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Joint optimization of production planning and capacity adjustment for assembly system

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Abstract

Manufacturing companies are confronted with increasing market volatility, which is characterized by the increasing of product variants and decreasing of production volume of each variant to meet customers' demands. To stay competitive and to fulfill quickly changing market needs, manufacturing companies have to cope with rapidly changing customer demands concerning product types, quantities and delivery dates and have the ability to enable a fast modification and system-change of future manufacturing systems. Production planning and control must compensate the resulting fluctuations in capacity demand. This paper deals with a problem of joint optimization of production planning and capacity adjustment based on products specifications, delivery time constraints and reconfigurable machines capabilities for assembly systems. At the production planning level, the production planning problem consists in a multi-product capacitated lot-sizing problem. At the capacity adjustment level, the machine can be reconfigured to meet the changing needs in terms of capacity and functionality. In this context, the same machine can be modified in order to perform different tasks depending on the offered axes of motion in each configuration and the availability of tools. The main objective of this paper is to determine simultaneously the economic production quantity of each product variants and the optimal capacity of assembly systems to ensure the adherence to delivery dates. A stochastic mathematical model is developed and solved using a simulation optimization approach based on the response surface methodology. The obtained results show clearly strong interactions between production quantity, delivery time constraints and capacity of assembly line which confirm the necessity of jointly considering production planning and capacity adjustment in an integrated model.

1. Introduction

Nowadays, manufacturers confronted with more troubles due to the rapidly changing market. Manufacturing companies have to produce high-quality products and response to market changes rapidly in an economical way. [1] Reconfigurable manufacturing system (RMS) is a feasible solution to help manufacturing companies fulfill the quickly changing market needs. [2] RMS is a system, designed from outset, for rapid changes in both hardware and software components, in order to quickly adjust its production capacity to fluctuations in market demand and adapt its functionality to new products. [3] Scalability is a key characteristic for reconfigurable manufacturing systems, which allows system throughput capacity to be rapidly and cost-effectively adjusted to abrupt changes in market demand. [4] In order to make full use of this system, production capacity need to be properly coordinated to achieve reduction in production time. In this context, production planning and capacity adjustment are two serious problems in utilization of reconfigurable manufacturing system. What's more, the result of these two problems effect each other. So joint optimization of these two problems becomes more complex. And the aim of this paper is to model this new problem and propose an algorithm to solve it.

Previously many researches on production planning of RMS have been published. Zhao et al developed the first stochastic model of an RMS and gave a thorough insight in modeling RMS.[5] Their second paper proposed an algorithm to choose the optimal configuration in production to maximize the average profit.[6] And their third discussed the optimal

selection policy.[7] Morteza Abbasi and Housemand developed a mixed integer nonlinear programming model to determine optimum sequence of production tasks, corresponding configurations, and batch sizes. In this paper, the orders are described by Poisson distribution and a genetic algorithm-based procedure is used to solve the problem [8] Azab and Gomaa focused on operations sequencing of RMS. They proposed an integer model and a variant of the canonical genetic algorithm to minimize changeover time or cost.[9] Ahmed Azab and Bahman Naderi developed a mathematical model to formally model the problem. And they adapted simulated annealing metaheuristics to solve large instances of problem. [10] Musharavati and Hamouda study processing planning problem in RMS. A simulated-annealing-based algorithm which includes other algorithm concepts is developed.[11] M. Chen and D. Tsai proposed a direct search algorithm to locate satisfactory solutions for multi-objective simulation models.[12]

In following sections, a joint optimization of production planning and capacity adjustment model is developed. To solve the model, an algorithm based on enumeration and dynamic programming is proposed. Finally a numerical example is used to evaluate the model and its solution procedures.

2. Model

2.1. Problem description

The assembly system which is discussed in this paper is designed to manufacture a collection of product families. The machine in the system can be reconfigured to meet the changings needs in terms of capacity and functionality. And there is a cluster of configurations having different production rates and changeover time for each product family. When a product family is selected to be manufactured, the system needs to choose a feasible configuration to produce a number of them. When the system configuration changes from one to another, the system needs to spend some time which is called changeover time to make it. To maximize the advantages of this assembly system, production planning and capacity adjustment must be considered carefully. The fundamental objective of this paper is to determine the best production plan and capacity adjustment plan. We propose below a practical method to determine the best production planning and the most effective system configuration to meet the market demands. To perform system production planning and capacity adjustment, many subproblems need to be taken into consideration. These include production batch size, production sequence and selection of configuration.

The dispatcher receives a set of orders in a period of time. Some of the orders only need a little products. If we change system configuration for these small orders, it will waste lots of time to reconfigure system. So we need to merge some orders to form a new production batch size. Then how to merge these orders become a problem which needs to be solved. When production batch size is settled, we get a set of production task. Then the dispatcher needs to determine which one should be manufacture earlier and take what kind of configuration.

2.2. Input

- Orders information
  The orders from customers can be described as follows:

$$\begin{bmatrix} 1 & f_1 & Q_1 & DT_1 \\ \vdots & \vdots & \vdots & \vdots \\ j & f_j & Q_j & DT_j \\ \vdots & \vdots & \vdots & \vdots \\ n & f_n & Q_n & DT_n \end{bmatrix} \quad (1)$$

Where $_jf$, $_jQ$ and $_jDT$ are the variety, quantity and delivery date of j th order.

- Production planning information

$$\begin{bmatrix} P_{11} & \cdots & P_{1j} & \cdots & P_{1l} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ P_{i1} & \cdots & P_{ij} & \cdots & P_{il} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ P_{n1} & \cdots & P_{nj} & \cdots & P_{nl} \end{bmatrix} \quad (2)$$

Production planning information can be described as follows: Where $_{ij}P$ represents whether the order j is processed in the i th production. If it is, $_{ij}P$ is equal to 1, otherwise $_{ij}P$ is equal to 0.

- Capacity adjustment planning
  Capacity adjustment planning information can be described as follows:

$$\begin{bmatrix} C_{11} & \cdots & C_{1k} & \cdots & C_{1v} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ C_{i1} & \cdots & C_{ik} & \cdots & C_{iv} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ C_{n1} & \cdots & C_{nk} & \cdots & C_{nv} \end{bmatrix} \quad (3)$$

Where $_{ik}C$ represents whether the k th configuration is selected in the i th production task. v is the maximum of configuration number.

- Changeover time matrix

$$\begin{bmatrix} GT(C_{i,j}, C_{k,l}) & \cdots & GT(C_{i,j}, C_{k,l}) & \cdots & GT(C_{i,j}, C_{k,l}) \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ GT(C_{i,j}, C_{k,l}) & \cdots & GT(C_{i,j}, C_{k,l}) & \cdots & GT(C_{i,j}, C_{k,l}) \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ GT(C_{i,j}, C_{k,l}) & \cdots & GT(C_{i,j}, C_{k,l}) & \cdots & GT(C_{i,j}, C_{k,l}) \end{bmatrix} \quad (4)$$