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A heuristic based on multi-stage programming approach for machine-loading problem in a flexible manufacturing system

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Abstract

Manufacturing industries are rapidly changing from economies of scale to economies of scope, characterized by short product life cycles and increased product varieties. This implies a need to improve the efficiency of job shops while still maintaining their flexibility. These objectives are achieved by Flexible manufacturing systems (FMS). The basic aim of FMS is to bring together the productivity of flow lines and the flexibility of job shops. This duality of objectives makes the management of an FMS complex. In this article, the loading problem in random type FMS, which is viewed as selecting a subset of jobs from the job pool and allocating them among available machines, is considered. A heuristic based on multi-stage programming approach is proposed to solve this problem. The objective considered is to minimize the system unbalance while satisfying the technological constraints such as availability of machining time and tool slots. The performance of the proposed heuristic is tested on 10 sample problems available in FMS literature and compared with existing solution methods. It has been found that the proposed heuristic gives good results.

Keywords: Heuristic; Machine-loading problem; Flexible manufacturing system; Multi-stage programming; System unbalance; Throughput

1. Introduction

A flexible manufacturing system (FMS) can be defined as an integrated computer-controlled configuration of numerical control (NC) machine tools, other auxiliary production equipment, and a material handling system (MHS) designed to simultaneously manufacture a low to medium volumes of a wide variety of high quality products at low cost [1].

FMS is a production system based on economies of scope wherein several part types are simultaneously resident in the system. The subsystems are versatile computer-controlled equipment such as NC machines, automated guided vehicles (AGV), coordinate measuring machines and robots. The setup times are small and the number of buffer spaces provided in the system is minimal. Thus the system follows a flow-type work-piece movement so that the manufacturing lead time almost equals the processing time and at the same time flexibility of job shop is retained. The material flow integration is achieved through a computer-controlled MHS. The benefits that can be accrued due to installation of an FMS are: increased machine utilization, fewer machines, reduction in required factory floor space, greater responsiveness to change, reduced inventory requirements, lower manufacturing lead times, reduced direct labor requirements, higher labor productivity, opportunity for unattended production, etc. [2].

The unique characteristic that distinguishes FMS from other factory automation technologies is the ability to achieve flexible automation i.e., the capacity to efficiently produce a great variety of part types in variable quantities. However, managing the production of an FMS is more difficult than managing production lines or job shops because the additional flexibility-related degrees of freedom greatly increase the scope of decision variables. The

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decisions involved in the management of an FMS can broadly be classified as pre- and post-release decisions. FMS planning problem that deals with pre-arrangement of jobs and tools, before it begins to process, falls under pre-release decisions, whereas FMS scheduling problem, which considers the sequencing and routing of jobs at the time the system is in operation falls under post-release decisions. Stecke [3] described FMS planning problem into five sub-problems: (1) Machine grouping (2) part type selection (3) production ratio determination (4) resource allocation and (5) loading.

In this article, machine-loading problem, which can be viewed as, "selecting a subset of jobs from the job pool and allocating them among machines" is addressed. The objective considered is minimization of system unbalance while satisfying the constraints viz., available machining time and tool slots.

The paper is organized as follows. In the next section, the literature available is briefly reviewed. In Section 3, problem environment is given and modeled. In Section 4, the proposed heuristic is described. In Section 5, numerical illustration of the proposed heuristic is given. In Section 6, the proposed heuristic is compared with methodologies available in FMS literature. The conclusions are given in Section 7.

2. Literature review

Basnet and Mize [4] classified available FMS literature for solving machine-loading problems into four different approaches:

(1) Mathematical programming approaches
(2) Multi-criteria decision-making approaches
(3) Simulation-based approaches
(4) Heuristic-based approaches

2.1. Mathematical programming approaches

The first mathematical formulation for FMS-loading problem was given by stecke [3]. The grouping and loading were formulated as non-linear 0–1 mixed integer programs. Solution methodologies with several computational simplifications had been developed. These formulations assumed that a product-mix problem was already solved and therefore limit the models to be suitable only for dedicated FMS [14]. O'Grady and Menon [5] employed a goal programming model for loading a real-life FMS. Berrada and Stecke [6] developed a branch-and-bound algorithm for balancing workloads on machines. Guerrero et al. [7] developed mixed-integer linear program considering alternative routes for each part type. Also, the optimal number of copies of each tool type to be loaded into each tool magazine was directly determined.

2.2. Multi-criteria decision-making approaches

Ammons et al. [8] developed a bicriterion objective for the loading problem, i.e., balancing workloads and minimizing visits to the workstations. Shanker and Tzen [9] addressed the machine-loading problem in random FMS with the bi-criterion objective of balancing the workload amongst the machining centers and meeting the due dates of the jobs. Heuristic procedures were suggested and were compared with the exact solution given by mathematical models. Then a simulation model was developed and effects of loading on system performance under different dispatching rules were examined. Shanker and Srinivasulu [10] developed a two-stage branch and backtrack procedure with the objective of minimizing the assigned workload. Heuristic procedures were also developed with a bicriterion objective of minimizing the workload imbalance and maximizing the throughput for critical resources such as the number of tool slots on machines and the number of working hours in a scheduling period. Swamkar and Tiwari [11] addressed machine-loading problem of an FMS having the bicriterion objectives of minimizing system unbalance and maximizing the throughput. A hybrid algorithm based on tabu search and simulated annealing (SA) was employed to solve the problem. The main advantage of this approach is that a short-term memory provided by the tabu list can be used to avoid revisiting the solution while preserving the stochastic nature of the SA method.

2.3. Simulation-based approaches

Stecke and Solberg [12] had carried out a simulation study for dedicated type FMS examining five loading strategies versus 16 dispatching rules. The study had drawn several significant conclusions about how the system should be controlled and indicated that the choice of applicable loading and scheduling strategies depended on many variables particular to the system. As their study was based on a dedicated type of FMS, the loading strategies were simply the procedures to allocate operations to a number of same types of machines [14]. Gupta et al. [13] described a dispatching approach for FMSs where all parts were stored in a central buffer. Parts were selected according to pre-determined loading rules. Simulation experiments showed that proposed dispatching approach outperformed the traditional one with respect to make-spans, average flow time and average tardiness.

2.4. Heuristic-based approaches

Mukhopadhyay et al. [14] developed a heuristic solution to the loading problem in FMS by developing the concept of essentiality ratio for the objective of minimization of system unbalance and maximizing the throughput. Tiwari et al. [15] used fixed pre-determined job ordering/job sequencing rule as input to their proposed heuristics. The