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Optimum loading of machines in a flexible manufacturing system using a mixed-integer linear mathematical programming model and genetic algorithm

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ABSTRACT

Machine loading problem in a flexible manufacturing system (FMS) encompasses various types of flexibility aspects pertaining to part selection and operation assignments. The evolution of flexible manufacturing systems offers great potential for increasing flexibility by ensuring both cost-effectiveness and customized manufacturing at the same time. This paper proposes a linear mathematical programming model with both continuous and zero-one variables for job selection and operation allocation problems in an FMS to maximize profitability and utilization of system. The proposed model assigns operations to different machines considering capacity of machines, batch-sizes, processing time of operations, machine costs, tool requirements, and capacity of tool magazine. A genetic algorithm (GA) is then proposed to solve the formulated problem. Performance of the proposed GA is evaluated based on some benchmark problems adopted from the literature. A statistical test is conducted which implies that the proposed algorithm is robust in finding near-optimal solutions. Comparison of the results with those published in the literature indicates supremacy of the solutions obtained by the proposed algorithm for attempted model.

1. Introduction

A flexible manufacturing system (FMS) can be defined as an integrated configuration of numerical control (NC) machine tools, some auxiliary production equipment, and a material handling system designed to simultaneously manufacture a low to medium volumes of a wide variety of high quality products at low cost (Nagarjuna, Mahesh, & Rajagopal, 2006). An FMS can achieve the benefits of both flow shop and job shop factories, though its installation may be relatively complex because of the additional flexibility-related degrees of freedom. 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 changes, reduced inventory requirements, lower manufacturing lead times, reduced direct labor requirement, higher labor productivity, opportunity for automated production, etc. (Groover, 2003).

In general, operational decisions in an FMS can be categorized into pre- and post-release decisions. Pre-release decisions, also called the FMS planning problem, consider the pre-arrangement of parts and tools before the FMS begins to process. Post-release decisions, also called the FMS scheduling problem, deal with the sequencing and routing of parts, when the system is in operation. Pre-release decisions, viz. machine grouping, part type selection, production ratio determination, resource allocation and loading problems must be solved while setting up of a FMS. Among pre-release decisions, machine loading is considered as one of the most vital production planning problems as it can largely affect performance of the FMS. Machine loading problem, in particular, deals with the allocation of jobs to various machines under technological constraints to meet certain performance measures.

Stecke (1983) and Sarin and Chen (1987) divided machine loading problem (MLP) into five sub-problems:

1. Machine grouping.
2. Part type selection.
3. Production rate determination.
4. Resource allocation.
5. Loading.

Although formulation of all these problems in a single mathematical model may not be impossible, it will lead to a quite complex mathematical model whose solution may be difficult to determine in a polynomial order of time. This fact has motivated different researchers to develop solution approaches for each sub-problem separately. The mathematical model attempted in this paper integrates part type selection, resource allocation, and loading sub-problems together.

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From a managerial viewpoint, several objectives may be affected by the solution of machine loading problem. Stecke (1983) has outlined six objectives in loading an FMS:

1. Balancing the machine processing time.
2. Minimizing the number of movements.
3. Balancing the workload per machine for a system of groups of pooled machines of equal sizes.
4. Unbalancing the workload per machine for a system of pooled machines of unequal sizes.
5. Filling the tool magazines as densely as possible.
6. Maximizing the sum of priorities of operations.

This paper is organized as follows: Section 2 reviews some research studies in the field of machine loading problem and then presents the objective of this paper. Section 3 describes in detail the machine loading problem. A mathematical model is formulated in this section to represent the attempted problem. A genetic algorithm is proposed in Section 4 to solve the proposed mathematical model. Some benchmark problems adopted from the literature are solved in Section 5 to evaluate performance of the proposed algorithm as compared to methods available in the literature. Section 6 includes conclusions and discussions.

2. Literature review

Ammons, Lofgren, and McGinnis (1985) resolve the machine loading problem (MLP) considering two objectives, namely balancing workload and minimizing work stations visits. Shankar and Tzen (1985) consider balancing workload and meeting due-date of part types. Tiwari, Hazarika, Jaggi, Vidyarthi, and Mukhopadhyay (1997) and Mukhopadhyay, Midha, and Krishna (1992) tackle MLP using heuristic approaches with an objective of minimizing system unbalance and maximizing throughput. Kazerooni, Chan, and Abhary (1997) investigated the operational problems of FMSs through simulation, and evaluated different combinations of scheduling rules by a fuzzy integrated decision-making support system. Swarnkar and Tiwari (2004) develop a systematic integrated procedure and use a hybrid tabu search and simulated annealing-based heuristic for solving it. They consider minimization of system unbalance and maximization of throughput by taking into account the technological constraints such as available machining time and tool slots on machines. Chan and Chan (2004) presented a simulation study to evaluate the performance of a flexible manufacturing system (FMS) in terms of makespan, average flow time, average delay time at local buffers and average machine utilization, subject to different control strategies which include routing flexibilities and dispatching rules. Chan, Chung, Chan, Finke, and Tiwari (2006) considered machine maintenance constraint in the scheduling of distributed flexible manufacturing systems. They simultaneously solved two issues by genetic algorithm with dominant genes approach: (i) allocation of jobs to suitable factories and (ii) determination of the production scheduling in each factory. Prakash, Khilwani, Tiwari, and Cohen (2008) used a modified immune algorithm for MLP with the objectives same as Swarnkar and Tiwari (2004) and considered both under-utilized and over-utilized times on machines for calculating system unbalance. Biswas and Mahapatra (2007) proposed swarm optimization approach to solve the MLP in a random FMS with the objective function of minimization of system unbalance. In continuation, Biswas and Mahapatra (2008) developed a modified particle swarm optimization for solving the MLP already published in Biswas and Mahapatra (2007). The MLP is formulated as a bi-criterion problem in Yogeswaran, Ponnambalam, and Tiwari (2007), where minimization of system unbalance and maximization of system throughput are optimized through a hybrid genetic algorithm and simulated annealing. Chan and Swarnkar (2006) treated this problem as the machine-tool operation allocation with the objective to determine the optimal machine tool combination and the assignment of operations to the available machines while maintaining the machining cost and set up cost within certain limits. They used a fuzzy goal programming model to tackle this problem and then used ant colony approach for solving it.

Chan, Bhagwat, and Wadhwa (2008) presented a comparative study of an FMS operating under real-time control, review-period-based control and reactive control. They also focused on the comparative performances of the key parameters such as routing flexibility and control strategies of an FMS operating under different modes of a decision-and-information system.

Prakash et al. (2008) developed an algorithm based on ant colony optimization for handling such a complex solution space. Prakash, Chan, and Deshmukh (2011) addressed scheduling problem in flexible manufacturing with a knowledge-based genetic algorithm approach.

The references reviewed above have provided insights about machine loading problem (MLP) and have presented different solution approaches for solving MLP. As defined above, an FMS is a set of flexible NC machines coupled with an automated material handling system, operating under the control of a central computer. Hence, an FMS is normally an expensive manufacturing unit and therefore its management is crucial for a desired utilization and less investment risk. One of the important aspects in the effective utilization of an FMS is to reduce the costs of under-utilized and over-utilized times of machines. Despite the existing literature on MLPs, this paper provides an accurate and realized formulation to calculate these times. Additionally, the solution approach proposed in this paper takes into account many real parameters including capacity of machines, batch-sizes, processing times of operations, machining costs, tool requirements, and capacity of tool magazine. Due to the comprehensiveness of the proposed approach, it provides practical solutions for loading machines in an FMS.

3. Mathematical formulation

3.1. Problem environment

The FMS studied in this paper consists of a number of multi-functional CNC machines and tools with the potential to execute several operations, automated material handling devices and other amenities, where several types of jobs arrive with varied processing requirements. Jobs are available in batches and some of them are to be selected for processing during a given planning horizon. Job selection and loading constitute two major components of a tactical planning problem of any FMS.

The MLP can be defined as "...given a set of jobs to be produced, a set of tools that are needed for processing the jobs on a set of machines, and using a set of resources such as material handling systems, pallets and fixtures, how the jobs are to be assigned and tools be allocated so that some measures of productivity are optimized" (Swarnkar & Tiwari, 2004).

A job includes one or more operations and each of them can be performed by one or more machines. It is assumed that the particularities related to the production requirements of the job, number of operations for each job and their machining time and number of tool slots required by each operation of each job are known in advance. Essential and optional types of operations are allied with each job. Essential operations of a job means that this operation can be performed only on a particular machine using a certain number of tool slots whereas optional operations imply that they