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Optimal job-shop scheduling with random operations and cost objectives

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Abstract

We consider a job-shop manufacturing cell of n jobs (orders), J_i, $1 \leqslant i \leqslant n$, and m machines M_k, $1 \leqslant k \leqslant m$. Each job-operation $O_{i\ell}$ (the ℓth operation of job i) has a random time duration $t_{i\ell}$ with the average value $\bar{t}_{i\ell}$ and the variance $V_{i\ell}$. Each job J_i has its due date D_i and the penalty cost C_i^* for not delivering the job on time (to be paid once to the customer). An additional penalty C_i^{**} has to be paid for each time unit of delay, i.e., when waiting for the job's delivery after the due date. If job J_i is accomplished before D_i it has to be stored until the due date with the expenses C_i^{***} per time unit.

The problem is to determine optimal earliest start times S_i of jobs J_i, $1 \leqslant i \leqslant n$, in order to minimize the average value of total penalty and storage expenses. Three basic principles are incorporated in the model:

1. At each time moment when several jobs are ready to be served on one and the same machine, a competition among them is introduced. It is based on the newly developed heuristic decision-making rule with cost objectives.
2. A simulation model of manufacturing the job-shop and comprising decision-making for each competitive situation, is developed.
3. Optimization is carried out by applying to the simulation model the coordinate descent search method. The variables to be optimized are the earliest start times S_i.

A numerical example of a simulation run is presented to clarify the decision-making rule. The optimization model is verified via extensive simulation.

Keywords: Job-shop problem; Pairwise comparison; Coordinate descent search algorithm; Random operation; Total penalty and storage expenses

1. Introduction

It can be well-recognized from recent publications [1–7] that optimal analytical models can be applied only to specific cases in job-shop and flow-shop scheduling with random operations. As for general job-shop problems with random

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operations, optimization problems have not obtained an analytical solution. Our recent publications [8,9] consider general job-shop manufacturing cells with random operations. The results obtained center on suggesting heuristic decision-making rules in situations when several jobs are ready to be served on one and the same machine and the problem is to choose one of the competitive jobs to be passed to that machine. But in these publications, we have not considered optimization problems. Only non-cost parameters (total time to accomplish all the jobs, probabilities for each job to meet its due date on time, etc.) have been used in the models.

This publication is an essential development of our previous papers [8,9].

We consider a job-shop manufacturing cell of n jobs (orders), J_i, $1 \leqslant i \leqslant n$, and m machines M_k, $1 \leqslant k \leqslant m$. Each job-operation $O_{i\ell}$ (the ℓth operation of job i) has a random time duration $t_{i\ell}$ with the average value $\bar{t}_{i\ell}$ and the variance $V_{i\ell}$. Each job J_i has its due date D_i and the penalty cost C_i^* for not delivering the job on time (to be paid once to the customer). An additional penalty C_i^{**} has to be paid for each time unit of delay, i.e., when waiting for the job's delivery after the due date. If job J_i is accomplished before D_i it has to be stored until the due date with the expenses C_i^{***} per time unit storage.

The problem is to determine optimal earliest times S_i, $1 \leqslant i \leqslant n$, to start processing jobs J_i, in order to minimize the average value of total penalty and storage expenses.

In order to solve the problem, we have developed a new decision-making rule for choosing a job from the line. The rule is, in essence, a combination of the pairwise comparison model for stochastic job-shop scheduling outlined in [8] and the cost objective calculated for the competitive pair of jobs. Developing the decision-making rule enables a job-shop's simulation model by random sampling of the actual job-operation's time durations. By simulating the manufacturing cell many times, the average value of the total penalty and storage expenses can be evaluated. Note that the average expenses value depends on values S_i, $1 \leqslant i \leqslant n$. This, in turn, enables application of one of the approximate search methods [7] in order to determine optimal values S_i to minimize the average expenses. We have chosen the cyclic coordinate descent algorithm which minimizes the cost objective cyclically with respect to the coordinate variables. The algorithm is easy to use and can be applied to any kind of non-linear multidimensional problems. The algorithm has been successfully used in various production and scheduling problems, e.g. in [11].

The developed optimization model can be used for job-shop manufacturing cells with random operations and various cost penalties and expenses. Similar studies by other authors have not been published elsewhere.

The structure of the paper is as follows. In Section 2, we present the system description, while Section 3 considers a notation and the problem formulation. In Section 4, we consider the idea of the pairwise comparison, while Section 5 presents the decision-making rule for two competitive jobs with a cost objective. In Section 6, the coordinate descent method to solve the optimization problem is outlined, while Section 7 presents a numerical example of a simulation run. In Section 8, extensive experimentation based on computer usage will be undertaken. Section 9 presents conclusions and suggests future research.

2. Description of the system

We are concerned with a problem of machine scheduling known as the general job-shop scheduling problem [12,13,8,9]. A flexible manufacturing cell comprises a set of n jobs J_i, $1 \leqslant i \leqslant n$, and a set of m machines M_k, $1 \leqslant k \leqslant m$. Each job (order) consists of a chain of operations, each of which needs to be processed during an uninterrupted period on a given machine. Each machine can process at most one operation at a time. If, in the course of manufacturing, one or more jobs are ready to be processed on a certain machine *and that machine is free*, a job has to be chosen from the line and passed on the machine immediately. Choosing the job from the line is carried out by using a certain decision-making rule, e.g., by undertaking a pairwise comparison [8,9]. If at a certain moment, more than one job is ready to be served on the machine, these jobs are compared