Computers & Industrial Engineering 56 (2009) 283–293

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Optimization of operation and changeover time for production planning and scheduling in a flexible manufacturing system ☆

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ARTICLE INFO

Article history:
Received 29 June 2006
Received in revised form 6 May 2008
Accepted 3 June 2008
Available online 11 June 2008

Keywords:
Process planning
Sequencing
Flexible manufacturing system
Machining
Integer programming
Part grouping
Machine loading
Tool allocation

ABSTRACT

This paper deals with the production planning problem of a flexible manufacturing system. It specifically addresses issues of machine loading, tool allocation, and part type grouping with the intent of developing an operation sequencing technique capable of optimizing operation time, non-productive tool change times, and orientation change times when processing a group's design features. A hierarchical approach has been adopted to determine the part groups – depending on the operation, tool change and orientation change times at the upper level. At the next level, we sequence the operations of the part groups. Integer programming models are formulated to group the parts and to address the operation-sequencing problem. The model is illustrated with an example related to an auto engine cylinder head machining plant.

1. Introduction

Machines in modern, flexible, manufacturing systems are capable of performing all planned operations. The inherent efficiency of a flexible manufacturing system (FMS), combined with additional capabilities, can be harnassed by developing a suitable production plan. As Stecke (1983) mentions, in order to best utilize an FMS's capabilities, a careful system set up is required prior to production. This paper considers the specific production planning problem of complex parts, similar to an automobile engine cylinder head, which combines design features (DFUs) equivalent to part types, and unit manufacturing features (UMFs) equivalent to operations. The DFUs are located at different locations and, in some situations, at different faces. Although the tool change time is minimal in modern FMSs, the movement of tool heads from one DFU to the next, combined with the time needed for tool retracting and positioning, makes each tool change considerably time consuming. In addition to the tool changes, orientation changes required to reach the DFUs at different faces of the cylinder heads make the system more complex. We follow the general framework introduced by Stecke (1983) as a guideline, but resort to a system-dependent planning approach more suitable to our problem.

Among the FMS planning models, the machine loading one is most frequently cited. Part grouping is the next most studied model, as in Hwang and Shogun (1989), Kulkarni and Kiang (1995), Liang and Dutta (1993a, 1993b), Rajagopalan (1986), Sawik (1990), and Stecke and Kim (1988, 1991). Mohammed, Kumar, and Motwani (1999), Mukhopadhyay, Maiti, and Garg (1991), Rajagopalan (1986), Sodhi, Askin, and Sen (1994) consider an approach that combines part grouping and machine loading in conjunction with tool loading. Part grouping, machine loading, and tool provisioning for part groups are, in essence, linked. This paper takes a joint approach, collectively addressing these three problem areas for a more comprehensive solution.

To implement the above-mentioned joint approach, this paper introduces a methodology for considering operations, tool change and orientation change times that addresses the FMS planning problems of part grouping, machine loading, and tool allocation. Assigning machines to a part group equipped with the required number of tools is a crucial part of both the machine loading and tool provisioning phases. As discussed, modern FMS machines are capable of performing all operations. However, a different set of tools gives a machine a different capability as required by the planning model to process a planned part, mix, or group. The output is then taken from this planning model, and a detailed operation schedule is generated in the later stage.

Section 2 reviews the relevant literature. Section 3 presents the mathematical programming models for the part grouping, machine

☆ This manuscript was processed by Area Editor Gursel A. Suer.
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doi:10.1016/j.cie.2008.06.001

loading, tool allocation, and scheduling, and Section 4 provides examples that illustrate the planning and scheduling model. Conclusions are given in Section 5.

2. Literature review

The FMS production planning problem has attracted numerous authors over the past two decades, due to its inherent potential for flexibility, quality, and high productivity – all of which are vital for providing a quick response to market needs.

Stecke (1983) outlines a general framework for the implementation of system set-up decisions prior to production in a FMS. The framework divides the FMS production planning problem into several hierarchically structured sub problems: part type selection, machine grouping, production ratio, resource allocation, machine loading, and scheduling. The part type selection and machine grouping problems are aimed at reducing set up times and increasing the throughput of machining centers by taking the tool allocation problem and other tool specific constraints into account.

Sarin and Chen (1987) address machine loading and tool allocation problems. Their proposed MIP model considers tool life, tool slot availability, and tool-specific space requirements, with an objective to determine the part routing in an effort to minimize the total machining cost.

Modi and Shankar (1994) solve the operational assignment of tools and machines by minimizing part movement between the machines. Their approach attempts to maximize the number of operations a tool and a machine are capable of carrying out. Their study formulates the model as a quadratic programming problem and linearizes it, following the approach of Balas (1964) and Glover and Woolsey (1974).

Mohammed et al.'s (1999) research focuses on the FMS part-grouping problem to optimize makespan – developing an MIP model to solve the part grouping, machine loading, and tool allocation problems. Their model minimizes the deviation between the makespan's evaluation, where, initially, part grouping is considered, to where it is later ignored. To decide the target makespan time, they use a model that ignores part grouping. Their study determines the number of part groups by solving a formulation that depends on the compatibility between operations, tools and machines – later used as input for the part-grouping model. Their research compares the model output by taking examples from literature – garnered through experimental analysis – and concludes that the model efficiently generates lower makespan and enhanced routing flexibility.

Persi, Ukovich, Pesenti, and Nicolich (1999) propose a two-level FMS production-planning model with the intention of improving a real industrial problem related to machine utilization experienced by Grandi Motori in Italy. First, part grouping, tool allocation, and machine loading models are addressed. The focus then switches to the scheduling problem at the factory level, depending on the outcomes of the first level models. Persi et al. propose an MIP model for the machine loading and batching model, providing a 10-part illustration. For the sequencing problem, they test local dispatching rules such as FIFO, LIFO, SRPT, EDD, and others. Various performance measures, including WIP, are used to evaluate the suitability of the scheduling model.

Sinriech, Rubinovitz, Milo, and Nakbily (2001) develop a 0–1 integer programming model to determine a job sequencing plan with the objective of minimizing unproductive tool change time by reducing the number of dissimilar tools needed by adjacent jobs that are subject to the availability of the fixturing devices. This study concludes with a heuristic procedure to solve the model. The solution quality of the heuristic is tested using a hi-tech company's practical data, and is found to be satisfactory when compared to an optimal solution of the model.

Gamila and Motavalli (2003) develop an integrated model to address the FMS production-planning problem. Their first step solves an integrated model for machine loading and tool loading. Then the operation schedule is obtained according to the outcomes of the first step. A 0–1 MIP model is proposed to minimize the summation of maximum completion time, material handling time, and total processing time.

Bard (1988) formulates a non-linear integer-programming model to solve the FMS job-sequencing problem while seeking to minimize the number of tool switches. The tool switching and job-sequencing problems ultimately result in a reduction in makespan. Tool switches are instances when the tool is loaded in the magazine from local storage (as needed) to process a job in its scheduled position. The study assumes that each tool change time is identical and uses a dual-based Lagrangian relaxation heuristic to solve the problem.

Koo and Tanchoco (1999) analyze the tool and operation selection problem of single-stage multifunctional machining systems (SSMS), where tools are dynamically shared between machines. Avci and Akturk (1996) propose an approach to solve FMS tool magazine arrangement and operation sequencing problems. The objective of this study is to minimize the total manufacturing cost by using an efficient tool-sharing concept. The model accounts for a precedence constraint, tool magazine capacity, tool availability, and tool life in developing solutions. Grieco, Semeraro, Tolio, and Toma (1995) conduct a tool management study with the objective of evaluating the impact of a reduction of tools on the overall performance of the FMS. This study investigates the possibility of reducing investment in tools by allowing machines to share them in a simulated environment.

Hertz, Laporte, Mittaz, and Stecke (1998), Crama, Colen, Oerlemans, and Spieksma (1994) and Tang and Denardo (1988a, 1988b) address the tool-switching problem. All tools required for processing must be installed before a part is processed. However, the installation of tools in the tool magazine is time consuming. These studies focus on sequencing jobs that minimize the number of tool switches needed. Ecker and Gupta (2005) look at the problem of tool change time when scheduling FMS tasks – hoping to optimize the total tool change time by considering precedence requirements.

This paper introduces the problem of moving a tool head from one position to another during the interchange of tools, in contrast to only tool change or tool switch instants. The machines under consideration in this study have automatic tool changers that carry out tool changeover within a very short time span. While tool changeover time is insignificant compared to operational time in UMFs, tool movement time has been found to be quite substantial in the case of jobs involving engine cylinder heads and engine blocks. In addition, this paper also considers a change in orientation in reducing cycle time and in developing an efficient schedule.

3. Problem statement

We intend to develop a process-planning model for machining cylinder heads in a typical engine manufacturing plant. The process-planning problem includes an extensive number of issues that must be addressed in an industry setting. This paper attempts to address important issues that, if implemented, would make the process-planning system more efficient. We consider jobs similar to auto engine cylinder heads. In a typical cylinder head there are several design features, DFUs, r (equivalent to part types), while each feature processes one or more UMF, o (operations) for its completion. The DFUs are located at various faces of the head and, as such, are processed on flexible manufacturing machines by changing their orientation through a tilting fixture. Each UMF