ABSTRACT

Design and Development of Flexible Manufacturing Cells - A Case Study

by
Behrouz Barzani

This paper covers the typical ills of American manufacturing companies and provides steps to selecting a flexible manufacturing cell(s) or system as a remedy. For that reason various definition of different types of flexibilities in manufacturing and the inter-relationships between the several types have been examined. In addition, their purposes, means of obtaining them and some measurement and evaluations has been discussed. This was done to cover the basic but necessary requirements for understanding and selecting a flexible manufacturing system. Finally, the design process of a flexible system and its intuitive justification were discussed.

DESIGN AND DEVELOPMENT OF FLEXIBLE MANUFACTURING CELLS - A CASE STUDY

by
Behrouz Barzani

A Thesis
Submitted to the Faculty of
New Jersey Institute of Technology
In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Manufacturing Systems Engineering

Manufacturing Engineering Division
May 1993

Blank Page

APPROVAL PAGE

Design and Development of Flexible Manufacturing Cells - A Case Study

by
Behrouz Barzani

Dr. Sanchoy K. Das, Thesis Advisor (date)
Assistant Professor, Department of Mechanical & Industrial Engineering,
New Jersey Institute of Technology

Dr. Nouri Levy, Committee Member (date)
Associate Professor, Department of Mechanical & Industrial Engineering,
New Jersey Institute of Technology

Dr. Raj Sodhi, Committee Member (date)
Associate Professor, Department of Mechanical & Industrial Engineering,
New Jersey Institute of Technology

BIOGRAPHICAL SKETCH

Author: Behrouz Barzani

Degree: Master of Science in Manufacturing Systems Engineering

Date: May 1993

Undergraduate and Graduate Education:

- Master of Science in Manufacturing Systems Engineering, New Jersey Institute of Technology, Newark, NJ, 1992.

- Bachelor of Science in Industrial Engineering, University of Wisconsin, Milwaukee, WI, 1985.

This thesis is dedicated to the memory of my father

Always in my heart...

ACKNOWLEDGMENT

With this vehicle I would like to convey my sincere thanks and deepest gratitude to my thesis advisor, Dr. Sanchoy K. Das, for his untiring moral support and continued direction during the entire period of this educational exploration.

Special note of thanks to Associate Professor Dr. Nouri Levy and Dr. Raj Sodhi for serving as members of the committee.

In addition, the author is appreciative to the staff of Industrial Engineering and Manufacturing Systems Engineering, and the staff of Van Houten Library for their assistance for providing research material.

The author would also like to extend his thanks and gratitude to the management of Breeze Eastern Corporation for providing the support for this educational opportunity.

TABLE OF CONTENTS

Chapter | Page

1 INTRODUCTION 1

1.1 Introduction to Flexibility 1
1.2 Thesis Objective 6
1.3 Description of Thesis Activities 6

2 LITERATURE REVIEW 8

2.1 Different Type of Flexibility and Their Purposes 8
2.2 Inter-relationship Between Various Flexibilities 14
2.3 Means of Manufacturing Flexibilities 14
2.4 Flexibility Measurement 19
2.5 Flexibility Selection Process 20

3 FLEXIBILITY NEEDS OF THE COMPANY 23

3.1 Description of the Company, Products, & Facility 23
3.2 Problems faced and desired features 25

4 DESIGN OF THE PROPOSED CELLS 29

4.1 Design of Flexible Manufacturing Cells 29
4.2 Detailed Cell Design 33
4.3 Layout Design 37
4.4 Estimated Costs and Time of Implementation 40
4.5 Expected Benefits 45
4.6 Intuitive Justification 47

5 SUMMARY AND CONCLUSIONS 50

REFERENCES 53

LIST OF FIGURES

Figure **Page**

1. Evaluating Flexibility Options 3
2. A Process to Justify Flexible Manufacturing Technologies 5
3. Relationship Between the Flexibility Types 15
4. The Five Flexibility Measurement Levels 21
5. Ideal vs. Conventional Lead Times 31
6. Alternative Types of Layouts 39
7. "U" Cell Layout 41
8. More "U" Cell Re-arrangement 42
9. Present Machine Shop layout 43
10. Proposed Cell Layout 44

CHAPTER ONE

INTRODUCTION

1.1 Introduction to Flexibility

Manufacturing facilities experience change on a regular basis. Some of these changes are small and are easily absorbed by the facility. Other are quite significant in their impact, and require special management or technology interventions. The nature and structure of these changes vary greatly, but in relevance to manufacturing, two general types of changes can be identified, these are external and internal. External changes are a consequence of a market stimulus, and are generated by either customer wants or supplier constraints. Internal changes originate from within the facility, and are typically one of three kinds, that is those generated as a consequence of (i) an external change, (ii) an internal policy, or (iii) an internal failure. In general external changes occur over a longer time horizon, while internal changes occur over a relatively shorter horizon.

As an illustration of the above changes consider the case in which the market demands that a firm produce multiple products in time changing mixes. Then the mix change is an example of external change. Further, assume all the products are manufactured in the same facility. We can therefore expect that several of the facility's work centers experience processing changes. These processing changes are labelled as internal as a consequence of an external change. Alternatively, consider the case in which a single product is manufactured in a small facility. Assuming workers are capable of performing multiple operations, then periodically they experience a processing change. A change of this type is labelled as internal as a consequence of an internal policy. Finally consider the case in which, due to frequent absenteeism, workers are often required to perform additional operations. A change of this type is labelled as internal as a consequence of an internal failure.

In today's global and competitive market environment, it is necessary that a firm's manufacturing facilities be capable of efficiently responding to the above changes. This capability is generally referred to as flexible manufacturing. There are are only a few approaches or theories that a firm may pursue in increasing the flexibility of its manufacturing operations. Firms which have traditionally prospered under the paradigm that "minimal change" and "minimal" variety lead to high productivity, are thus finding it difficult to initiate flexibility efforts. In this thesis we study an example company, and then define how that company can build a flexible manufacturing facility, so as to respond to the changes that it experiences.

In designing a flexible facility one may incorporate a variety of technologies, including process automation, information systems, and other procedural methods. The selection and configuration of these technologies must be based on the needs of the facility. Clearly, what manufacturers need is a process which will help them identify their flexibility requirements, and then design facilities accordingly. While a structured process for developing a flexible facility is not presented in this thesis, it is expected that the results of this case study will contribute to the development of such a process. Luggen (1991) proposes a preliminary methods for assessing and evaluating flexible manufacturing technology. The basic logic of his method is illustrated in figure 1, but his approach only serves as an initial evaluator and does not help in detailed design.

Several studies have confirmed that manufacturing flexibility has major implications for a firm's competitive effectiveness. Because of its important role, flexibility should become a part of every firm's strategy. Where strategy is defined as a "set of plans and policies by which a company tries to gain advantage over its competitors" (Skinner 1985). Hence development of manufacturing flexibility necessitates considerable upper management attention, and can not be considered as the job only of operational managers. Skinner (1985) points out that it is not always easy to grasp the inter-relationship between manufacturing operation and corporate strategy. From a

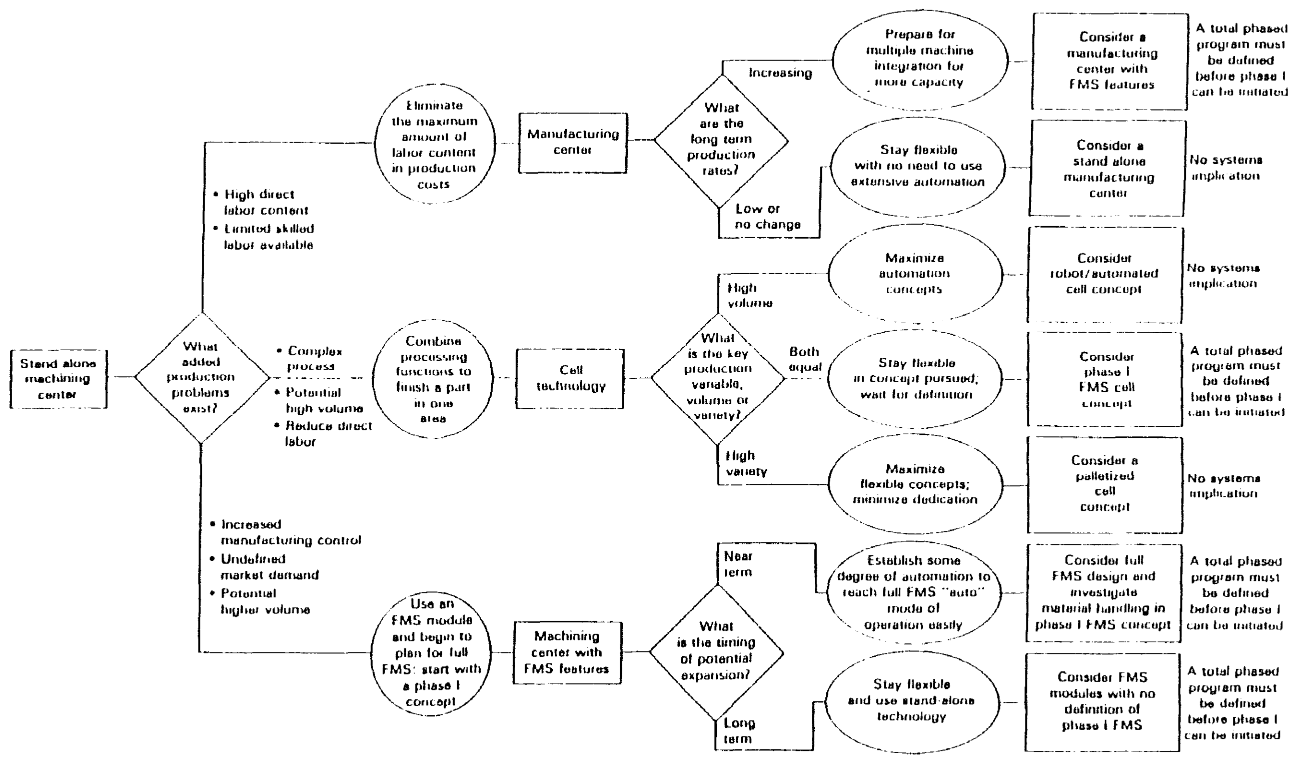

Figure 1. Evaluating Flexibility Options

flexible manufacturing perspective, this relationship is key to justifying the associated monetary investment. In figure 2, we present an approach that may be used to justify the importance and relevance of flexible manufacturing technologies.

By definition, manufacturing flexibility is described as the ability to adapt to a wide range of possible environments that a facility, or system, may encounter. More importantly a flexible system must be capable of rapid alteration in order to deal with the changing environment. As defined by Sethi and Sethi (1990), flexibility in manufacturing means "being able to change the configuration of manufacturing resources so as to produce efficiently different products of acceptable quality". Several types of flexibility are possible, definitions of some are as follows:

Machine Flexibility - refers to the various types of operations that the machine can perform without requiring a prohibitive effort in switching from one operations to another.

Routing Flexibility - of a manufacturing system is its ability to manufacture a product by alternate routes through the system.

Process Flexibility - of a manufacturing system refers to the set of product types that the system can produce without major setups.

Product Flexibility - is the ease with which new products can be added or substituted for existing products.

Volume Flexibility - of a manufacturing system is its ability to be operated economically at different overall output levels.

Surveys by Lim (1987) and Slack (1987) have found these to be among the most commonly pursued flexibilities. In this case study, our focus will be primarily on product and machine flexibility.

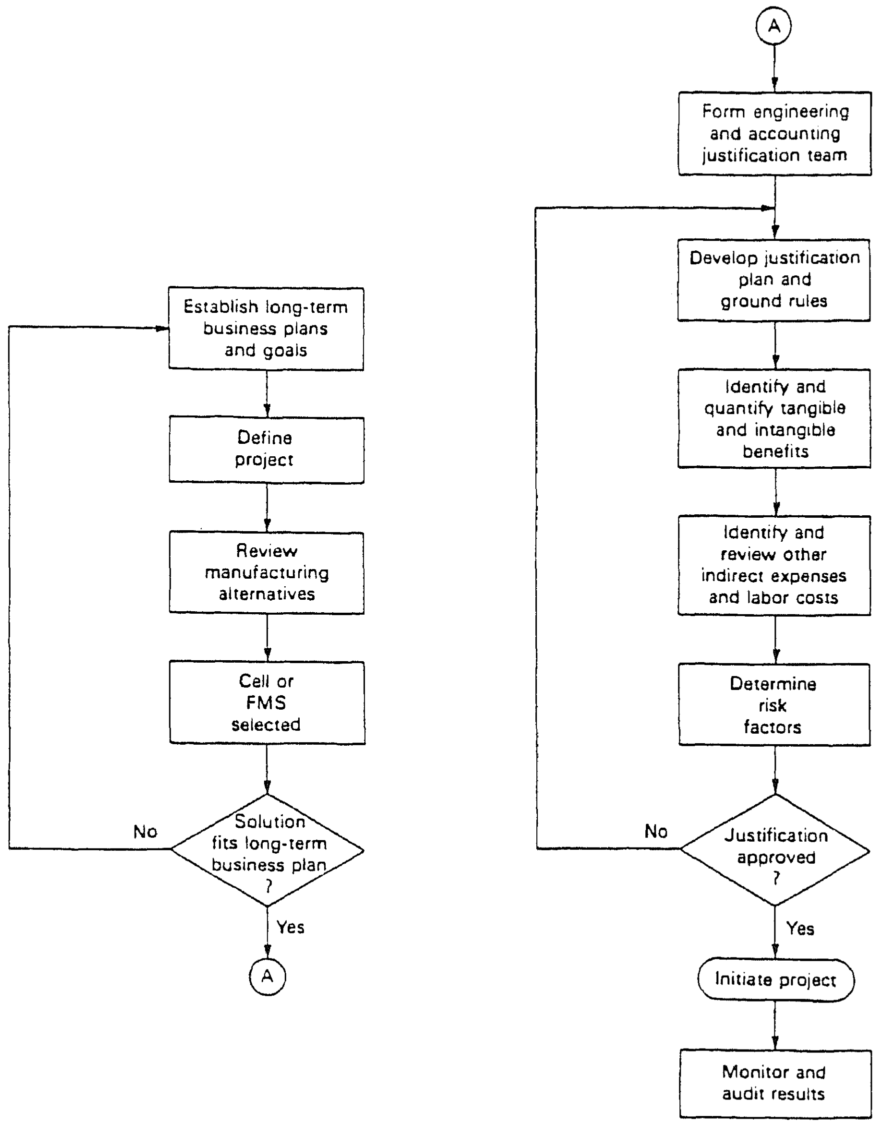

Figure 2. A Process to Justify Flexible Manufacturing Technologies

1.2. Thesis Objective

The increasing competition abroad, and recent developments in the global economy, have further enlarged the existing competitive gap straining American manufacturing companies. The purpose of this thesis is to illustrate a method of improving market competitiveness through restructuring of manufacturing operations, so as to increase flexibility. Our focus is restricted to small scale manufacturers. Our objective is to illustrate the feasibility and a process for this restructuring via a case study. The case study concerns a company that is representative of a typical manufacturer.

In support of the above objective it is necessary to exemplify some of the typical problems that American manufacturing industries are faceing today, in order recognize and then apply the vital remedies. One such highly recognized remedy is the degree of flexibility by which a firm can adapt to or quickly respond to, external changes. However there are various types of flexibility arrangements for different manufacturing strategies. Hence a definition of the different types of flexibilities in manufacturing, the inter-relationships between the several types, their purposes, means of obtaining them, and measurement are also presented and discussed in this thesis.

1.3. Description of Thesis Activities

The thesis consists of five chapters. The introduction to flexibility in manufacturing and why its needed, a case study utilizing flexibility and the objective of the thesis is given in chapter one. Chapter two gives a review of different flexibilities, their means, purposes, inter-relationship, brief description of flexibility measurement and finally discusses the selection process of a firm's flexibility prior to describing the design procedure of a flexible manufacturing cell. Chapter three introduces the detailed description of the company, its product and facility layout. The current problems faced are listed and a summary of needed flexibilities are presented. Chapter four is dedicated to the actual design of the proposed cell. Giving specific details of machines, features, estimated at cost and time of implementation, expected benefit, and the intuitive justification facing most managers. The last chapter of the thesis, chapter five, contains a brief summary and conclusion of the entire research.

CHAPTER TWO

LITERATURE REVIEW

2.1. Different Types of Flexibility and Their Purposes

We begin by providing the most appropriate definition for flexibility from the enormous literature that has become available in the past twenty years. *The International Journal of Flexible Manufacturing Systems* has been a major source of surveying the vast literature on FMS technology. Even though flexibility is a complex, multi-dimensional and hard to understand concept, the journal's vast research of different schools of thought and its elite authors in the field have rendered better understanding of different terms and types of flexibilities that can be found.

At first a brief economic view and definition of flexibility in general is necessary before moving to an organizational view. Hart (1940) declares that the deferment of decisions until more information becomes available, or that is to say, the conservation of flexibility is a fundamental means of meeting future uncertainty. Mandelbaum (1989) defines flexibility as "the ability to respond effectively to changing circumstances". He showed that it can be grouped into two different configuration: ACTION flexibility "(the capacity for taking new action to meet new circumstances") and STATE flexibility, "(the capacity to continue functioning effectively despite changes in the environment").

Organization flexibility however, is viewed differently. Feiblemen and Friend (1945) define organizational flexibility as "the ability of an organization to suffer limited changes without severe disorganization. One concept of limiting disorganization was introduced by March and Simon (1958) as organizational slack. This provides an organization with the excess resources to cope with the internal, as well as some environmental uncertainties. In recent years, a new form of organizational hierarchical or functional structure has been evolving. This class of organizational rearrangement is capable of faster response to uncertainties known as product focused forms. This type of organization focuses around output function rather than input functions.

Another concept of labor productivity developed by the Institute of Manpower Studies (United Kingdom) identifies three types of labor flexibilities. Numerical flexibility which is concerned with the readiness of a number of people to meet and adjust with the fluctuation of demand; Functional flexibility which is the ability of the workers to readily change task with the change in the level of demand; Financial flexibility which is the extent to which compensation practices encourage and support the other two flexibilities that companies seek.

Hayes and Wheelwright (1984) define manufacturing strategy as a concept that "consists of a sequence of decision that, over time, enables business to achieve desired manufacturing structure, (i.e., capacity, facilities, technology and vertical integration), infrastructure (i.e.,work force, quality, production, planning/material control and organization) and a set of specific capabilities (that enables it to pursue its chosen competitive strategy over the long term)". An appropriate statement by Beset (1958) is that " the idea of flexibility can not just be bought, and must be managed" is a crucial one. At this stage, potential managers of manufacturing flexibility would probably ask; how many types of flexibilities are there, and what is the "optimal" levels of these types? To answer this difficult questions management must identify and be willing and able to measure the various flexibilities that a system must have in order to acquire maximum competitive advantage. It is important to realize that at the root of these flexibilities lies sophisticated computer and information technology. It is because of this rapid microprocessor evolution that more flexibility in manufacturing has become feasible, without a significant reduction in productivity.

Based on the literature, a summary of the different types of flexibilities and their purpose was done. For each of the summarized flexibilities we introduce a definition, and then discuss its purpose within a manufacturing facility.

Machine Flexibility - Flexibility of a machine refers to various types of operation such as drilling, milling, or grinding that can be performed with minimal cost and time. In assembly operation machine can take the place of assembly robot. What is really meant here is that a machine is flexible when it contains the capability to perform several different operations with minimum prohibitive effort. For example a machine with 3 tools in the tool magazine, 3 processing instruction and 3 different parts can be concluded to be 3x3x3= 27 times flexible compared to a single tool, single instruction and single part machine.

Purpose - Machine flexibility is a basic and necessary requirement for other flexibilities. According to Ranta (1989) "The machine level provides the basic framework for flexibility. Software functions can not help to provide any extra flexibility, if the machines are hard and expensive to change". A flexible machine provides various benefits, such as quick tool change, shorter cycle time, higher utilization, lower batch sizes, lower inventory and less obsolete parts. Also "better product quality realization in the face of random variations in input quality" (Tarondeau 1986).

Material Handling Flexibility - The definition of material handling flexibility as stated in *The International Journal of Flexible Manufacturing System* (IJFMS) is: "Flexibility of a material handling system is its ability to move different part types significantly for proper positioning and processing through the manufacturing facility it serves". By this definition loading, unloading of parts, transportation from machine to machine and storage under various condition is covered.

Purpose - A material handling system is an important part of various manufacturing flexibilities. Its timely use allows for higher utilization of machines and thus, reduces the product lead-time. As indicated by Rattner (1988) " material handling robots and automated storage and retrieval systems increase the information processing capabilities of the production system". This capability will in turn, highly reduce the information processing time and decrease its inaccuracy when proceeding from one operation to the next.

Operation flexibility - Operation flexibility refers to ability of a part, which can be produced in alternate ways or process plans. This means a part should contain properties that would allow it to be manufactured with different sequences of operation when needed. An example of different process plan would be to permit the original operations to be substituted by alternate orders, or by using alternate operations.

Purpose - Operation flexibility should be used when machine utilization and reliability are of major concern. This type of flexibility allows for easier scheduling of parts in real time (Browne et al.1984).

Process Flexibility - When a system is capable of producing a set of part types without major setups, it is referred to as process flexible. Falkner (1986) considers a system to be flexible if the manufacturing costs are relatively stable over widely ranging product mixes.

Purpose - Process flexibility allows machines to be shared and thus minimize the number of similar machines. However, the main purpose of process flexibility according to (Browne et al. 1984), is to reduce the batch sizes and reduce inventory costs. Because of insignificant setup times, a shift in the level demand of product mix by the market can easily be adjusted.

Product Flexibility - It is "the ease with which new parts can be added or substituted for existing parts. It also describes the product flexibility as being the ease with which the part mix currently being produced can be changed inexpensively and rapidly. For the record, it should be noted that a survey by Lim's (1987) of FMS's in the U.K. has shown eleven out of twelve reporting companies considered flexibility in manufacturing to mean product flexibility.

Purpose - When a company needs to be responsive to surrounding environment, and market newly designed product in a short period of time, product flexibility comes into play. Because most future product designs are usually unknown, it is a good logic to develop and design production facility to be product flexible.

Routing Flexibility - A system capable of producing a part in different routes through the system is referred to as Routine flexible. In a different route a part may use alternate machines, different operations or sequence of operations. It should be realized that routing flexibility is different than operation flexibility, where routing flexibility is a property of the system while operation flexibility is property of part. To further clarify this, a part without any operation flexibility has the property of being processed using different routes through the system.

Purpose - Routing flexibility allows for efficient scheduling of parts by better balancing of machine loads. Further, it allows the system to continue producing a given set of part types, perhaps at a reduced rate, when unanticipated events such as machine breakdowns, late receipt of tools, a preemptive order of parts, or the discovery of a defective part occur (Sethi and Sethi, 1990). Routing flexibility also allows for capacity expansion when required.

Volume Flexibility - A system capable of running profitably at various overall output levels is defined as volume flexible.

Purpose - Volume Flexibility allows the shift in upward or downward production demands to be adjusted within wide limits. As Hayes and Schmenner (1978) point out " successful companies in cyclic industries, such as furniture often exhibit this trait". According to Slack (1987), volume flexibility has two aspects: quickness of response and range of variations, which are useful in short term and long term respectively.

Expansion Flexibility - is defined as the ability of a system which, with ease can increase its capacity and capability. The capacity refers to availability of manpower, machines, and other manufacturing resources to increase the output rate per unit of time. The capability refers to such characteristics as quality, technology and other flexibility. In such a flexibility replacement, removal or addition of new machines is easily possible due to the fact that the original design of expansion flexibility provides such connections or disconnections.

Purpose - A firm heavily concerned with growth strategies and investment into new markets would allow for such systems. Whereas volume flexibility facilitates stability strategies in maintaining existing market share and profitability.

Program Flexibility - As defined in *The International Journal of Flexible Manufacturing Systems*, program flexibility is "the ability of a system to run virtually unattended for a long enough period".

Purpose - When dealing with mass production, program flexibility can provide the capacity required to meet throughput and, simultaneously reduce lead-time by reducing or eliminating setup times, improving inspection and providing better tools and fixtures, while increasing productivity and quality.

Production Flexibilities - This would allow a world of part types to be produced without adding major capital investment.

Purpose - Production flexibility allows the firm to compete where new products are frequently demand. Production flexibility minimizes the implementation time for new products, or major modification of existing products (Carter 1986). When viewed from the operational level it would allow the firm to diversify its risk and increase its part families.

Market Flexibility - Market flexibility refers to the ability of a system to adapt to a shift in market conditions.

Purpose - Because of swift technological innovations, short product cycle times and change in customer tastes, market flexibility is essential for a firm 's survival in a competitive world. This type of flexibility allows a firm to quickly respond to new conditions, and cash in on new business opportunities before its less flexible competitors are able to, and do all this without putting the firm at risk.

Now that we have surveyed the different flexibilities we can discuss the inter-relationships between them and the role each component plays in contributing to the system's performance.

2.2. Inter-Relationship Between Various Flexibilities

Figure 3 describes the relationship that exists between the various flexibilities. According to Yilmaz and Davis (1987), flexibilities can be characterized in terms of three attributes; at times, after a time and over time. Where machine and routing flexibilities can be related to flexibility at times; operation, process, and product flexibilities can be related to flexibility after a time; and volume, expansion and production can be related to flexibility over time.

2.3 Means of Manufacturing Flexibility

Study of flexibilities showed several terms referring to the same flexibility. These flexibilities as redefined by Sethi and Sethi (1990) have been reduce from over 50 different terms to 11 "universal" terms. Since various FMSs and their purposes, some strategic and operational objectives for management to implement a flexible manufacturing system was explained, the next question in management's mind by now would be, what are the

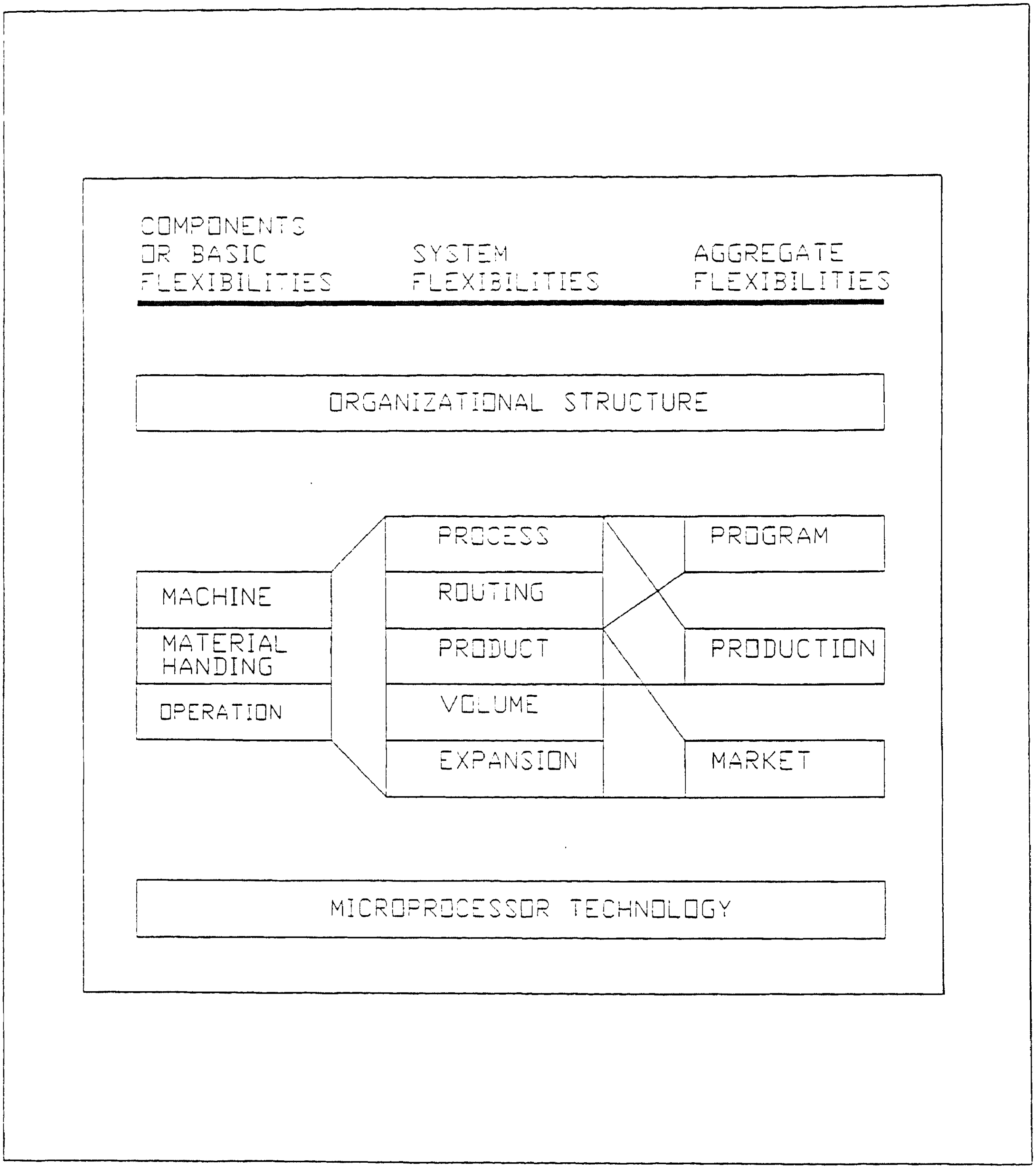

Figure 3. Relationship Between the Flexibility Types

means of obtaining these flexibilities and their components. The question is answered by defining the means for each flexibility defined.

Means of machine flexibility - The technological origin of machine flexibility are NC, readily accessible programs, state of the art part loading and tool-changing devices that ensure comfortable changeability of work part and tools, " size of tool magazine, availability of pallets and fixtures, number of axis, automatic chip removal, adaptive control to optimize metal removal, diagnostic software, integration with CAD/CAM, etc." So it could be inferred that a multi-axis, multipurpose adaptable CNC machining center is highly machine flexible. A survey of 12 firms with different FMS design by Lim (1987) has concluded that "the weakest part in machine flexibility seemed to be the unavailability of automated fixture assembly and mounting".

Means of material handling flexibility - Material handling flexibility can be acquired by retaining various transporting devices such as forklift trucks, hi- lows, push carts and conveyor belts in regular facilities; and robots, automated guided vehicles and track rails, in computer control environments which would allow the alternate paths in case of unpracticed events. Multi-purpose fixtures also increase the flexibility of the system. A system described in Newman (1986) allows about 350 parts to be mounted on four different fixture attachments, which in turn are mounted on a general purpose fixture. Enhancement to the material handling flexibility could be made by employing automatic tool changes, multi-axis robots and other automation devices.

Means of operation flexibilities - Operation flexibility of a part is a characteristic of its design. An operation flexible designed part would produce surfaces that are easily accessible for various operations. Parts that are assembled from standardize components, or parts that are modular, are likely to exhibit operation flexibility.

Means of process flexibility - Process flexibility is the characteristic of a system which derives from machine flexibility of machines, operation flexibility of parts and material handling system flexibility. Reduced labor classification, or multi-tasked workers who can handle variety of parts and products as well as the ability to transfer different fixtures and tooling into and out of the system, can enhance the process flexibility Gerwin (1989).

Means of product flexibility - Product flexibility derives from a combination of several other flexibilities such as; material handling flexibility, operation flexibility, computer aided process planning, CAD/CAM interface, availability of similar part programming routines, quick tool and die setups, flexible fixtures, group technology, etc. One very important key emphasized by (Gerwin 1989) is that workers must be willing and able to continually learn new operating procedures. (Gustavsson 1984) sees product flexibility with the manufacture and assembly of standardized parts.

Means of routing flexibility - Routing flexibility depends on having multi-purpose machines, machines that have overlapping process envelops and pooling of identical equipment into machine groups (Stecke and Kim 1989) as well as system control software, flexibility of material handling systems and operation flexibility of parts (Brown et al. 1984; Yao 1985). Some planned under utilization of machine capacity, or redundancy in number similar machines, is necessary to let the system maintain its production rate in case of a machine break down (Falkner 1986). A survey of 12 FMSs by Lim 1987 showed that the existing systems had very small or no routing flexibility. Lim 1987 cited the reason as " the lack of routing flexibility reflected both the state of technology and management requirements for the system. Having different routes for each part, for instance, would not only entail extra memory capacity but also require some real time reasoning power on the part of the supervisory computer (intelligence) in order to "understand" the nature of a breakdown, sort out the next best alternative, transmit the diagnostics and necessary instruction on the altered route, and update schedule on the appropriate sub-systems including the operative(s) and support personnel". All of these facts and observation reflect the heavy dependency of routing flexibility on duplicate processing assignments, tooling and machine redundancy, which all add up to substantially greater capital costs and longer project time.

Means of volume flexibility - A highly automated FMS system with small number of labor can produce volume flexibility. This would allow it to adjust to large increases or significant drops in the level of production demand without having to deal with labor costs and capacity adjustments both in downward or upward times. As cited in by Linsky (1983) the case of the Yamazaki plant near Nagoya, Japan, which employees about 215 people (in comparison to 2500 in a conventional company) with a maximum capacity of producing $230 million worth of machine tools a year. It has been claimed that this plant is capable of reducing down to $80 million when needed, without having to layoff a single employee. If for the purpose of simplification and modeling we were to reduce the manufacturing costs to only two components fixed cost, and variable cost then the average manufacturing cost of a system would be less sensitive to a system that has a relatively higher fixed cost in order to have lower variable costs than of a system which has a given fixed and variable costs (Sethi and Sethi 1990).

Means of expansion flexibility - There are several ways of obtaining an expansion flexible facility such as; building modular flexible manufacturing cells (Brown et al. 1984), or acquiring multipurpose machinery that does not require a special foundation, and a material handling system that can easily be routed (Carter 1986, Lim 1986) building small production units (Buzacott and Mandelbaum 1985).

Means of program flexibility - Program flexibility heavily depends on process and routing flexibility and integrating sensors and computer controls for sensing and managing unanticipated problems that may occur such as part flow jams and tool breakage. Program flexibility is a stringent requirement, since it necessitates a thorough understanding of the system. Only then can all of the contingencies of the system be proceduralized.

Means of production flexibility - Several scholars in the field have implied that production flexibility depends on the variety and versatility of the machines that are available, the availability of the material handling system in use, and the factory information and control system.

Means of market flexibility - Market flexibility is an aggregate flexibility which, depends on several other system flexibilities such as; product flexibility to develop and manufacture new products, production flexibility to deal effectively with fluctuating market demand and finally expansion flexibility to undergo capacity changes.

2.4. Flexibility Measurement

Measuring flexibility of a system requires collection of data and understanding of the capability and the actual performance of the system to be measured. In general it has been assumed that there will be only one measure for each flexibility type. However, Das (1992) in his measurement of flexibility in manufacturing systems has shown why there are at least two, and possibly as many as five, levels of measures for each type of flexibility. When the ideal objective of a FMS system, which is to permit effortless response to manufacturing environment without significant loss in its performance, is compared with the actual or real strain required with each state change, some loss in performance is detected.

In measuring this change, focus should be on i) the change effort expanded, ii) the drop in system performance, iii) a general or physical scale of the difference between two states, or iv) a measure combining all three (Das

1992). Since flexibility in the most fundamental form can be measured with the level of change difference between two states, then once this change difference has been detected and quantified, higher levels of flexibility can be pursued. A graphical representation of the five flexibility measurement levels is shown in figure 4.

2.5. Flexibility Selection Process

So far the definition of various FMSs, their means, purposes and measurement have been discussed. This provides the basic understanding we need before we begin selecting and designing a flexible manufacturing system (FMS). The following are milestone criteria for establishing a selection process:

1 - Management should question the lack of flexibilities and capabilities of its existing system to overcome environmental uncertainties.

2 - Management needs to understand the difference between capabilities of various flexibilities, its means, purposes, methods of measurement and its available resources.

3 - Management must define its strategic plan from which it can then decide which flexible manufacturing system to implement.

The result of one survey indicates that management seems to lack understanding of the need for flexibility in the planning process of new technological projects (Lim 1987) as well as of their implementation and their management (Jaikumar 1986; Boker et al. 1986). Finally new working methods should take the place of Taylor's scientific management. According to Jaikumar (1986), the use of small technologically proficient teams to design, run and improve FMSs represents a shift in focus from managing people to managing knowledge, and from production planning to project selection.

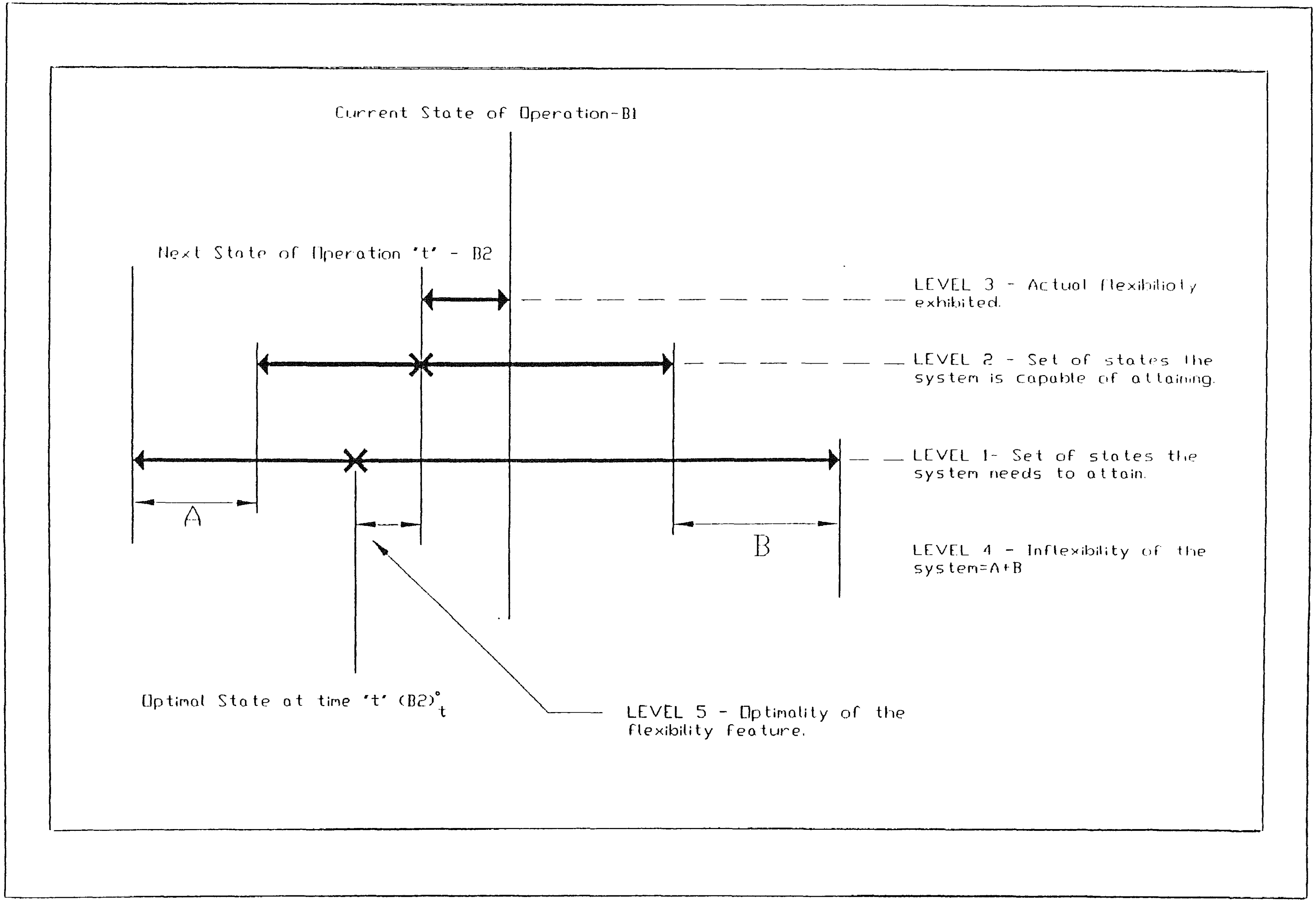

Figure 4. The Five Flexibility Measurement Levels

Thus engineering acquires line responsibilities, while manufacturing becomes a service responsible for customizing its offering to the preferences of special market segments. Making the right decision, comes down to a firm's strategy which dictates the extent of system flexibilities and in turn, of component flexibilities that the firm must possess.

CHAPTER THREE

FLEXIBILITY NEEDS OF THE COMPANY

3.1 Detailed Description of the Company, Products and Facility

As an example of a company in great need of change, we studied a company which specializes in the design, development and production of high tech lifting and restraining products mainly for helicopter rescue hoists, reeling machines, external hook systems, winches and hoists for aircraft systems and for weapons handling systems, aircraft and cargo tie downs. The company is the industry leader in personnel rescue hoist and cargo hook technologies with over 50 percent of the world market. The company's external cargo lift hook systems are original equipment on most helicopters manufactured today.

These hook systems are capable of lifting from 1000 pounds to 36000 pounds capacity. Single point hook applications are found on smaller craft like the French LAMA and McDonnell Douglas MD-500. A dual or triple hook system for better in flight cargo controls are used on larger military helicopters. Winch system applications range from cargo handling on fixed wing aircraft, to positioning television cameras on blimps that provide overhead coverage of outdoor sporting events.

The company also provides equipment for the U.S. and European Multiple Launch Rocket System (MLRS), which uses two specialized hoists to load and unload rocket-pod containers. As with most of its products, the company delivers the hoists with its electronic control boxes to facilitate remote operation. The company's leadership in hook and hoist technologies, enabled it to develop the rescue hoist system, cargo winch, cargo hooks, and forward cabin control system for the Bell-Boeing V-22 Osprey tilt rotor aircraft.

Technologies developed for the revolutionary Osprey, particularly in the area of lightweight composite material, are a valuable corporate resource. Other motion control products manufactured, include antenna and gear drives, and components for the helicopter tow boom assembly used by the Navy's Sea Dragon minesweeping platform.

The production facility of the company is over 150,000 square ft. in size, and all located under one roof. The facility is dedicated to engineering, manufacturing and assembly operations. The workers are members of the United Auto Worker (UAW) union. Unfortunately, during the last ten years the management of the company had created and focused on incorrect objectives and strategy. This resulted in reduced quality, poor service, late deliveries, almost zero new product development, 100% delinquency, 100% backlog and large capital debt to credit holders. All of the above placed the company on the verge of bankruptcy.

The new management brought in last year, has inherited a nightmare of problems as mentioned above, as well as an extremely careless working atmosphere and zero accountability. But the management is committed to changing the company's culture so that its reputation is regained, and quality products with competitive prices are shipped as scheduled. Accomplishing this goal requires recognition of the existing problems, restructuring of the organizational hierarchy, processes, layout, employee spirits, introduction of new technologies, tools, training, team work, effective information and communication management.

Having these features in place would create the base line needed to further enhance the operation activities through added flexibility, JIT, TQM, SQC, employee problem solving and other appropriate methods. The ultimate goal being to change the company's strategy from comparative manufacturing by leaping forward into competitive manufacturing.

3.2 Problems Faced and Desired Features

There are several types of manufacturing problems facing the company, these include:

1- Invalid scheduling and capacity analysis
2- Poor quality parts (inherited through design, purchasing and lack of accountability)
3- Lack of aggressive product development policy
4- Low productivity rate
5- Inadequate technology

In the past year, the firm had actually started using the master schedule module of an MRP system for its production planing, inventory control and scheduling. Unfortunately, as of today the company faces difficulty in meeting the planned finished time of scheduled parts. Personal study of the system has lead me to believe there are several major reasons equally contributing to maintain this unbalanced status quo. The three primary reasons are elaborated below:

1. Inaccurate setup, process and queue time (smaller time than required to do the job in system will actually lead the supervisors to believe that job will be ready on time).

2. Improper alteration in the master schedule horizon and invalid scheduling problems have created a constant expediting mode for production planners and procurement people.

3. Low quality output. Presently parts produced in this plant yield an average of 8% nonconformities either by attribute or variable. Our study revealed that the causes of the quality problems fall under two categories as described below:

(i) Quality is directly related to its cost. The lower the cost, the poorer the quality.

(ii) Quality is a combination of several various agents, thus controlling the quality means controlling all the other factors. If we break down the two categories mentioned above, it should be easier to see the root causes of quality problems encountered in this company.

The above two quality problem causes were further investigated, since they relate closely to the flexibility objectives.

Quality-Cost factors:

1- Purchasing lowest price usually results in lower quality and higher cost to management.

2- Saving on training, education, machines and all other kinds of tools required to properly accomplish the job has produce lower quality parts.

3- Excessive amount of work than physically possible to accomplish a job within specification in a given frame of time is another major contributor which leaving the door open for inviting quality problems.

In addition to the above direct cost-quality problems, there are other factors in this organization that give way to quality problems. These are the result of incorrect paradigms or approaches of thinking and these are listed as undesired agents of quality attributes. where quality attributes are;

Undesired Quality Agents:

1- Poor designing criteria; leads to poor quality in most cases as well as some small fraction of precision design specifications which make conformance a very difficult and expensive task.

2. Missing transition phase; of newly developed products from prototype to production. This missing link hides all the problems that will later be faced by production personnel. It is because under prototyping almost any parts could be made in the Laboratory, but when it comes to production the shop may not have the necessary equipment or talent to manufacture them. In addition all of the problem conveniently solved by Laboratory people has not been documented and thus methods of correction remain unknown when the part hits the shop floor for production.

3- There is significant amount of reliance on workers to make decision and insignificant amount of tools to improve their decision making or thinking processes.

4- Lack of flexibility; or large numbers of grade levels with the union employees prohibits job rotation and multi-tasking.

6- Non-systematic problem solving; (i.e, fix it for now and worry about re-curing problems later careless attitude) is directly related to lack of accountability in the organization company wide.

7- Ignoring drafting standards; are making blue print reading extremely difficult. Off course once drawing details are not coherent enough to be understood, mis interpretation can easily be made and non conformities will occur.

8- Absence of team work and group technology; internally as well as cross departmental, tremendously increase problem solving time, associated costs and produces lower quality work than otherwise attainable. Every time a part is introduced it could cost as much as $15,00 to $14,000 including expenses for design, planning, purchasing, tools and fixture. thus by reducing number of parts a company can save significant amount of money. it should be noted that the essence of group technology is to invest on similarities in recurring tasks in three ways.

i- By performing similar activities together, thereby avoiding wasteful time in changing from one unrelated activity to the next.

ii- By standardizing closely related activities, thereby focusing on distinct differences and avoiding unnecessary duplication effort.

iii- By efficiency storing and retrieving and information related to recurring, thereby increasing the search time for the information and eliminating the need to solve the problem again.

9- Lack of strategy and communication; as to purposefully state the short and long term goals and objectives of the departments or company creates an environment unhealthy to manufacturing competitiveness.

10- Long setup times leading to larger lot quantities in order to justify setup costs and thus increasing the chances of scraping a larger lot size when non conformities occur instead of smaller lot. In addition obsolescence cost is greater with large inventory and lot size. However if the company could theoretically produce lot size of one then the quality reject or rework would be one and correction action much faster and more focused. it can be easily concluded that the above problems lead to long lead-time, poor quality, higher product cost and a company that soon is not capable of sustaining its current operations as usual.

In this project we shall attempt to resolve the quality and lead-time problems through added flexibility. We expect this improvement will enable the company to capture its lost momentum. The proposal includes creation of a flexible machine cell initially as a pilot program and then expanding to several cells. However for the purpose of this study only a flexible machine cell will be discussed.

CHAPTER FOUR

DESIGN OF THE FLEXIBLE CELL

4.1. Design of Flexible Manufacturing Cells

As the first step towards designing a FMC, we propose that the following questions be answered. The resulting data sets the stage for the design effort. We arrived at these questions by analyzing what data is required for a successful design effort.

1) What are the product line, families, groups, components or part types to be manufactured?

   Begin with the initial specification of what was to be produced on the system and then select a specific subset, or range of parts, to be manufactured or assembled by the FMC. From this initial specification a broad guideline can be drawn to show the necessary capacity and functional requirements needed to operate the system in terms of machine utilization , labor hours, cutting tools and fixtures.

2) How to manufacture the selected part types ?

   From the above decision the types and number of machine tools equipment, tool management and robots can be determined. In order to find what type of machine tool, cutting tools or cutting condition are needed, a process plan is essential for each part type required. From this we can determine the speed, feed rate and depth of each cut for each operation. Once having obtained these information, it can be applied to calculate the processing time of each operation from which the required capacity both in terms of tool magazine capacity and processing time or number of machine tools needed can be established.

3) What types of flexibility or what type of FMC should be acquired ?

In questioning the need for flexibility a variety of factors need to be addressed. For instance, does the company have the required ability to quickly change from one part to another or one model to another or one product family to another. Further, do the existing machines and equipment have the capacity and intelligence to run the calculated number parts designated for FMS and allow for sudden in increase demand. How easily can the machines be re-setup to produce a different part.

Setup times on all machines should be reduced to minutes or as low as possible. Shingo's methods of setup reduction are widely recognized and should be used as the tool for quick change over. It should be noted that reducing only a few machine setup time as part of the larger system does not help the over all process as required. The result of shorter setup times are production of small lot sizes and shorter product lead time. When lead times are short all machines will run and produce at the same rate demanded by the market and with the variety of mix demanded but at lower inventory and cycle time.

Figure 5 shows the conventional lead time chart components, A & B are purchased and delivered. Usually there is a period between receiving the part and the start of production to allow for paper work processing start of production of component A. Product B however, sits in the warehouse until its time to produce, hence carrying inventory cost. On the other hand in an ideal situation parts are received just when needed and no paper processing time is allowed, hence lead time and inventory carrying costs are reduced and many more benefits are gained.

Are workers flexible enough to perform many different jobs, Examine the inflexibilities in work contract which create inefficiencies and are critical to both shop and office productivity. In most cases lack of white collar

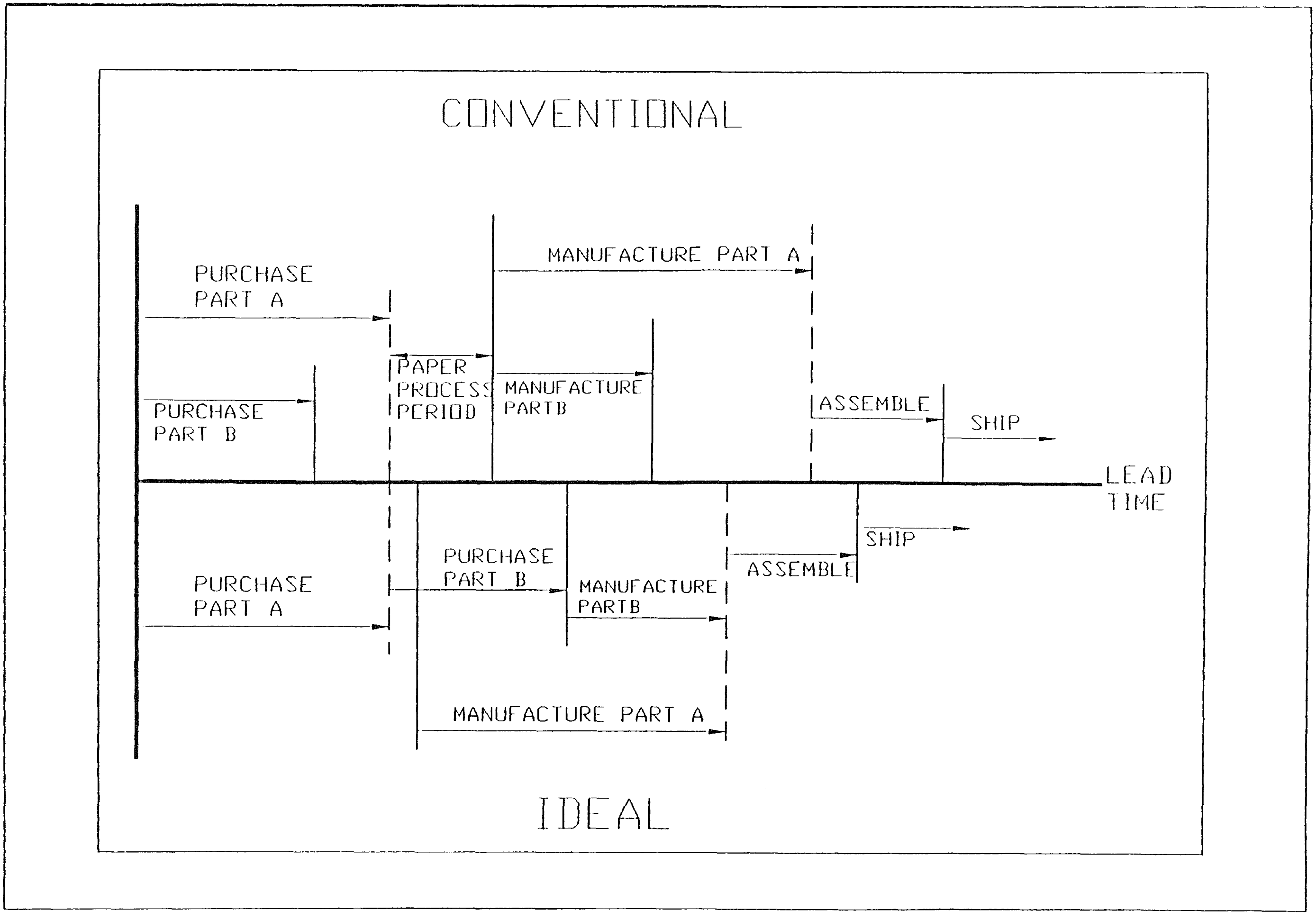

Figure 5. Ideal vs. Conventional Lead Times

willingness or inability to perform certain task, results in a more inflexible and perhaps harder to recognize situation.

4) What should be the class of material handling system that is implemented and what is its capacity ?

Study the means of the existing material handling system to determine the efficiency and flexibility of material handling. Since parts spend more time in off-process than in-process, the material handling system must be flexible enough to deliver any desired part to the right work center at the right time. One option is to have the parts automatically transported through the system by way of roller conveyors, automated guided vehicles, wire guided carts or two way tow lines. Where appropriate, the number of carts or vehicles should be calculated in meeting the capacity requirements.

5) What type and size of buffer space for work in process inventory must be maintained ?

To keep the machine tools utilized, there may be a need to provide queuing storage location for work in process inventory. This location can be a satellite, or in point of use, or on the material handling system. Some system may contain all, or a combination, or none of these elements. The benefits in each type must be studied for best buffer coverage.

6) What is the hierarchical relationship between computer control and manual control of the system ?

7) What is the design of the cell layout ?

Layout design of the cell together with the type of material handling system plays a very important role in the effective utilization of space being used and the time needed to travel from machine to machine, or work center to work center and, its total system travel time.

8) What is the required number of pallets or baskets.

The exact number of pallets used in a system is critical in terms of the systems capacity. Too many pallets creates system overflow and unnecessary expenses. On the other hand, too few pallets put the system under normal operating capacity which, in turn, creates system wide waste of resources.

9) What are the FMS control objectives ?

System wide control and planning objectives and scheduling are required to insure the FMS design is practical, and can perform as represented. If computer controlled, software procurement and development need to be addressed.

In designing a system many of the questions listed above can be simultaneously solved. However, there will be a great amount of repetition back and forth between different solutions before the final arrangement is obtained.

4.2. Detailed Cell Design

Inquiry into the company's line of products has focused our attention on one family of products known as cargo hooks. The following are factors influencing the selection of this group as the starting, or pilot, program for establishing a flexible machine cell to provide the required flexibility and quality needed.

1- Exclude the group of products that are the bread and butter of the company.

2- Select a collection of product lines or products that have a relatively small number of parts to process, approximately 20 to 35 parts not including hardware items.

3- Out of the selected groups pick one where the design by characteristic or nature would be easy to machine and process on equipment currently used in the facility or could easily be redesigned to contain Design For Manufacturability criterion.

4- Determine the components or parts to be manufactured. Once we know what to manufacture, it can be determined how to make the selected parts.

The next step was to create a bill of material and process plan for the product(s). This involved identifying the required routing or processes needed to manufacture the parts. Therefore, proper types of tools, equipment, fixtures or others can be decided upon based on the process plan made for each part type. Thorough study of the operation processes has provided us with a list of equipment needed to completely process the selected parts from start to finish. Based on the process chart, a cut off saw is needed to cut the raw stock into machine able sizes. Depending on the following processes, the parts will go through their respective machines. Two CNC machines will provide the added base flexibility needed for the low volume, but diversified family, of products. The complete list of selected machines are as follows:

one cut off saw
one HS5A milling machine
one 25S machining center
one Cincinnati vertical miller
one grind machine
one drill press
one horizontal honing
one tool presentation
three WIP-inventory buffer table
one incoming pallet

one out going pallet.
one Irrodite (chemical filming) facility

From the above list of equipment, one can immediately remove the environmental hazardous facilities from the machining cell. The rest of the equipment can be selected as permanent members of the cell if their utilization rate is higher in this group of products, or long term rate of pay back is justified and accepted by the management.

All selected equipment must accommodate a quick setup, or zero setup property as the primary requirement for cellular manufacturing. If characteristic of quick change over does not exist, then Shingo's setup analysis known as Single Minute Exchange of Die or SMED for press machines can with some modification, be applied to almost all other types of factory machines.

Shingo analyzed and broke the setup procedure into two categories of External and Internal setups. External setup is defined as any preparation of parts, tools, fixturing, maintenance and so forth that can be done while the machine is running. Internal setup is defined as any operation that can only be performed when the machine is off, such as attaching tools to the machine, and sliding the next work piece onto table. The key in set up reduction is converting as much internal setup as possible into external setup.

In addition to above, there is a third category which we call "software setup reduction". Through observation, knowledge of programming and talking with CNC operators, we observed there are some setup reductions that can be performed while writing the main CNC program. For example, a programmer should assign one specific tool to one specific pocket on the magazine throughout all parts and programs. This will reduce manual change over time of tool from pocket and to pocket, from program to program.

The next step in the design process involved time phasing the routing so as to determine the necessary machine utilization rate and labor hours. This was done by inputting accurate processing time into appropriate routing file. This above information was presented to the management for selection of the most fitting type of Flexible Manufacturing system, based on management's long term goals and objective. It was decided that the selected system must possess the capability to easily exchange or to replace new parts for existing parts as well as providing added responsiveness to surrounding environment and marketing newly designed products in a short period of time. The result of management's decision was to implement a "Product Flexible Cell" of manufacturing but leaving room to be able expandable into a Flexible Manufacturing System.

Upon determination of the desired system, the next step in design of a cell(s) is to pick the class of material handling system and then its capacity. It is critical that material transport within the cell and later with FMSs, work in process must be done as quickly and reliably as possible. Parts must be stored so they are easily accessible and retrieved when needed. There for the selected automated material handler should be viewed as a integral part of the cell with the FMSs. The selected material handling system should contain the following property.

1- Controlled acceleration/ declaration capability. This is necessary to avoid shifting of the work piece caused by the abrupt starting or stopping of the material handler during the initial and final transport phase. This shifting may mar the quality of manufacturing parts, or may cause damage to other equipment, products or human beings.

2- As part of the bigger picture this transport system should also contain the capability to be dispatched by a computer. This added feature enables the parts to quickly move within the system and meet variability in production fluctuation.

Another very important factor in the selection to be considered is the capability of the system to expand or integrate as the marketing requirement of the company change. Thus a modular system is preferable. Determining the type and size of the cushion for work in process inventory is the next step in the development of a machine cell. To keep machines fully utilized, we can provide room for buffering or queuing location. If space is available in the cell, then this location can be picked at point of use, otherwise a satellite location may be picked. Some design of the system allow buffering room to be on the material handling system.

In conjunction with actions previously stated the vendor base should be reduced as part of implementing an FMS. There are several reasons why a reduction will help to improve the quality, and deliverability of parts.

1- Buying more from one vendor means greater expectation on behalf of buyer. This means these vendors must meet buyers requirements or the buyer takes the business elsewhere. Since a large percent of the vendor's sell is dedicated to a single buyer, it would be difficult for vendor the not to comply.

2- It produces lower administrative costs, since dealing with only few known vendors is less costly.

3- Lower transportation costs are recognized because more parts can be delivered at one time by one vendor.

4- When designing new product, vendor participation becomes easier, since there is fewer of then to participate.

4.3. Layout Design

Once the machines, equipment and material handling system have been selected the cell layout can be determined. The first rule of design is that layout must be as flexible as possible so that it can readily be expand to increase the capacity, or take in members of the family. If the long term objective is to link the cells into a large manned or unmanned integrated manufacturing system, then the design should allow the capability to do so.

A manned cell which consists of NC's or CNC machines with operators who have been cross trained to handle more than one machine, is generally more efficient because the number of operators can be adjusted and minimized to produce required output, compared to manned cell without operators which cross training. The type of layout and cell design discussed, possesses the capability to completely process one piece at a time. It is also know as one piece flow production.

Several types of layouts are presented in figure 6. Process layout, which is one of the most common layout types used in industry is a functional layout. In this type of layout all equipment are arranged with respect to their type i.e. all mills, drills, shapers, etc. are clustered in their respective departments. The advantage of a process layout is its allocation of tooling and fixturing within departments, which allows for accumulation of information regarding a limited set of operation within these department. On the other side of the coin however, it requires flow of parts throughout the factory in some random fashion.

A product layout significantly reduces the material handling and lead-time of parts to be produced simply by establishing a part family. This requires grouping different required machines and clustering them into one department or cell to produce a family of products which have similar routing processes. It can be seen that the flow of material throughout the system is much more efficient and organized.

Cellular manufacturing does not necessarily have to be operated under a one piece flow concept but in just in time this type of production flow receives orders to replace the goods used up by the assembly department. The assembly department on the other hand, receives a weekly production plan

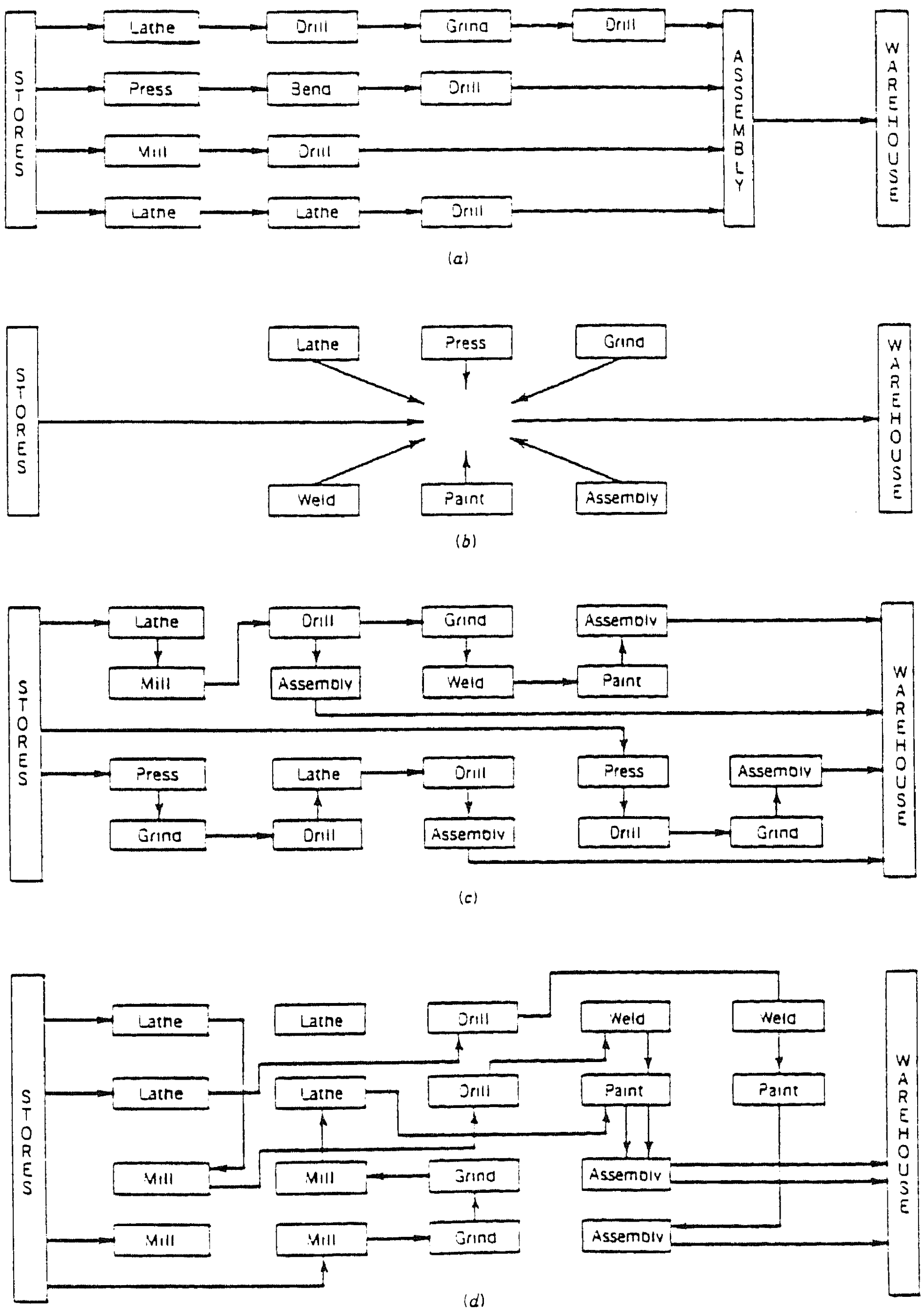

Figure 6 Alternative types of layouts. (*a*) Production line product departments. (*b*) Fixed material location product departments. (*c*) Product family product departments. (*d*) Process departments.

based on the latest market information. Since upstream process pull orders from assembly area it can be said that the factory follows a pull production system. Out of various product layouts, It has been noted that U shaped cells offer the greatest flexibility. See figures 7 and 8 for possible cell layout configuration.

Figure 9 describes the present machine shop layout of the case study company. To develop a flexible system it will be necessary to convert this functional, or process, layout into a cellular layout. We have developed such a layout for one product family. A U-shaped layout was generated and the results are described in figure 10.

4.4. Estimated Costs and Time of Implementation

In dealing with the estimated cost the of proposed cell, several factors must be looked at as follows; Is there any need for the purchase of new equipment? In this case since, the objective was to establish a non automated cell, non of the material handling systems such as AGV, roller conveyors, robots or other automation devices are required. However the cell layout has left room for future enhancement.

After analyzing the process plan of parts to be produced, the scheduling effect and capacity need of the plant it was determined relocation of machines into the cell will not change the capacity level of the plant. Therefore because the company already has in its facility all of the machined needed to run the cell, the cost for the purchase of new equipment is zero.

The proposed cell will simply relocate some of the existing machine from different corners of the plant and bring them into one confined area in which the family of parts will be manufactured in on-discrete fashion. One cost for this basic level of flexible machine cell is relocating the machines. If implemented during production bearing days, the cost may also include the

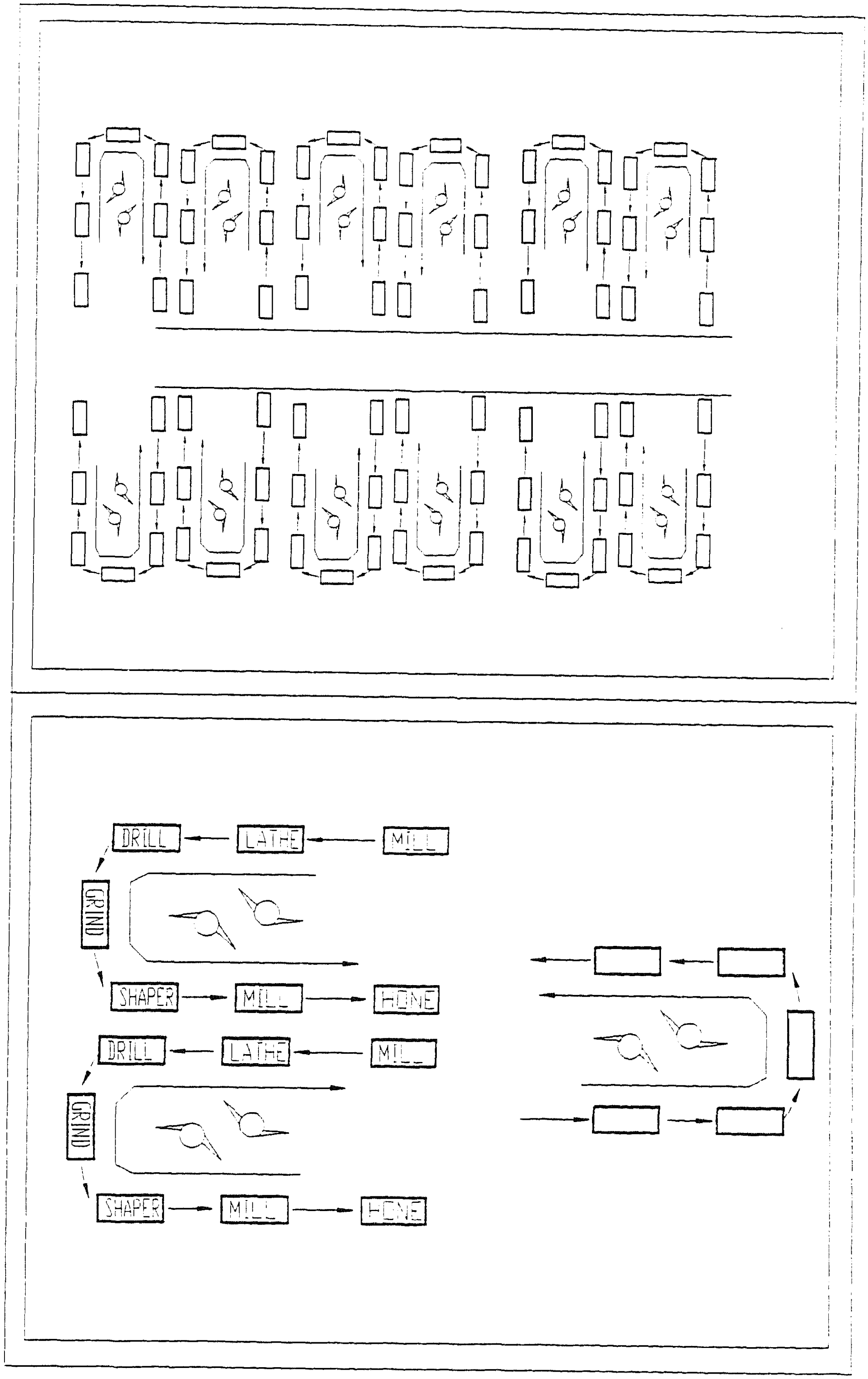

Figure 7 "U" Cell Layout

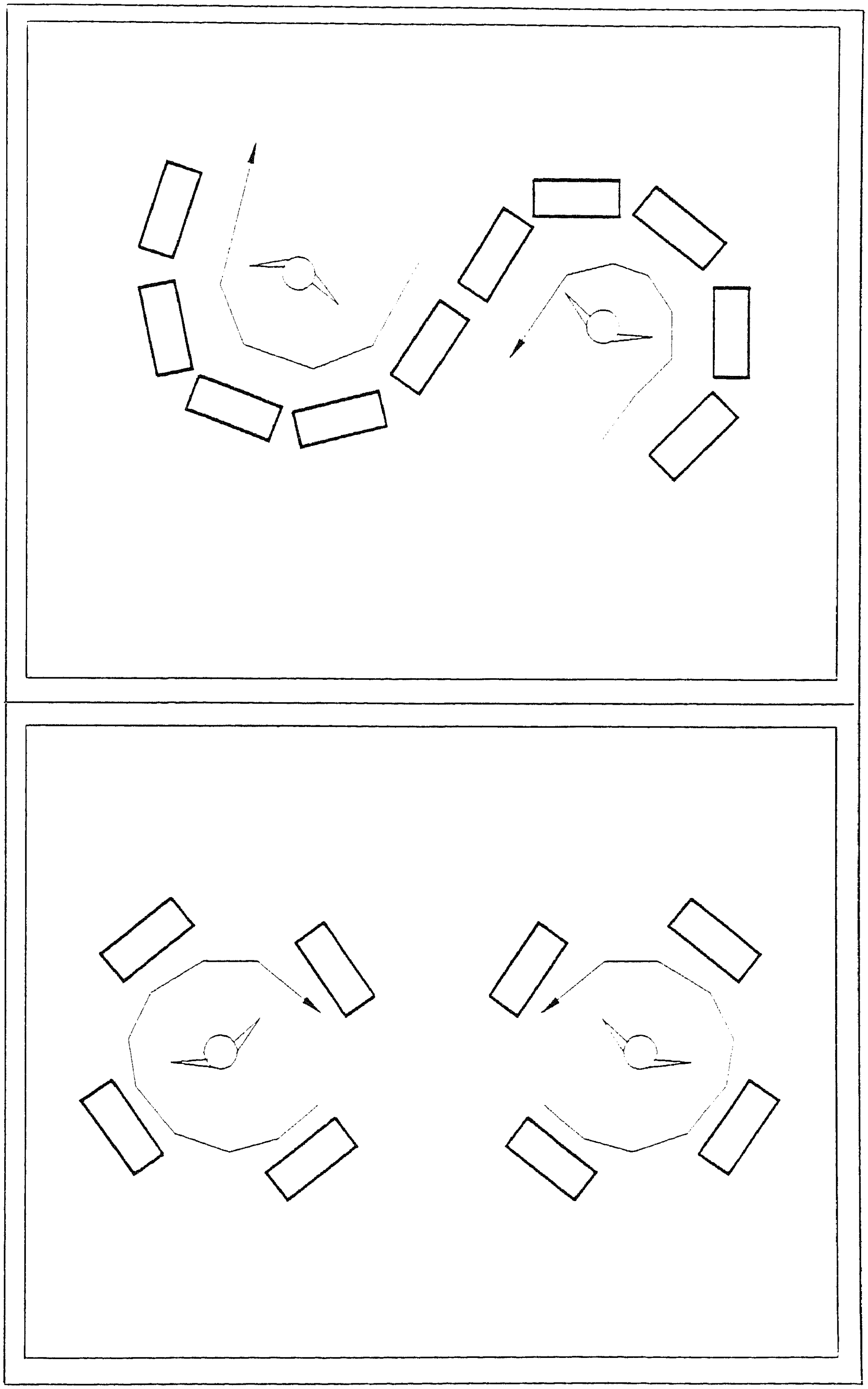

Figure 8 More "U" Cell Re-arrangement

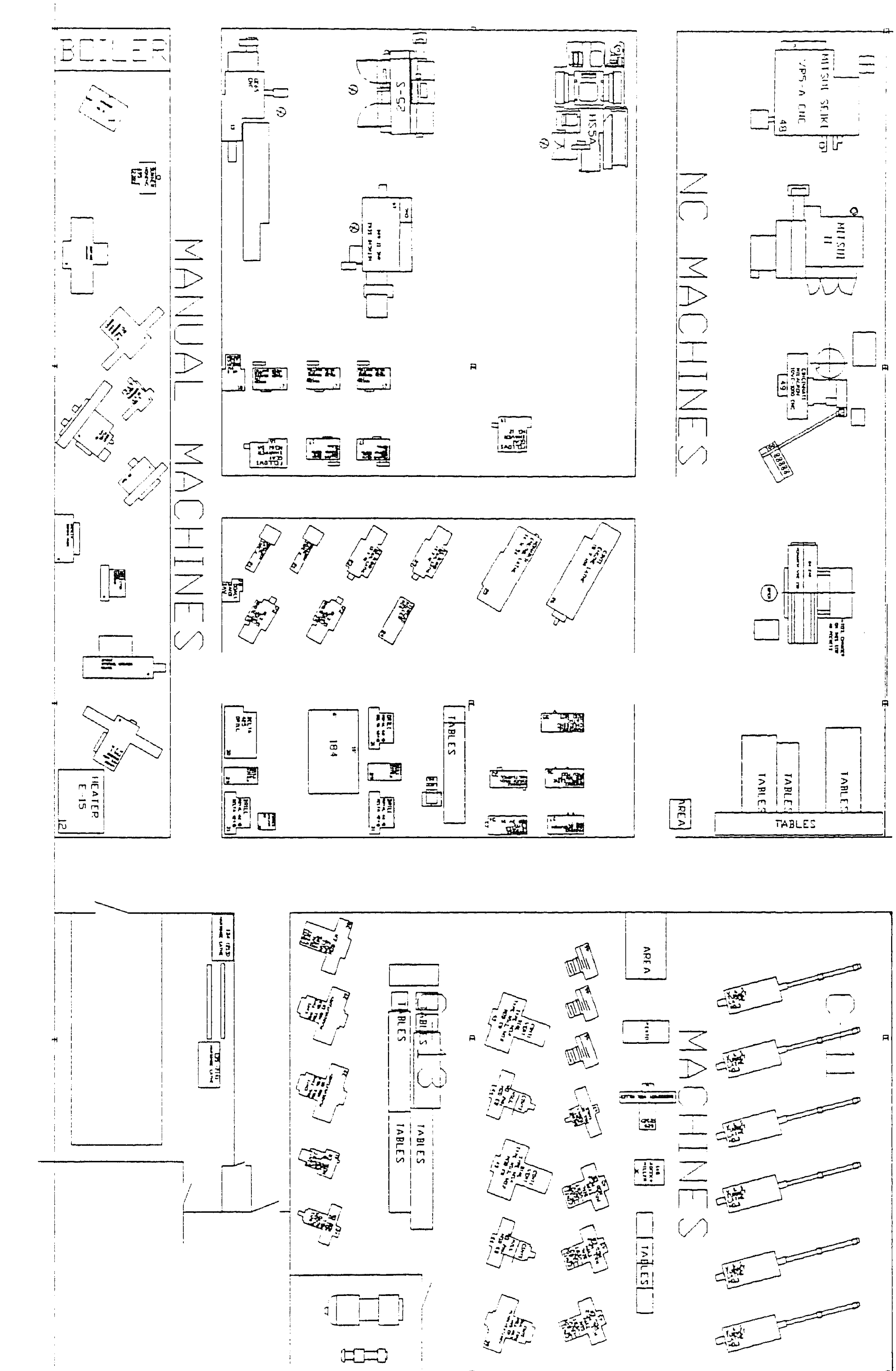

Figure 9. Present Machine Shop Layout

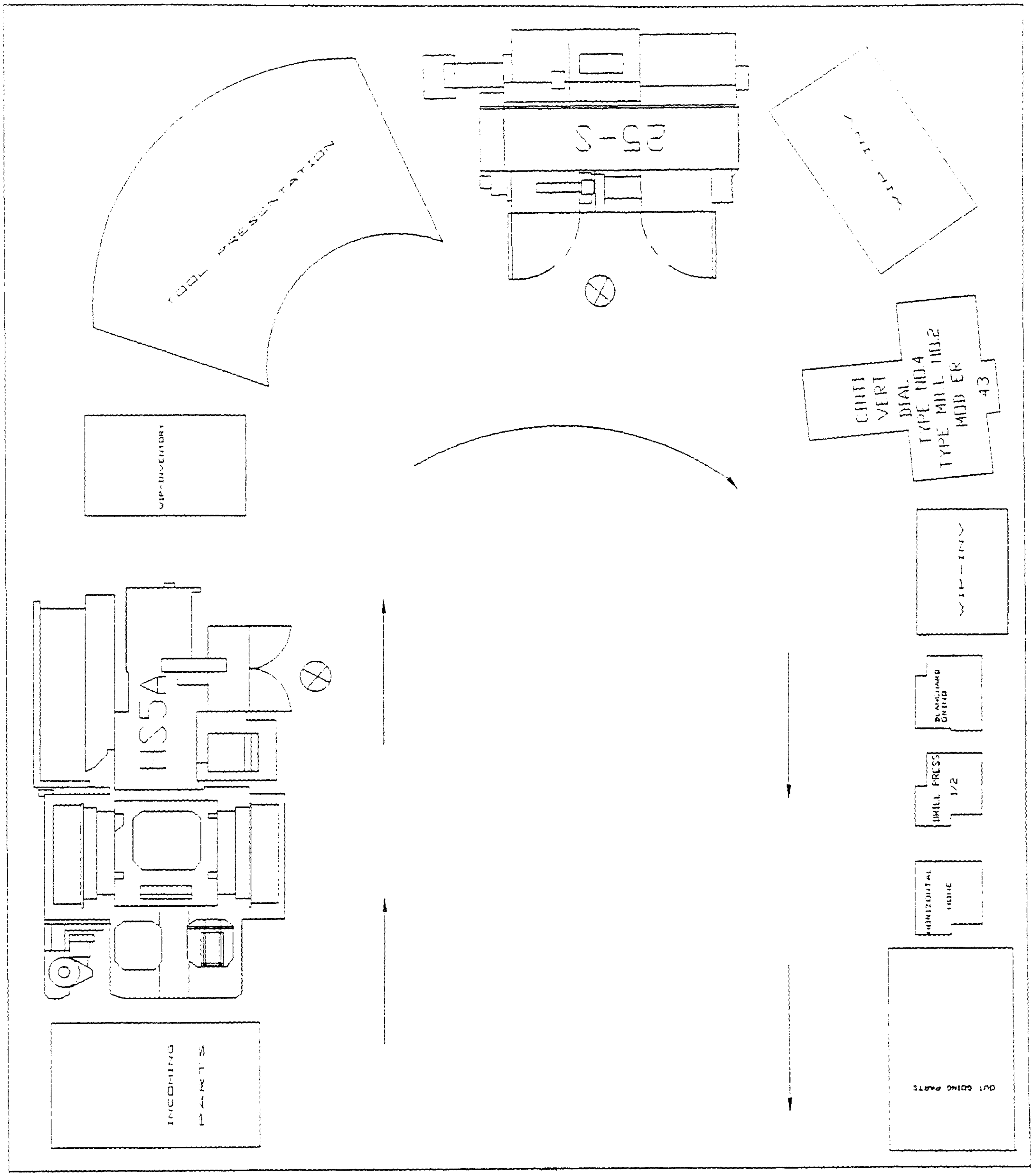

Figure 10. Proposed Cell Layout

cost associated with not producing and selling parts, and paying workers maintaining for idle time. Thus it is best to layout a changeover plan and implement it during a shutdown or vacation period so that production activity is not effected.

Additional cost with running the cell involves the development of a CNC program for parts that previously were machined on conventional equipment. Finally, last but not least, the cost setup reduction which is the absolute requirement for any flexible cell. The cost of reduction includes retrofitting the machines to operate in palletizing mode and cost of quick fixture setting jigs and tools. Future enhancement of the cell may include the addition of point of use storage and an assembly area for parts so that machine parts can quickly be assembled once the machining operation is complete.

4.4. Expected Benefits

Cellular manufacturing has been widely recognized and is increasingly implemented as the tool to provide added flexibility. It is managed to being operate under a one piece flow production method to satisfy more customers. As Oriental motors president, Mr. Kuraishi said once "it is better for the sake of long term management efficiency to fill 100 orders for 100 customers one at time than it is to fill an order for 100 products from just one customer".

Cellular production is a market oriented production. Recent changes in technology and the global economy have transferred the manufacturing base from a demand surplus to a supply surplus economy. What this change means is that the era in which producers were able to sell anything because of short supply is over. In today's global economy almost any product can be made cheaper and better somewhere in this globe and that is easily identified by conscious consumers, thus forcing competition between other producers to match or die. This match can only be come possible through elimination of all levels of wastes.

Flexible machine cells by way of designs are laid out to minimize shop floor waste. For example integration of all, or most, necessary machines to completely produce the desired parts within one specific area eliminates the excessive transportation of parts in and out of storage and from machine to machine which takes time and requires non-value added man-hours. Thus parts needed to produce the finished goods are made and inspected in a relatively smaller area.

Since all equipment needed to manufacture the desired components from start to finish are arranged in a U shaped layout, within a confined area, and the machines have been setup to achieve quick changeover or possibly zero setup time (when using dedicated setups) then the time to finish one piece completely is immensely shortened. The result is that the end item assembled and subsequently shipped in a much shorter time than was previously possible. Another benefit of cellular manufacturing is realized with small lot production. Small lot sizes require a low work in process inventory and small finished goods inventory. It is obvious that inventory storage requires installation of racks, pallets, bins, and so forth, all of which cost money. When inventory becomes too large installation of Automated Storage/Retrieval System (AS/RS) becomes necessary and requires resources to manage the inventory. Consequently inventory turnover rates are greater with large lot sizes and carry higher interest burden. This is quite the opposite with small lot production since it deals with elimination of waste instead of handling them.

In addition, since fewer parts are made with small lot sizes, the number of rejects will also be relatively smaller if the process should go out of control. Because of the nature of the cell, problems are immediately magnified and communicated to appropriate channels for resolution.and the cell is at a stand still position until the problem is addressed. In non-cellular manufacturing, visibility of a quality problem islow and goes unattended for some time which creates recurring problematic situations.

With the introduction of robots and other automated mechanism, and integration of equipment within a confined area accessible within few walking steps, the ratio of man/machine decreases. This primarily is the result of one man running more than one automated machine at a time. Finally, since the worker has to operate several machines during his/her shift, multi skilled are developed which results in a team effort and the individuals thus help each other as they can also participate in the total system of a factory and feel greater job satisfaction.

4.6. Intuitive Justification

Today's global economy and competitive markets have created a serious situation for manufacturers in that they must face competitive challenges, or vanish forever, unless the company is the unlikely sole producer of a certain product. One particular challenge is the market need for diversified production requirements. This may simply require cost effectiveness with very short lead times, and added flexibility through automation. When acquiring new machinery and deciding between a flexible machining center with various degrees of automation (tool holders, instructions, multi parts) and a machines with rigid characteristics, the utilization, cost and objective of the company should be considered. For example, if three dedicated rigid machines can finish the job in an eight hour shift then it is preferred to a flexible machine that may only operate one third of the day to produce the same level of quality output and cost many times more. However if the firm's strategy is to constantly develop and deliver new products to the market in order to maintain market share or stay ahead of competition, then rigid machining and tooling will not yield the required flexibility needed to achieve a net moving average competitive edge during the phases of strategic implementation.

The following is a list of advantages associated with cellular manufacturing technologies:

1- Cellular manufacturing significantly reduces in-process inventory.

2- Cellular manufacturing reduces direct labor costs.
3- Cellular manufacturing minimizes the floor space required for manufacturing.
4- Cellular manufacturing significantly reduces the product lead-time.
5- Cellular manufacturing can achieve very high equipment utilization.
6- It requires reduction in setup times and thus reduction in throughput time for single product or when changing over from one to another product.
7- Provides managers with full control of parts flow on the shop floor.
8- Reduces the number of quality nonconformities and improves consistency in producing higher quality parts.

When analyzing a cell on its own, or as part of a flexible manufacturing system, the benefits of NC machines, material handling systems and product layouts becomes apparent, and more so if the system is controlled by an executive computer. It is the inherent efficiency in this type of manufacturing which is the driving force for its justification. Furthermore a cell with automated capabilities can reduce the vulnerability by reducing the dependence on labor in times of labor conflicts.

Because cellular manufacturing permits the firm to quickly respond to changing market environments and to curtail the investment risks involved, it should thoughtfully be considered as one of the few surviving methods in today's manufacturing environment. Furthermore studies and surveys taken from users of flexible manufacturing cells and systems, solidly show a large number of strategic and desirable benefits. However, as the amount of required investment capital increases from single cellular manufacturing to multiples of cells and then to a fully integrated flexible manufacturing system, the risk respective to capital investment increases as well. The justification of the cost of implementation of any of the above, unlike other tactical investments can not be based on desirability aspects alone, where middle managers would be able to approve.

Adding a flexible manufacturing cell is a strategic decision and requires top level management support. It is a strong belief that managers involved with its implementation are taking the positive step toward the integration of cellular manufacturing with the rest of firm's progressive total management approach.

CHAPTER FIVE

SUMMARY AND CONCLUSION

Various definitions and types of flexibility exist. In this thesis we have discussed the means, purposes, and application, of these types. These were applied as the basis for understanding the selection criteria of appropriate flexibilities in a manufacturing environment. The case study presented in this paper marked some of the typical industry problems facing the United States manufacturing companies and then presented a selection process for eliminating those problems by way of designing flexible manufacturing cells or systems where appropriate. The company selected for this case study was chosen because it presented the most typical ills of American manufacturing companies plus the fact that we were able to compile the general problem history of the company.

In the real business world it is absolutely essential to justify the costs of any investments, analyze the rate of return or period of pay back accepted by the finance managers. Usually this rate of return is a period of 2-3 years for the U.S. companies, and 7-10 years for the Japanese. An immediate observation of the pay back period will reveal why it would be much more difficult for U.S. companies to justify new equipments costs and other investments that would help boost the productivity than it will be for Japanese firm. Because of longer pay back period considered by the Japanese, and the long term objectives of the their companies, it is easier to invest in new equipments and other productivity improving technologies.

It is rather critical for finance managers to change their point of view from strictly looking at the immediate return on investment onto the futuristic benefits and intuitive aspects of return on investment. This is why the benefits and intuitive managerial justification were discussed in a non-quantitative approach.

As clearly observed by the reader, flexibility has both adverse and advantageous effects on the system performance. A case pointing out both would be the situations where a system is required to produce families of parts. It becomes necessary to hold more inventory in order to balance the production rate with demand whereas, a single product system can produce at a rate which balances the demand rate. On the other hand a system capable of producing variety of different job types is less susceptible to distortion. These more reasons situations emphasize why, the design and analysis of modern manufacturing is a complex task and requires complete understanding of alternatives.

Designers may use computer software as a means for simulating and evaluating the system design. Flexible manufacturing technologies, produce new products or respond to changing demands. These attributes define the flexibility space of a system, but how flexible a system can be is a strategic and economic decision made by top management which requires adaptability as a critical part of its system design in order to absorb new process .

After nearly twenty years from its initial overblown expectations, we now in the 1990s have come to a recognition of the need for a more focused ambition, but eith wider scopes of flexible manufacturing system. It should be clear that only constant vigilance by participating management can reject or rectify manufacturing ills. Obviously Management realize there is a price tag on flexibility and it does not come for free.

Over a decade of industrial activities and dealing with FMS has created a sentiment which strongly replaces wholesale devotion to FMS with selective consideration of how much flexibility a company requires to meet its business objectives. The recent changes in world events has contributed to the creation of global, thus economy together with changes in market place from a demand surplus into a supply surplus economy means that manufacturers are going to be forced to embrace low-volume, high mixed production techniques. Added flexibility can achieve the run of production necessary to produce lower costs, shorter lead times and justify shorter product life cycles. Therefore one of the most important issues which must be conceived as intregal part of business is the "manufacturing strategy". The strategy should include consideration of the volume of parts to be produced. As volume goes up flexibility should go down. Higher volume of a single model product may get away with lower cost fixed automation systems.

If the question is how much to invest on flexibility versus low cost and market uncertainty, the the answer may lie with management on how to justify flexibility as a defensive measure against equipment that can be utilized to produce other products in case the current product should fail.

In conclusion, flexibility with its negative and positive contribution has become an absolute part of an aggressive, growing company. The MRP systems are made to forecast demand and load manufacturing system from top to bottom. But in today's market we must be able to produce quality products that match customer demand in a short period of time, lower costs and produce smaller batches. The choice is clear we can either continue to load the system top to bottom and stay behind in the ever faster moving competitive race, or become flexible and respond to market uncertainties as quickly as computers permit.

REFERENCES

Beste, T. "Groessere Elastizitaet durch unternehmerische Planunh von Standpunkt der Wissenschaft", *Zeitschrift fuer handelswissenschaftliche Forschung*, Vol. 10, p. 75 (1958).

Bocker, H. J., Daniels, J.P., Prasad, J.N., and Shane, H. M. "The Factory of Tomorrow: Challenges of the Future", *Management International Review*, Vol. 26, pp. 36-49 (1986).

Browne, J., Dubois, D. Rathmill, K., Sethi, S.P. and Stecke, K.E. "Classification of Flexible Manufacturing Systems.", *The FMS Magazine* (April 1984).

Buzacott, J. and Mandelbaum, M. "Flexibility and Productivity in Manufacturing Systems", in *Proceedings of the IIE Conference,* (Chicago, IL), Industrial Engineering and Management Press, Atlanta, CA, pp. 404-413 (1985).

Carter, M. F. "Designing Flexibility into Automated Manufacturing Systems", in *Proceedings of the Second ORSA/TIMS Conference on Flexible Manufacturing Systems* (Ann Arbor, MI), K. E. Stecke and R. Suri (Eds.), Elsevier, Amsterdam, The Netherlands, pp. 107-118 (1986).

F. Choobineh and R. Suri, "Flexible Manufacturing System", Industrial Engineering and Management Press, Institute of Industrial Engineers. 1996.

Das S.K. "The Measurement of Flexibility in Manufacturing Systems", Submitted to International Journal of Flexible Manufacturing Systems, June 1992.

Falkner, C. H. "Flexibility in Manufacturing Plants" in *Proceedings of the Second ORSA/TIMS Conference on Flexible Manufacturing Systems,* (Ann Arbor, MI), K. E. Stecke and R. Suri (Eds.), Elsevier, Amsterdam, The Netherlands, pp. 95-106 (1986).

Gerwin, D. and Tarondeau, J.C. "International Comparisons of Manufacturing Flexibility.", In Managing International Manufacturing, K. Ferdows (Ed.), Elsevier, Amsterdam, The Netherlands, pp. 169-185 (1989).

Goddard E. W, *Just-In-Time*, Surviving by Breaking the Tradition, Oliver Wight Limited Publication, Inc., (1986).

Goddard E. W, *Just-In-Time*, Surviving by Breaking the Tradition, Oliver Wright Limited Publication, Inc., (1986).

Groover P. M., *Automation, Production Systems, and Computer Integrated Manufacturing*, Prentice Hall, Inc., (1980).

Gustavsson, S. O. "Flexibility and Productivity in Complex Production Processes", *International Journal of Production Research*, Vol. 22, No. 5, pp. 801-808 (1984).

Hall R.W, *Attaining Manufacturing Excellence*, Dow Jones-Irwin and Company Inc. ,pp. 30, 103-108, (1987).

Hall R.W, *Zero Inventories*, Dow Jones-Irwin and Company Inc., (1983).

Hart, A. G. *Anticipations, Uncertainty, and Dynamic Planning*. New York, N. Y. (1940).

Hayes, R.H. and Wheelwright, S. C. *Restoring Our Competitive Edge: Competing through Manufacturing*. Wiley, New York, N.Y. (1984).

Kenichi S, *Cell Design for Transforming the Production Process*, Productivity Press, PP.7-14, (1992).

Lim, S. H. "Flexibility in Manufacturing System-A Competitive Study of Three Systems.", *in Managing Advanced Manufacturing Technology*, C.A. Voss (Ed.), IFS Publications, London, U.K, pp.125-147 (1986).

Lim, S. H. "Flexible Manufacturing Systems and Manufacturing Flexibility in the United Kingdom.", *International Journal of Operations and Production Management*, Vol. 7, No. 6, pp. 44-54 (1987).

Luggen W. William, *Flexible Manufacturing Cells and Systems*, Prentice Hall, Inc., (1991).

March, J. G. and Simon, H. A. *Organizations*, Wiley, New York, N. Y. (1958).

Newman, W. E., Jr. "Models to Evaluate the Benefits of FMS Pallet Flexibility.", In Proceedings of the Second ORSA/TIMS Conference on

Flexible Manufacturing Systems (Ann Arbor, MI), K.E. Stecke and R. Suri (Eds.), Elsevier, Amsterdam, The Netherlands, pp. 209-220 (1986).

Ranta, J. "The Impact of Electronics and Information Technology on the Future Trends and Applications of CIM Technologies.", In *Trends and Impacts of Computer Integrated Manufacturing*, J. Ranta (Ed.), IIASA, A-2361 Laxenburg, Austria (1989).

Rattner, L., Orne, D., And Wallace, W. A. "What Can We Learn From the Past?: A Comparison of Historical Manufacturing Systems With Computer Integrated Manufacturing", Technical Report, Rensselaer Polytechnic Institute, Troy, N. Y. (1988).

Schonberger J. R, *World Class Manufacturing*, The Lessons of Simplicity Applied, The Free Press, New York, 1986.

Sethi S. P. and Sethi A., "Design, Analysis, and Operation of Manufacturing and Assembly Systems", Volume 2, Number 4, July 1990.

Shingo S., *Key Strategies for Plant Improvement*, English Translation By Productivity Press, Inc. 1987.

Slack, N. " The Flexibility of Manufacturing Systems.", *International Journal of Operations and Production Management*, Vol. 7, No. 4. pp. 35-45 (1987).

Stecke, K. and Kim, I. "Performance Evaluation for Systems of Pooled Machines of Unequal Sizes: Unbalancing versus Balancing.", *European Journal of Operational research*, Vol. 42, No. 1, pp. 22-38 (1989).

Taiichii O, *Toyota Production System,* Beyond Large Scale Production, English Translation by Productivity Press Inc., 1988.

Tarondeau, J. C. "Technologies Flexibles et performances.", Working Paper, ESSEC, Cergy, France (1986).

Tien-Chen Chang, *Computer Aided Manufacturing*, Prentice Hall Inc., pp..383-384, 1991.

Thomas Publication, "Managing Automation", FMS Underlies Modern Trend In Manufacturing, pp. 20-22, 1993.

Wright W. Oliver, *Manufacturing Resource Planing MRPII,* Unlocking America's Productivity potential, 1984.

Wu B., " Manufacturing System Design and Analysis" , Chapman & Hall, London, 1992.

Yilmaz, O. S. and Davis, R. P. "Flexible Manufacturing Systems: Characteristics and Assessment.", *Engineering Management International*, Vol. 4, pp. 209-221 (1987).