithm for finding the optimum exists, as except for special cases scheduling problems are NP-complete. Therefore, we present an algorithm that finds a good solution, whose computational effort grows just (pseudo-) linear in the number of operations and machines and supplies a lower bound as well. If the processing times required for the operations are within a reasonable range, a reaction to a machine breakdown should be achievable in real time, especially if the algorithm is parallelized [1]. To reduce the response time, the relaxed problems for the jobs may be solved in parallel, as they are independent.

The paper is organized as follows: Section 2 contains a short literature review and other approaches to the problem. The model description and a constrained discrete-time integer optimization formulation of the problem is presented in Section 3. Section 4 describes the Lagrangian relaxation technique, the solution of the subproblems, the modification of the multipliers via a subgradient technique and the heuristic to get a feasible solution. Test results are presented in Section 5 and the

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correctness of the algorithm is shown in the appendix.

2. Literature review and other approaches

Most schedulers in industry use heuristic procedures, like rules that use criteria of slack, processing times, the amount of work-in-process or combinations of them to decide, which operation to be processed next on the earliest available machine. The computation requirements for these heuristic rules are moderate and they can give a quick answer, if one has to react to dynamic changes [2]. But in general there is not way to tell, if the resulting schedule is good or not, unless the optimum is known. Enumerative methods that find the optimum still need a prohibitive amount of computation time for even rather small problem sizes. The time grows exponentially with the number of operations, despite results like [3,4], who solved the 10/10 problem posed in [5] within reasonable time for the function makespan, which is easier as those involving due dates. Lagrangian relaxation was first successfully applied to the travelling salesman problem. Fisher [6] adapted this method to scheduling problems with limited resources. Alternative process plans have been investigated in e.g. [7]. The technique presented here is based on [8]. It is extended to alternative process plans, i.e. resources with possibly different efficiency for the same operation. We require just one relaxation and develop a fast algorithm for solving the subproblems in (pseudo-) linear time.

3. Model and optimization problem formulation

We consider the non-preemptive scheduling of jobs with due dates that have to be met and alternative process plans. Each *job* consists of a given number of *operations* to be processed in a specific order. There may be timeouts between the operations, but once begun, an operation has to be finished. There may be graph-like precedence constraints among the operations of a job. For simplicity of definitions we assume to have a linear ordering. The operations require *resources* for a specified amount of time. The considered resources are implicitly understood to be machines, but this could be tools, transport vehicles or containers, pallets or workers as well. In the process plan the resources or groups of machines are fixed, that may process an operation and how long it takes. This processing time for an operation may vary for different resources that may process this operation. The machine capacities are finite and may be time dependent like shifts and timeouts for maintenance, but are known in advance. Each job may have a weight according to its importance and has an earliest start time and a due date and a penalty is applied when the due date is not met. As we want to produce just-in-time, this penalty could be some function of the tardiness. The objective function chosen to be minimized is the sum of the weighted quadratic tardiness for each job A_i. Thus the incremental penalty of a job increases as the tardiness increases and the penalty is higher for a job being two time units late than two jobs being just one unit late. The schedule is given in terms of start times of the operations.

The planning horizon will be divided into discrete time units (e.g. minutes, hours, shifts, days) and is assumed to be long enough. The length may be determined using a heuristic. Following [8] and [7] in a slightly different setting we formulate the constrained discrete-time integer optimization problem using the following variables:

A_i	ith job,
OP_{ij}	jth operation of the ith job,
N_{Time}	number of time units, i.e. length of time horizon,
N_{Job}	number of jobs,
N_{G}	number of different groups of machines,
N_{Opi}	number of operations of job A_i,
f_i	earliest start time of job A_i,
s_i	due date of job A_i,
$M_{l,t}$	number of available machines in group l at time unit t,
K_{ij}	set of machine groups that may process operation OP_{ij},
g_{ij}	possible machine group for processing operation OP_{ij}, $g_{ij} \in K_{ij}$,
d_{ijl}	processing time for operation OP_{ij} of a machine of group l, if possible ($l \in K_{ij}$),

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