International Journal of Production Research

ISSN: 0020-7543 (Print) 1366-588X (Online) Journal homepage: https://www.tandfonline.com/loi/tprs20

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To cite this article: M. YAMAMOTO & S. Y. NOF (1985) Scheduling/rescheduling in the manufacturing operating system environment , International Journal of Production Research, 23:4, 705-722, DOI: 10.1080/00207548508904739

To link to this article: https://doi.org/10.1080/00207548508904739

Published online: 03 Apr 2007.

INT. J. PROD. RES., 1985, VOL. 23, NO. 4, 705–722

Scheduling/rescheduling in the manufacturing operating system environment†

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A scheduling/rescheduling procedure is proposed for real-time control of a computerized manufacturing facility managed by a central manufacturing operating system. The procedure implies schedule revisions upon significant operational changes such as machine breakdowns. Experiments to evaluate the total production time of a computerized manufacturing system with breakdowns under scheduling/rescheduling have yielded advantages of between 2·5% to 7·0% compared to fixed sequencing and priority despatching procedures, respectively. Computation times required for the scheduling procedures on a CDC 6500/6600 have also been studied. The scheduling/rescheduling procedure for an actual facility required less than two minutes, and the computation time can be regulated by the selection of parameters in an approximate method of scheduling.

Introduction

Job shop type machine scheduling problems have been well-known subjects in operations research for the last 25 years and extensive work about them has been presented (Baker 1974, Conway *et al.* 1967). Nevertheless, these theories and methods have scarcely been used to solve actual job shop problems in practice. Though the causes of this inability can be investigated from several aspects, it has been considered that one of the major causes is the high variability of schedule factors in an actual process. Significant differences can be shown between a schedule that results from traditional scheduling approaches and the real progress in a shop; for example, see Bestwick and Lockyer (1979). If we want to correct these differences and maintain control by the schedule we cannot avoid ceaseless rescheduling. Such a practice is usually undesirable from the standpoint of shop management and administrative cost. However, two major developments have taken place in recent years: computer aided scheduling and computerized manufacturing systems. This work develops and analyses the idea of rescheduling in the new environment of computerized manufacturing.

Computer aided scheduling

Computer aided scheduling includes the following.

(1) The development of interactive scheduling techniques that rely on computer systems, e.g., Godin (1978), Kerry (1980) and Hodgson and McDonald (1981).

(2) Scheduling with graphics capabilities, e.g., Hurrion (1978).

Revision received June 1984.

† A shorter version of this article has appeared in Japanese (Yamamoto and Nof 1982).

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(3) Decision support systems for manufacturing control, e.g., Nof and Gurecki (1980).

The main contribution of such approaches is that they allow non-experts to review and revise many schedule alternatives quickly. As a result, scheduling control of dynamic production systems becomes responsive and more effective.

Computerised manufacturing systems

The other major development is of computerized, or flexible, manufacturing systems (CMS). CMS are comprised of control computers, DNC machines, automatic transportation and material handling facilities, automatic tool changers, etc. CMS provide production flexibility and programmability, and therefore have been applied over the last decade in order to increase productivity in non-mass products, batch type production. CMS system design and the analysis of CMS operating for rules are investigated by many researchers (for example, see Buzzacot and Shantikumar 1981, Nof *et al.* 1978). A fundamental requirement for the effective use of CMS is a good central control.

The manufacturing operating system environment

The manufacturing operating system (MOS), was suggested by Nof, Whinston and Bullers (1980) for central control of automatic manufacturing. The MOS is a framework of multi-stage decision making in controlling the total system operation.

The MOS has three main components, namely, data management, logic management, and interfaces to human users and machine controllers. The data management component is responsible for the representation, storage, and retrieval of data used for operations management decisions. The logic management component involves the representation, storage, retrieval, and execution of algorithms (e.g., reasoning logic) at decision points in the system. Decision-making algorithms are applied for structured decision where automatic resolution is allowed. Decision support algorithms, on the other hand, manipulate and evaluate information that is useful as an aid to human decisions for non-automatic, unstructured decisions.

Such control is quite difficult to achieve in a regular job shop environment. A CMS, however, requires significant investment cost and intensive use of computers, thus it is possible to justify the more sophisticated and accurate shop control of the MOS type.

One of the major functions of the MOS is sequencing and timing of parts movement in a CMS. Since a CMS facility is an integrated complex equipment, proper coordination and synchronization are paramount. Examples of scheduling control issues are the control of the parts mix concurrently produced by the system; initial entry of parts to the system (i.e., entry to an empty system after each restart); general entry of parts; dynamic process selection when alternative processes are available for parts; dynamic selection of transporter and transfer route; rerouting of parts upon machine breakdown, and so on.

Nof *et al.* (1978) applied various heuristics for decision making in a CMS for priority despatching of parts in a particular CMS. An important factor in the ability to apply such decision making for control in a CMS is the fact that operations, process, and transfer time values in the automatic environment are much less variable than in systems involving human work. This relative stability of automatic performance time suggests, therefore, that the above-mentioned scheduling control has practical promise. On the other hand, dynamic changes in production requirements and frequent machine stoppage and breakdown complicate the CMS operation.

The purpose of this article is to present a concept of scheduling/rescheduling in the dynamic MOS environment, and examine its feasibility and use to increase the CMS operational efficiency.

The scheduling/rescheduling approach

A scheduling/rescheduling approach implies that a set schedule is revised at given points in time due to certain significant changes in operation requirements. A fundamental characteristic of the scheduling/rescheduling approach is that it is not planned in advance for a certain future time, but is invoked under certain circumstances. An approach of this type has mainly been applied for production and inventory control. For example, Mather (1977), describes rescheduling in application of MRP. He states that MRP rescheduling procedure is called upon for a variety of causes, such as vendor failure to supply, unexpected scrap or spoilage, lot-size changes, etc.

While rescheduling in production and inventory control is considered over periods of weeks or days, our focus is on applying the scheduling/rescheduling approach by the MOS more frequently if necessary, and in real-time control.

General scheme

The main feature of a scheduling/rescheduling approach is to establish a schedule of all operations in a system for a fixed time period in advance. The schedule is generated in consideration of the optimality or near optimality of the total system, instead of a series of local decisions by some priority rule applied at each machine and each time point. In order to realize this idea, a scheduling/rescheduling approach will have the following general scheme.

(1) Planning phase
- (*a*) Part-mix assignment
- (*b*) Initial scheduling
- (*c*) Machine loading table generation

(2) Control phase
- (*a*) Machine loading order instructions
- (*b*) Checking progress
- (*c*) Testing for abnormal status

(3) Rescheduling phase
- (*a*) Rescheduling
- (*b*) Revising loading table
- (*c*) Resorting to control phase

Each of the phases will now be described.

Planning phase

In the planning phase, an 'initial schedule' is generated just prior to the start of a new work period, based on all available production requirements data. The planning phase prepares all the information necessary for the operations during a given work period, say a work day or a shift. In the part-mix assignment the types and quantities of parts to be processed in the work period are decided according to the production requirement given for this CMS. The part-mix assignment has to satisfy requirements according to part types, quantities, and due dates in production during the same time period, in order to assume the proper loading for each machine. Next, a schedule is generated to process these part types and quantities. For all operations necessary for performing jobs in the work period, starting and finishing times on each machine are determined. A loading table can then be developed for each machine and facility directly from the resulting schedule. In some cases, we can assign only a processing sequence, instead of producing a complete timetable for each facility.

Control phase

Next, the control phase begins with the start of the work period. Operations are initiated one by one following instructions from the loading tables of the initial schedule, and progress is checked. If the loading table contains loading times, a signal is issued to begin the next operation when its starting time in the loading table is reached. However, if specified conditions that are required to start an operation are not met, e.g., a set temperature is not yet available, this signal will be held until the necessary conditions are satisfied. Similarly, the signal will be held if all preceding operations have not been completed. In the case of instructions given by a loading sequence, a signal to start an operation is issued as soon as all preceding operations in the sequence are completed and the specified conditions are met.

The actual progress data of operations are compared with a current schedule every time a new operation begins and finishes. If the difference exceeds a specified limit, the MOS will decide to enter a rescheduling phase. In addition, certain abnormal status such as machine troubles and operator's interruptions can cause entry into the rescheduling phase. In the latter situation, the rescheduling will be accompanied by other actions deemed necessary to respond to the abnormal status.

Rescheduling phase

In the rescheduling phase, the schedule times of operations already processed, in process, or expected immediately to follow into processing are fixed at first. The remaining operations are considered to be free operations. For them, computation of a revised schedule is carried out, considering the operational changes that have triggered the rescheduling. For instance, if a new part mix is required, then a revised schedule has to be generated. In the case of machine breakdown, the expected duration of the breakdown has to be considered. As a result, revised loading tables are generated. The scheduling procedure itself is essentially the same as in the planning phase, except that the schedule of the non-free operations is fixed.

Scheduling/rescheduling experiment

The scheduling/rescheduling approach has been tested on two case studies of typical CMSs with machine breakdowns, and compared to operations under two scheduling techniques: one following strictly the sequence of the original schedule; the other, applying priority despatching rules. The former corresponds to the extreme case that MOS doesn't enter the rescheduling phase at all in the scheduling/rescheduling approach. The latter is a traditional procedure in shop control. Figure 1 (*a*), (*b*) and (*c*) show the logic of the three scheduling procedures that have been compared, i.e., (*a*) scheduling/rescheduling; (*b*) fixed sequence; (*c*) priority despatching.

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