Lot-sizing Decisions for Cellular Manufacturing

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บทคัดย่อ

การศึกษานี้เกี่ยวกับการวางแผนและควบคุมการผลิตในระบบการผลิตแบบเซลลูลาร์แมนูแฟคเจอริ่ง (Cellular Manufacturing) โดยศึกษาเฉพาะการตัดสินใจในการกำหนดปริมาณสินค้าที่จะผลิต (Lot-sizing Decisions) ซึ่งมีความสำคัญมากต่อการนำระบบการผลิตแบบเซลลูลาร์แมนูแฟคเจอริ่งมาใช้ให้ประสบความสำเร็จ ในบทความนี้ ได้เสนอการตัดสินใจกำหนดปริมาณสินค้าที่จะผลิตในระบบการผลิตแบบเซลลูลาร์แมนูแฟคเจอริ่งควรทำอย่างไร วิธีการตัดสินใจในการกำหนดปริมาณสินค้าที่จะผลิตแบบทั่วไปที่ใช้กันแพร่หลายในระบบวางแผนและควบคุมการผลิตจะสามารถถูกดัดแปลงมาใช้ในระบบการผลิตแบบเซลลูลาร์แมนูแฟคเจอริ่งได้อย่างไร

Key words: lot-sizing, production planning and control, inventory management, cellular manufacturing

ABSTRACT

This study is concerned primarily with the production planning and control aspect of cellular manufacturing systems. It focuses on lot-sizing decisions which are critical to the successful implementation and operation of cellular manufacturing systems. The paper addresses how lot-sizing decisions in a cellular manufacturing environment be made and how some of the traditional lot-sizing procedures currently available in the most widely-used production planning and control systems can be modified to accommodate the unique characteristics of cellular manufacturing systems.

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INTRODUCTION

In the field of operations management, cellular manufacturing is one of the areas that has gained considerable interest and attention from both practitioners and researchers for many years. Despite the abundance of past writings and the presently growing volume of cellular manufacturing literature, the existing literature has not yet adequately addressed a number of issues related to cellular manufacturing systems (e.g., applicability, justification, system design, production planning and control, and implementation).

This study is concerned primarily with the production planning and control aspect of cellular manufacturing systems. It focuses on lot-sizing decisions which are critical to the successful implementation and operation of cellular manufacturing systems. This study addresses two major issues. First, how lot-sizing decisions in a cellular manufacturing environment should be made. Second, how some of the traditional lot-sizing procedures currently available in the most widely-used production planning and control systems can be modified to accommodate the unique characteristics of cellular manufacturing systems.

An Overview of Cellular Manufacturing

Cellular manufacturing is an application of group technology. The main conceptual idea behind group technology is to explore the similarities which exist among component parts to improve production efficiencies and productivity (Arn, 1975; Burbidge, 1975, 1979; DeVries, Harvey & Tipnis, 1976; Edwards, 1971; Gallagher & Night, 1973; Ham, Hitomi & Yoshida, 1985; Hyer, 1984a, 1984b; Hyer, Wemerlov & Hyer, 1982, 1984; Mitrofanov, 1966; Petrov, 1966, 1968; Ranson, 1972; Wemmerlov & Hyer, 1987). The group technology philosophy has broad applications which can affect many areas of a manufacturing organization of component parts into part families. Another application is the organization of machines and processes on the shop floor.

The organization of component parts into part families can be done on either the basis of design or manufacturing process similarities or both. When the organization of part families is done by design similarity, the benefits are that new part designs and component part variety may be reduced and part standardization improved. When part families are organized on the basis of manufacturing process similarity, the impact is upon the structure or layout of production process itself.

The manufacturing of small and medium-sized batches of component parts has traditionally taken place in a functional or job shop layout where functionally similar machines are placed together in one area of the manufacturing system (i.e., a work center). Thus, batches of component parts must be moved through various work centers according to a pre-specified sequence of operations. The group technology philosophy can be applied in a functional layout in various forms, but the extreme application of group technology to batch production involves a physical rearrangement of machines and processes in a production system. Instead of organizing a production system around machine similarity, groups of different machines on which a part family or a set of part families may be produced are identified and placed together to form a production or manufacturing cell. Each production cell is then dedicated to the manufacture of those part families. This type of layout is commonly referred to as a group or cellular layout.

Focus of the Study

This study examines the production planning and control aspect of cellular manufacturing systems. Specifically, it focuses on the lot-sizing decisions which are critical in achieving high efficiency and productivity in manufacturing systems. The rational for the need for studying the lot-sizing problems in cellular manufacturing systems is that most of the lot-sizing research has focused on job shops and the characteristics of cellular manufacturing systems are quite different from those found in job shops. Some of these different characteristics are:

(1) Component parts in cellular manufacturing are grouped into part families according to their design or manufacturing similarity.

(2) Machines and operating processes in cellular manufacturing systems are also grouped together to form production cells so that a certain set of part families can be completely processed within each cell.

(3) In many circumstances especially when part families are formed on the basis of their setup requirement similarity, cellular manufacturing provides an opportunity to reduce setup times by organizing the setup requirements into major setup and minor setups. Major setups in cellular manufacturing stem from changes in the production of part families from one part family to another and not from changes within part families, whereas minor setups stem from changes within part families and not from changes between part families.

Therefore, if component parts which belong to the same part family are scheduled together, the overall setup times can be reduced.

Because of the unique characteristics of cellular manufacturing, an argument can be made that traditional lot-sizing procedures commonly used in job shops may not generate a good result in cellular manufacturing systems. The major questions to be asked are:

- How can lot-sizing decisions be made in cellular manufacturing?
- Can traditional lot-sizing procedures currently available in most of production planning and control systems, such as Material Requirement Planning (MRP) systems, be modified for use in cellular manufacturing environments?
- If so, what modifications should or can be made?
- How beneficial are these modifications?

Objective of the Study

The objectives of this study are to explore how lot-sizing decisions in a cellular manufacturing environment be made and how some of the traditional lot-sizing procedures currently available in the most widely-used production planning and control systems can be modified to accommodate the unique characteristics of cellular manufacturing systems.

In this paper, lot-sizing problems in a cellular manufacturing environment is defined and two different approaches for modifying traditional lot-sizing procedures are proposed. In brief, the first approach involves adjusting the setup cost parameter for each component part by considering the relationships which exist between component parts and part families. This adjusted setup cost parameter can then be used in place of the original setup cost parameter in the traditional single-level lot-sizing models, such as periodic order quantity, Silver-Meal, and many others. The second approach involves modifying the algorithms of traditional single-level lot-sizing procedures so that lot-sizing decisions for the component parts can be made by part families rather than by individual parts. In this study, the first lot-sizing approach is referred to as the "adjusted setup cost lot-sizing approach" and the second approach as the "family-oriented lot-sizing approach."

LITERATURE REVIEW

The introduction of cellular manufacturing into production systems presents lot-sizing problems that are quite different from those found in job shop. It is apparent that lot-sizing in cellular manufacturing environments should be done differently from lot-sizing in job shop environments. Most researcher studying lot-sizing problems in cellular manufacturing environments have adopted an idea that since major setup times in cellular manufacturing stem from changes in part families and not from changes within part families, therefore, lot-sizing in cellular manufacturing should be done by part families rather than by individual parts.

One group of researchers (Burbidge, 1975; Levulis, 1978; New, 1977; Suresh, 1979) has suggested the use of single-cycle, single- phase ordering (also known as "Period Batch Control" or "PBC") approach to determine lot sizes by part families. With this approach, all parts are ordered with a frequency determined by the common production cycle, and parts scheduled for production in a given cycle are then categorized by families. In fact, the PBC approach is quite similar to the lot-for-lot (LFL) procedure in MRP systems with the size of planning time bucket set equal to the common planning cycle. Surprisingly, no formal method for determining a proper planning cycle length has been proposed in the PBC literature.

Fogarty and Barringer (1984, 1987) considered the family lot-sizing problem as one of deciding which parts to be included in an order so as to minimize costs (i.e., joint order replenishment problem). They proposed a least total cost (LTC) approach and a dynamic programming approach for solving this problem. However, their least total cost approach is impractical for use since this approach requires a large number of possible solution can be given. Their dynamic programming approach also has a limitation in that it can only be used in the case of a single part family produced on non-dedicated equipment.

Rabbi and Lakhmani (1984) conducted simulation experiments to investigate the performance of an MRP-based specifically for their study and a family-oriented LTC lot-sizing procedure similar to the one proposed by Fogarty and Barringer (1984). The results of their experiments show that the modified MRP system with the family-oriented LTC lot-sizing procedure outperforms the standard MRP system with the traditional LTC procedure in terms of inventory setup time to total individual setup times is low and the number of parts in a family is large.

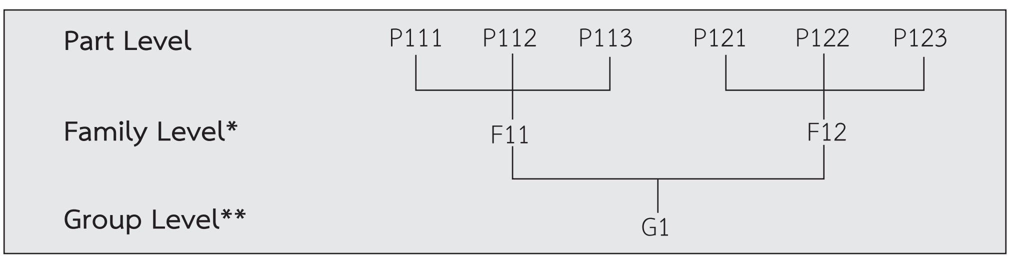
LOT-SIZING PROBLEMS FOR CELLULAR MANUFACTURING DEFINED

Consider a typical cellular manufacturing environment in which parts have been classified into part families so that the parts within the same family are similar with respect to setup and manufacturing requirements, and part families have been classified into groups of part families so that each group of part families can be completely processed within a single production cell. Figure 1 shows the hierarchical relationships between individual parts, part families, and groups of part families. There are two kinds of setups in the production processes: major setup and minor setup. A major setup is required whenever there is a production changeover from one part family to another, whereas a minor setup is required whenever there is a production changeover from one part to another part within the same part family. It is assumed in this research that the major costs are independents of a sequence of parts within the same part family.

Given periodic demand, minor setup cost, inventory holding cost per unit per time period of each part, and major setup cost of each part family, the lot-sizing problem is to determine order quantities and timing for each part so that the total setup and inventory holding costs are minimized.

Notations:

The following notations are used consistently throughout this dissertation in describing the lot-sizing approaches and procedures for cellular manufacturing proposed in the research.



Note: * Parts within the same family share a common major setup.
** Parts within the same group are processed in the same production cell.

Figure 1. Hierarchical relationships between individual parts, part families, and groups of part families

i denote the family index;
j denote the part index;
t denote the time period;
N_i = the number of parts in family i;
S_i = major setup cost of family i;
S_{ij} = minor setup cost of part j in family i;
AS_{ij} = adjusted setup cost of part j in family i;
h_{ij} = inventory holding cost per unit per period of part j in family i;
TC_{ij} = the sum of total annual setup and holding costs of all parts j in family i;
d_{ij} = the average demand rate per period of part j in family i;
d_{ijt} = demand of part j in family i in period t;
T_{ij} = economic cycle time of part j in family i;
T_i = economic cycle time of family i; and
x_{ij} = 0-1 type variable used for determining whether the minor setup for part j in family I is required in the current production cycle.

PROPOSED LOT-SIZING PROCEDURES FOR CELLULAR MANUFACTURING

The lot-sizing problem for a typical cellular manufacturing environment was defined and two different approaches for modifying traditional lot-sizing procedures so that they can cope better with the unique characteristics of cellular manufacturing (e.g., part families, major/minor setups) were presented. The first approach, the adjusted setup cost-based lot-sizing approach, involves adjusting the setup cost parameter for each part by dividing the major setup cost by number of parts in the family and adding the result to the minor setup cost of that part. The adjusted setup cost is then used in place of that original setup cost in traditional lot-sizing procedures. The second approach, the family-oriented lot-sizing approach, involves modifying lot-sizing algorithms in the traditional lot-sizing methods so that lot-sizing can be made by part families. Although these two approaches may be used to modify many static and dynamic lot-sizing procedures already available in MRP systems, this research selectively focuses on examining the performance of modified Periodic Order Quantity and Silver-Meal lot-sizing procedures.

Adjusted setup Cost-Based Lot-sizing Approach

In the most of the traditional lot-sizing procedures, lot-sizing decisions are made by considering the basic trade-off between the setup cost and the inventory holding cost. However, the traditional lo-sizing procedures do not recognize the unique characteristics of cellular manufacturing (e.g., part families, production cells, and major and minor setups). This suggests that the traditional lot-sizing procedures, if they are used in their original forms, may not be appropriate for use in cellular manufacturing. Some modifications to the traditional lot-sizing procedures are required in order to make them cope better with the unique characteristics of cellular manufacturing.

One approach for modifying the traditional lot-sizing procedures is to adjust the setup cost parameter by considering the relationships between part families and their members. Since all parts in the same family share the same major setup, it is suggested that the major setup cost of a part family be equally weighted and distributed to its members. This will yield the following adjusted setup cost equation for part j in family i.

$$AS_{ij} = \frac{1}{N_i} S_i + S_{ij} \tag{1}$$

It should be noted that the adjusted setup cost computed by equation (1) provides only an approximation of the total setup cost for the part since it is assumed that all parts within the family are produced together, and that there is always one order for each part released to the shop in every production cycle. Once the adjusted setup cost for each part has been determined, it then can be used in place of the original setup cost in the traditional single- level lot-sizing heuristics currently available in MRP systems.

The adjusted setups cost-bases lot-sizing approach should be attractive from a practical standpoint for two major reasons. First, this lot-sizing approach provides a simple way to adjust the setup cost so that the relationships between individual parts and part families are considered in the lot-sizing decisions. Second, this lot-sizing approach can be easily implemented in currently available production planning and control systems such as MRP systems because there is no needs for modifying the lot-sizing algorithms and computer programming codes.

While it is possible to use the adjusted setup cost approach in conjunction with many traditional single-level lot-sizing procedures, this research selectively examines the performance of modified versions of the Periodic Order Quantity and the Silver-Meal procedures with the adjusted setup cost parameter. These two lot-sizing procedures are described in the following section.

Adjusted Setups Cost-Based Periodic Order Quantity Procedure

The adjusted setup cost-based Periodic Order Quantity procedure (abbreviated herein as APOQ) is similar to the traditional POQ procedure in that it attempts to minimize the total setup and holding costs. However, the setup cost parameter in APOQ is adjusted using equation (1) in order to take the relationship between parts and part families into account when making lot-sizing decisions.

The following equation presents the total setup and holding costs for part j in family i.

$$TC_{ij} = \frac{1}{T_{ij}} AS_{ij} + \frac{T_{ij}}{2} h_{ij} \bar{d}_{ij} \tag{2}$$

By taking the partial derivatives of TC_{ij} with respect to T_{ij}, setting the results equal to zero, and solving for T_{ij}, the optimal value of T_{ij} is

$$T_{ij}^* = \sqrt{\frac{2.AS_{ij}}{h_{ij}\bar{d}_{ij}}} \tag{3}$$

Then, the lot sizes for part j in family i are set equal to the demand for the economic cycle time interval (T_{ij}^*) computed by equation (3).

Adjusted Setup Cost-Based Silver-Meal Procedure

In the adjusted setup cost-based Silver-Meal procedure (abbreviated herein as ASM), successive future periods of demand are included incrementally in the current order until the total setup and holding costs per period start to increase. Specifically, the demand of part j in family i in period n is included in the order placed in period 1 if, for n ≥ 2,

$$\frac{1}{n}\left[AS_{ij} + \sum_{t=1}^{n}(t-1)h_{ij}d_{ijt}\right] \le \frac{1}{n-1}\left[AS_{ij} + \sum_{t=1}^{n-1}(t-1)h_{ij}d_{ijt}\right] \tag{4}$$

Family-oriented Lot-sizing Approach

The family-oriented lot-sizing approach is based on the idea that lot-sizing decisions for the parts should be made by part families and not by individual items. Since the major setups in cellular manufacturing stem from changes within part families, the family-oriented lot-sizing approach eliminates unnecessary major setups by timing production so that all parts within the same family are produced together. To implement this lot-sizing approach, the lot-sizing algorithms must be modified so that lot sizing decisions for all parts within the same family are made at same time on a family-by-family basis.

The following sections describe how the family-oriented lot-sizing approach can be applied to the POQ and Silver-Meal lot-sizing procedures.

Family-Oriented Periodic Order Quantity Procedure

The family-oriented Periodic Order Quantity procedure (abbreviated herein as FPOQ) is similar to the traditional POQ and the APOQ procedure in that it attempts to minimize the total setup and holding costs. However, with the FPOQ procedure lot sizes for the parts are made by part families rather than individual items.

To determine order quantities for the parts under the FPOQ procedure, the first step is to determine the economic cycle time for each part family so that the total annual setup and holding costs for all parts in that family are minimized. The following equation presents the total setup and holding costs for family i.

$$TC_i = \sum_{j=1}^{N_i} T_{ij} = \frac{1}{T_i}\left[S_i + \sum_{j=1}^{N_i} S_{ij}\right] + \frac{T_i}{2}\sum_{j=1}^{N_i} h_{ij}\bar{d}_{ij} \tag{5}$$

The optimal value of T_i can be found by taking the partial derivatives of TC_i with respect to T_i, setting the result equal to zero, and solving for T_i. The result is:

$$T_i^* = \sqrt{\frac{2\left[S_i + \sum_{j=1}^{N_i} S_{ij}\right]}{\sum_{j=1}^{N_i} h_{ij}\bar{d}_{ij}}} \tag{6}$$

With the FPOQ procedure, all parts in family i are ordered in the quantities equal to their demand in the economic cycle time (T_i*) computed by equation (6).

Family-Oriented Silver-Meal Procedure

The family-oriented Silver-Meal procedure (abbreviated herein as FSM) is similar to the ASM procedure with two exceptions: (1) it does not use adjusts setup cost parameter, and (2) lot sizes for all parts belonging to the same family are determined at the same time. In the FSM procedure, successive periods of demand of all parts within the same family are included in the current order until the total setup and holding costs per period start to increase. Specifically, demand for all parts in family i in period n is included in the order placed in period 1 if, for n ≥2,

$$\begin{aligned} &\frac{1}{n}\left[S_i + \sum_{j=1}^{N_i} X_{ij}S_{ij} + \sum_{t=1}^{n}\sum_{j=1}^{N_i}(t-1)h_{ij}d_{ijt}\right] \\ &\leq \frac{1}{n-1}\left[S_i + \sum_{j=1}^{N_i} X_{ij}S_{ij} + \sum_{t=1}^{n-1}\sum_{j=1}^{N_i}(t-1)h_{ij}d_{ijt}\right] \end{aligned} \tag{7}$$

The variable x_{ij} in the above equation is a zero-one type variable used to determine whether the minor setup cost for part j in family i (S_{ij}) is required in the current production cycle. The following equation is used to determine the value of x_i

$$X_{ij} = \begin{cases} 0, \mathit{if} \sum_{t=1}^{n} d_{ijt} = 0 \\ 1, \mathit{if} \sum_{t=1}^{n} d_{ijt} > 0 \end{cases} \tag{8}$$

SUMMARY AND SUGGESTED FUTHER STUDY

In this paper, the lot-sizing problem for a typical cellular manufacturing environment was defined and two different approaches for modifying traditional lot-sizing procedures so that they can cope better with the unique characteristics of cellular manufacturing (e.g., part families, major/minor setups) were presented. The first approach, the adjusted setup cost-based lot-sizing approach, involves adjusting the setup cost parameter for each part by dividing the major setup cost by number of parts in the family and adding the result to the minor setup cost of that part. The adjusted setup cost is then used in place of that original setup cost in traditional lot-sizing procedures. The second approach, the family-oriented lot-sizing approach, involves modifying lot-sizing algorithms in the traditional lot-sizing methods so that lot-sizing can be made by part families. Although these two approaches may be used to modify many static and dynamic lot-sizing procedures already available in MRP systems, this research selectively focuses on examining the performance of modified Periodic Order Quantity and Silver-Meal lot-sizing procedures.

The adjusted setup cost-based lot-sizing approach is very easy to implement since it does not need any modifications to the source codes of currently-used production planning and control systems. The family-oriented lot-sizing approach, however, requires substantial modifications to the source codes of existing production planning and control systems. Although the adjusted setup cost-based approach is easier to implement than the family-oriented approach, the relative performance of these two lot-sizing approaches is unknown. Therefore, the next logical phase of the study is to conduct a series of experiments to investigate their relative performances under different operating conditions.

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