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Just-in-Time Scheduling with Machining Economics for Single-Machine Turning Process

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Abstract

Traditional machining economics looks into the optimal set of machining conditions under which the production cost or time per part is minimized. No due dates are included in the consideration. Job sequencing searches for the optimal order of jobs so that lateness and/or earliness is minimized. The optimization assumes that processing times are fixed. In practice, processing times are variable within a certain range by adjusting the combination of machining conditions. This paper presents the modeling of a machining sequencing problem that is integrated with the lower-level machining process optimization problem of a turning process in a just-in-time delivery environment. A combination of dynamic programming and an enumerative procedure is used to solve the optimization problem.

Keywords: *Just-in-Time, Sequencing, Machining Economics, Due Window Scheduling*

Introduction

The widespread adoption of the just-in-time (JIT) philosophy has led manufacturers to develop scheduling policies with the goal of producing products at the necessary time, that is, simultaneously minimizing both earliness and tardiness costs. There are a number of papers on scheduling problems involving tardiness and earliness costs. For a recent comprehensive review, see Baker and Scudder.[1] However, the literature is scanty on earliness/tardiness problems with controllable job processing times. Actually, processing time can be easily adjusted by changing the machine parameters such as cutting speed and feeding rate. Work on controllable job processing times was initialized by Vickson.[2,3] Van Wassenhove and Baker,[4] Nowicki and Zdrzalka,[5] and Panwalker and Rajagopalan[6] have also contributed notably to this topic. Their considerations are more in the traditional production environment where JIT is not practiced. For a good summary of the known results of the problems concerning controllable processing times, the reader is referred to the survey paper by Nowicki and Zdrzalka.[7]

Solutions to machine economics problems seek the optimal machining conditions that minimize the production cost or production cycle time. There are also many papers on this topic, for example, Wysk,[8] Hati and Rao,[9] Challa and Berra,[10] Subbarao and Jacobs,[11] Hayes, Davis, and Wysk,[12] Chang et al.,[13] Arsecularatne, Hinduja, and Barrow,[14] Zhou and Wysk,[15] Linn and Mishra,[16] and Yeo.[17] Generally speaking, these studies sought the optimal cutting speed, feed rate, and/or depth of cut for either minimal production time or cost to produce a batch of the same parts. The due dates were not considered in the problems.

In practice, job sequencing and machining process parameters should be determined simultaneously to achieve best performance. This study integrates machining process optimization with the job sequencing problem of a single turning process. Considered is a single-machine problem with due windows and controllable job processing times by changing machining parameters. The objective is to minimize the total sum of earliness, tardiness, and machining costs.

Problem Description

Consider a single-machine scheduling problem in which there is a set of n parts, $N = \{1, 2, 3, ..., n\}$, to be processed on the machine without preemption. The processing time p_j of part j is a variable and can be adjusted by altering the machining conditions. Let S denote the set of all permutations of all parts 1, 2, ..., n, let s be a sequence of the parts while $s \in S$, let t be the vector of the starting time of the parts in the sequence, and let r be the vector of machining parameters for each part in the sequence. Then the problem is to find a set (s,t,r) that minimizes the total cost (including various costs in the production, which are discussed in the following section). In reality, a multipass turning process is commonly practiced and jobs can be started at any time when a machine is idle. Therefore, idle time can be inserted between jobs if necessary. However, the modeling complexity for this real-life situation is very involved. To reduce the complexity to a manageable level, non-idle time between jobs and a single-pass turning process are assumed for the current study.

Formulation of Problem

As described in the previous section, the goal of the scheduling problem is to minimize the total production cost with a set of operational constraints. The production cost includes operation cost, tool cost, tool change cost, and job lateness/earliness costs, where the sum of operation cost, tool cost, and tool change cost is called manufacturing cost. While deciding on the job sequence and machining parameters, it is necessary to satisfy certain equipment constraints. The formulation of various costs and constraints is presented in the following subsections.

Operation Cost

Operation cost is considered first. Let f_i and V_i be the feed rate (ipr) and the cutting velocity (fpm) for part i, respectively. The machining operation can be partitioned into three parts: machining, handling, and setup. The setup operation sets up the machining parameters, fixtures, and so on, for the whole lot, while the handling operation mounts a part into the machine for machining and removes a part from machine after machining is completed. The operation cost for part i, denoted by $C_i(V_i, f_i)$, can be represented as follows:

$$C_i(V_i, f_i) = C_{mi} + C_{hi} + C_{si} = C_o(t_{mi} + t_{hi} + t_{si}) = C_o t_{mi} + C_o t_{hi} + C_o t_{si}$$

where

- C_{mi} machining cost for part i
- C_{hi} handling cost for part i
- C_{si} setup cost for part i
- C_o cost of operating, including operators and machine (\$/min.)
- t_{mi} machining time (min.) for part i
- t_{hi} time (min.) required for loading and unloading a workpiece
- t_{si} time (min.) required for setting up the process
  $t_{si} = 0$ if the current job type is same as previous one

The *machining cost* for part i, denoted by C_{mi}, can be represented as follows:

$$C_{mi} = C_o t_{mi}$$

because

$$t_{mi} = \frac{l_i}{f_i N_i} \text{ and } N_i = \frac{12V_i}{\pi D_{oi}}$$

$$C_{mi} = C_o t_{mi} = C_o \frac{\pi D_{oi} l_i}{12 V_i f_i}$$

where

- l_i length of cut for part i
- D_{oi} outer diameter of part i (in.)

Thus, the *operation cost* for part i, denoted by $C_i(V_i, f_i)$, can be represented as follows:

$$C_i(V_i, f_i) = C_{mi} + C_{hi} + C_{si}$$

$$= C_o \frac{\pi D_{oi} l_i}{12 V_i f_i} + C_o t_{hi} + C_o t_{si} \qquad (1)$$

Tool Cost

Now is considered the tool cost, C_t. This is the purchase cost of tools needed for the entire sequence of jobs, as follows:

$$C_t = C_{ut} n_t \qquad (2)$$

where

- C_t tool cost
- C_{ut} unit cost of tools, including cost of regrinding and number of regrinds allowed
- n_t number of tools needed for the sequence of jobs