Journal of Manufacturing Systems 32 (2013) 308–314

Contents lists available at SciVerse ScienceDirect

Journal of Manufacturing Systems

journal homepage: www.elsevier.com/locate/jmansys

Technical Paper

Production planning and worker training in dynamic manufacturing systems

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ARTICLE INFO

Article history:
Received 13 July 2010
Received in revised form
30 September 2012
Accepted 16 December 2012
Available online 26 February 2013

Keywords:
Production planning
Dynamic manufacturing systems
Worker training
Mathematical model

ABSTRACT

Production planning is a vital activity in any manufacturing system, and naturally implies assigning the available resources to the required operations. This paper develops and analyzes a comprehensive mathematical model for dynamic manufacturing systems. The proposed model integrates production planning and worker training considering machine and worker time availability, operation sequence and multi-period planning horizon. The objective is to minimize machine maintenance and overhead, system reconfiguration, backorder and inventory holding, training and salary of worker costs. Computational results are presented to verify the proposed model.

1. Introduction

The most important ultimate goal of every activity in every company, including machine industry plants, is generating maximum benefits. All actions taken in a company should be with a step in the way of reaching this goal. The processes of creating production planning are the most complex and the most important elements influencing the financial effect. The goal of production planning is to make planning decisions optimizing the trade-off between economic objectives like cost minimization. To achieve this goal, manufacturing planning systems are becoming more complicated in order to increase both the productivity and the flexibility in satisfying customer demand [1]. In reality, production quantity may not be equal to the demand because it may be satisfied by inventory or there may be backorders. Production quantity should be satisfied based on production planning decisions in order to determine the number and type of machines to be installed in the system. By consideration of machine capacity, the production quantities in each planning period affect the number and types of machines to be installed in manufacturing system.

With increasing global competition and shorter product life cycles, there has been a move from planning for static condition (in which system is formed for a single time period with known and constant product mix and demand) to planning for dynamic situation. In dynamic environment a multi-period planning horizon is considered in which in each period has a different product mix and demand requirements. Consequently, the system optimized for a single period may be not optimal and efficient for the next periods. Reconfiguration has two aspects: (1) adding new machines to the system, and (2) removing existing machines from the system.

The facts related to workers in developing a production plan may significantly affect the productivity and efficiency of manufacturing. For instance, a study by Park [2] shows how training multi-skill workers can increase production flexibility. It is essential to develop multi-skilled worked who can perform multiple tasks. This, enhances system flexibility, improves worker motivation, and relaxes constraints on workers assignments. Identifying the current levels of skills for each worker can help the decision makers determine the type and duration of training needed for each worker [3].

In this paper, we design a mathematical model for production planning in dynamic environment with an extensive coverage of important manufacturing features considering multi-period production planning, sequence of operations, system reconfiguration, duplicate machines, machine capacity and training of workers. The main constraints are demand satisfaction, machine availability, machine time-capacity, available time of worker and training.

The rest of the paper is organized as follows. The literature review related to production planning is presented in Section 2. In Section 3, a mathematical model integrating most of attributes of manufacturing for production planning is formulated and linearization procedure is explained. A clustering method applied for worker training is described in Section 4. We present computational results in Section 5. Finally, conclusions and further research is described in Section 6.

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0278-6125/$ – see front matter
http://dx.doi.org/10.1016/j.jmsy.2012.12.007

2. Literature review

The literature on production planning is very rich. Therefore, we limit our review to the most recent research carried out considering the aforementioned significant features. Hung and Cheng [4] addressed a hybrid capacity modeling for alternative machine types in linear programming production planning which relaxes the requirement of satisfying the uniform assumption. Aghezzaf and Landeghem [5] presented a solution approach to solve a two-stage hybrid flow-shop production problem in which the first stage is a process production system and the second is a batch production system. The objectives of optimizing the production and inventory costs at the two stages of the system, including the warehouse, while satisfying customer demands, were considered. Jain and Palekar [6] proposed a configuration-based formulation for one such manufacturing environment where production may involve dissimilar machines performing similar operations at different rates and equipments can be connected together to form different production lines. Byrne and Hossain [7] proposed an extended linear programming model following a hybrid approach in which the workload of jobs is sub-divided to introduce the unit load concept of JIT. Da Silva et al. [8] presented an aggregate production planning model considering maximization of profit, minimization of late orders, and minimization of work force level changes. They purposed the model to determine the number of workers for each worker type, the number of overtime hours, the inventory level for each product category and the level of subcontracting in order to meet the forecasted demand for a planning period. Corominas et al. [9] proposed two mixed-integer linear program models for solving the problem of production planning, the working hours and the holiday weeks for the members of a human team operating in a multi-product process where products are perishable, demand can be deferred and temporary workers are hired to stand in for employees. Lukac et al. [10] considered production planning problem with sequence dependent setups as a bi-level mixed 0–1 integer programming problem. The objective of the leader is to assign the products to the machines in order to minimize the total sequence dependent setup time, while the objective of the follower is to minimize the production, storage and setup cost of the machine. Liu and Tu [11] considered the production planning problem with inventory capacity as a limiting factor. They considered the problem with the following features: (1) the stockout is allowed, (2) production and lost sale cost functions are time varying and non-increasing, and (3) inventory capacity is constant. Cormier and Rezg [12] developed a mathematical model for simultaneously generating production plans for molds and the end items that are made with them. The inputs considered are the item demand, holding costs and shortage costs, together with the molds' statistical lifetime distribution and costs pertaining to amortization, preventive replacements and corrective replacements. Cyplik et al. [13] presented a production planning model with simultaneous production of identical components for the need of own assembly and as spare parts in machine industry plants. The proposed production planning model is applied on the classical stock management theory and material requirement planning methods.

3. Problem formulation

In this section, the mathematical model for production planning is presented based on dynamic manufacturing system considering worker assignment. The objective is to minimize the sum of the penalty for production volume deviation from the desirable value of the part demand (holding and backorder costs), training and salary costs of workers, maintenance and overhead cost and reconfiguration cost. The proposed model is formulated based on three principles: (1) Production planning, (2) Worker assignment and worker training, and (3) Machine reconfiguration. These principles include some assumption in dynamic environment.

3.1. Assumptions

The problem is formulated according to the following assumptions:

1. Consecutive operations of each part type are processed on different machine types in a given sequence. Moreover, each operation is processed by only one machine and logically, this process cannot be performed on more than one machine simultaneously.
2. The processing time for all operations of part types on each machine type is known and deterministic.
3. The demand for each part type in each period is known and deterministic. Also, total demands are given during the production planning horizon.
4. The manufacturing system is considered in multiple time periods. A time period may be a month, a season, a year, etc.
5. Each machine type has a limited capacity expressed in hours during each time period and is constant over the planning horizon.
6. There are several identical machines of each type to satisfy capacity requirements.
7. Maintenance and overhead cost for each machine type is known. This cost is incurred for each machine utilized in each period, i.e., idle machines have no maintenance cost.
8. System reconfiguration involves the addition and removal of machine types to and from the system in any cell and relocation of machines from one cell to another between periods.
9. Number of worker types is known. We divide the worker types to some clusters each of which includes workers that have similar skills.
10. The available time for workers is known in each period. This time is independent from skill levels.
11. The salary cost of each worker type is known. This cost is dependent to skill levels, i.e., the higher the skill level, the more the salary.
12. Only one worker (skill level) is allowed for processing each operation-part on each corresponding machine type.
13. Holding and backorder inventories are allowed between periods with known costs. Thus, the demand for a part type in a given period can be satisfied in the preceding or succeeding periods.

3.2. Mathematical model

Subscripts

Q	number of part types
S_i	number of operations of part type i
C	number of clusters of worker type
W	number of worker types
L_c	number of skill level of cluster c
M	number of machine types
H	number of periods
i	index set of part type ($i = 1,2,\ldots Q$)
s	index set of the operations of part type i ($s = 1, 2,\ldots,S_i$)
c	index set of cluster of worker type($c = 1,2,\ldots,C$)
w	index set of worker types ($w = 1, 2,\ldots W$)
l	index set of skill level of cluster c ($l = 1, 2,\ldots L_c$)
m	index set of machine type ($m = 1, 2,\ldots M$)
h	index set of period ($h = 1,2,\ldots H$)