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The Implementation of Cellular Manufacturing on to a Functional Factory Floor

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THE IMPLIMENTATION OF CELLULAR MANUFACTURING ON TO A FUNCTIONAL FACTORY FLOOR

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ABSTRACT

This thesis will focus on the implimentation of cellular manufacturing and the issues that must be addressed for the successful transformation from a traditional functionally partitioned manufacturing environment.

A large percentage of companies who attempt to transform a functionally partitioned factory into a cellular layout fail to obtain the benefits that it can bring. Research has attributed this to the lack of planning for all the issues involved in cellular manufacturing. It is necessary to address all the issues, not just one or two, or the negative effects of partitioning a factory floor (the loss of pooling synergy) may offset some of the benefits obtained from cellular manufacturing.

The purpose of this study is to provide a manual that gives a general set of guidelines covering the major issues that must be addressed if the competitive

advantages of cellular manufacturing are to be obtained. Specifically, it will cover cell design, special problems that can occur when designing cells, setup time reduction, worker assignment within the cell, preventive maintenance, and labor issues involved in this type of manufacturing environment.

Three business professionals participated in the study as evaluators. The evaluators work in three different disciplines; Purchasing, Operations Management, and Industrial Engineering. The evaluators were administered the manual and a questionnaire for the purpose of gathering their professional feedback. The questionnaire asked for validity/coverage, errors, and additions that need to be made to the manual.

The results of the evaluation revealed the overall coverage is good. This indicates the manual covers the major issues of cellular manufacturing and it solves the problems occurring when the transformation fails. There are a few issues that were removed as well as added to the manual. This made the manual more applicable in a real life business situation.

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A Culminating Project Presented to the Faculty of the
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This Thesis is Dedicated to My Family

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Chapter 1

INTRODUCTION

Current Manufacturing Trends

Manufacturing during the 1990s is reflecting a trend for quality products that are aimed at satisfying customer needs. These customers are now recognized as both internal and external. Internal customers are those within the organization that will use a product previously produced internally for further value added work. That is, employees within an organization see each other as customers. Quality must be measured in the terms of the customer, if it is to be used as a strategic competitive weapon (Brown 34).

External customers are becoming more demanding and meeting their needs, while maintaining profitability, is becoming increasingly difficult. An example of this trend is the aerospace and defense industry. Manufacturing in this industry requires designing, producing, and testing small quantities of electronic assemblies in compressed schedules before actual production of small quantities begin (Ferras 1). The frequent changing of production equipment to produce these small quantities will erode profitability if proper manufacturing techniques are not implemented (Jordan and Frazier 70).

In addition to manufacturing high quality products, today's manufacturers face domestic and global competition in the areas of rapid production innovation, cost efficiency, and customer responsiveness. Manufacturers must set up their production facilities in the most efficient way to meet this competition.

Today's manufacturers must deal with increasingly demanding customers. More and more customers (both internal and external) are switching to just-in-time (JIT) deliveries of parts. This will require frequent delivery of small quantities of parts resulting in the manufacturers frequent changeovers, short lead times, and high demand on quality (Destefani 43). Manufacturing facilities that are partitioned in a functional setup will be stressed to meet these demands unless they build huge inventories of finished goods. This action will begin to erode profitability and restrict a company from responding quickly to customers needs. Flexibility in manufacturing is the key to meeting these customers demands and maintaining profitability (Choi and Song 399).

Cellular Manufacturing

In response to these changing needs, companies are implementing cellular manufacturing. Cellular manufacturing is defined as the division of manufacturing facilities into cells of dissimilar machines such that families of production parts can be produced, to the fullest extent possible, within a single cell (Askin and Iyer 438). The main benifits of this type of manufacturing are reduced inventories, reduced cycle time, and improved quality control. In more detail, the benefits of cellular manufacturing are listed in Table 1. In addition to these physical benefits, employee morale (with its obvious benefits) is improved as this style of manufacturing allows the employee to see their work turn raw material into a

Table 1

The Benefits of Cellular Manufacturing

1. **Elimination of or decrease in setup time and setup cost.**
2. **Greater manufacturing flexibility.**
3. **Reduced work-in-process and lower inventory (Just-in-Time).**
4. **Less floor space around the machines.**
5. **Lower raw material.**
6. **Reduction in the cost of good produced.**
7. **Capability to use high-investment machinery in the production.**
8. **Reduction in direct labor cost.**
9. **Higher productivity.**
10. **Minimization of through-put times.**
11. **Minimization of material movement during production.**
12. **Improved quality.**

SOURCE: Computers and Industrial Engineering. **Exhibit from "A Methodology for forming Manufacturing cells using Manufacturing and Design Attributes," by Ali K. Kamrani and Hamid R. Parsaei (1992).**

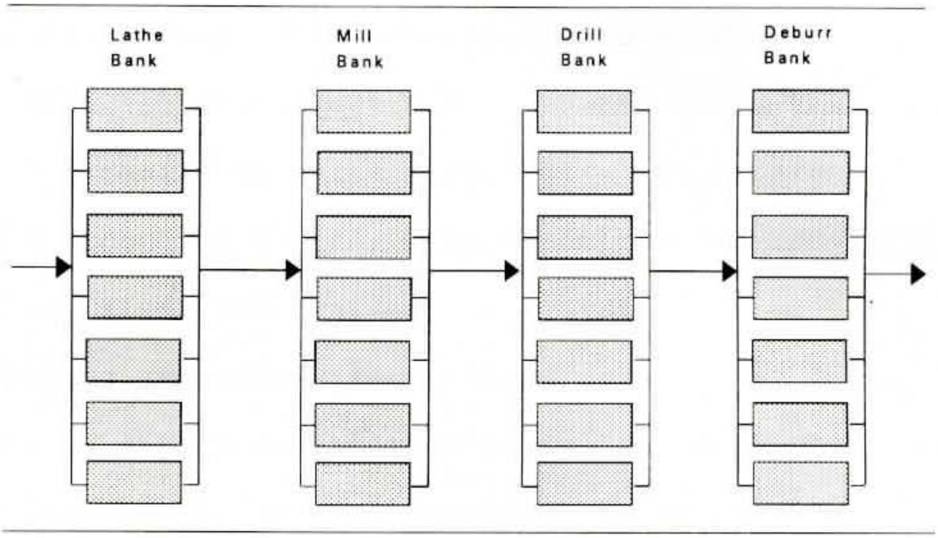
finished product.

Cellular manufacturing allows a company to respond rapidly to changing customer needs. Short product life cycles, small lot sizes, and high quality requirements are economically justified using cellular manufacturing techniques. Companies utilizing this philosophy will have a great strategic competitive advantage over competitors (Yang and Deane 413). When a company decides to change from a traditionally functional factory layout to a cellular manufacturing layout, management must consider many options during design and implementation. Part families and machine grouping must be determined. This is very complicated because sequencing and setup/change-over times must be included in the groupings. A preventative maintenance program must be developed. Human productivity (union vs. non-union) must also be considered (Faizul 15).

Figure 1 illustrates a traditional functional factory manufacturing flow diagram. Machines of the same type are located in functional areas of the factory. In this simple example, lathe machines are located in one area of the factory as are the other three machine types. During production, raw material is taken from storage to the lathe function area where the required work is done. With this style of manufacturing (functional layout), large lots of parts are sent to functional areas where the required work is completed on all the parts before they are returned to storage. The parts then wait until machines are

Figure 1

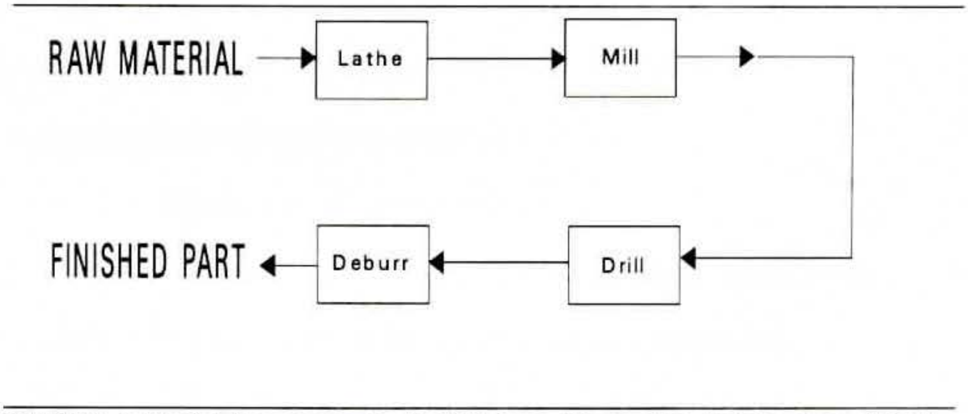
Functional Production Flow



SOURCE: Industrial Management. Exhibit from "Preventive Maintenence: Stand Alone Manufacturing Compared with Cellular Manufacturing," by Jon F. Bateman (1995).

Figure 2

Cellular Production Flow



SOURCE: Industrial Management. Exhibit from "Preventive Maintenence: Stand Alone Manufacturing Compared with Cellular Manufacturing," by Jon F. Bateman (1995).

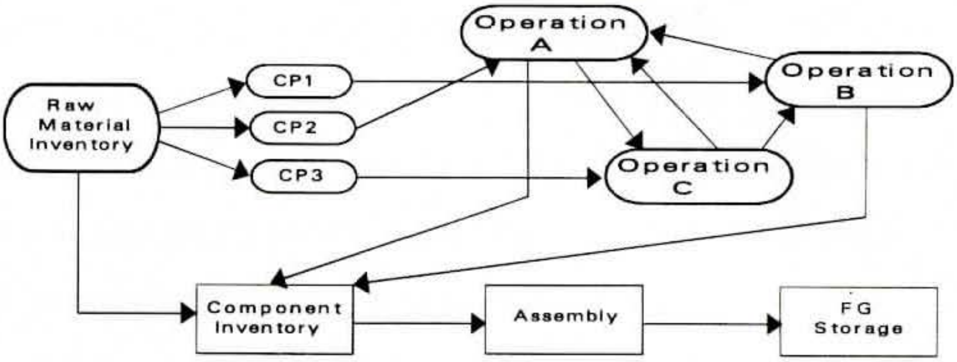
available in the next functional area. This is done for all parts until they have completed each of the functions.

Cellular manufacturing ideologies rearrange the functional factory layout into u-shaped cells that will produce a family of parts (Inman 31). Parts are grouped according to their design attributes (physical shape and size) and manufacturing attributes (processing sequence) (Kamrani and Parsaei 73). The factory is set up in a series of cells. Machines are taken from the functional groupings to cells where the particular parts require that type of operation. Figure 2 illustrates a cellular manufacturing flow diagram. Smaller lots sizes of parts are processed because they are economically justified by the reduction in setup time achieved in cellular manufacturing (Jordan and Frazier 70).

Most manufacturing requires more operations/machines than the flow diagrams previously illustrated. Many finished parts will require components added to them some time during the production cycle. Figure 3 illustrates a traditional

Figure 3

Traditional Manufacturing

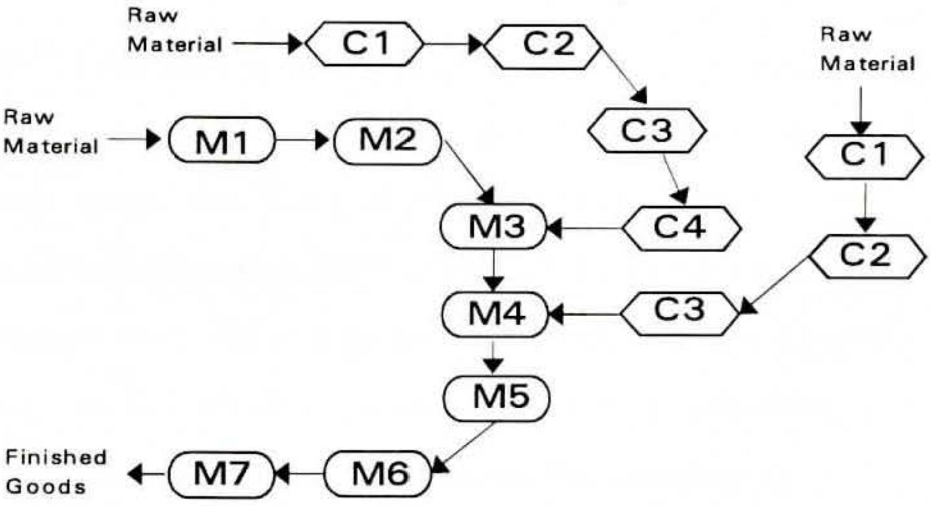


CP = Component Parts FG = Finished Goods

SOURCE: Material Handling Engineering. Exhibit from "Eaton Corporation Doesn't Build'em Like They Used To," by Clyde E. Witt (1994).

Figure 4

Focused Factory



M = Machines in Assembly C = Machines in Component Cells-

SOURCE: Material Handling Engineering. Exhibit from "Eaton Corporation Doesn't Build'em Like They Used To," by Clyde E. Witt (1994).

manufacturing system producing a finished good that has three components added to it during production. Figure 4 shows the same finished good produced in a cellular manufacturing environment. There are three independently functioning cells. Each cell has been designed around a part family. The component cells are sequenced and positioned with the main assembly cell so the completed component arrives at the main cell just as it is needed. This factory layout is termed a focused factory and illustrates how cells can be linked for maximum productivity (Hanks, Freid, and Huber 25).

Historical Perspective

Cellular manufacturing philosophies of exploiting the similarities of parts and processes have been in evidence since the turn of the century (Kamrani, Parsaei, and Chuadhry 487). In 1919, Frederick Taylor introduced the ideologies behind cellular manufacturing as a way to increase productivity (Kroll and Wang 21). Professor Mitrofanov of Leningrad University coined the word 'Group Technology' (a synonym for cellular manufacturing) in 1946 to establish the relationship between component shape and processing (Singh 281). The adoption of cellular manufacturing techniques and practices first became common in the assembly industries, particularly electronics and automobile manufacturers (Knudsen, Jacobs, Conway, and Blake 186). The early uses of this type of manufacturing were concentrated on part family manufacturing for batch type industries listed above. Parts were brought together that required similar production facilities. They were then processed in sequence to reduce setup times, in-process inventories and throughput times (Kamrani, Parsaei, and Chaudhry 487).

Currently, cellular manufacturing is used in batch and jobbing production with the primary objective of partitioning the factory into cells having a group of machines and associated families of parts (Singh 281). In 1984, the estimated number of cells in the united states was 525; in 1989 that number had grown to 8,000 (Choi 66). A 1989 survey of 23 American companies using cellular manufacturing revealed that 61% had reduced setup time by an average of 41% (Jordan and Frazer 70). For example, Gilbarco has reduced The setup time on a 100-ton press from 45 minutes to five minutes (Kinni 52). This reduction in setup times leads to multiple benefits. For example, Arizona Precision Sheet Metal was able to reduce throughput time by 70% on cabinet manufacturing (Destefani 43), and Eaton Corporation has reduced work-in-process (WIP) inventory from fifteen million to five million parts after a reduction in setup time (Witt 49).

Companies in the 1990s are facing unprecedented domestic and global competition. Their customers are forcing them to change the way manufacturing is carried out to meet their needs. Cellular manufacturing is a means to achieving the desired quality and service requirements of customers while still maintaining profitability.

Need for Research

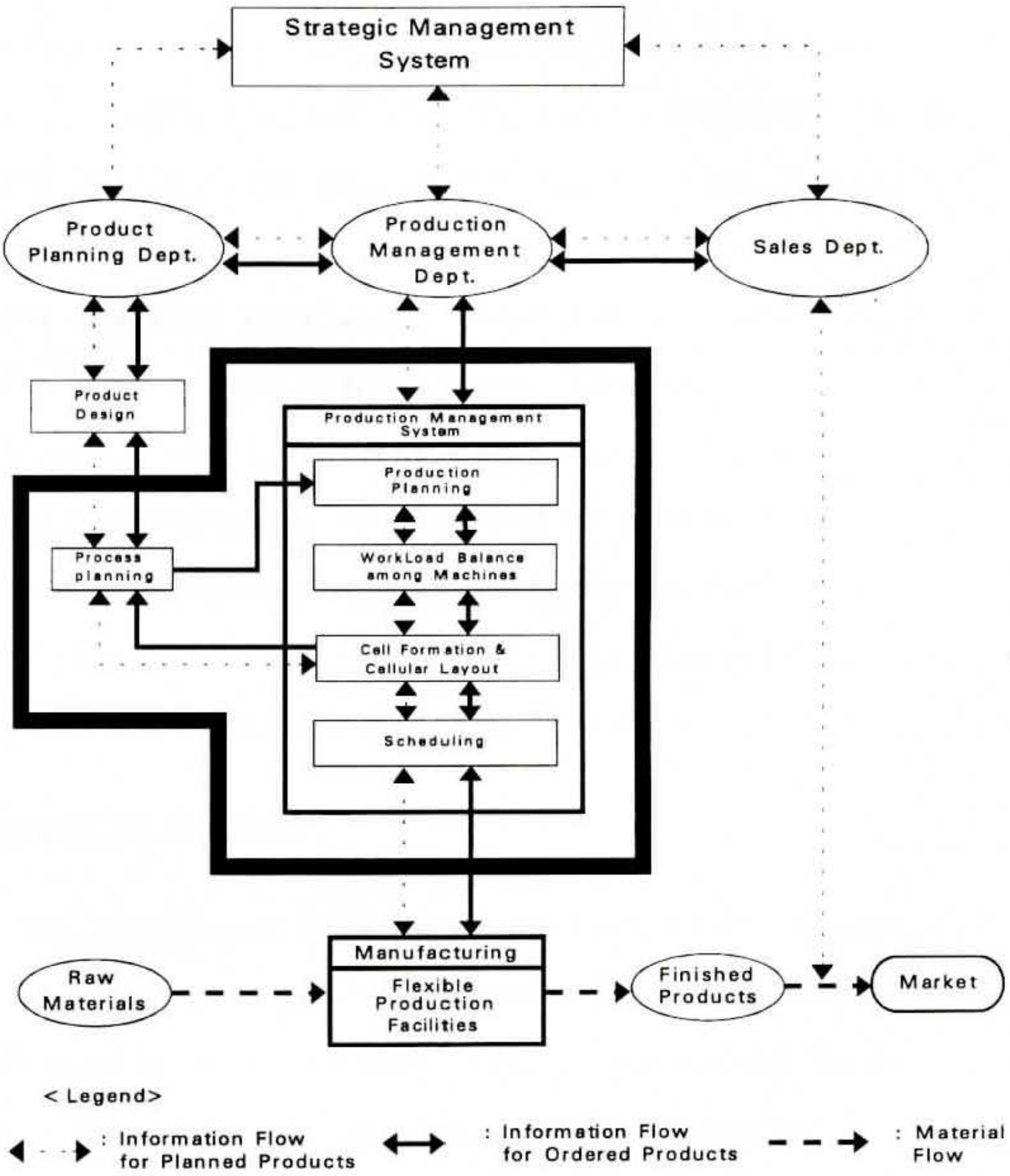
The previously mentioned statistic that 61% of companies that have implemented cellular manufacturing are realizing a reduction in setup time illustrates a problem: 39% are not realizing this reduction. Burgess Brothers Inc. was losing money because their customers were ordering 300 parts but wanted 10 to arrive every week, they could not afford to store 200 parts (Destefani 43). The reduction in setup time is only one benefit but it leads to many others. Many companies are not properly or fully implementing cellular manufacturing. Therefore, many of the benefits sought are not being realized.

In the United States, 80-90 percent of manufacturing facilities are organized as job shops (Knudsen, Jacobs, Conway, and Blake 184). These manufacturing facilities represent a situation where cellular manufacturing techniques can be implemented to meet changing needs. Entire factories can be converted to cellular layouts making them more efficient and productive.

Before implementation can occur, however, much planning and decision making must take place. The only way the full benefits of cellular manufacturing can be achieved is to take in to account all of the issues involved with proper implementation. Figure 5 shows the complexity of planning and operation that must occur to gain the benefits of cellular manufacturing.

Figure 5

Planning and Operation



Source: Eropean Journal of Operations Research. Exhibit from "Optimization Analysis of Flexible Manufacturing: Route Selection and Determining the Optimal Production Conditions for Ordered Products," by Sangjae Sond and Junghee Choi (1993).

Product planning, production management, sales, and upper management must all be involved in the decision making process to insure all aspects of the transformation are completed in the best possible manner. Simply instructing industrial engineers to use massive mathematical models and computer simulations to identify part families and machine groupings will not achieve the full benefits. There are many other factors such as the human issues, preventive maintenance, and investment decisions that must be actively addressed in the planing of a cellular manufacturing environment if it is to perform in a manner that will allow the particular organization to achieve a strategic competitive advantage.

Statement of Purpose

The purpose of this paper is to give the reader a plan of action for the implementation of cellular manufacturing on to a traditionally functional factory floor. The plan will be given in such a manner as to include, or be directed by, a business manager. The plan will not be industry specific but will be general in that it takes a manager through all the issues that must be addressed for the proper implementation of cellular manufacturing in any manufacturing environment. General guidelines will be given allowing a manager to make informed decisions during the planning and implementation stages.

Chapter II

LITERATURE REVIEW

The transformation of a functionally partitioned factory layout to a cellular layout requires decision making involving many factors. Cellular manufacturing is defined as the division of manufacturing facilities into cells of dissimilar machines such that families of production parts can be produced, to the fullest extent possible, within a single cell (Askin and Iyer 438). Singh states the process of designing cellular manufacturing systems is very complex since it involves interaction of many strategic, tactical, and operational level issues (editorial). Managers involved in this division must consider all issues if the full benefits of cellular manufacturing are to be obtained.

The design phase of cellular manufacturing is where the benefits can be properly planned. Kamrani, Parsaei, and Chaudry offer five stages of cellular design in Table 2 (488). Within these stages must be included the human element (Faizul 15), setup time reduction (Jordan and Frazier 70), cell flexibility to meet changing market conditions (Choi and Song 339), and preventive maintenance (Bateman 19). All of these issues must be involved in the design phase if the benefits in Table 1 are to be obtained.

Obtaining the benefits of cellular manufacturing is what will cost justify the transformation. Many studies have been conducted to determine how different variables in the operation of the cell effect its

Table 2

Design Stages of Cellular Manufacturing

1. **Selection of part populations and grouping of parts into families.**
2. **Selection of machine and process populations and grouping of these into cells.**
3. **Selection of tools, fixtures, and pallets.**
4. **Selection of material handling equipment.**
5. **Choice of equipment layout.**

SOURCE: Computers and Industrial Engineering. Exhibit from "A Survey of Design Methods for Manufacturing Cells," by Ali K. Kamrani, Hamid R. Parsaei, and Mahfooz A. Chaudhry (1993).

performance. The results of these studies need to be combined for all issues involved in the design of an efficient cellular manufacturing system that reaps all the prescribed benefits.

Cell Formation

Key variables in the manufacturing cell design include the number of cells, cell size, total number of machine types, part characteristics, part routing, number of operations per part, and selection of material handling equipment (Kamrani, Parsaei, and Chaudhry 487). All these variables apply because normally a part family can be produced entirely within the cell. These variables validate a two stage cell development procedure: 1) the identification of part families; and 2) the physical makeup (number of cells, number of machine types, and number of tools and fixtures) of the cell (Kamrani and Parsaei 74).

There are four methods for creating part families and machine layout: 1) eye-balling; 2) coding and classification; 3) mathematical and heuristic; and 4) clustering (Singh 285-287). Of these methods, coding and classification is the most powerful because it uses the most information to create part families. The following paragraphs give a description of each method.

The eye-balling method for developing part families and machine layout is informal and manual. An experienced operator will examine information and simply rely on this experience to determine part groups (Kamrani, Parsaei, and Chaudhry 487). Depending on the size of the company and the number and varieties of products, this can be an acceptable approach. When the number of machines and parts become large, this approach becomes infeasible (Choi 66).

The first mathematical method suggested by Singh was a 1988 Choobineh study using a sequential approach to form part families and a cost based approach to form the machine layout within the cell (Singh 286). In 1990, Rajamani et al developed an integer program to sequentially as well as simultaneously form cells (Singh 286). This study provided a framework for cell design using real life issues such as alternative process plans, relocation of machines, material handling, investment cost, and cell operating (Singh

286). A follow up study by Rajamani et al in 1991 added an efficient column generation based solution algorithms (Singh 286).

Singh also lists a number of hueristics developed for the formation of manufacturing cells. In 1988 Choi and Araar proposed a three stage procedure to determine the number and cell composition to which was added in 1990, a heuristic on intercell and intracell moves along with workstation utilization (Singh 287).

The clustering method has also been briefly mentioned for cell design. This method utilizes a calculation of similarity and dissimilarity coefficients known as clustering factors (Kamrani and Parsaei 74). These coefficients define how the characturistics of a part match those of other parts. Once the coefficients are calculated (the coefficients range from 0 to 1), the machines with the closest measure are grouped into a cell (Kamrani and Parsaei 74).

Coding and classification methods use a process of assigning symbols to parts and then classing them into part families based on similar design and manufacturing attributes (Singh 285). Each part is checked individually for its particular attributes. Coding and classification can be broadly classified into two systems: 1) universal coding and classification, which is a system that uses industry accepted codes to identify characuristics; and 2) customized coding and classification, which is a system that uses company specific codes to identify parts (Choi 66). The most widely used systems are universal coding and classification software packages such as OPITZ, MICLASS, and KK-3 (Choi 66). Additional coding systems include KK-1 System, TEKLA System, Code System, and VUOSO System (Kroll and Wang 22). Each system has different length codes but each code is generally divided into two areas. These areas are: 1) general codes that describe industry-wide characteristics of products, equipment, and operations; and 2) supplemental codes for company specific usage (Choi 66).

Kamrani and Parsaei provide a study that indicates the coding and classification is the most powerful method for designing manufacturing cells (73).

The authors contend a well designed coding and classification will result in the benefits listed in Table 3.

Kamrani and Parsaei's paper presents a two-phase methodology for the formation of cells (73). Phase I of the study uses a coding system called KAMKODE to develop part families (Kamrani and Parsaei 500). The KAMKODE is an eighteen digit number that gives

Table 3

Benefits of Coding and Classification Method

---

1. **It facilitates the formation of part families and machine cells.**
2. **It permits quick retrieval of designs, drawings, and process plans.**
3. **It minimizes design duplication.**
4. **It facilitates the accurate estimation of machine tool requirements and logical control.**
5. **It provides reliable workpiece statistics.**
6. **It aids production planning and scheduling procedures.**
7. **It improves cost estimation and facilitates cost accounting procedures.**
8. **It provides for better machine tool utilization and better use of tools, fixture and manpower.**

SOURCE: Computers and Industrial Engineering. Exhibit from "A Methodology for Forming Manufacturing Cells using Manufacturing and Design Attributes" by Ali K. Kamrani and Hamid R. Parsaei (1992).

information on both design and manufacturing attributes of the part. Each digit represents a different attribute of the part. Coding information can be obtained from a design and manufacturing data base. Table 4 shows a KAMKODE structure (Kamrani and Parsaei 73-77).

Kamrani and Parsaei present the code structure as a mixed combination of variable types (binary, nominal, and ordinal). The authors give a disagreement formula which gives a weighted dissimilarity measure between two parts. The formula is as follows:

$$D_{ij} = \text{SUMMATION}_k(W_k * d_{ijk}) / \text{SUMMATION}_k W_k$$

Where: W_k = weight assigned to attribute k; d_{ijk} = disagreement index between parts i and j for attribute k; D_{ij} = weighted dissimilarity measure between parts i and j.

Following the calculations of dissimilarity measures of parts, part families are identified using a 0-1 linear integer program. This program uses a technique that minimizes the sum of the dissimilarities between parts. Parts are then selected into families with similar design and manufacturing features. The constraints of the model are listed as: 1) each part is assigned to only one family; 2) the number of part families are selected by the user; and 3) parts are assigned to a family if and only if that family has been created (74-75).

Phase II of Kamrani and Parsaei's study involves the machines and tools that will comprise the manufacturing cells that are formed. An objective

Table 4

KAMKODE Structure

Design Attributes	Manufacturing Attributes
-General shape	-No. of processing step
-Material	-Processing sequence
-Maximum Diameter	-No. of processing machine
-Overall length	-Process machine type
-Inside hole diameter	-No. of tool
-Product type	-tool type
	-No. of fixture
	-Fixture type
	-No. of end operation
	-End operation sequence
	-No. of E.O. machine
	-E.O. machine type

SOURCE: Computers and Industrial Engineering. Exhibit from "A Methodology for Forming Manufacturing Cells using Manufacturing and Design Attributes" by Ali K. Kamrani and Hamid R. Parsaei (1992).

function is created by the authors that minimizes the total cost for machine investment, fixture investment, tool investment, material handling, inspection, setup, and machine operation. The constraints of the model are: 1) the limit of the expenses based on the available budgets set for machine, fixture, tool, inspection and material handling by the firm; 2) capacities of machine types assigned to each cell are not validated; 3) tool life of each tool type; 4) guaranties the required number of fixtures for each machine type, since each duplicated machine requires matching number of fixtures; 5) the maximum number of parts allowed in a cell for flexibility; 6) each part family is assigned to one cell, and assignment of all members of a part family to one cell is guaranteed; and 7) the integerality and binary results of the decision variables (75).

The authors develop a pascal program to generate a 0-1 integer formulation and mixed-integer formulation for the two phases (75). Each part code is entered into the program for phase I. Cost information, machine-part, fixture, tool, operation and family matrixes are entered for the mixed-integer formulation of phase II. These formulations are then solved by a LINDO software package (Kamrani and Parsaei 75).

Setup Time Reduction

The reduction in setup time within the manufacturing cell should be carefully planned for during the design of cells. Jordan and Frazier believe that many present cellular manufacturing concepts and methodologies for cell formation do not achieve full benefits because setup time reduction is not the primary objective. The authors state that the reduction in setup time results in further benefits. These benefits are the economic justification of smaller lot sizes, leading to reduced work-in-process and queue times, which leads to reduced throughput times. All these benefits result in faster response to market and lower finished goods inventory. This leads the authors to state that setup time reduction should be the primary objective of cell design (70).

Jordan and Frazier contend that setup times are sequence dependent. That is, by sequencing parts requiring similar operations, some of the previous setup operations can be used by the previous part, thus eliminating the setup procedure. Cellular manufacturing should utilize sequence-dependent setup times in order to insure a reduction in setup time (70).

The authors believe that cell formation methods with objectives other than setup time reduction can undermine the multiple benefits of cellular manufacturing. These methods can result in parts with similar setup operations being assigned to different cells. The study gives the following examples of different objectives for cell formation: the number of inter-cell transfers, the number or cost of exceptional parts, the number of exceptional elements in the machine matrix, machine utilization imbalance between or within cells, or to maximize capacity utilization (Jordan and Frazier 70).

Jordan and Frazier believe the approach most often taken in cell formation is the exploitation of part similarities and machine requirements. For setup time reduction to occur, two parts must use the same machine. This does not mean that setup time reduction will automatically occur just because they use the same machine. Therefore, methods using only part similarities and machine requirements can group parts with little or no setup similarities (70).

The authors suggest using sequence dependent setup times in cell formation and cell scheduling. The study examines a matrix for determining sequence-dependent times presented by Foo and Wagner. An example of this matrix is given in Figure 6. From this matrix, a specific sequence of parts that has the lowest amount of setup times can be determined (Jordan and Frazier 71).

Jordan and Frazier continue by stating companies must analyze setup operations for each ordered pair of parts. Companies need to determine standard setup times for machine loading and planning. The standard time is the time required to setup the particular machine for a part when there are no shared operations with the proceeding part. This is the worst case setup time. The comparison of actual setup times for a part with the setup operations of another part will identify

Figure 6

Sequence-Dependent Setup Times Matrix

Current Part Number

	1	2	3	4	5	6	7	8
1	-	2.0	3.1	1.0	1.8	1.7	2.0	2.1
2	1.6	-	3.1	1.1	0.0	0.8	1.2	0.4
3	3.0	1.4	-	1.3	1.8	0.0	2.0	2.1
4	1.0	0.7	1.3	-	0.2	1.9	1.4	0.7
5	1.7	0.0	3.1	0.9	-	1.9	2.0	2.1
6	1.7	0.8	0.0	0.7	0.6	-	1.2	2.1
7	1.5	1.0	0.2	1.3	1.8	0.0	-	0.8
8	2.1	1.0	3.1	1.3	0.8	1.9	2.0	-
	3.0	2.5	4.0	1.3	2.0	2.1	2.0	2.4

Standard Setup Time

SOURCE: <u>Production & Inventory Control</u>. Exhibit from "Is the Full Potential of Cellular Manufacturing Being Achieved," by Paul C. Jordan and Gregory V. Frazier (1994).

those parts that share the same operations. In Figure 6, each number shown is the time required to setup for a part (current part) when it is proceeded by the part listed in the left hand column. The standard setup time for each part on this machine is given in the last row (71).

The authors give an example to illustrate how the matrix would be created. Parts #7 and #2 require processing on this particular machine. Part #2 requires 2.5 hours of setup time on this machine when a part that is totally dissimilar (standard setup time by definition) proceeds it on the machine. If part #2 is proceeded by part #7, the setup time for part #2 is reduced to 1.0 hours. If part #7 is proceeded by part #2, the setup time is 1.2 hours. This process is continued until all the combinations of parts for this machine are listed. From this matrix, an operations manager can schedule using sequence dependency to plan for the least amount of setup time during the planning period (Jordan and Frazier 71).

Yang and Deane, in their study on setup time reduction, address the relationship between the reduction of setup time and performance improvement. This improvement is linked to a competitive advantage in the market place. Table 5 lists the intermediate consequences and competitive advantages of product setup time reduction. The study is conducted on a closed manufacturing cell which produces to stock rather than to order. This means that the cell produces to a predetermined and limited amount of products in batches for finished goods inventory or component inventory (413).

The authors of this study make the assumption for this research that arrival of product batches are stochastic (the expected rate of batch arrival is dependnt on total expected demand) and the total expected demand of these products can be forecasted with reasonable accuracy. Other assumptions are that due dates are set within the cell, and the objectives of the cell (closed cell) are the minimization of mean job flow through the cell and the minimization of job flow time variation through the cell. These objectives are directly related to the competitive advantages the firm offers in delivery speed and reliability (Yang and Deane 414).

Yang and Deane's research objectives are to address three issues. The first is the investigation of the general relationship between setup time reduction and major cell flow time performance measures (flow time, variance of cell flow time, and optimal product lot sizes). Second, the impact of demand rates and unit processing time (production parameters) on setup time reduction choices. Third, the research investigates the relationship between setup time reduction and competitive advantages. Finally,

Table 5

Improvements from Setup Time Reduction

Intermediate Consequences	Competitive Advantage
1. Reduced variance of job flow time.	1. Improved delivery reliability.
2. Improved queuing and flow time performance.	2. Stabilizing production scheduling and control activities.
3. Reduced optimal product lot sizes.	3. Reduced safety stock requirements.
	4. Improved delivery speed.
	5. Reduced WIP inventory.
	6. Fast response to market changes.
	7. Fast feedback to quality control.
	8. More flexibility in product scheduling.
	9. Better control of work flow.
	10. Efficient utilization of tooling and transportation.

SOURCE: European Journal of Operations Research. Exhibit from "Setup Time Reduction and Competitive Advantage in a Closed Manufacturing Cell," by Jiaqin Yang and Richard H. Deane (1993).

the issues discussed above are addressed for a heterogeneous product mix. The authors define a homogeneous product mix as one that includes products with similar setup and processing time requirements. A heterogeneous product mix is defined as one in which products have significantly different setup and processing times (414).

The study derives four propositions which focus on the relationship between setup time reduction and expected cell performance improvements. This relationship is measured in terms of job queuing time, variance of job queuing time, and the optimal product batch sizes that minimize mean cell queuing time (this means the minimzation of setup times between jobs). Propositions one through three assume a homogeneous product mix. Proposition four assumes a heterogeneous product mix (Yang and deane 415).

The propositions are as follows:

> **Proposition 1.** Expected job queuing time within the cell will decrease at a decreasing rate as product setup times are reduced. That is, there are decreasing marginal returns from setup time reduction, in terms of expected cell queuing times

> and flow time. (416)
>
> **Proposition 2**. The optimal product batch size that minimizes the expected cell queuing time will decrease at a decreasing rate as product setup times are reduced. That is, there are decreasing marginal returns from setup time reduction, in terms of optimal product lot size. (416)
>
> **Proposition 3**. The variance of job queuing times within the cell will decrease at a decreasing rate as product setup times are reduced. That is, there are decreasing marginal returns from setup reduction, in terms of job queuing time variance and flow time variance. (416)
>
> **Proposition 4**. The marginal queuing time improvement from a product setup time reduction is proportional to the product's work in process inventory level. Therefore, for two products in a given mix, the product which has a relatively higher WIP level will generate a larger marginal queuing time improvement from setup time reduction. (417)

An empirical examination is given to verify each proposition.

The authors then offer managerial implications derived from propositions 1-3. All three propositions backup the value of reducing setup times between jobs when moving from a traditional manufacturing facility to a cellular layout in a multiple item environment. The propositions re-enforce the benefits of setup time reduction (in terms of reduction of the mean and variance of batch flow time and reduction of the optimal batch sizes) for gaining a competitive advantage. Table 5 covers the potential competitive advantages. The authors offer a further breakdown of advantages by type of improvement. First, a reduction in flow time will improve delivery speed, reduce work-in-process (WIP) inventory, and improve response time to market requirements. Second, a reduction in batch flow time variance improves delivery reliability, stabilizes the scheduling of production, and reduces the amount of safety stock. Finally, The reduction in batch sizes gives better control of work flows, quicker feedback for quality control, increased efficiency of tooling, and more flexibility in planning and scheduling production (Yange and Deane 417).

In addition to the previously mentioned competitive advantages, Yang and Deane state that propositions 1-3 show a marginal cost of setup time reduction. This means the cost required to reduce the setup time an additional unit is increasing. Also, the marginal return from flow time improvement (with resulting savings) is decreasing. The authors therefore suggest there exists an optimal setup time reduction investment decision where the marginal cost and marginal return are balanced. The operations and accounting departments must get together to make this decision (417).

Yang and Deane propose four corollaries to proposition 4 concerning a heterogeneous product mix. They are stated below:

> **Corollary 1.** For two products that have identical batch processing time requirements, the product that has a relatively higher batch arrival rate will generate a greater marginal queuing time improvement from setup time reduction. (418)
>
> **Corollary 2.** For two products that have identical setup time and processing requirements, the product that has a relatively higher unit arrival rate will generate a greater marginal queuing time improvement from setup time reduction. (418)
>
> **Corollary 3.** For two products that have identical batch arrival rates, The product that has the relatively longer batch processing time will generate a greater marginal queuing time improvement from setup time reduction. (418)

> **Corollary 4**. For two products that have identical setup time requirements, the product which has a relatively larger mean processing workload will generate a greater marginal queuing time improvement from setup time reduction. (418)

The authors show that different circumstances in each corollary contributes differently to work-in-process inventory and flow time in a heterogeneous product mix environment. These corollaries illustrate the fact that when the objective is to reduce batch flow time through reduced setup time, the effort should focus first on the product that contributes the largest amount to work-in-process inventory. The corollaries describe situations involving batch arrival rate, unit arrival rate, batch processing time, and mean processing workload. This information provides a guideline for managers when allocating limited capital resources among products for the purpose of setup time reduction (Yang and Deane 418).

Loss of Pooling Synergy

The conversion of a functional layout to a cellular manufacturing layout can result in a significant loss of pooling synergy (Sunresh and Meredith 466). Sunresh and Meredith provide a paper that studies the impact of several measures to overcome the loss of synergy. The synergy lost is the ability of a group of similar machines to rapidly process a large batch of parts. The authors state that partitioning of a functional layout can have an adverse effect on flow time, work-in-process, and machine utilization. Adil, Rajamani, and Strong agree stating cellular systems perform more poorly in terms of work-in-process inventory, average job waiting time, and job flow time than improved job shops (330). These effects can be eliminated by a reduction in setup times and lot sizes (Sunresh and Meredith 466).

Sunresh and Meredith contend that performance of cellular manufacturing may be inferior to an efficient functional layout under many parameter ranges. They state that the loss of pooling synergy that occurs when a functional layout is partitioned into a cellular layout can be great. This loss negatively effects flow time, work-in-process, and machine utilization. The claim is defended by studies conducted by Leonard and Rathmill. In addition, Morris and Tersine demonstrate that an efficiently operated functional layout achieves better flow time and work-in-process. The study investigates how the adverse effects can be overcome by lot sizing, reduction in setup time, reduction in the variability of processes and job arrivals, and the reduction in processing times through productivity improvements (466).

Sunresh and Meredith quote previous studies that have indicated achieving the benefits of cellular manufacturing requires that setup time within the cell must be reduced significantly. In addition, the authors quote studies conducted by Karmarkar showing low lot sizes and larger cells are also required for cellular manufacturing to compare favorably with an efficiently run functional layout. The objective of the author's study is to investigate the impact of other improvements (other than the reduction in setup time and smaller lot sizes previously discussed), such as reduction in the variability of job arrivals, reduction in processing times and productivity improvements, and for coping with the loss of pooling synergy (467).

The study first uses analytical models to determine insights into the problem. A single work center is the format considered for the investigation. First, a functional layout system is improved to become an efficient functional layout. Then five cellular manufacturing systems are considered to investigate the effects of setup time reduction, lot sizes, variability in job arrivals and process times, and productivity improvements. A simulation is then run to compare the analytical results with an actual trial (Sunresh and Meredith 467).

The simulation compares an unpartitioned system (efficient functional layout) with five partitioned systems (cellular manufacturing layout). The first partitioned system dedicates one machine to each part family and the effects of partitioning and setup time reduction due to part family similarities. The second partitioned system uses processing times based on general distribution. This system is used to investigate the effects of reducing process time variability, in addition to lot sizing and setup time reduction. The third partitioned system is used to show the effects of reduction in the variability of job arrivals. The fourth partitioned system is used to check the effect of process times being reduced as a result of productivity improvements. Finally, the combined effects of all of the previous partitioned systems are investigated in partitioned system number five (Sunresh and Meredith 468).

The analytical models of Sunresh and Meredith show improving a functional layout to an efficient functional layout significantly improved flow time and WIP inventory. But, the improvements that were gained from a comprehensive and complete implementation of a cellular manufacturing layout were clearly greater. The improvements gained from the fifth partitioned system (cellular manufacturing system completely and comprehensively implemented) ranged from 42% to 89% better than the unpartitioned system in the lower lot size region. In higher lot size regions, cellular manufacturing systems still out-performed efficient functional layout systems with moderate setup time reductions. The results of the simulation showed a statistically significant agreedment with the analytical models (480).

The authors conclude that of the five partitioned systems that were studied, the reduction in setup time and improved productivity, resulting in better processing times, has the greatest effect of overcoming the loss of pooling synergy. Reducing lot sizes, variability in processing and interarrival times have a lesser impact. But, it is also stressed by the authors that the combinations of all of the above mentioned should be applied in the conversion of a functional layout to a cellular manufacturing layout if the adverse effects of partitioning are to be overcome (Sunresh and Meredith 481).

Worker Assignment

Askin and Iyer conducted a study investigating and comparing three different approaches to assigning workers to tasks and controlling jobs as they flow through a manufacturing cell. The objective of each approach is to minimize the throughput time of batches of parts. The three approaches studied are: 1) individual machine loading with batches being sequenced on a first come, first serve basis; 2) a cell dedication strategy where a cell is devoted to a single product type at a time; and 3) a job enrichment strategy where each batch is assigned to a single, cross trained operator who must perform all batch operations. Each approach is compared and studied by queuing approximations and a simulation under a variety of conditions (438).

Askin and Iyer investigate three scheduling approaches in their study. The approaches are: 1) traditional machine-based; 2) loading the cell as a multiproduct system; 3) and a worker oriented, cross training based strategy. The approaches are compared by the authors with analytical approximations and a simulation experiment. Table 6 lists the assumptions made for this study (439).

The authors then describe the conditions for each scheduling strategy. The machine-based batch loading strategy begins with parts waiting in a central dispatch area outside the cell until space becomes available at the first machine in the cell (i.e. the machine becomes idle). The cell's queuing discipline for jobs is first come, first serve. Workers within the cell are assigned to machines as long as there is work to be completed at the machine. When the work at the machine is complete, the input queue is checked out by the worker. If the worker finds a batch waiting, they begin immediately working on that batch (queued jobs at the machine take precedence over jobs in the central dispatch area). If the worker finds the queue at the machine empty, they go to the central dispatch area for reassignment. The worker then goes to a machine that is not occupied and has a queue waiting. If a situation occurs with multiple machines with waiting queues, the worker will be assigned to the machine with the longest queue. When cells have more machines than workers, they are treated as a limited resource. The authors intend this strategy to mirror traditional manufacturing shop scheduling (440).

Askin and Iyer then define the strategy of dedicated cell loading. In this strategy the cell is dedicated to one part type at a time. The batch size to be transferred through the cell is one. As soon as a machine completes the process required, the part

Table 6

Manufacturing Environment Assumptions

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1. **The manufacturing system is serial in nature although not all parts require all machines in the cell.**
2. **The arrival rate of jobs is a stationary Poisson process. Each arrival is a batch of parts with all parts in the batch being of the same nature.**
3. **Multiple part types may be produced in the cell, but arrivals are independent in terms of part type.**
4. **All parts belong to the same family therefore setup times are sequence independent.**
5. **Machines can process only one part at a time and once an operation is begun at a machine it is not interrupted.**
6. **Machines do not break down.**
7. **Machines can operate only when an operator is present.**
8. **The first two moments of all machine service time distributions are finite and mean service times are less than mean interarrival times for batches (there exists adequate capacity).**

SOURCE: European Journal of Operations Research. Exhibit from "A Comparison of Scheduling Philosophies for Manufacturing Cells," by Ronald G. Askin and Anand Iyer (1992).

moves on to the next machine and the next part from the batch is started at this machine. Therefore, the batch is being simultaneously produced at different machines until it is completed. The cell appears as an assembly line system. When the last part of the current batch finishes at the first machine, that machine begins setup for the next queued batch. The next batch waits at the central dispatch area until the first machine has completed setup (Askin and Iyer 440).

The authors then define the worker-batch assignment strategy. This strategy is designed for high quality-oriented manufacturing cells with cross trained workers. Each batch that enters the cell is assigned to a single worker. The worker that is assigned to the batch will be responsible for taking it through the cell and completing all the operations required. To expand, the worker takes the batch to the first required machine. They then complete the required operation on all the parts in the batch. The batch is then taken to the next required machine and the operation is again completed on all the parts in the batch. This is continued until all the operations are completed on all the parts in the batch. If the worker takes the batch to the next required machine and it is not available (it is in use), The worker can switch to work on another batch that has been assigned to them (Askin and Iyer 440).

Askin and Iyer compared these strategies by using analytical approximations and an experimental comparison. The numbers of machines, setup times, and cell utilization were all varied to compare the strategies under different conditions. The worker-batch assignment was tested with workers allowed to have one, two or four batches assigned at one time (445).

The authors found that the scheduling strategy can have a major impact on the throughput time of a cell. In cells with multiple machines, the best scheduling strategy depends on machine utilization, lot sizes, and quality requirements. It was found that in most cases that dedicated cell loading strategy was the best choice. When batch flows become random, this strategy becomes less dominating but still performs better than the machine-based batch loading strategy. The dedicated cell loading strategy also performs better as lot sizes increase. But this strategy loses some of its advantages when setup times increase relative to unit processing time. Dedicated cells do fail in high utilization situations. The experimental comparison highlighted this problem. A five-machine cell with 90% utilization resulted in the waiting time being less than the machine processing time. Here, the dedicated cell could not handle the demand (Askin and Iyer 447).

Askin and Iyer also determined that the worker-batch assignment strategy performed well except in high machine utilization situations. To avoid worker blocking, the research suggests that workers be assigned several batches at a time so they can switch batches if a required machine is occupied. The dedicated cell loading strategy was the best performer when all the machines in the cell were occupied. However, it was out performed every time by the worker-batch assignment strategy (with workers assigned to four batches) when the cell did not require all the machines to be occupied by workers. Askin and Iyer state that this suggests a combination strategy could be used in partially manned cells where workers take responsibility for more than a single operation.

Problems with Cell Layout

Many problems can arise when designing manufacturing cells, and management needs to be prepared to solve them. Exceptional parts and processes is one of those problems. Choi defines exceptional parts as those that do not fit a part family after the families have been formed or require an exceptional process like heat treating or chemical processing (67). This problem can be minimized by reengineering the product design to better fit a part family or the part can be purchased from a vendor (Choi 67).

Another problem that can occur in cell design is machine shortage. The easy answer to this problem is to purchase additional equipment. But if the capital is not available, there are some other solutions. Choi suggests that if two cells require the same short machine, the cells can be combined into one cell (67). Alternatively, the short machine could also be located between the two cells to be shared by both (Choi 67). Both of these methods avoid the additional investment but sacrifice material flow and control within the cells. Managers must weigh the cost and benefits of the alternatives.

When the purchase of additional machines is required, the problem exists of what capabilities the machine must posses. There is no reason to purchase a sophisticated machine when a simple machine can perform the task. Choi suggests the purchase of inexpensive single purpose machines for the cells (68). The advantages of this option are the maintaining of autonomy of individual cells resulting in reduced setup times and simplicity of manufacturing (Choi 68). The following factors should be considered when purchasing new machines: 1) the cost of the machine, 2) tangible benefits from improved productivity and quality, 3) training costs, and 4) the potential losses of flexibility in future cell readjustments (Choi 68).

Choi also discusses the difficulty with rearranging special processes and very heavy or anchored machines (68). These situations often occur because of environmental constraints, physical constraints, and specialized capital equipment (Choi

68). Ferras lists the lack of funds for facility expenditures required to move large equipment as another situation that can cause problems (3). Managers need to decide how to design these special processes into the cell. Choi suggests creating a common work area where these processes and machines are located (68). As material is moved through the cell, and it requires a special process, the material is sent to the common work area. If the number of parts that require the special process is small, they should be sent to the work area and then returned to the cell to continue throughput (Choi 68). If many of the parts require this special process, the cell should be split into two cells before and after the process instead of sending the parts back and forth to the work area (Choi 68).

Preventive Maintenance

With the change from traditional factory layout to a cellular manufacturing layout comes new challenges for machine maintenance. Bateman defines three types of maintenance which are reactive maintenance, preventive maintenance, and predictive maintenance (19). Preventive and predictive maintenance are proactive in nature and offer advantages such as reliable production capacity and reduced maintenance cost (Bateman 19). Bateman defines preventive maintenance as the regularly scheduled process of performing certain types of maintenance, inspections, adjustments, and lubrications on a machine (19). Table 7 lists the objectives of preventive maintenance.

Bateman defends preventive maintenance by contending that it is cheaper to repair or replace a component before it fails. He writes that when a component on a machine fails it is normally catastrophic in nature and causes further collateral damage beyond the failed component. Preventive maintenance provides a savings point in this instance (19).

Bateman believes that for preventive maintenance to be effective there must be a defined schedule in place. This schedule should detail the types and frequency of maintenance activities to be performed (19). Management must be disciplined in strictly abiding to the schedule if the objectives are to be met.

The problem with conducting maintenance is the machine to be worked on must be idle in order to perform the activity. This is not a big problem for traditional factory layouts because when one machine in the functional block is down, a similar machine in that block can perform the needed operation during the down time. In cellular manufacturing there is a much

Table 7

Objectives of Preventive Maintenance

1. **Reduce the incidence of breakdown or failure of equipment.**
2. **Extent the useful life of production machinery.**
3. **Reduce total maintenance cost by substituting preventive maintenance cost for repair cost.**
4. **Provide a safe working environment for employees.**
5. **Improve product quality by keeping equipment in proper adjustment, well serviced and in good operating condition.**

SOURCE: Industrial Management. Exhibit from "Preventive Maintenance: Stand Alone Manufacturing Compared with Cellular Manufacturing," by Jon F. Bateman (1995).

greater problem. When a single machine within the cell is down, the entire cell is out of operation. Therefore, timely scheduling of preventive maintenance in a cellular manufacturing environment is required if there is not to be an interruption in production.

Each machine in the cell is critical to the operation of the cell as a whole and hence the need for a preventive maintenance program to keep any of the machines from breaking down. Bateman believes that the entire cell (all the machines in the cell) should be scheduled for preventive maintenance rather than each individual machine (21). There are several methods for scheduling preventive maintenance with the least amount of production interruption possible.

The first is to schedule the maintenance on off shifts or single-shift operations when the cell is not in operation. A second scheduling possibility is to conduct the maintenance on all of the machines in the cell when one machine breaks down. This is effective because the cell can not perform anyway so all the other machines in the cell will be idle. The third possibility is to schedule the maintenance on major factory shut-downs such as holidays. A final possibility offered by Bateman is to enter a dummy part number into the production schedule. When the dummy number comes up to be run, the cell will be clear for the preventive maintenance required because the time required to conduct the maintenance will be entered as the dummy part's cycle time in the production schedule. A preventive maintenance program is key to the successful implementation of cellular manufacturing (Bateman 21).

Labor Issues

The previously mentioned approaches to manufacturing cell design and implementation have for the most part not considered the human interface. Faizul recognized the lack of human interface and the absence of time and motion studies in cell design studies and states that this could lead to loading and scheduling problems (16). The optimal part/machine/cell combination may not be achieved if operator capacity is not considered.

Faizul quotes Slocum and Sims stating that when converting from a conventional process-oriented manufacturing to a more advanced manufacturing technology (cellular manufacturing), managers must consider several factors from the worker's point of view: 1) the amount of cooperation required between coworkers; 2) new amounts of information processing and decision making required; 3) new work environment; and 4) the psychological factors of the growth needs of workers. The new task design will center around self regulated groups within the cell whose members must have the skills, information, and autonomy to control technical and environmental variances as close to the production as possible (16).

Selection and training of workers for a cell should include several factors. Faizul suggests that selection practices should be aimed at workers with high growth needs. That is, workers who want to continually improve and learn new skills (Faizul 16-17). Training programs should provide workers with multiple skills, and reward and compensation systems should promote learning skills (Faizul 16-17). Once the proper workers have been selected for the cell, a training strategy for skills upgrade should be started (Faizul 17). Because this training will take time, it should be considered early in the cell design stage. Faizul suggests that any training program should meet the following criteria: an increase in the standard and competence of the worker being trained, a broader base in the training with the aim of producing multirole/multiskill workers, and increased training in techniques aimed at developing analytical abilities for evaluating and using information (17).

Compensating the team of workers within the cell must be carefully considered. Should each individual be compensated separately or should the team be compensated as a group? Zuidema and Kleiner believe that although individual effort must still be recognized, compensating each individual in the group separately would be in direct conflict with the team concept. They believe this type of merit pay would require the supervisor to differentiate between team members (23).

Zuidema and Kleiner offer several compensation ideas. The first is starting team workers at a base salary and rewarding them with raises as skills are learned. Similarly, a team-based training pay would be offered to a worker and as new skills are learned, their pay is increased. Another suggestion is having only two rates, a learning rate and a team rate. The authors also believe there should be a team reward system where performance (based on improved profitability or cost savings) improvements with-in the cell are recognized with compensation shared by the group. There is very little hard research in the area of motivating cellular manufacturing teams. The authors offer only suggestions but no empirically tested methods (24).

Plant supervisor's roles will change in a cellular manufacturing environment. Faizul states that they will need to make a transition towards dealing with system problems which include for example equipment failure and material shortage (17). The supervisors will become trouble shooters whose roles will be enhanced to include the use of information and control systems as aids to human decision making for coordinating production across functional boundaries

(Faizul 17).

Unions will have to be considered when moving to cellular manufacturing. Faizul suggests unions should be informed that the reason for the change to cellular manufacturing is a response to competitive pressures in price and quality (17-18). It must be communicated to them that a change causing some loss of jobs and reduction in wages is better than the failure of the company and the resulting loss of all the jobs at the company. It must also be communicated to the union that the change is a move to increase market share which would result in the employment of more union personnel.

Reason for Manual

The conversion of a traditionally functionally laid out factory to a cellular manufacturing layout requires the incorporation of many factors. Cellular manufacturing is very complex and must be planned for carefully if it is to be implemented properly. There are many benefits of cellular manufacturing that can be obtained but only if the proper steps are taken in the design and implementation stage. If the proper steps are not followed, the negative effects of partitioning a factory floor will erode the benefits obtained from cellular manufacturing.

The following plan for the design and implementation of cellular manufacturing is a general guideline of all the factors that must be considered when preparing the conversion. The plan is not industry specific but covers all aspects of the conversion in a manufacturing environment. It must be recognized that every manufacturing environment is different and specific implementation factors will be company unique, but to achieve the benefits of cellular manufacturing, the concepts covered by the plan need to be considered.

Chapter III

METHODS AND EVALUATION

Materials

The Guidelines for the Implementation of Cellular Manufacturing (Appendix A) is created as a set of guidelines for the transformation of a functional factory layout to a cellular manufacturing system. The purpose of the manual is to give a project team the basic factors that must be addressed if the benefits of cellular manufacturing are to be achieved. The manual is not industry-specific with regard to design details. Rather, it gives guidelines on all relevant factors that must be addressed during the transformation. Each industry/company's manufacturing environment is unique, but all the factors covered by the manual must be addressed in any cellular manufacturing system.

The manual covers six factors involved in successful cellular manufacturing. The first factor is cell design. Step one in cell design is the formation of part families. Coding and classification methods are discussed as a means to part family development. The benefits are also listed from using this type of system for the development of part families.

Step two in cell design covers physical design of the cell around each part family. The u-shaped nature of the cell is discussed as well as partitioning the factory's functionally grouped machines into cells. Illustrations of cellular production flow, a cell on paper, and an example of an actual cell are given to help the team visualize cellular manufacturing.

The manual then covers problems that can arise when cells are designed. The first problem pertains to exceptional manufacturing processes that require a part to leave a cell to be finished. Heavy equipment, safety and physical constraints are cited as reasons for this problem. Two options are given as solutions to this problem: sending the parts to the special process area and then back to the cell or split the cell in two, one before the process and one after it. The second problem discussed is parts not fitting into a family because of a unique attribute or processing requirements. This situation is resolved by reengineering the part or purchasing it. Finally, machine shortage during cell design is discussed. Again, there are two solutions covered. The first is to change the cell design to either share the machine between the two cells or combine the two cells into one. The second solution is to purchase additional machines to complete the cells as designed. Guidelines are then given on what types of machines should be purchased.

The manual then discusses the reduction in setup time required to achieve the benefits of cellular manufacturing. The consequences and resulting benefits are then listed to illustrate the importance of the reduction in setup time. The two steps involved in setup time reduction are then covered.

The first step is making the choices, under budget constraint, on how to spend the capital for machine improvements. There are two ways to attack setup time reduction through machine improvement. The first is to improve cell flow time performance. The manual gives four guidelines which discuss the cost increases as setup time is reduced for each additional unit and the marginal return from flow time improvement is decreasing. This reveals that there exists an optimal setup time reduction investment decision.

The second area to attack setup time reduction through machine improvement is concentrating on parts that have high demand or long processing times. The manual gives four guidelines for allocating capital to parts in order to get the best results. The guidelines indicate the most capital should be spent on parts that contribute the most to work-in-process inventory.

The next step in setup time reduction (after machine improvement) entails establishing sequence-dependent setup procedures. The manual covers the construction of a sequence-dependent setup time matrix. This matrix gives setup times for each part in a family if it were proceeded by every other part in the family. A numerical example of a matrix is given to illustrate how one is created and what it looks like. The manual then discuses how the cell members can use this matrix to schedule the cells work flow to require the least amount of setup time possible during the planning period.

The manual then covers worker assignment within the cell. Two approaches are explained in detail. The first is a dedicated cell-loading method. This method dictates that the cell is setup for and runs only one particular part batch at a time. Parts go through the cell one at a time until the entire batch is complete.

The second method is worker batch assignment. This method assigns one worker to an entire batch of parts. The worker takes the batch through the cell completing all required processes. The worker completes the required processing at each machine on the entire batch before moving to the next machine.

The manual then describes the situations that dictate which method to use. The worker batch assignment method works best in very high quality manufacturing and in cells where all the machines are not simultaneously manned. The dedicated cell loading method works best in large lot size situations as well as in cells where volume dictates all machines being simultaneously occupied.

Preventive maintenance is then covered. The manual discusses the importance of keeping machines running in a cell. This is important because if one machine fails the entire cell is down. The scheduling of preventive maintenance is outlined in this section. There are four methods of scheduling preventive maintenance to limit down time. First, schedule the work to be completed during down times (nights or weekends). Second, conduct the maintenance on the entire cell when one machine breaks down. Third, schedule the work on major factory shut downs (holidays). Finally, enter a dummy part number in the production schedule. The preventive maintenance will be conducted when this part number is scheduled.

The final area covered by the manual is labor issues. This is a very important area in cellular manufacturing because the team of workers within the cell will have the autonomy to make key decisions. The selection of the workers to make up the team is discussed first. The characteristics of the workers are listed as high growth needs, willingness to learn multiple skills, and positive reaction to compensation packages that reward learning new skills.

The training program for the workers selected is covered next. The criteria that a training program should cover is giving a worker an increased standard of competence, producing multirole/multiskill workers, and develop analytical abilities for using information.

Finally, the manual covers the compensation package for team members within the cell. Workers start at a team based training salary. As the worker learns skills, they are given raises. In addition, a team shared bonus is given for improve cell profitability or cost saving measures.

Subjects

Three evaluators critiqued the manual. Two of these individuals are purchasing managers. The other is an operations manager. Their diverse education and work experience provided in-depth feedback on the validity of the manual.

The first evaluator is James P. Reagan. Reagan received his Bachelors in Business Administration with a major in Management Science from the University of Missouri. Reagan is also a member of the National

Association of Purchasing Managers (NAPM) and is CPIM certified. He currently is a Purchasing Manager for Coin Acceptors, Inc. in St. Louis. Fifteen years of experience in operations and purchasing management in various industries has given him a wealth of knowledge in the manufacturing sector on cellular manufacturing.

The second evaluator is Brian Fergason. Fergason received both his Bachelors in Business Administration with a major in Economics and his Masters in Business Administration from the University of Missouri. Fergson currently is a Purchasing Manager at MEMC Electronic Materials. He also has fifteen years experience in various industries and companies that utilize cellular manufacturing.

The third evaluator is John Meier. Meier has a Bachelors of Science in Industrial Engineering from the University of Missouri. Meier is currently the Production Coordinator at Buckeye International where he has eight years of production scheduling/industrial engineering experience. An industrial engineer, Meier brings technical and scheduling expertise to the evaluation of the manual.

Instrument

The manual was evaluated using a self-designed questionnaire (Appendix B). The questionnaire is designed to gain feedback on the validity/correctness of each factor in the manual. It is also designed to test the manuals ability, as a whole, to solve the problems associated with the implementation of cellular manufacturing. Questions 1, 2, 4-10, 12, and 14-18 ask if the manual is correct or complete in its nature. Questions 3, 11, 13, 19 and 20 ask for additional information in the mentioned areas.

Procedure

A cover letter (Appendix C), questionnaire and the manual were mailed to each evaluator. The evaluators were asked to read the manual and complete the questionnaire. The answers will then be mailed back to the author in a self addressed stamped envelope for evaluation. The evaluators were given one week to read and evaluate the manual.

The data will be tabulated by each question that asks about the correctness/completeness of the manual (questions 1, 2, 4-10, 12, and 14-18). For each question, the number of positive responses (meaning the manual was correct/complete) are listed and the number of negative responses (meaning the manual was not correct on incomplete) are listed. The other questions on the questionnaire are used for further discussion. Any questions that arose from the questionnaire were resolved with follow-up telephone interviews.

Chapter IV

RESULTS

The results are segregated by each of the six factors covered in the manual: cell design, special problems, reduction in setup time, worker assignment, preventive maintenance, and labor issues. In addition, a section of the chapter provides the evaluators overall comments on the manual as a whole. Table 8 provides a list of question numbers that have an agree or disagree answer about the manual. The number or the question is on the top row. The name of the evaluator is in the left column. If the evaluator agreed the manual covered correctly what was asked in the question, an "A" was placed in the appropriate box. If the evaluator thought the manual did not adequately cover what was asked by the question or the manual was in error, a "D" was placed in the appropriate box.

Cell Design

The first two questions on the questionnaire

Table 8

Questionnaire Responses

	1	2	4	5	6	7	8	9	10	12	14	15	16	17
Reagan	A	A	A	D	D	D	D	D	A	A	A	D	A	D
Fergu.	A	A	A	A	A	A	A	D	A	A	A	A	D	A
Meier	A	A	A	A	A	A	A	D	A	A	A	A	D	A

covered cell design. The first question asked if the coding and classification method of choosing part families was an appropriate method. Reagan and Fergason agreed, both citing that process attributes (machine/tooling) follow design attributes in cell design. Meier also agreed with this method but added two insights. First, after the computerized coding had been completed, it should be reviewed by a manufacturing engineer and experienced production workers to validate the findings. Second, this type of method would not be necessary in a manufacturing environment where only a limited amount of products were being produced and groupings are readily obvious.

The second question asked the evaluators if the diagrams in Figure 3 of the manual make the physical layout of a cell clear. All three evaluators agreed that the figure is clear but Reagan suggested these are too restrictive. He gave more detail of this problem later in the questionnaire.

Special Problems

Questions number three and number four addressed the area of the manual which covers problems that can occur when setting up cells. Question number three asked the evaluators if they had experienced or knew of other problems besides those mentioned. Fergason had not, but Reagan and Meier had comments here. Reagan commented on the restrictive and wasteful nature of U-shaped cells. He stated that a factory full of these U-shaped cells leaves a lot of unused space. The waste occurs where two closed ends of two cells come together. Reagan said this could be eliminated if cells were made into straight lines (assembly lines). Meier believes that problems will occur if the type of worker assignment within the cell is not taken into account when the cell layout is planned. His concern lies in the inter-cell movement of workers during cell operation.

Question number four asked the evaluators to comment on the solutions offered by the manual. Reagan said the manual offers too many general answers to problems which would be company specific, depending on each case. Meier suggested that a common work area may not be feasible if the machines can not be positioned there due to physical restraints. He also added the common work area might become disruptive if a dedicated cell strategy was used. Fergason added a solution to the problem of a part not fitting into a family. He suggested a portion of the factory be set aside for the production of this part.

Reduction in Setup Time

Questions number five, six, seven and eight focused on the manual's coverage of setup time reduction. Question number five asked if the manual is correct on the subject of setup time reduction through improved cell performance. Reagan stated the manual is incorrect. He claims that process control should be addressed before setup time reduction or scrap will be produced faster. Meier and Fergason agreed with the manual, with Fergason adding that simplicity in machine design and commonality of machines will also reduce setup time.

Questions number six, seven and eight deal with the sequence-dependent setup time matrix offered by the manual. Question number six asked the evaluators if the construction of this matrix is feasible. Reagan answered negatively, citing that too much skill would be required by the cell workers. Fergason and Meier said it was feasible, but both stated that with many parts it would be very cumbersome because of the time studies required.

Question number seven asked if the use of this matrix is possible in high volume manufacturing. Fergason said yes, but in longer runs delivery requirements may dictate run sequence more than efficiency of set ups. Meier also agreed the matrix can be used in high volume situations with computer software aiding.

The last question regarding the sequence-dependent setup time matrix asked if the manual provides adequate instructions on the construction of the matrix. Reagan stated that he did not understand the manual very well. Meier and Fergason said the manual is clear but Meier suggested an example be included showing an actual schedule being developed with the matrix.

Worker Assignment

The next three questions number nine, ten, and eleven addressed the worker assignment section of the manual. Question number eight asked if the evaluator agrees with the two worker assignment methods proposed by the manual. Reagan agreed with using the dedicated cell-loading method, but disagreed with using the worker-batch assignment method. He disagreed with the worker-batch method because he believes the lack of process control would lead to workers clogging the cell during high volume efficient production. He also added that workers should be cross trained and rotated on equal intervals. Fergason's answer mirrors Reagan's. In addition to production disruption, Fergason added, the worker assigned to the entire batch could produce the entire batch out of spec before going to the next machine and discovering the error.

Meier gave advantages and disadvantages of both methods. For dedicated cell-loading, Meier listed low work in process inventory, work throughput, and high machine utilization as advantages. As disadvantages he listed complicated line balancing and the cell is more adversely affected by down time. For worker-batch assignment, Meier said the advantages are; better utilization of manpower, quality of parts, and the cell is less affected by machine down time. Meier goes on to say the big disadvantage of worker- batch assignment is the existence of work in process inventory. This lead him to question the improvement from a functional layout.

Question number ten simply asked the evaluators if the manual clearly explains the two worker assignment methods. All three evaluators agreed the manual sufficiently covered the material.

Question number eleven asked if the evaluators knew of other methods that may be a more appropriate form of worker assignment. Fergason and Reagan answered negatively. Meier made a suggestion that a combination of the two methods could be used in certain situations. The situation he discussed is one in which machines in the cell had significantly different processing. The cell would be operated in an assembly line fashion. As parts worked their way through the cell they would be queued at machines with long lead times which are preceded by machines with a short processing time. At this time, the worker on the machine with longer processing time would process the batch of parts that has built up in the queue. This would keep the work flow smooth and the line balanced.

Preventive Maintenance

Questions number twelve and thirteen addressed preventive maintenance in a cellular manufacturing environment. Question number 12 asked if the methods of scheduling preventive maintenance provided by the manual are appropriate. Fergason stated that he agreed with the methods and commented on the importance of preventive maintenance to keep cells running. Reagan also agreed, stating the importance of using down time to complete preventive maintenance. Meier again agreed with the methods, but believed the method of conducting preventive maintenance on all machines in a cell when one machine goes down would not work in a worker-batch assignment situation.

Question number thirteen asked if the evaluators knew of other scheduling methods for preventive maintenance. Meier did not know of other methods. Fergason suggested that if a part passing through a cell does not use a particular machine, that machine can have the maintenance preformed on it. Reagan suggested that temporarily idle cell team members can perform the maintenance.

Labor Issues

The questionnaire also focused on the labor issues in cellular manufacturing. Question number fourteen asked if the manual is clear on the criteria required for cell team members. All three evaluators responded with yes, but Reagan said the manual neglected to discuss the development of cell personality and team member contribution.

Question number fifteen asked the evaluators if they agree with the areas that must be covered in a training program. Each evaluator agreed with what the manual covered with Reagan and Meier adding some items. Meier added that cell members should be cross trained at each machine in the cell. Therefore, if cell members are missing, any member could operate the unoccupied machine. Reagan added that interpersonal and team building skills should be added to training for better team function.

Question number sixteen asked if the compensation program offered by the manual is appropriate for cellular manufacturing. Again all three evaluators agreed with the manual and Fergason made an additional suggestion. He said the compensation package should include significant incentives to reduce scrap and improve quality. He added that a bonus could be formulated to address this idea.

The remainder of the questionnaire, numbers sixteen through twenty, asked the evaluators to comment on the manual as a whole, and to add any additional areas that need to be addressed by the manual. Fergason stated that the manual covers the major areas of cellular manufacturing that he has experienced. He believes that two things need to be added to the manual for it to be more complete. The first is what cost accounting methods would be used with this style of manufacturing. Second, he suggested a study be conducted putting machine utilization versus cell utilization.

Meier also agrees the manual covers the six major factors involved in the transformation to cellular manufacturing. Meier believes the manual should cover some aspects of quality control. He said that a program should be in place before the transformation but will need to be modified for this new type of manufacturing. He also stated that cellular manufacturing would not be appropriate for all manufacturing situations and should not be forced if it will not run efficiently.

Reagan said the manual is "pretty good" overall. He stated the immediacy of feedback is the number one benefit of cellular manufacturing and it should be another factor covered. Reagan goes on to say immediate feedback can stop an out-of-tolerance process before scrap is produced. He said the cell should be autonomous and have the responsibility to produce quality goods. This allows the worker (in the cell) to develop a sense of pride because they see finished goods leave the cell and have some control of their destiny.

Chapter V

DISCUSSION

The manual (Appendix A) was written from various empirical studies as well as papers printed in scholarly journals. Most of the empirical studies were done by industrial engineers. There is a lack of research on cellular manufacturing conducted by business professionals. The feedback from the evaluators gives an insight from business professionals on how well the manual would perform in a real life business environment. The feedback is excellent and offers some suggestions which differ from the empirical studies.

The feedback from the evaluators on the manual's coverage of cell design was positive. All three evaluators agreed that a coding and classification system of grouping parts is an appropriate method judging from their experience. This is in agreement with the literature in that area. Meier also brought up a point which was added to the manual. After a software package has produced part families, an experienced operations manager should look at each family and determine if it is logical. This will further validate the findings. This is a very good idea and is critical to the success of the process.

The next portion of the manual discusses the problems that can occur when a factory is partitioned into cells. In general, the evaluators agree with the solutions offered to the problems mentioned in the manual, but Reagan believes the answers are too general for problems that would be company specific. This is true, but the purpose of the manual is to give general guidelines for solving specific problems. It would be impossible to list all the company specific problems that could arise.

Reagan also talked about another problem that is not covered by the manual. He said that a factory full of cells will have a lot of wasted space. This wasted space occurs where the rounded ends of two U-shaped cells back up against each other. The solution he offered is to set up the cells in straight lines as in assembly line fashion. This is a good point because it is critical that all space in a factory be utilized. Straight line cells do not go against cellular manufacturing philosophy and should not negatively affect the benefits obtained from it. Therefore, this option was added to the manual for facilities where space utilization is critical.

Fergason added a solution to the problem of a part not fitting into a part family. He suggested that a portion of a factory could be set aside to manufacture this special part in a traditional manufacturing fashion. This is a good idea if the part is important enough to be cost justified. An addition to the manual was made to incorporate this solution.

The manual then covers setup time reduction in cellular manufacturing. Meier and Fergason agree with all the points covered in the manual. Reagan believes that setup time is important but it is not the number one objective the manual states it is. Reagan believes that process control is the most important factor. He stated the cell's ability to stop an out of spec process immediately, before scrap is produced, is the most beneficial attribute of cellular manufacturing. This input by Reagan was added to the manual because it failed to address this issue adequately.

A sequence-dependent setup time matrix is suggested by the manual as a tool to reduce setup times in a cell. From the comments by the evaluators, it would seem as though this concept would not work. Both

Meier and Fergason believe it is possible to construct one, but it might not be feasible due to the time studies required to construct it and it would be cumbersome to use. Reagan believes the use of the matrix would only spread out the setup times, but not reduce them. Therefore, it seemed only logical, from the evaluators feedback, to remove the sequence dependent setup time matrix from the manual.

The manual then discusses worker assignment within the cell. The manual offered two approaches to assigning workers to jobs in a cell. The first is dedicated-cell loading. This method assigns a single worker to each machine in the cell. Parts would flow through the cell one at a time until the entire batch is processed (the lot size is one at each machine). The second method is worker-batch assignment. This method assigns an entire batch to a single worker who will take the entire batch to each required machine in the cell. The worker will complete the entire batch at a machine then move to the next machine until the batch has been completely processed.

All three evaluators agree with the dedicated-cell loading method. They believe this approach is the only way to reach the benefits of cellular manufacturing.

Reagan adds, this worker assignment method gives the process control that he believes is the most important aspect of cellular manufacturing.

Two of the evaluators strongly disagree with the worker-batch assignment method. The two evaluators are Fergason and Reagan. Their comments are nearly identical. They stress the loss of process control. If a worker assigned to a batch processes the entire batch out of spec at a machine, the entire batch is scrapped. They state that a dedicated-cell loading approach would have caught the out of spec process after only one part had been scrapped. The process could then have been fixed and production could have continued with minimal scrap. Reagan also added the cell would become clogged during high volume, causing loss of efficiency. It is clear the worker-batch assignment method is inappropriate, therefore, it was removed from the manual.

The manual then covered preventive maintenance. The evaluators had positive comments on this section of the manual. Meier, Fergason, and Reagan agreed with the methods offered by the manual. Fergason and Reagan each added a method that could be used to conduct preventive maintenance. Fergason suggested that if a part passing through the cell does not require processing time on a machine, then preventive maintenance could be conducted on the idle machine. Reagan suggested that idle cell team members could conduct preventive maintenance. Both of these methods are excellent and were added to the manual.

Finally, the manual discusses the issue of labor within the cell. The manual covers the criteria for cell team members, the training program, and a compensation program. All three evaluators agreed with the manual on what criteria should be looked for when selecting cell team members. The manual is clear and correct on what characteristics are required for effective cell team members.

On the issue of training cell team members, the evaluators agreed with what the manual suggested should be included in a training program, but Reagan and Meier had some additions that they believed need to be covered. Meier stated that each cell team member needs to be cross trained on each machine in the cell. Reagan agreed saying this allows any team member to cover for absent members and it allows for rotating team members between machines at regular intervals. Reagan also said the manual needs to include interpersonal and team building skills to the training program. Again, these three additions to the training program were added to the manual.

All three evaluators believe the compensation program is appropriate in the manual. Fergason made a suggestion that a bonus could be developed to reward cell team members for reduced scrap and improved quality. This is an idea that is not covered in literature and proved to be a valuable addition to the manual.

Summary

As illustrated by Table 8, the evaluators agreed with the majority of the manual. They did, however, highlight some deficiencies and offer some very useful additions that were made to the manual. The diversity of the evaluators (purchasing, operations, and industrial engineering) is key to the wealth of information they provided from their different prospectives.

There are two things that had to be removed from the manual. The sequence-dependent setup time matrix was be removed from the manual. All three evaluators strongly disagreed with its use contradicting the literature piece used for the manual. The feasibility of the matrix is in serious question in the real world.

The worker-batch assignment method of assigning workers to jobs within the cell was also removed from the manual. Two of the three evaluators disagreed with the method and therefore the literature in this area. They cite the loss of process control and cell work-flow disruption as the main reason for their disagreement. Those two areas are critical if the benefits of cellular manufacturing are to be achieved. Therefore, this method was removed as an option offered by the manual.

There were several valuable suggestions made by the evaluators that would improve the manual. The first is made by Meier in the cell design area. He suggested an experienced operations manager review the part families produced by the coding and classification software. This brings up a good point that part families need to be approved to assure they are logical. The second addition that needs to be made is one suggested by Reagan. Under the physical layout of the cell, he said space is wasted where the rounded ends of two U-shaped cells back up against each other. What was added to the manual is the option of laying out cells in a straight line as in assembly line fashion. This would more efficiently use space in situations where space is critical.

There are two items that were suggested by the evaluators that need to be added to the preventive maintenance scheduling section of the manual. The first was suggested by Fergason. He suggested that if a part passing through the cell does not require processing, preventive maintenance can be conducted on the idle machine. The second was suggested by Reagan. He suggested that idle cell team members conduct preventive maintenance. Both of these methods made positive additions to the manual because they take advantage of down time without disrupting production.

Finally, the evaluators made some suggestions that should be added to the labor issues covered by the manual. First, Meier suggested that cell team members be cross trained at each machine in the cell. This is important because the cell will still be able to operate when team members are absent. Second, Reagan suggested that interpersonal and team building skills need to be added to the training program described in the manual. Finally, Fergason suggested a bonus be added to the compensation package. The bonus is to be designed to reward cell team members for reducing scrap and increasing quality. All three of these suggestions were positive additions to the manual.

The evaluators all agree the manual has the ability to solve the problem, with a few deletions and additions mentioned above, of transforming a traditionally functional factory floor into a cellular manufacturing layout. Again, the evaluators agree the manual attacks the key factors that must be addressed if the benefits of this type of manufacturing are to be obtained.

Limitations

The biggest problem faced was data collection. There is limited printed research on cellular manufacturing. There are several factors involved with this type of manufacturing and in most cases there were only one or two empirical studies done in each area. This did not allow for verification of procedures and findings by other researchers. This was particularly true in the area of labor issues. There were no empirical studies conducted on training programs, selection of cell team members, or compensation programs. The literature found was a few articles making suggestions without empirical evidence to verify them.

Suggestions For Further Research

Given a chance to replicate the study, concentration on the labor issues involved in cellular manufacturing would be the focus of the study. There is very little research in this area. Primary research would be conducted using empirical studies to verify the most effective way to develop and manage the cell teams. There is a noticeable lack of labor variables in most empirical studies conducted on cellular manufacturing. This could be the result of most research being conducted by industrial engineers and not by business scholars/professionals.

APPENDIX A

GUIDELINES FOR THE IMPLEMENTATION OF CELLULAR MANUFACTURING

Todd E. Richter

October 10, 1995

TABLE OF CONTENTS

Introduction

The following manual offers guidelines intended to cover the major factors involved in the transformation of a functionally partitioned factory floor into a cellular manufacturing layout. This manual is not intended to give detailed plans for a transformation because of the diversity of industries/products and business operations. Its intent, however, is to cover broad factors that must be addressed if a transformation is to be successful.

The following six factors will be covered by this manual:

1) Cell design
2) Special problems
3) Setup time reduction
4) Worker assignment
5) Preventive maintenance
6) Labor issues

General guidelines will be given in each of these areas.

Cell Design

The first step in converting a functional manufacturing facility into a cellular manufacturing facility is the formation of part families. The type and number of different products being produced dictates the complexity of this process. The number and layout of cells is increasingly complex as the number of different products produced by a manufacturing facility increases. The formation of part families will require active participation of design/industrial engineers and operations managers. A coding and classification method should be used to identify parts that have similar design and manufacturing attributes. There are several software packages available for this (i.e. OPITZ, MICLASS, KK-3, and KAMKODE). Regardless of the package, a series of digits (18 or more) representing an individual part should be developed giving that parts unique design and manufacturing attributes.

The code should represent the following types of information:

Design attributes

- General shape
- Material required
- Diameter
- Length
- Product type
- Custom attributes

Manufacturing attributes

- Number of processing step
- Processing sequence
- Physical requirements of labor
- Number of processing machine
- Processing machine type
- Number of tool
- Tool type
- Number of end operation
- End operation sequence
- Custom attributes.

The coding information can be obtained from a design and manufacturing database. The benefits that will be obtained from this coding and classifying of parts are as follows:

- It facilitates the formation of part families and machine cells.
- It allows the use of setup time reduction in the formation of part families and machine cells.
- It permits the quick retrieval of designs, drawing, and process plans.
- It minimizes design duplication.
- It facilitates the accurate estimation of machine tool requirements and logical control.

- It provides reliable work-piece statistics.
- It aids production planning and scheduling procedures.
- It improves cost estimation and facilitates cost accounting procedures.
- It provides for better machine tool utilization and better use of tools, fixture and manpower.

Once all of the parts are coded and entered, the software package will group parts into families with similar attributes. Experienced operations and engineering managers should then examine the part families to determine if they are logical. If it is agreed the part families are logical, then it is time to design the cells that will produce each part family by partitioning the machines that will comprise each cell.

Each part in a family should be able to be produced entirely within the cell (obviously there will be exceptions in processing which will be covered in the special problems section). Therefore, each cell will consist of all the machines required for each individual part to be completely processed. The machines for each cell will be taken from various functional areas of the plant (again exceptions will arise with lack of machines for cells which will be covered in the special problems section) and placed in the cells.

The individual cell layout will be u-shaped. Figure 1 illustrates production flow within a cell. The machines should be placed in logical processing order for the part family (i.e. the machine that conducts the first process should be followed by the machine that conducts the second process, etc.). On paper, the cell layout should look like Figure 2. Each station contains a machine/tooling to conduct a process or the tools a worker uses to conduct a process. Parts travel from station to station (not all parts will require processing at each station) until the part is completely finished. Figure 3 is an example of what an actual cell layout looks like. The size and shape of the cell is dependent on the size and number of machines/processes required by each part family but should be u-shaped in general.

FIGURE 1

Cellular Production Flow

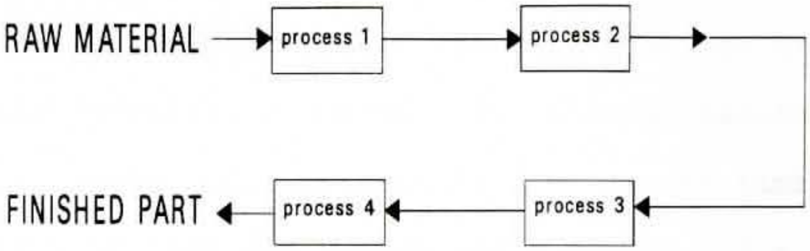


FIGURE 2

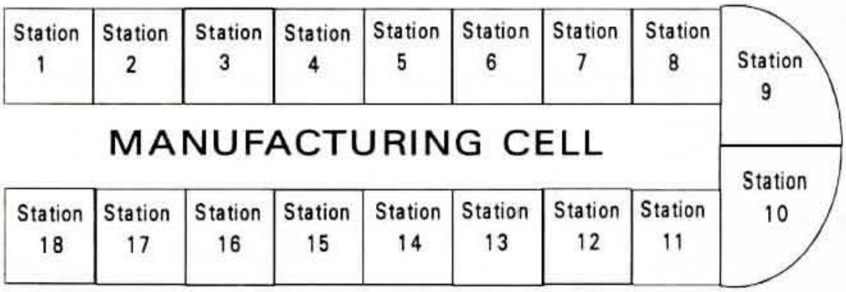
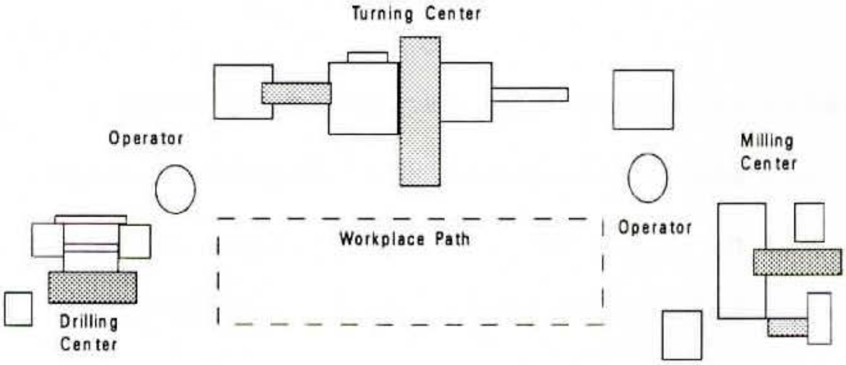


FIGURE 3



Special Problems

There are several problems that can arise during the formation of cells. Exceptional manufacturing processes, that are required by a part family, is one problem that can impede the formation of a cell. These processes will require parts to leave the cell during batch processing (i.e. the machine/tooling can not be physically placed in the cell). The following are situations in which machine can not be put in the cell:

1) Difficulty in moving very heavy or anchored machines.
2) Safety constraints (i.e. equipment that heat treats, chemical processing).
3) Physical constraints (size and shape of equipment).

These problems can be overcome by creating a common work area that contains the special processing equipment required by all the cells in the factory. The common work area should by located such that it is as close to the cells that use it as possible. As a batch is moved through the cell, and it requires a special process, the material is sent out of the cell to the common work area. If the number of parts in the part family requiring a special process is small, then the parts should be sent to the common work area and then returned to the cell for continued processing. If the number of parts in the part family requiring special process is large, then the cell should be split into two cells instead of sending the parts back and forth. Remember, one of the advantages of cellular manufacturing is reduced travel time of parts. One cell should be designed to process the part family prior to the required special process. The other cell should be designed to receive the parts, after the special process, and complete the processing on the part family.

Another problem that can occur during the transformation to cellular manufacturing is parts not fitting into a family (exceptional parts). Exceptional parts may be unique in size, shape, material, or may require special processing that no other parts in the factory have. There are three ways to solve this problem. The first is to reengineer the design of the part to fit a family. The second is to purchase the part from a vendor. A very careful make or buy analysis needs to be conducted to determine the best choice. A third method to solve this problem is to set a portion of the factory aside for the sole purpose of producing the particular part. This is an acceptable solution if the part is a significant enough revenue producer to cost justify it.

The most common problem in the partitioning of the factory floor is machine shortage. The easy answer to this problem is to purchase equipment. If there were not budget constraints, the purchasing department would simply buy the machines needed to complete each cell that has been shorted machines. But when there are capital restraints, there are other solutions to the problem of machine shortage.

If two cells are short the same machine, the two cells can be combined into one. Alternatively, the short machine could be located between the two cells and shared by both. Both of these methods avoid additional investment but will sacrifice work flow and control within the cells. Team members must decide a what level of lost benefits will the cost of additional investment be less than the cost of not investing in additional machinery.

If the capital exists, machines should be purchased to complete cells as they were designed. When the decision to purchase a machine to complete a cell is made, it must be determined what capabilities the machine must posses. The machine should be able to complete all processes needed by the part family. There is no reason to purchase a sophisticated machine when a simple, less expensive, single task machine can do the job. The advantages of this type of purchase are the maintaining of the autonomy of individual cells, reduced setup time (key to many benefits), and simplicity of manufacturing.

Finally, in situations where factory floor space is limited, U-shaped cells can leave wasted space. This space occurs where two rounded ends of cells come together. In situations of critical space shortage, the solution to this problem is to lay out the cells in a straight line as in assembly line fashion. The cell will lose its closed loop appearance but will not lose any of the benifits accuired.

Reduction in Setup Time

The reduction in setup time between parts being processed within the cell is an important undertaking in cellular manufacturing implementation. This reduction is the economic justification of cellular manufacturing because it makes profitable smaller lot sizes. Setup time reduction directly leads to the following consequences:

1) Reduced variance of job flow time.
2) Improved queuing and flow time performance.
3) Reduced optimal product lot sizes.

These consequences will result in the following benefits:

1) Improved delivery reliability.
2) Stabilizing production scheduling and control activities.
3) Reduced safety stock requirements.
4) Improved delivery speed.

5) Reduced WIP inventory.
6) Fast response to market change.
7) Fast feedback to quality control.
8) More flexibility in product scheduling.
9) Better control of work flow.
10) Efficient utilization of tooling and transportation.

Without the reduction in setup time, obtaining these benefits is impossible.

Because of the importance of setup time reduction, it should be the number one objective in cell development. The first step in setup time reduction was completed in the grouping of part families. The coding system contained information on similarities in setup procedures between parts. The two remaining steps in setup time reduction are sequence-dependent part scheduling and machine/tooling improvement.

The factory floor has been partitioned into cells and the machines/tooling has been placed in the u-shaped cells, it is now time to begin the task of setup time reduction. There is no doubt that a company transforming a factory to cellular manufaturing will be doing so under a budget. Therefore, choices must be made on how far to go and to what parts the money will be spent for setup time reduction. There are two areas to attack setup time reduction: 1) the improvement of cell flow time performance (work flow time, variance of cell flow time, and reduction of optimal product lot size); and 2) concentrating efforts on high demand products and those with long processing times.

There are four guidelines to follow when making decisions on setup time reduction to improve cell performance. These guidelines are as follows:

1) Job queuing time within the cell will decrease at a decreasing rate as product setup times are reduced.

2) The optimal product batch size that minimizes the expected cell queuing time will decrease at a decreasing rate as product setup times are reduced.

3) The variance of job queuing times within the cell will decrease at a decreasing rate as product queuing times are reduced.

4) The marginal queuing time improvement from a product setup time reduction is proportional to the product's WIP level. Therefore, for any two parts in a family, the one with a higher WIP will generate a larger marginal queuing time improvement from a reduction in setup time.

These rules indicate the cost required to reduce the setup time an additional unit is increasing (these costs are marginal). In addition, the marginal return from flow time improvement is decreasing. Therefore, there exists an optimal setup time reduction investment decision where the marginal cost and marginal returns are balanced. It must be found where these cost and returns are balanced so the funds are allocated in the best manner.

The second area where investment allocation decisions are made is defined by part demand and processing time requirements. The following guidelines apply:

1) For two parts that have identical batch processing times, the product that has a higher batch arrival rate will generate a greater marginal queuing time improvement from setup time reduction.

2) For two parts that have identical setup time and processing requirements, the part that has a higher unit arrival rate will generate a greater marginal queuing time improvement from setup time reduction.

3) For two parts that have identical batch arrival rates, the part that has a longer batch processing time a greater marginal

queuing time improvement from setup time reduction.

4) For two products that have identical setup time requirements, the part that has a larger mean processing workload will generate a greater marginal queuing time improvement from setup time reduction.

These guidelines illustrate the fact that when the objective is to reduce batch flow time through setup time reduction, the efforts (capital) should first focus on the parts that contribute the largest amount to WIP inventory. Therefore, limited capital should be allocated to parts with high demand and/or long processing times.

Just because two parts use the same machine does not mean there is an automatic setup time reduction between the two parts. Therefore, a significant amount of setup time reduction can be obtained by sequencing parts through the cell so as to take advantage of similarities in setup procedures. The operations manager and engineers should use their experience to determine a logical flow of parts through the cell.

Worker Assignment and Process Control

The objective of cell managers is to minimize the throughput time of batches of parts. The best approach in assigning workers in the cell is dedicated cell-loading. Under this strategy, the cell is dedicated (setup) for only one part at a time. The batch size to be transferred through the cell is one. For example, fifty of part #3 are to be processed for an order. The first part (#3) of the batch is sent to the first machine in the cell. When this machine is finished processing the part, it is sent to the next machine in the cell and the second part (#3) is sent to the first machine. This continues until all fifty of the parts are completed. Therefore, the batch is being simultaneously processed at different machines in the cell. The cell has the appearance of an assembly line. When the last part (#3) of the batch has completed processing at the first machine (and sent to the second machine), setup begins for the next part to be processed by the cell. Setup within the cell continues as the last part of the current batch passes through the cell. When setup has been completed at the first machine in the cell, the first part of the next batch is sent to this machine. Therefore, the throughput time for a batch of parts is the sum of the setup times at each required machine plus the processing time required by the parts. This underscores the importance of the reduction of setup time within the cell.

The use of dedicated-cell loading for assigning workers leads to the most important benifit of cellular manufacturing. That is process control. Process control comes from the ability of the cell to stop an out of spec process immeadiatly, before scrap is produced. As a single part travels through the cell, if an operator at the next macine in the cell detects a problem, the process is haulted with only a single part being scrap, not an entire batch. The process can then be corrected and production resumed.

Preventive Maintenance

Preventive maintenance is essential with the change from traditional manufacturing to cellular manufacturing. Conducting preventive maintenance is not difficult in a traditional manufacturing setting. When a machine is out of service for maintenance, another machine in the functional block can perform the needed operation while that machine is out of service. In cellular manufacturing there is a much greater problem. When one machine is out of service, the entire cell is not functional. Therefore, preventive maintenance is very important in cellular manufacturing in order to keep a single machine from breaking down and shutting down an entire cell.

The scheduling of preventive maintenance is critical if production interruption is to be limited or avoided all together. Preventive maintenance should not be scheduled for an individual machine in the cell (unless a particular machine is idle durring the current production run) but should be scheduled for the entire cell as a whole. One of the following five methods of scheduling preventive maintenance should be used to limit/avoid production interruption:

1) Schedule preventive maintenance for the cell during off shifts (i.e. nights, weekends).

2) Conduct preventive maintenance on an entire cell when one of its machines breaks down.

3) Conduct preventive maintenance during major factory shut downs (holidays).

4) Enter a dummy part number into the production schedule. When the dummy number comes up in the production schedule, the cell will be clear. The processing time entered for the dummy part will be the time required to complete the preventive maintenance on the entire cell.

5) Conduct preventive maintenance on machines that are not required for processing by the current batch of parts being produced by the cell. This maintenace could be conducted by idle cell workers.

Labor Issues

The human interface involved in the transformation to cellular manufacturing is a very important issue to be addressed if the process is to be successful. The cell is to be staffed by a self-regulated team whose members must have the skills, information, and autonomy to control technical and environmental variances as close to the production as possible. The creators of the team must understand the amount of cooperation required between co-workers, new amounts of information processing and decision making requirements of members, new work environment, and the psychological factors of the growth needs of workers. Because of the importance and time required to prepare these teams, the process should begin as early in the transformation as possible.

The selection of team members should focus on workers with high growth needs, willingness to learn multiple skills, and will positively react to compensation packages that promote learning skills. Once the proper cell team members have been chosen, training should begin. The training program should meet the following criteria:

1) An increase in the standard competence of the worker.
2) Broad based training with the aim of producing multirole/multiskill workers.
3) Developement of analytical abilities for evaluating and using information.
4) Interpersonal and team building skills.
5) Each cell member should be cross trained on all machines in the cell.

The training program should be designed to produce workers with the ability to analyze and use information for decision making within the cell without direct supervisory intervention. The worker should be able to detect quality problems as soon as they happen and stop production before any more value-added processes occur (process control).

A compensation package should be developed within the team concept. Workers start at a team-based training salary (all team members will be started at this level). As skills are learned, raises are given to reflect their success. A team reward system (bonus) based on performance should also be put in place. This reward system will compensate the cell team for improved profitability or cost saving ideas within the cell.

Conclusion

This manual has given a set of guidelines that covers the major issues involved in the transformation of a functional factory into a cellular manufacturing system. As a project team designs and implements this type of manufacturing, details unique to their company/industry will be incorporated into their designs. Although each manufacturing situation is unique, all of the factors covered in this manual must be addressed if the benefits of cellular manufacturing are to be achieved.

APPENDIX B

QUESTIONNAIRE

1. Under the cell design portion of the manual, do you agree or disagree with the use of a coding and classification method for the creation of part families? Explain.

2. Is the manual clear on the physical make-up of the cell? Why or why not?

3. Have you experienced or know of any other problems with the physical layout of cells? If yes, please explain and give solutions.

4. Given the listed problems that can occur in cell design, are the solutions feasible and adequate? Are there other solutions to the problems? Please support your answers.

5. Do you agree with the guidelines in the manual on setup time reduction through improved cell performance? Explain.

6. Is the construction of a sequence-dependent setup time matrix feasible? If yes, why? If no, why?

7. Is the use of this matrix possible in a high volume manufacturing environment? If yes, why? If no, why?

8. Does the manual provide adequate instructions for the construction of the matrix? If yes, why? If no, why?

9. Do you agree with the two worker assignment methods presented by the manual? Why or why not?

10. Does the manual properly explain the worker assignment methods? If yes, why? If no, why?

11. Do you know of more appropriate worker assignment methods? Explain.

12. Are the methods of scheduling preventive maintenance appropriate for cellular manufacturing? If yes, why? If no, why?

13. Are there other methods of scheduling? If yes, please list.

14. Does the manual make clear the criteria required in the selection of cell workers? Explain.

15. Do you agree with the areas that must be covered in a training program? Why or why not?

16. Is the compensation program suggested appropriate for cellular manufacturing? Explain.

17. Does the manual cover all the major areas of cellular manufacturing? Explain.

18. Are there any errors in the manual that the questionnaire did not cover? Please list and explain.

19. Would you add anything to the manual to make it more complete? Explain.

20. Please give any additional comments here.

APPENDIX C

COVER LETTER

October 9, 1995

Brian Fergason
1214 High school
Ladue, MO 63117

Dear Brian,

Thank you for agreeing to evaluate this manual. Please read the enclosed manual and fill out the questionnaire as completely as possible. A follow up call will be placed to you after you receive the questionnaire to briefly go over it. The purpose of your evaluation is to gauge the validity and completeness of the manual and add additional insights to the topic that you may have experienced in your profession and educational endeavors. When you complete the questionnaire, please return it in the enclosed self addressed envelope. Thank you for your participation in my research effort.

Sincerely,

Todd E. Richter

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