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Simulation modeling and analysis of tool sharing and part scheduling decisions in single-stage multimachine flexible manufacturing systems

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Abstract

This paper focuses on a simulation-based study of tool sharing problem in single-stage multimachine Flexible Manufacturing Systems. Three different scenarios are considered for investigation. A simulation model has been developed for each of these scenarios. A number of scheduling rules are incorporated in the simulation models for the decisions such as tool request selection and part launching in the context of tool sharing environment. The performance measures evaluated are mean tardiness, conditional mean tardiness and mean flow time. Based on the analysis of the simulation results, the best possible scheduling rule combinations for part launching and tool request selection have been identified for the three scenarios.

Keywords: Flexible manufacturing system; Tool sharing; Simulation; Scheduling

1. Introduction

Flexible Manufacturing System (FMS) is an integrated production system consisting of multifunctional numerically controlled machines connected with an automated material handling system, all controlled by a central computer system. FMS is an evolving technology particularly suitable for mid-volume, mid-variety production. Stecke [1] identifies four hierarchical levels in which the decision problems in FMS are partitioned: design, planning, scheduling and control problems. Tool management that involves the allocation and scheduling of tools is an important problem in FMS. The versatile machines in FMS can perform a variety of operations when it is provided with the required tools. Increase in part variety means increase in number of cutting tool types. This requires a large tool mix and proper methods to plan, monitor and control tools, thus adding to the system cost. It is found that tool costs correspond to about 25–30% of the variable and fixed costs involved in FMS applications [2]. Hence, proper tool management is very much essential.

In most FMSs, operations are allocated to machines and the corresponding tools are loaded into tool magazines of the machines [3,4]. In these systems, parts are transferred from one machine to another according to the routing determined by the operational allocation decisions. The operational policy for systems of this type is called the part movement policy. On the other hand, in some FMSs, each part visits only one of the machines for the entire processing. Such systems belong to the category of Single-Stage Multimachine Systems (SSMS). Fig. 1 shows the relationship between FMS and SSMS, as presented by Koo and Tanchoco [5].

The SSMS can be regarded as a special case of FMS, which consists of many cells with each cell containing one versatile machine. It can also be viewed as a group of independent flexible machining modules. A flexible machining module consisting of a single flexible machine is the basic building block of various FMS configurations [6].

A distinct characteristic of SSMS involves no part routing between machines. In SSMS, since all the operations of a part are performed on a single machine, the parts

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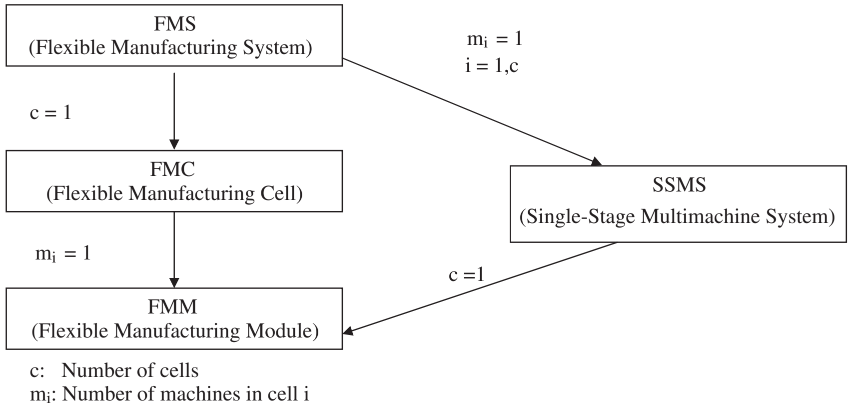

Fig. 1. Relationship between FMS and SSMS.

do not move between machines but only travel between the load/unload station and the machines. In such systems, tools required for a part but unavailable at a machine are transferred from another machine or the central tool store (tool crib) by a tool transport system. This operational policy is known as tool movement policy. In this policy, the assignment of tools is not necessary at the beginning of a planning horizon or a production batch since tools are delivered when they are needed, and therefore, parts remain on the same machine until the required machining is completed. This policy is possible when the system is equipped with fast tool delivery devices and an efficient tool control model. Technological developments in tool transport systems and shop floor information systems allow the tools to be dynamically shared by machines [7,8]. Tool sharing virtually increases the capacity of tool magazines and eliminates the movement of parts from machine to machine in searching for tools. In a tool sharing environment, when the required tool is not available, a machine places a tool request. If there are more than one tool requests at a particular instant, then appropriate tool request selection rules are used for selecting the request to be met. Accordingly, the tool is transferred to the required machine. Tool sharing policy minimizes the total number of tools in the system and maximizes tool utilization.

Although operation-tool allocation problems have been studied under the part movement policy extensively by several researchers like Stecke and Solberg [9], Shanker and Tzen [10], Berrada and Stecke [11], Mukhopadhyay et al. [12,13], Mukhopadhyay and Sahu [14], Nayak and Acharya [15], Tiwari and Vidyarthi [16], Kumar and Shankar [17], Rai et al. [18], and Srivinas et al. [19], there is relatively less number of research works reported on the decision problems under the tool movement policy. Gray et al. [20] provide a review of tool management issues involved in automated manufacturing systems. Elmaraghy [21] presents a simulation study for the sharing of tools between the machine tool magazine, intermediate tool magazine, intermediate tool storage and central tool storage. The objectives considered include minimization of the distance traveled by the tool transporter, minimization of machine idle time, maximization of equipment utilization and minimization of tool redundancy. Using simulation to study the feasibility of tool sharing in an FMS, Gaalman et al. [22] show that tool sharing created savings on the overall cost of FMS. A look ahead policy is used to determine both the requirement of tool at machine center and the availability of tool before actual operation takes place. Machine idle time due to non-availability of tools is used as a measure to study the effect of tool sharing and number of tool replications. Han et al. [23] proposed a mathematical model for tool loading with the objective of maximizing throughput. Heuristics have also been suggested and the performance of the heuristics was evaluated using a simulation model. Kashyap and Khator [24] have developed a simulation model to analyze the impact of tool sharing rules on makespan and transporter utilization. Mohamed and Bernardo [25] have analyzed the interface between tool planning and the FMS loading and routing decisions. It is shown that tool policy has a pronounced effect on the flexibility and the planned makespan of an FMS. Roh and Kim [3] propose an iterative approach for minimizing tardiness in a tool sharing environment with automatic tool transporter. Koo et al. [26] consider the tooling problem under dynamic tool assignment policy. An open queuing network-based model is presented to predict the tool requirement levels. Gougar et al. [8] present a study of the application of ultra fast material transfer system for tool delivery where cutting tools are delivered to and from machines instantaneously from a central tool storage area. They suggest that eliminating redundancy in cutting tools and eliminating tool magazines at individual machines can offset the cost of such a system. Fathi and Barnette [27] address the problem of scheduling a set of parts with given processing times and tool requirements on identical parallel machines. Three heuristic procedures are proposed for solving the problem; the local improvement approach, the list processing approach and the constructive approach. Their computational study shows that the local improvement approach and the constructive approach tend to perform better, especially in situations where the tool-requirement matrix has an apparent structure. Lee et al. [4]