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Ant colony optimization approach to a fuzzy goal programming model for a machine tool selection and operation allocation problem in an FMS

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Abstract

Due to the global competition in manufacturing environment, firms are forced to consider increasing the quality and responsiveness to customization, while decreasing costs. The evolution of flexible manufacturing systems (FMSs) offers great potential for increasing flexibility and changing the basis of competition by ensuring both cost effective and customized manufacturing at the same time. Some of the important planning problems that need realistic modelling and quicker solution especially in automated manufacturing systems have assumed greater significance in the recent past. The language used by the industrial workers is fuzzy in nature, which results in failure of the models considering deterministic situations. The situation in the real life shop floor demands to adopt fuzzy-based multi-objective goals to express the target set by the management. This paper presents a fuzzy goal programming approach to model the machine tool selection and operation allocation problem of FMS. An ant colony optimization (ACO)-based approach is applied to optimize the model and the results of the computational experiments are reported.

Keywords: Ant colony optimization; Fuzzy goal programming; Machine tool selection; Operation allocation; Flexible manufacturing systems; Production planning

1. Introduction

The manufacturing industry is presently being affected by the structural changes caused the internal and external factors for an enterprise. The market conditions are becoming more dynamic, more global, and more customer driven. The manufacturing performance is no longer driven by the product price; instead other competitive factors such as flexibility, quality, delivery, and customer service have become equally important. The demand of the customer for tailored product has resulted in a shorter product life, reduced batch quantities and increased product varieties. Manufacturing firms need to give prominence to issues such as reduction of manufacturing lead time and flexibility to adapt to changes in the market. The improvement in productivity and reduction of costs of goods and services has become the key for maintaining the market share.

Over the past few years, the concept of flexible manufacturing system (FMS) has emerged as a viable answer to the problems of flexibility and efficiency. Operations management in a FMS is more complex than that of the conventional manufacturing systems. Managing an FMS demands for more decisions for its effective performance compared to a transfer line or job shop production system. The optimal selection of machines and tools and the assignment of part operations to the selected machines turn out to be difficult tasks for the production planner. This is due to the versatile machine tools capable of performing many different operations resulting in many alternative routes for a part type, and due to system capability for processing of the parts concurrently [1].

The decisions related to FMS operations are of two types: pre-release and post-release decisions. Pre-release decisions include the FMS planning problem that deals

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with the pre-arrangements of jobs and tools before the processing begins, whereas post-release decisions deal with the scheduling problems of the FMS. Various types of post-release decision problems are part type selection, machine grouping, determination of production ratios, batching of the part type, allocation of pallets and fixtures, and allocations of operations and tools among machines, i.e. loading problem [1,2]. Stecke [1] formulated the loading problem in a flexible manufacturing system as a non-linear mixed integer program with the objective of balancing the workloads. Sarin and Chen [2] presented a mixed integer programming formulation of the machine loading–tool allocation problem in FMS, minimizing the total machining costs which are dependent on machine–tool combinations. A branch-and-bound algorithm to solve the problem was then developed by Berrada and Stecke [3]. Chan [4] discussed the effect of universal loading station along with operational control rules. Rajagopalan [5] presented a formulation and heuristic solution for the part grouping and tool loading in FMS. Ram et al. [6] developed a model and a solution procedure for the machine loading and tool allocation problem in FMS. Lashkari et al. [7] extended the formulation of the operation allocation problem to include the aspects of refixturing and limited tool availability.

Kusiak [8], Stecke and Morin [9], Singhal et al. [10] and van Looveren et al. [11] have addressed the interrelationship of various decisions and their hierarchies in FMS. Kim and Yano [12] presented a number of heuristic approaches for loading problems in flexible manufacturing systems; Kim and Yano [13] also presented a model of the loading problem in FMS with unequal workload targets across machine groups, and demonstrated how an existing branch-and-bound algorithm for the workload balancing objective may be used to solve the model. Stecke and Raman [14] presented a queuing network production planning model to determine the optimal machine workload assignments in an FMS. Liang [15] proposed a two-stage approach to the joint problem of part selection, machine loading, and machine speed selection problem in FMS. In the first stage, the mathematical model solves the part selection and machine loading problem, whereas in the second stage, it determines the optimal cutting speed for all job–tool–machine combinations.

A wide spectrum of multi-objective-loading problems by combining two or more criteria has been addressed in literature [13–22]. However, considering the multi-objective problems, some of the objectives turn to be contradictory in various situations, while in others, they may equally be applicable. When the machines are not pooled into groups, the loading objective used most commonly is balancing the workload on all the machines. It is established that this objective maximizes the expected production [9]. The mixed-integer programming (MIP) approach for solving the machine loading problem is proved to be computationally infeasible even for deterministic formulation. Moreover, even for a moderate-sized FMS, the computation time required for solving the loading problem is considerably large with the MIP approaches motivating the researchers to develop fast and effective heuristics for solving the loading problem of a large-sized FMS. Liang and Dutta [23–25] proposed an integrated approach to part selection and machine-loading problems. However, most researchers have treated job selection, machine loading and tool configuration in a discrete manner for the sake of simplicity, though they are connected by common restrictions such as tool magazine capacity, job tool–machine compatibility and available machining time.

This paper addresses a problem of machine tool operation allocation in FMS with the objective to determine the optimal machine tool combination and the assignment of the operation for the given part types to the available machines while maintaining the machining cost, material handling cost and set-up cost within certain limits. The constraints include limited tool magazine capacity, tool life and machine capacity. Similar problem has been attempted by Atmani and Lashkari [26] by formulating a 0–1 integer programming model of machine–tool assignment and operation allocation.

The above problem of machine–tool selection and operation allocation involves more than one conflicting objectives. In most of the real-life industrial scenario, the foreman and technicians express the goals and objectives in inexact and imprecise manner. Therefore, the assumption that all parameters of such a model are precisely known and can be expressed as 'crisp' numbers will only be a very rough approximation of the real problem. In this paper, the concept of fuzzy goal programming has been used to model the machine–tool selection and operation allocation problem with the objective of minimizing the total cost of machining operations, material handling and set-up while satisfying the constraints pertaining to the capacity of machines, tool magazine and tool life. Owing to computational complexities involved in solving such a problem, here a novel approach based on ant colony optimization (ACO) approach is applied to optimize the above multi-objective optimization problem.

2. Nature of the problem

An FMS with a number of multifunctional CNC machines with tools capable of executing several operations has been considered. Material handling will be taken care by automated guided vehicles. The part types arriving will be having varied processing requirements and they are to be processed by the system in batches. A part type includes one or more operations to be performed on certain machines with specific tools. Details related to the production requirements of the part types like number of operations, machining times, tool slots required, etc. are known in advance. The problem of machine–tool–operation allocation attempted here includes the selection of machines, the assignment of the selected tools to the machines and the assignment of operation of each part type