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Executing production schedules in the face of uncertainties: A review and some future directions

Haldun Aytug [a,*], Mark A. Lawley [b], Kenneth McKay [c], Shantha Mohan [d], Reha Uzsoy [e]

[a] *Department of Decision and Information Sciences, Warrington College of Business Administration, University of Florida, Gainesville, FL 32611, USA*
[b] *School of Industrial Engineering, 1287 Grissom Hall, Purdue University, West Lafayette, IN 47907-1287, USA*
[c] *Faculty of Business Administration, Memorial University of Newfoundland, St. John's, NF, Canada A1B 3X5*
[d] *Kaveri Inc., Software Technology and Management Consulting, 261 Parkside Drive, Palo Alto, CA 94306, USA*
[e] *Laboratory for Extended Enterprises at Purdue, 1287 Grissom Hall, Purdue University, West Lafayette, IN 47907-1287, USA*

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Abstract

We review the literature on executing production schedules in the presence of unforeseen disruptions on the shop floor. We discuss a number of issues related to problem formulation, and discuss the functions of the production schedule in the organization and provide a taxonomy of the different types of uncertainty faced by scheduling algorithms. We then review previous research relative to these issues, and suggest a number of directions for future work in this area.

Keywords: Production scheduling; Rescheduling; Structural control

1. Introduction

Manufacturing operations can be faced with a wide range of uncertainties and production control is charged with accommodating these in advance or reacting after the fact. There may be relatively little uncertainty, or a plant may experience pervasive and rampant chaos. When there are large amounts of uncertainty, Emerson's description may still be appropriate:

> … but most of the industrial plants of the world are still in the stage of civilization of which as to transportation the old freight wagons and prairie schooners across the plains were types. They started when they got ready, they arrived some time, and nobody knew where they were nor what route they were taking in between. (Emerson, 1913; p. 251).

* Corresponding author. Tel.: +1-352-3922468; fax: +1-352-3925438.

E-mail addresses: aytugh@ufl.edu (H. Aytug), malawley@ecn.purdue.edu (M.A. Lawley), kenmckay@mun.ca (K. McKay), shantha_mohan@alumni-mail.gsia.cmu.edu (S. Mohan), uzsoy@ecn.purdue.edu (R. Uzsoy).

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Uncertainty and the disruptions associated with the resulting perturbations have been topics of discussion since the early 1900s. For example, Gantt (1919) is known for what we call the Gantt Chart today, but he developed several different charts and the one that he considered the most useful was not the planning chart, but the chart prepared by the floor workers (operators or supervisors) providing feedback to the planners and schedulers—why the plan and schedule did not execute as planned. They reported back causes of delays, yield problems, and so forth associated with material, tools, and machinery. An early description of the scheduling task explicitly noted that the planners had to anticipate future difficulties and discount them (Coburn, 1918). Disruptions and uncertainty have been a problem since the beginning of systemized manufacturing and remain so today.

There has been an extensive body of research on production scheduling problems since the original mathematical formulation of these problems in the late 1950s. These formulations typically involve the assignment of scarce resources, usually machines, to competing tasks over time to optimize some aspect of system performance either exactly or approximately. This literature can be broadly classified into two main areas: deterministic scheduling research, where all problem parameters are assumed to be known with certainty, and stochastic scheduling, where at least some parameters are random variables. Much of the stochastic scheduling work has assumed that all parameters are random variables, and has thus focused on local control policies such as dispatching rules aimed at minimizing some measure of performance in the expectation. Most of these methods seldom use any information about the global state of the shop, or try to create a schedule for the entire shop prior to its execution. In deterministic scheduling research a larger view is taken and multiple machines are often modelled. The deterministic approach is to plan the work through the machines over a period of time in the best way possible given a specific objective to optimize. The implicit assumption here is often that a schedule can be executed directly as developed. However, in recent years many authors have recognized that this is an unlikely scenario in many manufacturing environments, and have made efforts to extend the deterministic approaches to situations with some form of uncertainty. The basic assumption in much of this work, which forms the focus of this paper, is that a system that works in a deterministic environment can be engineered to work under at least certain stochastic conditions.

A pervasive assumption in the deterministic scheduling field has been that the schedule once released to the production floor can be executed as planned. However, many production systems are subject to executional uncertainties that prevent the execution of a production schedule exactly as it is developed. Examples of such disruptions include machine failures, quality problems, arrival of urgent jobs and a myriad of other possibilities. Theoretical scheduling research also typically fails to consider the organizational discipline needed to execute a schedule correctly. Thus, for example, the specific incentives used for the shop-floor personnel may cause them to override the schedule, in effect introducing another type of uncertainty. The inability of much scheduling research to address the general issue of uncertainty is often cited as a major reason for the lack of influence of scheduling research on industrial practice. Although in recent years there has been a steadily increasing volume of research in this area, we believe there are several different approaches that have developed largely in isolation, and need to be evaluated and discussed together to provide a broad perspective on this important problem area.

For the purposes of this paper, we shall restrict ourselves to the type of scheduling problem encountered in manufacturing environments, where the basic problem is to allocate machines, and perhaps other resources such as tooling or operators, to jobs in order to exactly or approximately optimize system performance. Hence we shall ignore a number of other decisions, such as order release, due date setting and lot sizing, which are often considered part of the larger production planning decision, and whose solutions clearly affect the scheduling function. We shall use the term "schedule" to denote an assignment of machines