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Modified immune algorithm for job selection and operation allocation problem in flexible manufacturing systems

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Abstract

The advent of automated manufacturing systems and the variability in demand pattern have forced the manufacturers to increase the flexibility and efficiency of their automated systems to stay competitive in the dynamic market. Loading decisions play an important role in determining the efficiency of manufacturing systems. Machine loading problems in flexible manufacturing systems (FMSs) are known to be NP-hard problems. Although some NP-hard problems could still be optimized for very small instances, machine loading complexity is so extensive that even small problems take excessive computational time to reach the optimal solution. To ease the tedious computations, and to get a good solution for large problems, this paper develops a special Immune Algorithm (IA) named 'Modified immune algorithm (MIA)'. IA is a suitable method due to its self learning capability and memory acquisition. This paper improves some issues inherent in existing IAs and proposes a more effective immune algorithm with reduced memory requirements and reduced computational complexity. In order to verify the efficacy and robustness of the proposed algorithm, the paper presents comparisons to existing immune algorithms with benchmark functions and standard data sets related to the machine loading problem. In addition proposed algorithm has been tested at different noise level to examine the efficiency of algorithm on different platforms. The comparisons show consistently that the proposed algorithm outperforms the existing techniques. For all machine loading dataset proposed algorithm has shown good results as compared to the best results reported in the literature.

Keywords: Machine loading problem; NP-hard; Artificial immune system; Gaussian mutation; Cauchy mutation; Noise level

1. Introduction

Time effective production has become a key issue in manufacturing environments for striving in the hard global competitive markets. Loading decisions play an important role in time effective production by processing the job in a feasible sequencing schedule with the proper utilization of resources. Effective loading decisions are particularly important in the large, complex manufacturing systems encountered in high technology industries dealing with processing of customized products and many others, where, simple manual techniques are unlikely to yield good results [1]. According to Stecke [2], machine loading problem is one of six post-release decisions of a flexible manufacturing system that is known for its computational complexity and high variability. Due to inherent generality of FMS, it becomes necessary to define the configuration of an FMS. A typical FMS unit includes 5–25 Numerical Control (NC) machines, a central storage system and an automated material handling system. A computer system is used to control the above components of FMS. In general, two types of operational decisions (pre-release decision and post-release decision) are associated with

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operations of FMS. Pre-arrangement of jobs and tools comes under the category of pre-release decision of FMS whereas routing and sequencing of jobs comes under post-release decision of FMS. Various post-release decisions of FMS include:

(i) Job selection.
(ii) Machine grouping.
(iii) Determination of production ratio.
(iv) Batching of the jobs.
(v) Allocation of pallets and fixtures.
(vi) Allocation of operations and tools among machines (loading problem).

Hwang et al. [3] investigated the production planning problem and found that two sub-problems namely job selection and machine loading are critically important. Decisions pertaining to loading problem receive their inputs from the preceding decision levels (such as grouping of resources, selection of part-mix, and aggregate planning). These strategic antecedents generate inputs to the succeeding decisions related to scheduling resources, and dynamic operations planning and control. Hence, it is clear that loading decision acts as important link between strategic and operational level decisions in the manufacturing environment [4]. This paper aims to solve the well known FMS machine loading problem, by both maximizing throughput (equivalent to the sum of the batch size of the selected jobs) and maximizing the load balance (equivalent to minimization of system unbalance, i.e. the sum of remaining time of all machines after allocation all the operations of the jobs). These two objectives are the measurement that commonly adopted to reflect the system efficiency and utilization. Machine loading problem is mainly concerned with assignment of jobs and tools on machines. This entitles operation of selected jobs from a given set of jobs along with required tool slots while satisfying the technological constraints namely available machining time and tool slots. The combination of job sequencing and operation allocation on machine makes the machine loading problem a NP-hard problem [5] The complexity of the Machine loading problem is so immense that even for 8–10 jobs there can be more than 10^8 possible operation-machine allocation combinations (detailed in Section 2.2). The huge solution space slows the search convergence, and undermines the possibility to get close to the optimal solution.

In recent years success has been achieved by nature inspired intelligent random search techniques to tackle the complex combinatorial problems (e.g., example, Genetic Algorithms (GA), Ant Colony Optimization (ACO) and Immune Algorithms (IA)).

This article encouraged by the applications of a novel evolutionary technique, i.e. Artificial Immune System (AIS) have been considered in this article. Due to AIS self organizing and learning capability, this technique has been widely used in real world applications such as data manipulation, pattern recognition, machine learning, evolutionary computation, etc. [6]. Castro and Zuben [6] also found that the existing immune algorithms are not very interactive and need much more computational time to reach the optimal solution. In response to their claims, a modified version of Immune Algorithm entitled as 'Modified immune algorithm (MIA)' is proposed in this paper that results in better computing results with reduced computational cost. The modifications performed in the proposed algorithm are basically dealing with the existing drawbacks related to the basic driving forces of the immune algorithms. A new *hypermutation* operator is proposed that includes:

(1) Gaussian mutation strategy for higher affinity antibodies,
(2) Cauchy mutation strategy for lower affinity antibodies,
(3) Elitist based immune memory to preserve the superior antibodies present in clonal pool, and to pass its traits to the next generation.

In addition, chaotic sequence for initialization and roulette wheel rule for selection is utilized to amplify the efficiency of the proposed algorithm. In this paper, ten well known data sets of machine loading problems are solved, along with some benchmark functions taken form the literature. The performance of proposed algorithm is analyzed by comparing it with the existing heuristic procedures, and traditional clonal algorithms.

The rest of the paper is organized as follows: Section 2 describes in detail the machine loading problem along with its modeling. Section 3 explains the background to the solution methodology, followed by the details regarding the proposed solution methodology. Section 4 describes the proposed solution methodology. In Appendix A, benchmark functions are described. Implementation of proposed algorithm on the machine loading problem is provided in Section 5, followed by the computational results that are given in Section 6. Finally, 7 concludes the paper.

2. Machine loading problem

2.1. Introduction and historical development

The machine loading problem consist of J jobs each having O operations and each operation could be done by a subset of machines that may have different processing times for the same operation. The operations of each job are typically subject to precedence constraints and some operations must be done in certain time slots. Moreover, due to fixture, tolerance and tooling constraints, some operations must be done on the same machine as a group. Due to relatedness of machine loading problem with the real world applications, it is one of the most explored problems. Stecke and Solberg [7] have made the first attempt to solve the machine loading problem in FMS with the objec-