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A heuristic approach to solve an industrial scalability problem

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Abstract

In recent years, the rapid change of market demand is increasing the need for scalability as a key characteristic of manufacturing systems. Scalability allows production capacity to be rapidly and cost-effectively reconfigured in different situation with different requirements and constraints. Our industrial partners are facing quarterly scalability problems involving a multi-unit and multi-product manufacturing system. In this paper, an original approach is presented to solve this kind of problems. Starting from the original manufacturing system configuration and process plan, a set of practical principles are introduced to seek for the feasible configurations; a GA is designed to search in the global solution space. A balancing objective function is defined and used to rank the proposed configurations. A real case study with 4-unit / 4-product situation demonstrates both the validity and efficiency of the proposed approach.

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Keywords: Manufacturing System; Reconfiguration; Scalability;

1. Introduction

In this paper, we tackle the problem of manufacturing system reconfiguration known as “scalability” problem. Scalability may be defined as the ability to adjust the production capacity of a manufacturing system through reconfiguration that has the minimal impact on time and cost [1].

We refer to a case study of our industrial partner that is facing quarterly scalability problems involving a multi-unit and multi-product manufacturing system. In fact, the plant is characterized by four manufacturing units, each of them producing a part in the same part family (engine block). Each unit has several stations with identical machining centers. To face the changeable demand of the different products, engineers usually update the configuration of the stations inside each manufacturing unit. Applying not dedicated reconfiguration approaches, these activity is becoming too time consuming to reach a solution that is usually far from the optimal one, with the consequence of being unprofitable for the company.

Initially introduced by Koren et al. [2], the manufacturing system scalability problem has been extensively reviewed in [3]. Despite the vast literature on reconfigurable manufacturing system, the scalability problem tackle in this paper is not addressed. The most relevant and similar research on the previously stated problem has been presented by Wang and Koren [4]. After a comprehensive definition and modeling of the problem, they introduced a method to design a multi-stage machining line by genetic algorithm (GA). A recent evolution of this research has been presented in [5], in which the mathematical analysis is extended in order to consider buffers. Nevertheless, they refer to a one-product and one-unit case study. Moreover, the approach is based on a complete reconfiguration of the manufacturing system, as it is commonly considered in the literature, thus not considering the real industrial need of small variation with respect to the actual manufacturing system configuration and operations allocation. Section 2 defines an original scalability problem and presents the proposed solution approach. Section 3 introduces the case study and presents the results, while Section 4 is dedicated to the final discussion.

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2. Problem definition and solution approach

In the case study we are considering, the company prefers to keep unchanged the number of stations of a unit, which means that the original fixture and certain machining operations should be kept in the original station. Therefore, we address the situation in which the reconfiguration is limited and based on previous and well known and accepted process plans. This situation is not considered in the literature.

In order to model the manufacturing system, each unit is composed by S stations, named S_j with $j = 1..S$. M_j is the number of machining centers allocated to the station S_j. Due to the process plan constrains, each station of each unit is characterized by three sets of operations:

1. fixed operation set, set of operations which must be executed in that station;
2. changeable operation set, set of operations which could be executed in that station, so respecting the technological constraints;
3. not feasible operation set, set of operations which cannot be executed in that station, due to technological constraints.

For each unit and for each new product demand we define the expected cycle time (CT_{Exp}) as the ratio between the available manufacturing time (that consider the reliability of the machining centers, and other factors) and the new product demand (D_{new}). Moreover, the ideal cycle time (CT_{Ideal}) is introduced as the reference value of cycle time for the unit, being the ratio between the total machining time for the part manufactured in the unit and the total number of machining centers in the unit. This cycle time value corresponds to the situation of perfect balancing for the considered unit.

Being this scalability problem a combination of configuration selection and balancing problems, we propose to approach the solution considering two sub-problems. Initially, the total number of identical machining centers M is used to evaluate a configuration, the goal being the minimization of this number. Then, the balancing problem is tackled. Among all the possible objective functions for the balance the system, we consider the sum of square of cycle time deviations. In fact, the far deviate the cycle time of a single station from the average, the more critical the station is. Nevertheless, in the results we report not only the sum of square of the deviations, but also the sum of the absolute deviation, and the cycle time of the bottleneck station.

Approaching the solution as two sub-problems we developed an original approach in which a genetic algorithm to solve the balancing problem is nested in a heuristic approach for the minimization of the total number of machining centers for each unit, as shown in Figure 1.

In order to consider fasten the search of a solution with the minimum number of machining centers, we search the solution among a reduced set of possible configurations which are created considering these two main principles:

I. As the fixed operation set exists for each station, the number of machining centers of each station must guarantee the execution of at least the fixed operation set for the station;

II. The maximum number of machining centers that can be allocated to a station is the largest integer less than or equal to the ratio between the maximum machining time required to perform all operations in both the fixed operation set and the changeable operation set for the station, and the ideal cycle time in the case of perfect balancing.

These two principles enable to avoid searching for a solution among configurations that are clearly non-efficient, that is the case of having free time of a machining center that cannot be used by any operation in the process plan.

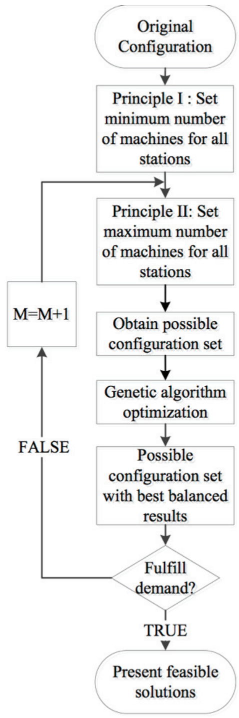

Figure 1. Proposed heuristic approach

Starting from the minimal number of machining centers to fulfill the new demand requirement, the allocation of them to each single station is done considering the heuristic principle, thus generating a small set of possible configurations of the manufacturing unit. For each possible configuration, a genetic algorithm optimization is applied in order to find the best balancing. If the best solution among the considered one is not respecting the new demand requirement, then the total number of machining centers is increased of one machine, and the full search start again. This iterative process is applied until the best feasible solution is found.

The proposed heuristic principles and the iterative approach guarantee the minimization of the number of machining centers, while we expect that the genetic algorithm optimization gives a sub-optimal solution for the balancing problem.