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Tool allocation in flexible manufacturing systems with tool alternatives

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Abstract

In this paper, a heuristic approach for tool selection in flexible manufacturing systems (FMS) is presented. The proposed approach utilizes the ratio of tool life over tool size (L/S) for tool selection and allocation. The proposed method selects tool types with high L/S ratios by considering tool alternatives for the operations assigned to each machine. The performance of the method is demonstrated in sample problems as static examples, as well as in a simulation study for further analysis. This study also presents a survey of several approaches related to loading and tool allocation problems in FMS, highlights the importance of tooling, and discusses the practical aspects of tool-oriented decision-making. An extended framework, which expands on the L/S concept, is also presented.

Keywords: Tool allocation; Tool management; Computer integrated manufacturing; Flexible manufacturing systems

1. Introduction

A flexible manufacturing system (FMS) consists of a computer-controlled, integrated configuration of numerically controlled machine tools with automated material handling systems. Combining the merits of job-shop and flow-shop production, an FMS provides a promising technology for mid-volume and mid-variety production. Problems related to flexible manufacturing technology are relatively complex compared to traditional manufacturing systems in which lead times are longer, inventory levels are higher, and utilization rates are lower. The difficulty originates primarily from the fundamental objective behind the FMS concept: be as efficient as a mass production facility and yet as flexible as a job shop facility. Since (1) each machine in an FMS is quite versatile and capable of performing many different operations; (2) the system can machine several part types simultaneously; and (3) each part may have alternate routes through the system, it becomes very complex to solve FMS planning, scheduling, and operational problems. Tool management is one of these types of problem.

Tool management can be defined as getting the right tool, to the right place at the right time and it seems to be one of the most cumbersome and difficult issues to deal with related to the effective operation of FMS [1,2]. The need for tool management stems from the high variety and number of cutting tools that are typically found in automated manufacturing systems. Considering the fact that the tool-related activities can account for about 25–30% of the on-going operating costs of FMS [2–6], significant costs can be avoided by appropriate tool management strategies. The adoption of appropriate tool management policies that consider alternative cutting tools allows the desired part mix and quantities to be manufactured efficiently while achieving improved system performance.

This paper is organized as follows. The literature survey is presented in Section 2. The proposed framework is explained in detail with sample problems and a simulation study in Section 3. Section 4 presents an extended framework that expands on the L/S concept. Finally, the conclusions and recommendations for future work are given in Section 5.

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2. Literature survey

To date, there is considerable amount of literature related to tool allocation issues in FMS. Most researches adapt hierarchical approaches to tackle FMS planning problems similar to that of Stecke [7]. FMS planning problems identified by Stecke are (1) part type selection, (2) machine grouping, (3) production ratio, (4) resource allocation, and (5) loading. Among these five sub-problems, loading refers to the allocation of operations of selected set of part types and cutting tools to the machines or machine groups. Due to the hierarchical structure of the five sub-problems, the decisions are interdependent. Decisions made at a higher level can be useless if they fail to provide a feasible solution to lower decisions [8–10].

Stecke [11] formulates the tool allocation problem as a nonlinear programming model. She solves the problem in connection with machine loading with the objectives of including load balancing on machines, maximizing the number of consecutive operations of a part on each machine, and maximizing the tool density of each tool magazine. Whitney and Shin [12] develop a sequential heuristic approach for part type selection and tool allocation based on a probabilistic decision criterion. Kusiak [13] formulates the part assignment problem as a 0–1 linear integer model with the objective of minimizing the total processing cost. However, the processing time of each operation in a batch is assumed to be identical and tool sharing by the parts loaded on the machines is ignored. Sarin and Chen [14] also formulate the machine loading and tool allocation as a 0–1 linear program. Part assignments and tool allocations are determined simultaneously considering tool life, tool size (i.e. number of slots a tool occupies on tool magazine) and magazine capacity. Ventura et al. [15] formulate FMS part-tool grouping problem as a 0–1 linear integer program. This formulation minimizes the interdependencies among the part-tool groups. In their study, Reddy et al. [4] underline the importance of tool management. With the objective of increasing machine utilization, they use Petri nets to solve tool management problem. Leung et al. [16] formulate part assignment and tool allocation concurrently as a linear integer model with explicit consideration given to material handling. Their model includes alternative tools, magazine capacity, but the same tool life and the same size for all the tools. In their paper, Amoako and Meredith [17] describe three heuristics that can be used to allocate tools in FMS. The three heuristic procedures are then evaluated, through a simulation study using SLAM II. Atan and Pandit [18] analyze a new approach to loading problems in FMS. Their model determines the allocation of tools to machines, which satisfies the tool requirements for each machine, and minimizes the total number of tools. Improvement of tool scheduling strategies is discussed by Li et al. [19]. They use combinations of various scheduling rules for tool exchange and analyze machine tool utilization by using simulation. Tetzlaff [20] presents an analytical model that allows the evaluation of performance of an FMS with a tool management system. The part and tool transportation systems are modeled as two interacting closed queuing networks. In their study, Rau and Chetty [10] develop a dynamic programming algorithm to minimize unbalanced workload of machines. They basically consider the system setup stage involving part type selection, production ratios, pallet and fixture assignment, and part and tool allocation. MacChiaroli and Riemma [21] present two different scheduling heuristics based on tool management issues in an FMS installed in an avionics components factory. Their heuristics include tool magazine capacities and the use of an automated tool handling system. Roh and Kim [22] focus on the problems of part loading, tool loading, and part sequencing. They suggest three heuristic approaches with the objective of minimizing the total tardiness.

Importance of tool management and its impact on productivity has been studied by several researchers. Tsukada and Shin [23] study distributed tool sharing and allocation problems in FMSs via simulation with emphasis on tool utilization and tool coordination among different cells. Uncertainty of the manufacturing system environment, where tooling requirements change unexpectedly, are handled by using distributed artificial intelligence techniques. Tap et al. [24] emphasize that being one of the critical resources for production, non-availability of tools can affect productivity of any manufacturing shop floor seriously. They propose a tool-tracking system in order to monitor the movements of tools in a shop floor to prevent tool loss and tool hoarding. Rahimifard and Newman [25] describe the design and realization of an integrated planning and control system in which a two-phase planning approach is adopted to generate schedules for medium-term and short-term planning horizons, in order to improve the reactivity of the system to the dynamic changes in demand and production capacities. Their model includes fixtures and cutting tools within flexible machining facilities to be carried out simultaneously in order to increase the cohesion among machining activities. In their study, Ranky and Ranky [26] propose generic solutions to the problem of dynamic scheduling with integrated tool, fixture, robot hand management and multimedia support in distributed, lean and flexible manufacturing and design systems that operate on a global basis. Leung and Hui [27] study a dynamic management model, which takes tool wear into consideration, for cutting tools that emphasizes the cost of machining quality. The model describes a heterogeneous environment typical of computerized manufacturing