1986

Development of an automation strategy for a discrete component manufacturer /

Joseph J. Allan, Jr.
Lehigh University

Recommended Citation

Allan,, Joseph J. Jr., "Development of an automation strategy for a discrete component manufacturer /" (1986). *Theses and Dissertations*. 4618.
https://preserve.lehigh.edu/etd/4618

Development of An Automation Strategy for a Discrete Component Manufacturer

by

Joseph J. Allan, Jr.

A Thesis
Presented to the Graduate Committee
of Lehigh University
in Candidacy for the Degree of
Master of Science
in
Manufacturing Systems Engineering

Lehigh University
1986

CERTIFICATE OF APPROVAL

This thesis is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science.

5-5-86
(date)

Roger N Nagel
Professor in Charge

Roger N Nagel
Director of MSE Program

Chairman of Industrial Engineering

ACKNOWLEDGEMENTS

Because of limited space, I cannot adequately acknowledge all those who contributed to make this thesis possible. To those of you I fail to mention here, I sincerely thank you for the invaluable information, time and inspiration you have given me. Of special appreciation, I'd like to thank the management of International Business Machines, Corporation for investing in the Manufacturing Systems Engineering program and sponsoring me here at Lehigh University.

I would like to thank Dr. Roger Nagel, the Director of the Manufacturing Systems Engineering program at Lehigh. As my thesis advisor, he was an invaluable source of insights into modern manufacturing and provided a great deal of knowledge and guidance.

Of special note, Orapong Thien-Ngern provided a great deal of material and knowledge on Group Technology and Machine Cell design, which was used throughout this thesis. And finally, I would like to thank Mark Delgiorno for creating the software that was used to define some of the machine cells.

TABLE OF CONTENTS

PART I. AUTOMATION STRATEGY AS RELATED TO THE SMALL TO MEDIUM SIZE MANUFACTURER

PART II. MACHINE CELL IMPLEMENTATION

PART III. ISSUES THAT AFFECT IMPLEMENTATION

ILLUSTRATIONS

Figure

Table

ABSTRACT

The role and importance of an automation strategy in a small batch manufacturing operation is investigated. Several companies were studied to identify critical aspects of an automation strategy including the establishment of machining cells. Real world constraints such as using existing technologies and resources, meshing management policies with system objectives, and skill profiles are described with experiences from real companies.

The analytical tools and methods used in planning and evaluating alternatives are described, and the respective advantages, disadvantages, applicability, and effectiveness are presented. This approach was used in describing various heuristic, group technology, and simulation techniques available to organize and define automation machine cells.

A road map of common problems is presented and suggestions are given on how to minimize their impact on successful automation projects. Finally, a summary of experiences gained in analyzing real projects at several companies is presented along with suggestions for future research required to provide better tools and techniques for future automation strategy implementation.

PART I. AUTOMATION STRATEGY AS RELATED TO THE SMALL TO MEDIUM SIZE MANUFACTURER

CHAPTER 1.

INTRODUCTION

1.1 Problems Facing Manufacturers

CIM, FMS, JIT, CAD/CAM/CAE, GT, Factory of the Future, and MAP are some of the more popular buzz-words used in today's manufacturing circles. The great engineering minds of our time are expending a lot of effort, and dollars, in trying to transform these phrases into working, profit producing systems. Of great concern to many of the world's manufacturers is whether these mystical systems are the sole domain of the few capital rich, high volume producing giants of the manufacturing community, or can they also be used to benefit the small to medium sized batch producer? Do the words "Automate, emigrate, or evaporate", espoused by GE's James Baker, have any real meaning to the smaller producers of manufactured goods? These are the concerns of many U.S. manufacturers who face continuing pressures from stepped up offshore production, compounded by a shrinking marketplace.

The small to medium size discrete component manufacturer, with production batches of less then fifty pieces, makes up approximately three-fourths of the U.S. metalworking industry. These companies are faced with a rapid proliferation of the varieties of products, forcing the average lot sizes to shrink, increasing unit cost, in addition to pressures to shorten manufacturing lead times. In order to keep up with the demands of today's marketplace, companies must develop strategies to advance from where they are today to a more competitive position in the future.

1.2 Scope of Thesis

This thesis focuses on the role and importance of an automation strategy to the small to medium size component manufacturer. The real issue is the formation of a strategy that could be implemented quickly, while minimizing capital expenditures. A company's motivations for creating an automation strategy includes the need to reduce direct labor costs, develop more efficient use of existing resources, and to assure that production operations became more competitive. The goal is to develop a method of achieving economies of scale while maintaining the flexibility inherent in small batch production.

1.3 Organization of the Thesis

This thesis is divided into three main sections. Part I is introductory and covers some fundamental concepts in automation strategies as they relate to the small to medium size component manufacturer. Included are the reasons and motivations for creating an automation strategy. The constraints associated with an automation strategy are identified. These are as follows :

- the strategy must be consistent with the companies long term manufacturing objectives
- the strategy should be implementable and uncomplicated
- it must be affordable

o it should utilize existing resources

o it is a short term strategy and must be part of a longer range assessment

The use of machine cells is identified as one of the most critical elements in the development of a viable automation strategy.

Part II of the thesis is devoted to the creation of machine cells, since it is the basis for automating a small to medium size manufacturing company. In Chapter 3, the conditions that favor the implementation of machine cells are discussed, followed by an outline of benefits associated with the use of machine cells over the traditional shop floor layout. Machine cells have many advantages over the traditional shop layout, while at the same time they can be inexpensive to implement. Next, in Chapter 4, three methods commonly used in creating machine cells are presented. These methods include trial and error, heuristic clustering methods, and the use of Group Technology software. Examples of each method are given, and are examined using experiences of companies involved in the implementation of machine cells. Finally, the advantages and disadvantages of each method are outlined and related to the experiences of each company.

Part III of the thesis is comprised of three chapters. This part of the thesis is devoted to summarizing the concepts presented in the preceding chapters. In Chapter 5, discussion is given to the importance of using simulation to model changes to manufacturing systems prior to implementation. A step by step process of simulation is outlined. This is followed by a listing of the advantages and disadvantages associated with manufacturing process simulation. Finally, in Chapters 6 and 7, the ideas presented in this thesis are summarized, followed by the thesis conclusions and suggestions for future research in this area.

CHAPTER 2.

AUTOMATION STRATEGY

The purpose of this chapter is to present the conceptual framework to be used in developing an automation strategy. The discussion begins with a definition of an automation strategy, and is followed by an outline of the reasons and motivations for creating such a strategy. The underlying objective of this thesis is to address the issue of how a company should deal with developing a viable, implementable automation strategy. To effectively cover this, the following areas are explored: the constraints associated with creating a viable strategy; the link between an automation strategy and a company's overall business strategy; and general guidelines to assure successful implementation.

2.1 Strategy Definition

The word "strategy" is associated with establishing a purpose, setting a direction, developing plans, and taking major actions. Within a business, a strategy serves to guide decisions and efforts throughout the organization. It gives a company a sense of clear purpose and leads to consistent results. This allows a company to translate its manufacturing capabilities into competitive success. Hayes and Wheelwright [18] list five important characteristics common to the use of strategy in business. These are listed below and discussed:

- Time Horizon
- Impact
- Concentration of Effort
- Pattern of Decisions
- Pervasiveness

The time horizon is generally used to describe activities that involve an extended time horizon, both with regard to the time it takes to carry out such activities and the time it takes to observe their impact.

Impact is important because the consequences of pursuing a given strategy may not be apparent for a long time, however, its eventual impact on the company will be significant.

The *concentration of effort*, or attention on a fairly narrow range of pursuits, is required to assure success of those efforts. Focussing on a few chosen activities implicitly reduces the resources available for other efforts.

The *pattern of decisions* made can either help or hinder a company's plans. Although some companies need to make only a few major decisions to implement their strategy, most strategies require that a series of certain types of decisions be made over time, which in turn, must support one another and follow a consistent pattern.

Pervasiveness is important in that, because a strategy embraces a wide spectrum of resources and activities, it must be consistent over time, and requires that decisions at all levels be made in ways that reinforce the strategy.

A complete strategy must possess these characteristics as they relate to manufacturing and the implementation of new technologies. A successful strategy will guide the company towards a more competitive position thus assuring its survival in the future. The strategy should apply to all manufacturing functions and promote the adoption of advanced technologies.

The manufacturing functions in which an <u>automation strategy</u> might apply were identified by Mikell Groover [14]. These include materials processing and assembly, materials handling, process/plant level control, and manufacturing data base development. The "fundamental" strategies to be used to improve the productivity in manufacturing operations, must address each of these functions.

Since small to medium size firms cannot compete based on capital-dominated strategies, they must compete using technology-dominated strategies. Historically, smaller firms spend a very small percentage of their budgets on manufacturing R&D. Even though larger corporations dominate the spending on advanced technologies, Edward

Roberts [27] states that a surprisingly large number of key innovations have come from small firms and individual inventors. The smaller companies seem to be more willing to take risks and exploit innovative ideas.

Two main elements of an automation strategy, for the medium-size firm, as identified by Roberts, are as follows:

> First, the company must be in a position to exploit new technologies. Companies must be willing to use technologies developed by other companies. This does not require a large R&D budget, but a willingness to keep an eye open and adopt new technological ideas, wherever found. Statistics indicate that few technological ideas are being exploited. Roberts sights that only 33% of these types of ideas were used in successful commercial innovations in the U.K., and only 22% had been adopted in the U.S. This is evidenced by the "not invented here" attitude that seems to be prevalent in many businesses.

Robert's second point is that companies should be concentrating on ideas that are relevant to their market or product needs. This is to assure valuable resources are expended in areas that are consistent with the company's goals.

2.2 Automation Strategy Outlined

Using the concepts developed above, an outline of an automation strategy is created. The formulation and development of an effective automation strategy requires a great deal of time and commitment from all levels of management. A company must decide to commit some of its resources to creating such a strategy before any useful work can be done. Once this is done, a strategy can be developed to exploit new ideas and innovations in manufacturing.

Listed below is an outline of an automation strategy that is applicable to the small to medium size component manufacturer:

1. Perform an evaluation of the present system.

2. Establish the roles of key people.
3. Determine product cycle times.
4. Identify Machine Cells.
5. Simulate Machine Cells.
6. Establish an implementation schedule.
7. Implement.

The first step is to perform an evaluation of the state of the present system. A company must determine where they are, in terms of manufacturing capabilities, in order to create an effective plan that will guide them to where they want to be in the future. The evaluation process will aid the company in understanding the system, with its strengths and weaknesses. A complete understanding of the system is required before trying to implement any new technologies.

The second step is to identify the roles of the key administrators of the strategy. These key people will assure the successful development and implementation of the automation strategy by making sure it runs smoothly and obtains the proper priorities, resources, and attention it needs. The major activities of this person should be similar to those of a project manager. These activities include overall planning, recruiting people and contracting of work to accomplish tasks, interface with company management, ability to adapt or change the activities as circumstances change, and to follow the development of the strategy from start to closing when it is implemented. It is essential that the key people be identified early, so that continuity is maintained throughout the development and implementation stages of the strategy.

The *product cycle time* is the amount of time a part spends in the manufacturing process from the time the raw material is delivered to the floor to the time the finished product is sent to stock. It is important to establish the existing production cycle times in order to identify the system's problem areas, bottlenecks, as well as areas that will gain most from change. This will help to focus the company's efforts on the parts of the system that will afford the highest rate of return from investments in automation.

For many companies, the most important aspect of the strategy is to develop *machine cells* that have the capability to produce a great variety of parts within a small amount of space. Machine cells, which are described in detain in Chapter 3, are comprised of all the machine tools that are needed to completely manufacture parts from raw material to finished products. The grouping of machine into cells is an inexpensive way of reducing labor costs, while utilizing existing resources. By producing a variety of parts in a machine cell, the distances the parts travel are drastically reduced, and the job of controlling work-in-process inventory is dramatically increased. Machine cells are easily implemented and are flexible. They give the manufacturing system modularity, permitting the company to introduce new technologies incrementally as they become available.

Next, the machine cells must be modeled using simulation. Simulation is required to determine the manufacturing capacities of the machine cells, as well as the operating parameters. It will provide information concerning how many parts can be processed through the cell, the process cycle times, the machine and operator utilization rates, and amount of work-in-process required. Much of this information cannot be obtained economically without the use of simulation.

The establishment of development and implementation schedules, and finally, the implementation of the automation strategy can be accomplished through the use of project management techniques. Critical events and dates must be identified, and implementation problems must be resolved. The use of project management techniques can assure the strategy is consistent with company policies and business strategies, and the strategy receives proper attention throughout the development and implementation phases.

Because machine cells can be a critical part of an automation strategy, they are the focus of Part II of this thesis. Before covering the details and methods of developing machine cells, the balance of this chapter focuses on the benefits of automation strategies and a brief discussion of alternatives.

2.3 Strategy Benefits

There are many reasons for generating an automation strategy. One reason, which is examined more in Section 2.4.2, is that there must be a means of developing and implementing automation plans that support and reinforce a company's basic strategies. Another reason is to assure technological progress in manufacturing. As Bela Gold [13] put it, "technological progress is universally recognized as essential to the maintenance of an effective competitive position over extended periods."

The benefits to creating an automation strategy are many. Most notably, these include developing a better understanding of the present system and the identification of potential problem areas and bottlenecks. The creation of a strategy would force a company into taking a closer look at its manufacturing operations. This would help define more precisely the nature of their business, and the basic logic in which to organize its various manufacturing tasks. It would aid management in recognizing problem areas, as well as getting people to step back and look at the system as a whole. This process is invaluable if the company is to pursue day-to-day operations that are consistent with the overall direction of the company, and to plan for orderly growth over the long term.

2.3.1 Reduce Labor Costs

The need to reduce labor costs commands a high priority in the push for automation. The high cost of labor is most often sighted as the reason why U.S. manufacturers can't compete effectively with such countries as Japan and South Korea. When discussing labor costs, it would be misleading to think that a reduction in direct labor alone would be sufficient to make U.S goods as competitive as Japan's. The cost of indirect labor can have a greater effect on the cost of the final product then does direct labor. Indirect labor, such as corporate overhead and engineering support, as a percentage of total labor costs, is increasing more and more as production technologies advance into the 21st century. As an illustration, the typical starting salary for a manufacturing engineer in Thailand is presently around $4000 a year. The same engineer in the United States would draw a yearly income of approximately $28,000. And this is only a small part of the overall cost differential. There are drastic differences in the cost of floor space, utilities, maintenance, insurance, local and federal taxes, the cost of borrowing money, and the list goes on.

2.3.2 Existing Resources

More efficient use of a facility's resources is needed to maintain competitive manufacturing operations. This includes the efficient use of existing machine tools, plant floor space, employees' time, as well as the efficient use of the company's valuable information data bases. With the traditional plant layout, machine tools are arranged by function, with each machine tool run by an operator. Parts are typically hand carried or moved by fork lift from one machine to the next, in what seems to be a complex maze of random part routings. When the parts arrive at a machine to be processed, they are set in a queue until the tool is available. After the parts are processed across the machine tool, they are again set in a queue to be move to the next operation. A part that must go through many operations may spend weeks, even months in such queues.

One of the objectives of a good automation strategy is to make more efficient use of machine tools and floor space. This can be accomplished through the use of machine cells, which as shown in Part II of this thesis, greatly reduce the distances and variation in part routings, and make production data easier to obtain and utilize.

2.3.3 Producing Parts at Lower Cost

One of the goals sought in creating an automation strategy is to become a low cost, high quality producer. A successful automation strategy will help achieve this goal by reducing the overall manufacturing costs, while at the same time reducing the exposure of shipping a product with a defect.

To reduce production costs, an automation strategy should address the following issues: inventory carrying costs, scrap and rework costs, tool setup and change-over time, product quality, machine or system downtime, product turnaround time, and customer satisfaction.
A way to reduce inventory carrying costs is to reduce the amount of time the parts spend in the manufacturing cycle. This can be achieved through better coordination of parts tracking and ordering systems, a better shop floor layout, and consistent part routings and processes.

Standardized processes, grouping parts by similar machining operations, and reducing the amount of handling time will reduce the chance of damaging a part or producing scrap. Solutions such as these can also aid in the reduction of tool setup and changeover times, producing a product of consistent quality, the reduction of machine tool downtime and increased up-time, and faster product turnaround times.

In creating an automation strategy, while addressing the issues of reducing production costs, the manufacturer must not overlook the importance of customer satisfaction. Greater customer satisfaction can be achieved through faster product turnaround times, better responsiveness to customer initiated part and schedule changes, higher quality standards, as well as giving the company an image of being an efficient, high technology producer.

2.4 Strategy Constraints

2.4.1 Consistent With Company's Goals

An automation strategy must be consistent with, and integrated into, the company's overall policies, Corporate Strategies, and the division's Manufacturing Strategy. With the absence of an effective automation strategy, the pressures for quick decisions tend to stifle strategic thinking and impel people to adopt stopgap measures derived from a wide variety of experiences. As a result, Hayes and Wheelwright [18] state, "these measures are likely to lack clear purpose and lead to inconsistent results."

Hayes and Wheelwright define a company philosophy as "the set of guiding principles, driving forces, and ingrained attitudes that help communicate goals, plans, and policies to all employees and that are reinforced through conscious and subconscious behavior at all levels of the organization." This "set of common values" is not a strategy, though it also serves to guide decisions and actions throughout an organization.

Corporate Strategies are a company's overall business strategies. These strategies constitute the resources, products, markets, funding, growth and portfolio plans for the company. It generally defines the businesses in which the corporation will engage. Corporate, or business, strategies establish guidelines for the creation of the marketing, financial, and manufacturing strategies. These functional strategies are developed to support the corporate strategy.

The manufacturing strategy is a guide for decisions affecting the key elements of a manufacturing system. This strategy ensures that the manufacturing function contributes to the overall success of the company and operates in concert with all its functions.

The automation strategy is developed to support the manufacturing strategy. To be effective, the automation strategy must support, through a consistent pattern of decisions, the objectives of the manufacturing strategy. For example, decisions affecting choice of material handling systems, use of robotics, a what machine tools to purchase - all parts of the automation strategy - would be very different if the manufacturing strategy was pursuing high volume/low cost production, rather than customized/build to order manufacturing.

2.4.2 Implementable

A successful automation strategy, for a small to medium size manufacturer, should be realistically created so that it takes into consideration the company's technological and budgetary constraints. It should be a strategy that is implementable. It must properly support decisions that are economically feasible, utilize existing technologies and provide adequate flexibility.

An implementable strategy is one that assures affordable implementation of appropriate manufacturing technologies. This is an economic constraint. Decisions affecting such areas as the selection of technologies to be pursued, whether to be a technological leader or follower, and whether to emphasize basic research or developmental engineering/manufacturing processes are all affected by the availability of capital and cash flow.

Existing technologies must be utilized. In order to minimize expenditures on the implementation of new automation technologies, it can be important to limit the alternatives to technologies that already exist. This allows the company to focus resources and efforts on the basic problems of manufacturing, and not the problems of developing new, unproven manufacturing technologies.

Another strategy constraint concerns the inherent need for production flexibility. Production and assembly operations must be designed so that the manufacturing process is not disrupted when changing from one product variation to another. Flexibility is required to increase product variations as future markets dictate, without the addition of new machinery.

There are many different forms of flexibility. The type of flexibility a company desires should be reflected in its automation strategy, and should be consistent with its manufacturing strategy. Five types of flexibility, as identified by Donald Gerwin [11], are listed below:

Mix Flexibility is the processing at any one time of a mix or group of similar parts. This allows the random scheduling of parts to the production floor that are loosely related to each other. This type of flexibility can be used by a company, which produces a large number of products at different volume levels, that wishes to minimize the costs of frequent setups.

Parts Flexibility allows parts to be added or removed from the mix over time. This type of flexibility makes it possible to add new parts to the product mix as new products are released.

Routing Flexibility permits the dynamic assignment of parts to machines. This makes it possible to easily reroute parts from one machine to another if a machine must be shut down for repairs.

Design-change Flexibility allows quick implementation of engineering changes for a particular part. This type of flexibility is desirable if a high rate of engineering changes is anticipated.

Volume Flexibility accommodates shifts in production volumes for a given part. This is very often the necessary for industries with cyclical demand patterns, or companies planning a gradual buildup in production capacity.

It is important that a company make a conscious decision on what type(s) of flexibility it desires in its manufacturing systems. The decision does not have to favor one type at the expense of all others, many combination or shifts in flexibility types are possible. The important thing is to decide, and to decide early.

The strategy to automate should not be too complicated. One can learn from the problems of some of the larger corporations that have installed Flexible Manufacturing Systems (FMS) on grand scales, such as General Electric's dish washer plant and Apple Computer's Macintosh plant. These are large, computer-driven, highly integrated systems. These systems were often plagued with software problems and downtime. The requirements for resources are very large and smaller companies are not able to match them. The complexity of these systems can be overwhelming, and the dollar investments required to install and maintain them are out of the reach of most manufacturing companies.

2.4.3 Limited Resources

The limited resources of a small to medium sized batch producer may be the biggest roadblock to achieving a computer integrated factory. A company's desires to create an automation strategy must be viewed in relation to the capital and manpower available to implement these goals.

The automation strategy must allow for incremental implementation of new manufacturing technologies as capital becomes available. The process of automating one step at a time also makes the task easier to manage. In addition, it permits companies of limited expertise or manpower to implement advanced technologies at their own pace.

The strategy should take advantage of the company's existing resources, such as machine tools, manpower, and the wealth of data it possess. A company's existing resources shouldn't be discarded just for the sake of introducing new technologies. Companies have invested heavily in their present systems and, if possible, these systems should be integrated with the newer technologies.

2.4.4 Implemented Quickly

The automation strategy should be implement quickly to avoid losing out to competitors. It is not essential to spend a large amount of time developing a strategy that will cover all possible decisions and circumstances. Developing a strategy is an evolutionary process. As the business grows and market conditions change, the automation strategy will change. The key is to create a viable strategy and start implementing it as soon as possible.

The ability to quickly implement an automation strategy gives the smaller companies an advantage over the larger, slower moving corporations. The advantage a small company has over a large company is its ability to move quickly.

2.4.5 Part of A Longer Range Strategy

An automation strategy is a functional short range strategy. It is developed primarily to guide decisions in the near-term implementation of existing technologies. With this in mind, a company should have an avenue for pursuing new, yet unproven advancements and innovations in manufacturing processes. For this, a long range strategy must be developed. The latest developments in manufacturing should be identified, along with the companies future technological needs, in order to be in a position to exploit these advancements when they become available.

2.5 Strategy Alternatives

A company's motivations for creating an automation strategy include the need to reduce labor costs, both direct and indirect, eliminated product defects, a desire for more efficient use of the companies resources, and to remain competitive by producing a quality product at lower costs. These objectives are to be achieved while maintaining the need for flexibility and quick product turnaround.

There can be alternatives to implementing an automation strategy. A popular implementation alternative is that of "vendoring-out", or sub-contracting much of the fabrication processes to companies that have lower operating costs. This in essence, transfers portions of a company's manufacturing responsibilities to another company. One of the main objectives of this policy is to have parts produced by a vendor who can manufacture them at lower costs then it would cost to produce them in the company. This cost savings comes at the expense of direct control of the manufacturing processes as well as responsiveness to engineering and production changes.

A second alternative is to manufacture parts, or even whole assemblies, is to establish company owned off-shore manufacturing facilities. This would be done to take advantage of reduced labor costs commonly found in countries like South Korea, Taiwan, or Mexico. Here, a company would assign all manufacturing responsibilities to a facility located in a foreign country, gaining lower production costs at the expensive of higher shipping costs, as well as, reduced responsiveness to design and manufacturing changes.

A final alternative to developing an automation strategy is simply to do nothing. The "business as usual" policy would prevail here. This attitude would be characteristic of a company secure in its present position, with little concerns of future competition, or lack of available resources to develop a viable strategy. This wouldn't have been a bad alternative in the past, when demand exceeded supply and the production capabilities in the Far East were nonexistent. However, in today's global market place, constant change and very high quality standards are required in order to assure survival. This "head in the sand" option is not viable except in very rare circumstances.

There really are no viable alternatives to the development of an automation strategy. The first two options above simply shift the implementation site, while the "head in the sand" option is in fact hoping the world will not be more competitive.

In the next part of the thesis, we focus on understanding the concept of machining cells, which can be the most important part of an automation strategy.

PART II. MACHINE CELL IMPLEMENTATION

CHAPTER 3.

MACHINE CELLS

Thus far, several topics relating to the development of an automation strategy have been discussed. The need to reduce labor costs, increase manufacturing throughput and reduce cycle times, the desire for more efficient use of the company's resources, and increase product quality standards have all been discussed. The ultimate goal of an automation strategy is to solve these manufacturing problems, thus assuring the company's survival in the light of future competition. The most important aspect of an automation strategy, as it relates to the small to medium size component manufacturer, is the identification and implementation of machine cells.

In general, there are three basic types of plant layout: (1) product layout, also called flow-line or production-line, used in mass production; (2) process or functional layout, used to manufacture discrete components; and (3) group or cell layout. The type suitable to a plant is dependent on the quanities of parts produced and the number of different production items. The fuctional and group layouts apply more to the small to medium size discrete component manufacturers because of their characteristic batch-type production environments.

The group layout, or machine cell, offers the most promising solutions to the manufacturing problems stated above. The machine cell provides savings associated with economies of scale, at far less than the cost of mass production systems typical in today's manufacturing.

3.1 The Machine Cell

A machine cell is a group of machine tools, which could be any combination of NC, CNC or manual machine tools, that is dedicated to the production of a "family" of parts. This grouping of machines includes all necessary machinery, tooling, and labor required to produce a part family. It is typically comprised of two to six machine tools with one to three operators, a material handling system, and a cell controller. Simpler cells may consist of just one operator with two machine tools. The part family to be fabricated in a cell may consist of a single part number or a large variety of parts, that are grouped based on similar manufacturing processes. An example of a part family are parts made from .25 to 1.5 inch in diameter bar stock, such as a group of shafts. Because a machine cell can produce different parts requiring similar machines and tooling, significant reductions can be made in set-up time, tooling costs, work-in-process, with increases in machine utilization and decreases in operator errors.

The parts under consideration are fabricated using multiple machine tools. Parts requiring machining on only one machine tool can be ignored because there is little to be gained at this stage. Parts requiring multiple machining operations can be produced at lower costs if the machines are grouped into cells. Great efficiencies can be achieved by grouping many machine tools together. The advantages sought are the reduction in distances the parts must travel between machine tools, increased product quality, as well as better control and tracking of parts within the manufacturing cycle.

The machine tools within the cell are grouped so that the parts can flow from one end, such as a storage area for raw materials, to the other end, to be sent on to finishing operations. It may be helpful here to consider the machine cell a factory within a factory. Waterbury [29] describes the factory-in-a-factory as having two doors; raw materials enter through one door and finished products exit through the next. After a machine grouping is determined, the next step is to simulate the operation of the cell. This is needed to obtain critical estimates for operating parameters such as cell capacity, machine and operator utilization, and cycle times.

3.2 Criteria for Selecting Machine Cells

The decision to incorporate machine cells into an automation strategy, and eventually on to the manufacturing floor, is affected by the manufacturing environment within the plant. One of the conditions that would favor the use of machine cells includes the necessity to produce a variety of parts in small batches. Here, flexibility is demanded of the system; flexibility in part variation as well as part quantity. Machine cells have many advantages over the traditional shop layout schemes, which are comprised of machine tools arranged in a functional machine layout, such as a turning area, milling area, etc., or arranged randomly throughout the facility. Figure 3.1 illustrates the difference between a functional layout and a machine cell or group layout. A functional layout is characterized by the great distances a part must travel between machine tools or operations, and what seems to be a completely random routing of parts through the system.

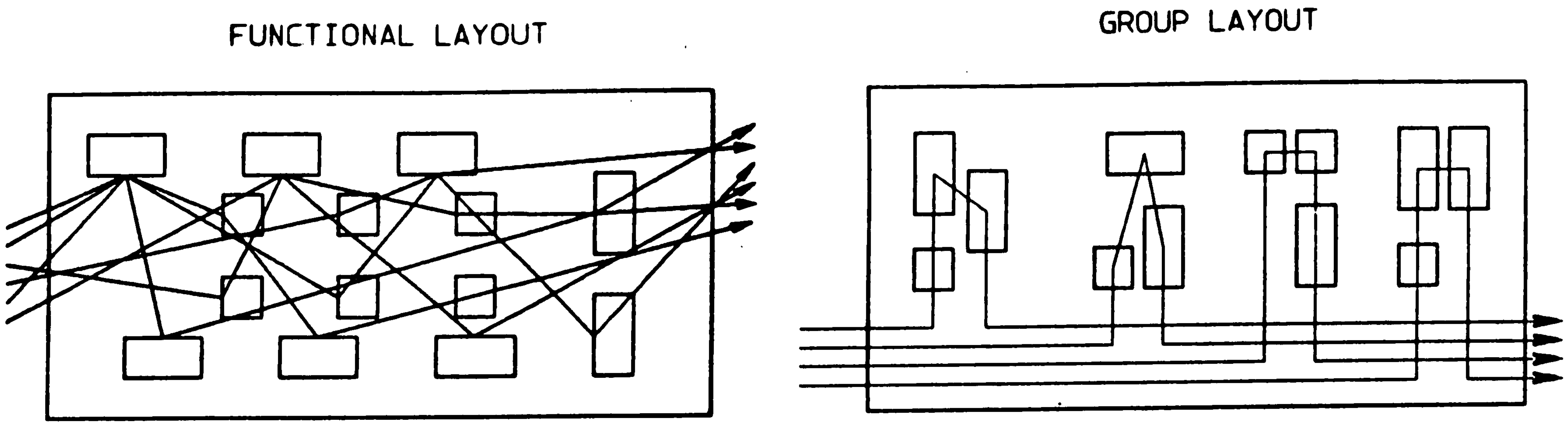

Figure 3.1. Functional Layout vs. Group Layout

Machine cells, on the other hand, are characterized by well organized subsystems within the plant. Parts typically travel very short distances from start to finish, and the control within these subsystems is much more manageable.

3.3 The Reasons for Creating Machine Cells

The reasons for creating machine cells include the need to reduce direct and indirect labor costs, take advantage of an inexpensive method of automating an existing facility, incrementally achieve a Flexible Manufacturing System, and to obtain better control of in-process inventory. Through the use of machine cells, jobs requiring similar machines and tooling are processed such that the number of parts per setup are increased and the distances between machines are greatly reduced. This reduces the overall setup time considerably and drastically reduces the scope of production scheduling and control problems. Tooling problems can also be simplified, and use of common fixtures can be implemented. With the use of machine cells, a company can realize significant savings associated with economies of scale while maintaining the flexibility inherent in batch production. In addition, Ham [16] states that "to achieve the goal for implementation of computer automated manufacturing this task (of putting machine tools into cells) is an essential requirement".

As sighted by Hyer and Wemmerlov [20],"EG&G Sealol in Warwick, Rhode Island, found that after producing 900 parts in manufacturing cells, work-in-process dropped by 20% to 30% and the need for floor space declined by 15%." They go on to say that "Sealol turned out 324 parts in one cell with seven machines, whereas before the parts had been routed to 22 machines. All of these improvements contributed to a 150% rise in total output."

3.3.1 Reduction of Labor Costs

Reduction in the cost of direct labor is achieved by placing one or two operators on several machines within a cell. These machine cell operators perform all of the operations required to completely manufacture a part or family of parts. This eliminates the inefficiencies experienced in traditional plants that employ one operator per machine tool. Since the machining operations are very similar across a part family, savings can be achieved by reduced time spent on part handling and tooling changes. This can also facilitate a reduction in the number of operators required to produce a given product, or allow a higher output without increasing the head count.

Not only will the use of machine cells reduce direct labor costs, but significant savings can be realized when it comes to indirect labor. One area of savings is that of tracking parts through the manufacturing cycle. The amount of time it takes to monitor and track parts through the manufacturing cycle is drastically reduced with the introduction of machine cells. Parts within a cell need only travel a few feet, from start to finish. There is also a significant reduction in the number of times a part must be handled between machine tools. A fork lift operator is no longer needed to move the work-in-process from one machining operation to the next. Through the implementation of its first cell, the Pomona Division of General Dynamics [15] reduced the distance of part travel from 2 1/2 miles to less than 200 feet.

Additional savings can be realized through an increase in product quality, or a decrease in operator errors, since only similar machining processes are used within the cell. Operators can become more familiar with the processes and tolerance requirements when only like parts are produced in the cell.

Another area that will see a savings is that of process planning. The standardization of part routings achieved through the formation of machine cells would result a reduced process planning effort. In the traditional shop layout, the variation in part routings is limited only by the imagination of the person creating the route sheets. Arn [6] comments, "When the relationship of the effort between process planning and manufacturing, in relation to the individual workpiece, is very close, then this crucial point of rationalization becomes a matter of importance". With the existence of machine cells, the process planner is almost forced to generate standard process sequences and operations.

3.3.2 Inexpensive to Implement

Capital expenditures are very limited in most batch manufacturing companies. The machine cell can be implemented at a fraction of the cost of a "full-blown" FMS, while achieving many of the same advantages. Flexible manufacturing systems, which are basically programmable job shops, are very expensive to implement. They incorporate many individual automation technologies, such as automated material handling systems, numerical control (NC) machine tools and computer controlled NC machine tools (CNC), computer integration of material handling systems and machine tools, robotics, and Group Technology principles.

A machine cell can be comprised of a facility's existing machine tools, and can be on-line, in operation, and returning on investment months before a more sophisticated system. These smaller systems are also much easier to justify than larger systems. Robin P. Bergstrom wrote [7], "you get a faster return on your investment" with the use of cells, while gaining many of the advantages of an FMS. The grouping of existing machine tools into cells allows tremendous productivity gains with little capital expenditures. There is no need to purchase newer machine tool centers. More efficient use of existing highly expensive machine tools and machining centers can be realized by grouping them into cells. Through an incremental introduction of cells onto the shop floor, a company can automate its operations at a pace that is more in line with cash flow availability.

3.3.3 Achieve Mini FMS's

As described above, through the implementation of machine cells a company can achieve mini Flexible Manufacturing Systems at far less then the cost of a full FMS. A Flexible Manufacturing System (FMS) is characterized by a grouping of machines or machine cells, which are controlled by a computer, and integrated with an automated material handling system. The manufacturing processes in a FMS can adapt automatically to random changes in product design, part quantities, and product mix. Machine cells can be designed to operate as mini FMS's at a fraction of the cost of a full FMS.

Machine cells used as mini FMS's allow greater system flexibility. This improved flexibility can be achieved in areas such as product mix, part family, routing, design-change, and volume. Mix flexibility allows the processing of a variety of different parts that are loosely related to each other. Parts flexibility permits the addition to a mix or the removal of parts from a part family over time. Routing flexibility provides the ability to dynamically assign parts to machine tools within a cell. Design-change flexibility assures quick implementation of engineering changes to a part. And volume flexibility accommodates changes in production quantities of a part.

Within the mini FMS, part sequencing can be random. Any part can be computer directed to any machine within the cell. Queues at each machine are virtually eliminated and in-process inventories are greatly reduced. Because of the shorter distances parts travel and the ease of controlling their flow, the mini FMS's provide increased throughput resulting in improved productivity.

Traditionally, a part's machining and process time, within a typical batch-type manufacturing facility, is on the order of three to five percent of the total time it takes to process the part through the plant. Most of the remaining 95 to 97 percent of its time is spent in queues waiting to be moved from one processing station to the next. This is illustrated graphically by Ham [16] (see Figure 3.2).

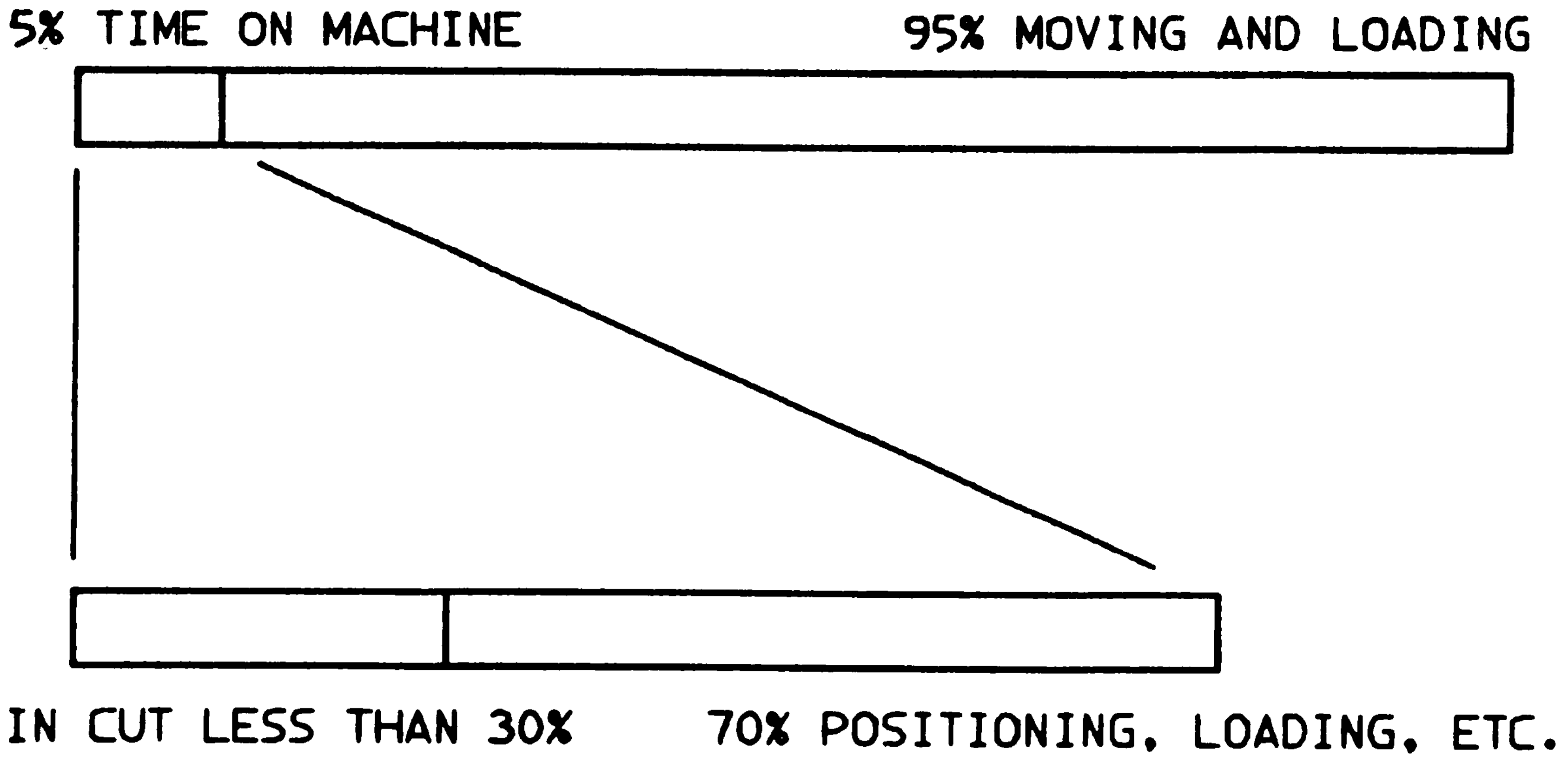

Figure 3.2. Percentages of the life of the average work piece in batch-type metal cutting production shop.

The grouping of machines into cells will drastically reduce the queuing time between machine tools. This will have an immediate affect on the levels of work-in-process inventories.

The establishment of the machine cell also sets the stage for the introduction of robotics into the plant. Once the proper machine tools are in place, robots can be easily added to the cell to perform such tasks as removing raw material or castings from incoming pallets, loading and unloading machine tools, aid in in-process and final inspection, and palletizing the finished product to be sent to stock. Robots are easily integrated into the cell environment because of their ability to be reprogrammed, handle objects of varying geometries, and maintain consistent cycle times. They also have the ability to interact with other components in the cell through the use of simple and complex sensors.

3.3.4 Better Inventory Control

Controlling the inventory of parts through a cell greatly reduces the task of prioritizing, monitoring, obtaining status, and part scheduling. The overall picture of the manufacturing process is reduced to an easily controllable sub-system within the plant.

The job of the expeditor becomes easier and much more efficient because of the short distance a part travels. To obtain the status of a critical item, all that is required of an expeditor is to walk out to the shop floor and observe the part's progress through the cell. This also makes it much easier to implement inventory control systems such as Just-In-Time manufacturing and

MRP shop floor control. The key issue here is to subdivide the shop floor into easily controllable subsystems which facilitate the implementation of modern automation and inventory control techniques.

3.4 Grouping Parts

The formation of parts into part families allows you to achieve the economies associated with large scale manufacturing in the small scale production environment. An approach to grouping parts into families with the greatest potential for success is Group Technology. Group Technology, as defines by Inyoung Ham [16], "is a method of manufacturing piece parts by classification of these parts into groups and subsequently applying to each group similar technological operations". There are two ways of constructing part families. A part family may consist of parts that have similar shapes or geometries, within a certain dimensional range, and have most or all the same machining operations. The second type consists of parts having dissimilar geometries, but have similar manufacturing processes [16].

The formation of part families will aid in identifying machine cells. Other advantages to grouping parts include more accurate estimates machine tool requirements, standardized tooling setup times, use of common tooling, and more accurate cost accounting and cost estimation.

3.5 Problems

Although the grouping of machines into cells has many advantages, it's appropriate at this point to mention some of the disadvantages and problems encountered in grouping machines into cells. First, there is the problem of balancing labor within the cell, as well as outside the cell. One company experienced problems in orchestrating the roles of two of its operators within a machine cell. One operator was occupied greater then 75% of the time, while the other operator was busy only about 40% of the time. An additional problem is that of machine utilization. While in the cell, machines are strictly dedicated to the family of parts produced by that cell. A careful study is required, which includes simulation, to determine a close approximation of machine and operator utilization. At the present, there doesn't seem to be any way of completely eliminating the exposure of underutilization of these resources.

However, the goal is to improve upon the present system through the use of machine cells.

Another problem attributed to the use of machine cells would be that of finding suitable supervisory personnel and cell operators. The type of people that are capable of handling these roles may be difficult to find. This and the issue of job classifications are crucial, especially in companies organized by unions. These issues present many conflicts for unions, with major implications challenging their classification systems and their views towards today's labor market.

CHAPTER 4.

METHODS OF CREATING MACHINE CELLS

Planning the layout for a shop floor includes three types of problems to be solved, as identified by Ham, Hitomi and Yoshida [17]. These are: (1) grouping machines into cells; (2) placing the cells in a shop floor layout; and (3) arranging the machine tools within the cell. Of the three layout planning problems, the problem of grouping machines into cells is the most important, and must be solved before considering the other two layout problems. The methods for creating machine cells described in this chapter include:

1. The Trial and Error approach
2. The use of heuristics
3. The use of Group Technology software

These methods are reviewed to show how machine cells are identified within an existing facility. Some methods perform well in one environment, yet poorly in others. Specific examples of each of the three methods are given, describing the experiences of three companies, which are in the process of installing machine cells for the fabrication of metal components. This will illustrate where each approach is best applied, in addition to their strengths and weaknesses.

There are many methods that have been used and can be used in developing machine cell groupings. Three of the most popular methods are presented in this chapter. The majority of the cases researched used one of these three methods to identify machine cells for implementation.

> The _Trial and Error_ approach is used to identify cells by a process of machine and part selection based on the experience and knowledge of key personnel.

> The _heuristics approach_ utilizes analytical methods to cluster parts and machine tools in a machine-part matrix. The most highly published method, the Rank Order Clustering Algorithm, is presented in this chapter.

The use of software packages in identifying machine cells is comparatively new to manufacturing. Although there are numerous cases of companies adopting Group Technology (GT) approaches to manufacturing, few have actually applied them to the design of machine cells. Because of the great potentials of GT software packages, many companies will either consider them or use them in configuring machine cells in the future.

4.1 Trial and Error

The Trial and Error approach to grouping machines is differentiated from the heuristics approach in that machine cells are chosen based on the experience of key personnel rather than on optimization techniques. Here, the machine-part groupings are determined intuitively by people who posses detailed knowledge of the specific manufacturing processes and parts under consideration. One approach used to identify the machine cell and the parts it will manufacture is based on part volumes. A part, or part family, would be chosen for analysis based on high usage and high dollar value. Following identification of the parts, the machine tools required to produce these parts would be identified and analyzed. Another popular approach is to base the cell on an expensive piece of equipment, such as a CNC machining center. The objective here is to try to assure maximum utilization of an expensive machine tool.

The Trial and Error approach to identifying machine cells is based on the experience, intuition, and knowledge of key people, with respect to specific processes and the flow of parts through the manufacturing cycle. The success of this approach is directly related to the ability of these people to identify proper machine cell combinations.

The first step in this process is to choose a popular part or part geometry for the formation of machine-part groupings. A survey must be taken, formally or informally, of the parts produced in the facility to determine the high usage or high volume parts. One way of determining a high usage part family is to look at the types of raw materials that are typically processed through the facility. Similar raw materials, such as bar stock or plate steel, may be used across a whole family of parts. The purpose of this search is to collect high volume parts into a cell, to obtain maximum utilization of the machines in the cell. It is essential that the cells are highly utilized because they tie up a lot of valuable equipment.

The next step is to determine the high value parts from those parts identified in the first step. The high value parts may be those parts that are fabricated from costly raw materials, or parts that require a lot of machining time. A costly raw material could be a casting purchased from a subcontractor which requires machining, or a shaft that is machined to very tight tolerances. To determine the machining time, route sheets must be reviewed and the machining time estimates must be compiled. Common operations, or those operations performed on all parts fabricated in the plant, can be ignored. The purpose of determining the high value parts is to ensure the machine cell is generating the highest rate of return possible.

4.2 Example of Trial and Error Approach

To illustrate the Trial and Error approach to determining machine cells, an analysis was made of the methods used in fabricating metal parts at a medium size East Coast industrial equipment manufacturer. This company, which is referred to as the Ajax Equipment Company, is a division of a Fortune 500 company. It employs about 250 people, and occupies approximately 200,000 square feet of floor space. The machine tool operators, as well as all the other hourly workers, are organized by a local chapter of a national labor union.

This facility does not produce to stock, but manufactures its products to order. The metal components are fabricated from raw materials, such as bar stock or purchased castings. The fabrication processes include metal machining, heat treating, plating and painting. They produce approximately 25,000 different part numbers at this plant, in batches of from one to fifty parts, several times a year. Although there seems to be an excessive number of different parts produced, the number of basic part geometries are very small.

The part family selected for its first machine cell was chosen base on a high usage raw material. The objective of the part selection was that the parts, that made up the part family, had to be used in a large number of production assemblies for the foreseeable future. It had to be a "repeater". The part family that was chosen consisted of parts produced from bar stock of six inches in diameter or less. The raw material dictated the configuration of the cell, and the process of machining the bar stock was pre-established.

The constraints used in determining the cell design were as follows: 1) the cell could only produce parts made from bar stock of six inches in diameter or less; 2) all machining operations had to be performed in the cell, from raw material to finished product (prior to surface treatment); 3) it had to consist mostly of existing machine tools (this was more of a guideline then a constraint); 4) only high usage parts would be produced in the cell - they couldn't justify generating CNC programs and storing raw material for low usage, one of a kind parts; and 5) the cell had to be utilized for two shifts. Route sheets were ignored because the processes were all similar.

The machine cell consists of a CNC saw, three CNC lathes (10, 20 and 40 horsepower), a CNC grinder, a six foot radial arm drill press, and two operators (see Figure 4.1.). About 250 different parts can be produced in the cell, fabricated completely from raw material to finished product. The machines in the cell run independent of each other; there is no machine-to-machine integration other then the cell operators. The raw material is stored in racks at one end of the cell, and is processed straight through to the opposite end where it is palletized and sent on to a finishing operation. The actions of the operators are so well orchestrated that there is no need for in-process part buffers. Once a machining operation is completed, the part is inspected by one operator and sent directly to the next machine tool for the next machining operation.

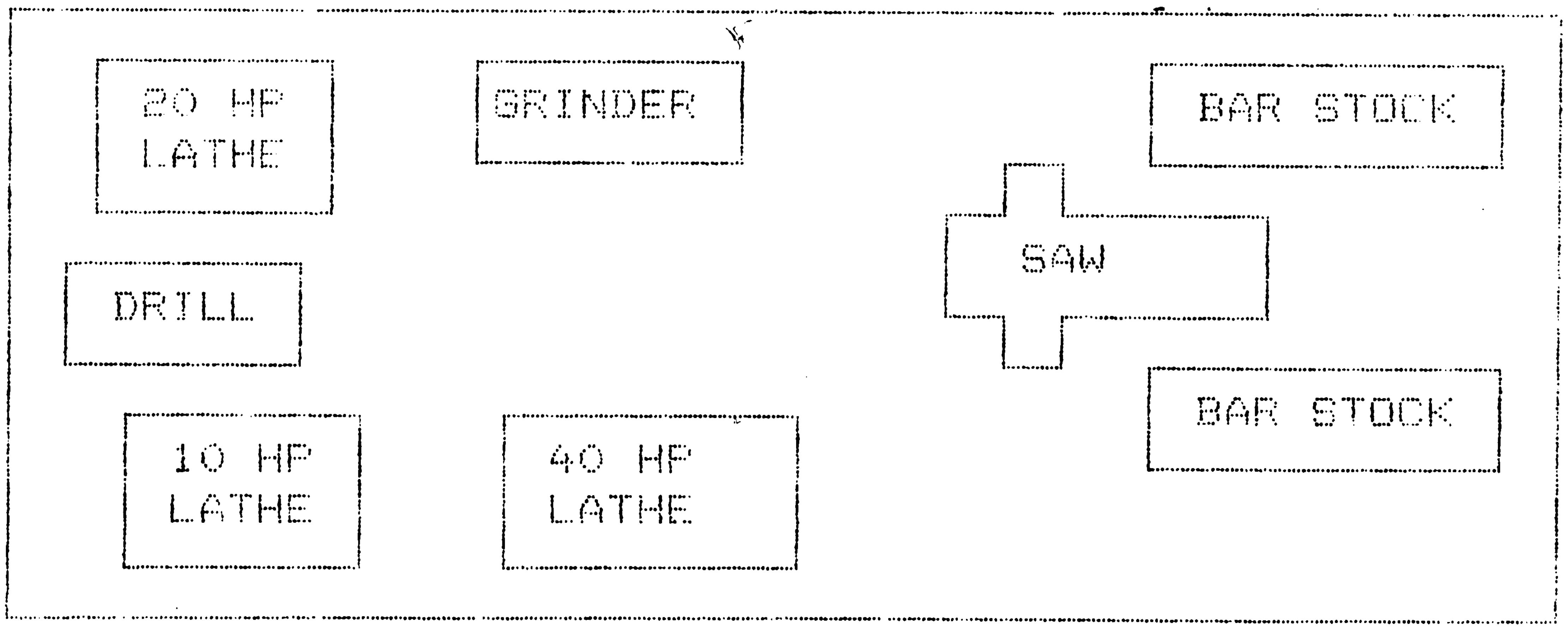

Figure 4.1 Machine Cell.

The most notable benefits achieved with the implementation of the cell were reduced direct labor costs and improved parts tracking and control. There were, however, two main problems encountered in creating the cell. The first involved the coordination of the two operators and machine tools within the cell. With a cell of this size, the problem of machine and operator utilization had to be worked out. Priority was given to achieving 100% machine utilization, with a secondary concern of assuring that both operators were busy the same length of time. The second problem was that of job classification of the cell operators. Since the plant was unionized, their job classification had to be redefined. A machinist no longer operated only one machine tool. Here, the operators were responsible for operating a saw, grinder, drill press, as well as performing inspection. The operators had to be skilled in all these areas, and willing to handle these multiple tasks.

4.3 Heuristics

The heuristics approach attempts to solve the machine cell design problem using a machine-part matrix. In this matrix, the machine tools are listed across the top (see Figure 4.2), and the part numbers are listed vertically along the y-axis. The 1's represent the machine tools that are used to produce each part, as indicated on the part route sheets. Heuristic approaches usually involve manipulating this matrix until the 1's form clusters representing machine cells.

	Machines				
Part Numbers	M01	M02	M03	M04	M05
01	1		1	1	
02	1		1		
03		1			1
04			1	1	
05	1			1	
06		1			1

Figure 4.2 Machine-Part Matrix.

The problem of grouping machine tools into cells as defined by Ham, Hitomi and Yoshida [17] is as follows: "Given the machine-part matrix showing which machines are required to produce each part, find groups of machines and families of parts in such a way that each part in a family can be processed in a group of machines." This problem can be solved by rearranging the rows and columns of this machine-part matrix until a good solution is obtained. The difficulties observed in this approach to solving the machine grouping problem are as follows: (1) this method is based on heuristics; and (2) some computational effort is required to determine appropriate machine cells and part families for large problems. In using heuristics, one is not looking for absolute optimization but instead for significant improvements over current operations. Heuristic approaches are based on sound logic and are designed to yield reasonable, not necessarily mathematically optimal, solutions to complex problems.

A method based on cluster analysis, developed by King [23], which has particular appeal, is the Rank Order Cluster Algorithm. This clustering algorithm is found to be a simple, effective analytical technique for the formation of machine-part groupings. The algorithm starts by reading the rows and columns in the machine-part matrix as binary numbers and calculates its decimal equivalent. The rows and columns are iteratively rearranged in order of decreasing rank, based on the decimal equivalents of the binary numbers (see Figure 4.3), until machine-part groupings, or cells, are formed on the diagonal of the matrix.

	Binary Weights 2^4	2^3	2^2	2^1	2^0		
Part Numbers	Machines M01	M02	M03	M04	M05	Decimal Equivalent	Rank Order
01	1		1	1		22	1
02	1		1			20	2
03		1			1	11	4
04			1	1		5	6
05	1			1		18	3
06		1			1	9	5

Figure 4.3 Rank Order Algorithm Step 1.

The advantage of this approach is that it takes into consideration all of the machine tools in the facility and all parts processed by those machines. The Trial and Error approach to defining machine cells, on the other hand, concentrates on a single part family while ignoring the other parts in the system.

The Rank Order Clustering Algorithm, from King [23], is designed to generate diagonalized groupings of machine-part matrix entries. Listed below is a step-by-step procedure developed by King that, through a finite number of iterations, will produce diagonalized machine-component groupings.

Rank Order Clustering Algorithm

(1) For each row of the machine-component matrix in turn, read the pattern of cell entries as a binary word.
Now, rank the rows in decreasing binary value. Rows with the same value can should be ranked arbitrarily from top to bottom.

(2) If the order of matrix rows is the same as the Rank Order, determined in step 1, then stop. If not, continue on to step 3.

(3) Transform the machine-part matrix by rearranging the rows in decreasing rank order, staring with the first row. To do this, read the pattern of cell entities as a binary word

for each column of the matrix. Then rank the columns in decreasing order by binary value. Columns with the same binary value should be arbitrarily ranked in the order they appear.

(4) If the current order of matrix columns is the same as the rank order, the algorithm is completed. Otherwise, continue on to step 5.

(5) Transform the machine-part matrix by rearranging the columns in decreasing rank order, starting with the first column on the left. Return to step 1 and repeat this procedure until the order of rows and columns is the same as their rank order.

This approach is probably best illustrated with an example using the matrix given above in Figure 4.2. Figure 4.3, above, shows the original machine-part matrix with the binary weights associated with the column entries of each row. The first row has a binary word of 10110, with a decimal equivalent of 22. The rank order of the rows is different from the current row order, so continue on to step 3. Figure 4.4 shows the machine-part matrix at step 3 of the algorithm, with the associated decimal equivalents of each row entry. Since the current matrix column order is different then the Rank Order, the columns are rearranged and the algorithm is repeated. This process repeated until the row and column orders are the same as their rank orders. The final result is shown in Figure 4.5.

		Machines				
Binary Weights	Parts	M01	M02	M03	M04	M05
2^5	01	1		1	1	
2^4	02	1		1		
2^3	05	1			1	
2^2	03		1			1
2^1	06		1			1
2^0	04			1	1	
Decimal Equiv.		56	6	49	45	6
Rank Order		1	4	2	3	5

Figure 4.4 Rank Order Algorithm Step 3.

Part Numbers	M01	M03	M04	M02	M05
01	1	1	1		
02	1	1			
05	1		1		
04		1	1		
03				1	1
06				1	1

Figure 4.5 Rank Order Algorithm Final Matrix.

4.4 Example of Rank Order Clustering Algorithm

To illustrate the use of the Rank Order Clustering Algorithm for the identification of machine cells, an analysis was made of the methods used to fabricate metal parts at a medium size facility located in the northeastern United States. This company, which is referred to as the Baxter Electronics Company, is a division of a Fortune 500 company. It employs about 600 people and occupies approximately 100,000 square feet of floor space. This facility produces most of the metal components used in the assembly of office automation equipment, in which they have full design, production and marketing responsibility. The metal components are fabricated from purchased castings and raw materials, such as bar stock, steel plate, or angle. This includes all machining operations in addition to heat treating, plating and painting. There are approximately 2000 part numbers produced at this plant, using over one hundred machine tools, in batches of from 50 to 150 parts, several times a year.

The 2000 part numbers produced at Baxter Electronics represent a very large variety of part geometries. Of the large number of parts that are used in a typical electronics assembly, very few parts are used more then once. Because there is such a variety of parts produced at this facility, efforts to create common tooling, and standardized production routings and flow, have been very slow and without much success.

The machine-part matrix used to identify possible machine cells represented 142 of the most complex parts produced and 18 different machine tools. The parts were chosen from a list of over 600 parts that were soon to go into production. The majority of the parts were ignored because they were purchased from subcontractors and only required surface finishing or only one machining operation was needed. Most of the information used to perform this analysis was taken from the part route sheets.

A sample of the initial machine-part matrix is given in Figure 4.6, and a listing of the machine tools is given in Table 4.1. Not shown in this matrix are the operations that could not be incorporated into a machine cell, such as the plating and painting operations.

PART	TOOL NUMBER									
NUMBER	122	123	126	127	145	224	322	327	523	822
508329									1	
509341		1			1					1
509363					1			1	1	
509365		1			1			1		1
509366		1			1					1
509367		1			1			1		1
509369	1								1	
509371						1				
509373		1							1	
509375			1						1	
509377			1						1	
509382			1						1	
509383								1	1	
509384									1	
509389						1				
509474						1				
509476						1				
509502		1			1			1		1
509505		1			1			1		1
509507		1								1
509510		1			1			1		1
509536			1						1	
⋮										

Figure 4.6 Baxter Machine-Part Matrix.

122	HORIZONTAL MILL	324	2" TURRET LATHE
123	DRILL PRESS	327	HYDRAULIC PRESS
126	SAW	523	CNC MILLING MACHINE
127	BENCH ASSEMBLY	524	HAND Hardinge
128	GRINDER	529	VMC Monarch 75 3 AXIS
144	AUTOMATIC Hardinge A.T.L.	622	0-8 MILL
145	CNC TURNING CENTER	629	VMC Monarch 150 3 AXIS
224	1.5" TURRET LATHE	722	0-30 MILL
322	VERTICAL MILL	822	Bridgeport Profiler

Table 4.1 Machine Tool Listing.

To perform the Rank Order Algorithm process, a simple computer program was created. The program was written in Pascal and executed on a microcomputer. The 142 parts and 18 machine tools were run through 25 iterations of the process to achieve the resultant matrix of machine-part clusters. (A sample of the final matrix is shown in Figure 4.7.)

PART NUMBER	TOOL NUMBER 523	122	327	126	123	145	822	224	127
509375	1			1					
509536	1			1					
509597	1			1					
825163	1			1					
509553		1						1	
509548		1						1	
509546		1						1	
509547		1						1	
509555		1						1	
509556		1						1	
509502			1		1	1	1		
509505			1		1	1	1		
509510			1		1	1	1		
509599			1		1	1	1		
509542			1		1	1	1		
509561			1		1	1	1		
825882								1	1
825883								1	1

Figure 4.7 Sample of Final Machine-Part Matrix.

The machine-part matrix shows a few well define clusters of machine tools and parts. However, the majority of the parts do not form neat groupings around the machines. To eliminate this problem, the matrix will have to be re-defined by replacing the machine tool numbers with types of machining operations. The drilling operation would replace tool numbers representing manual drill presses and CNC drill presses. The machine-part matrix would then be processed through the Rank Order Algorithm to obtain the new groupings. Each of the new clusters would have to be reviewed to determine if the cells can be designed by using more general purpose tooling.

This process of identifying machine cells has demonstrated to be a very good way of determining the initial machine-part groupings. The matrix must be manipulated to achieve cells for the remaining parts. This algorithm is shown to be very flexible in handling a wide range of cases.

4.5 Group Technology Software

Machine cell design can also be achieved through the use of Group Technology concepts. Group Technology is an approach or philosophy which tries to exploit the common features found in parts and processes [16]. These concepts can be used to group parts by similarities of shape, dimension, and/or manufacturing processes. For manufacturing purposes, components that are not similar in shape may still require similar manufacturing operations, and thus are considered to have common attributes. As an illustration, the parts shown in Figure 4.8 have different shapes and functions, but all require the same machining processes. Therefore, it can be concluded that these parts are similar, and belong to the same part family. The key to establishing unique part families is through the use of a GT classification and coding system. Group Technology is not a new system designed for mass production, rather it is a method of alleviating problems associated with short-run, batch-type production.

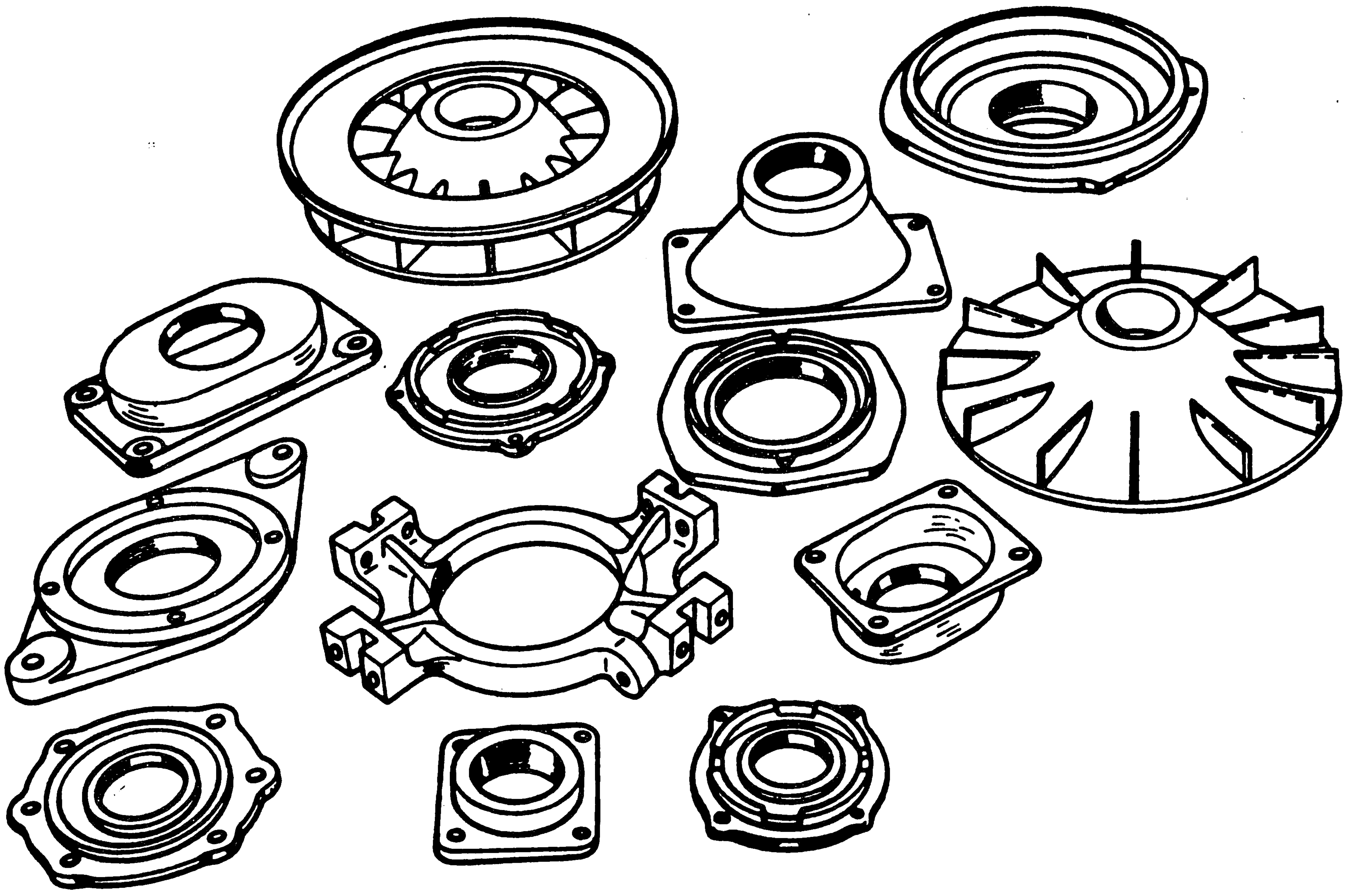

Figure 4.8 Production Family.

There are several software packages available today that can identify machine cells using the GT approach. These include MultiGroup by the Organization for Industrial Research (OIR), GECAPP by General Electric, and DCLASS by Brigham Young University, to name a few. In addition to identifying machine cells, these software packages can perform tasks such as computer automated process planning, identify what products are made on what machines, tell how well machine tools are utilized, identify what machine tools are needed, tell how well perspective new machine tools will be utilized, and a great deal more [15]. One of the advantages of using a Group Technology software package, in identifying machine cells, is that there is good potential for finding the optimal solution. Conversely, the trial and error, and heuristics approaches can only be expected to improve upon the present system.

4.6 Example Using DCLASS Software Package

To illustrate the capabilities of the Group Technology software approach, Brigham Young's DCLASS decision tree software is used to identify a machine cell. In order to design a machine cell, a classification scheme must be created that captures basic operations such as turning, drilling, boring, and milling. In addition, the scheme must encode all available machine tools and basic information about each part, such as the part functional name, main dimensions, external shape elements, and machining surface.

DCLASS is a decision tree software package. This means that the data input to the system must show relationships to previously defined system parameters. For example, to input process information about a part requiring a single drilled hole, the operator would enter such information as: the part's functional name, bracket; the type of process required, metal removal; the type of operation, drilling; the type of machine, manual drill press; and the machine number, D104. This is illustrated in Figure 4.9. An actual system would also need information concerning the parts dimensions, tolerances, and inspection requirements. With the input data, and the data the system already possess, the decision tree software can create route sheets, give machining time estimates, and identify the part family that this bracket belongs.

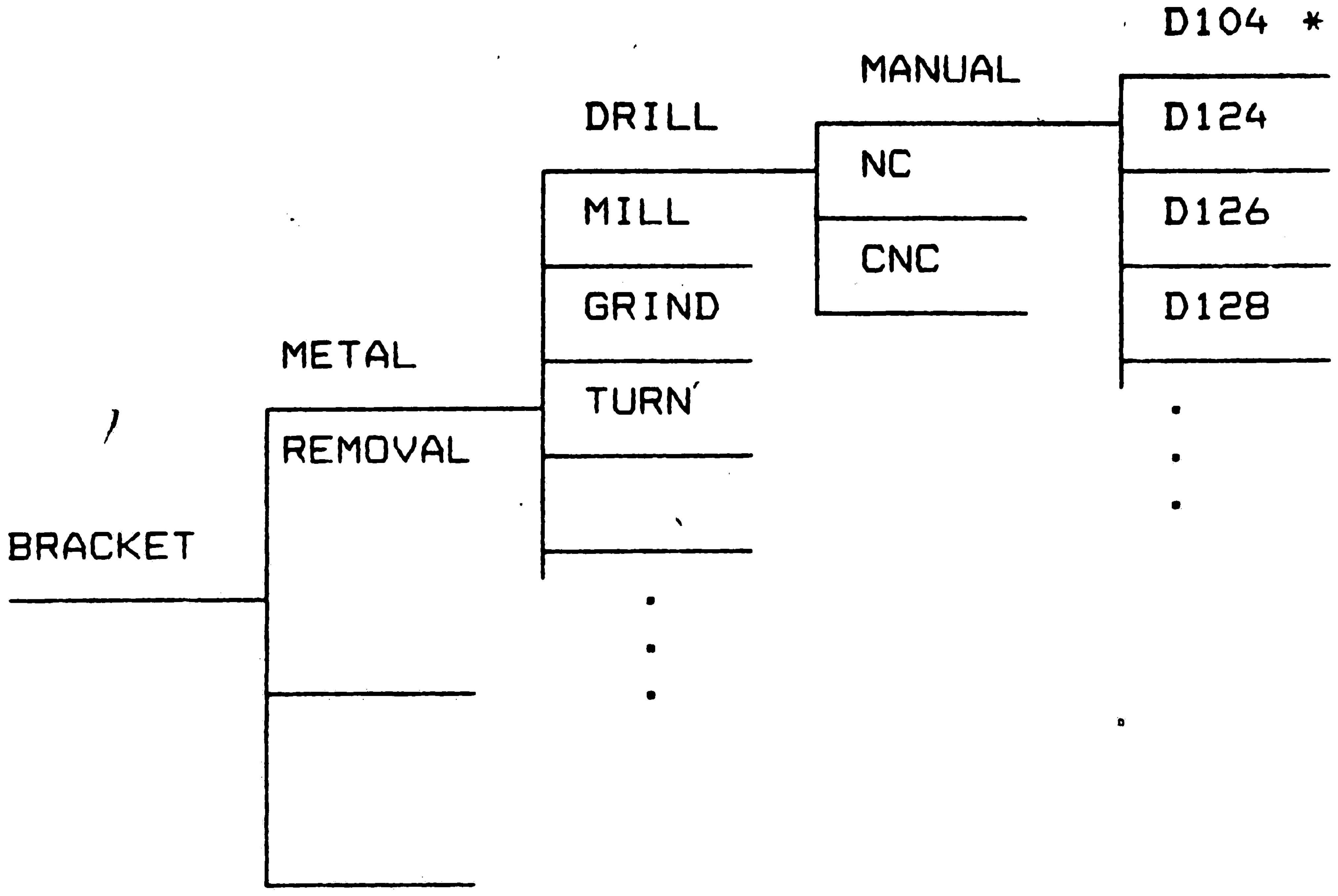

Figure 4.9 Decision Tree.

The DCLASS decision tree software package can identify machine cells as well as identify all the parts to be processed in machine cells. Figure 4.10 is a very simple printout from DCLASS. This decision tree shows the various machining operations, the types of machine tools, and the machine tool numbers with the tool codes. The tool codes for the manual horizontal milling machines are "6" and "7".

```
                                                                   2-24 "1"
                                                                :-------------
                                            MANUAL LATHE       1:  3-24 "2"
                                          :---------------------:-------------
                                          :                     :  6-24 "3"
                                TURNING  1:                     :-------------
                             :------------:
                             :            :                        5-24 "4"
                             :            : CNC LATHE          1:-------------
                             :            :---------------------:  1-45 "5"
                             :                                  :-------------
                             :
                             :                                     1-22 "6"
                             :              MANUAL HORIZONTAL  1:-------------
                             :            :---------------------:  2-22 "7"
                             :            :                     :-------------
                             :            :
                             :            :                        2-22 "8"
                             :  MILLING  1: MANUAL VERTICAL    1:-------------
                             :------------:---------------------:  3-22 "9"
                             :            :                     :-------------
                             :            :
                             :            :                        4-22 "10"
                             :            :                     :-------------
                             :            : CNC MILL           1:  5-22 "11"
  SELECT BASIC               :            :---------------------:-------------
  OPERATION(S).              :                                  :  8-22 "12"
-------------PC--------------:                                  :-------------
                             :
                             :                                     1-23 "13"
                             :              MANUAL DRILL PRESS 1:-------------
                             :            :---------------------:  OTHERS "14"
                             :            :                     :-------------
                             :            :
                             :            :                        2-23 "15"
                             :  DRILLING 1: TAPER DRILL        1:-------------
                             :------------:---------------------:  3-23 "16"
                             :            :                     :-------------
                             :            :
                             :            :                        5-23 "17"
                             :            : CNC                1:-------------
                             :            :---------------------:  OTHERS "18"
                             :                                  :-------------
                             :
                             :
```

Figure 4.10 DCLASS Printout

In order to use DCLASS to identify machine cells or part families, the part route sheets must be coded. This is done by going through the decision tree, such as the one shown in Figure 4.10, and assigning a code to each operation. For example, a part requiring machining on manual lathe 2-24 and grinder 1-25 would be coded "1, 19". The encoded part can now be retrieved using the code numbers. Once all the parts are coded, they can be retrieved from the system data base by code number. Given a request for parts that are coded "1,10", the system would give a list of parts, from the data base, that are processed across manual lathe 2-24 and CNC milling machine 4-22. Through this process of data retrieval, you can establish the part families that could be processed by specific machines cells.

An optimal solution to the machine cell design problem can be achieved by performing a "what if" analysis. This would be performed on each desired machine cell configuration to determine what parts will be processed across each machine tool combination.

4.7 Advantages and Disadvantages of Each Method

Each of the methods described has the potential for identifying workable machine cells. The concepts, structure, and complexity of each of these approaches are, however, very different. These methods are the most commonly used approaches to identifying machine cells today. Each has characteristic strengths and weaknesses that make them more or less applicable to varying situations. In choosing one approach over the others, a company should understand its system, what it wishes the machine grouping approach to accomplish, and how much of its resources it is willing to invest in this effort.

4.7.1 Trial and Error Method

The advantages of the trial and error approach center around its speed in obtaining results and its low development and implementation costs. For a company that has personnel with the proper experience and knowledge of manufacturing systems, this approach can be very desirable. This method provides quick results, and is inexpensive to implement. It is ideal for establishing a company's first machine cell. It has the advantage of not being affected by errors in part route sheets. The cell is based more on a particular process, rather then on the sequences of operations called out in the route sheets.

This approach is also best suited for cases involving parts that are easily grouped into families. It would be ideal for companies that manufacture large numbers of parts, which make up a few part families, and only vary slightly from one part to the next. An example would be a small to medium size manufacturer of small gasoline engines. The number of parts are few, and their differences are only minor dimensional changes from one engine to the next.

This method was particularly well suited for the Ajax Equipment Company. The quantity of part numbers was large, but the number of basic part geometries was quite small. By choosing parts produced from bar stock, Ajax was able to identify enough parts to keep the cell busy for two shifts a day. The machine tools to process the bar stock were also very easy to identify, and were easily integrated into a cell.

A disadvantage to this approach is that the results may not be as good at identifying machine cells as those obtained from the use of a heuristics approach or using Group Technology software. There is an exposure with this method of not identifying all the parts that could be processed through a given cell. This could be the case where there are large numbers of parts that are difficult to group into families, based on manufacturing processes or basic geometries. The trial and error approach is heavily reliant on the abilities, and memories, of the person(s) responsible for creating the cells and part families.

Another disadvantage of this approach is that it does not show how the cell relates to the rest of the manufacturing system. Additional research is required to determine how the system is affected by the implementation of the cell. The utilization of the other machine tools and operators may be changed. The cell designer(s) must also be conscious of the displacement of parts that may have been processed across the machine tools now used in the new cell.

4.7.2 Heuristics

The advantages of the heuristics approach to identifying machine cells are that they take into account all of the systems components, parts and machines, and provide good benchmarks for choosing cells. Using a machine-part matrix, it is easy to visualize how the cell fits into the manufacturing system. It is easy to see what parts and machines are contained within the cell, as well as, those that are not.

Methods based on heuristics are inexpensive to use, they have gained wide acceptance, and provide results rather quickly. These methods require little training, and are easy to comprehend. Once the proper information is gathered, these analytical methods can process the data in relatively little time. The computer program that was written for the Baxter Electronics Case allowed the input of almost unlimited numbers of machine tools and part numbers, and could process that data in a matter of seconds.

A disadvantage to the use of heuristics is that they provide only improvements over the present system - they cannot be expected to supply optimal solutions. As stated above, "heuristic approaches are based on sound logic and are designed to yield reasonable, not necessarily mathematically optimal, solutions".

With systems involving very large numbers of parts and machines, significant computational effort will be required to determine appropriate machine groups and part families. Matrices involving large numbers of machines and parts may become difficult to solve and analyze. To cope with this, it is almost essential that a computer program be generated to process the data through the algorithms.

These methods are often based on the information provided by the part route sheets. There is great exposure if the route sheets call out the wrong machine tools or identify incorrect processes. In the Baxter Electronics Case, of 80 part route sheets analyzed in detail, the methods of processing were changed for 15 parts. Conservatively, 10 to 20% of the routings were inaccurate. Parts with similar geometries were not always manufactured using similar processes. A big concern to Baxter was that they didn't have the resources to properly re-evaluate all the existing data on the route sheets.

4.7.3 Group Technology Software Approach

The advantages to using software based on Group Technology concepts are many. Although there is a probability that this approach may give the same results as one of the other methods, GT software will provide additional benefits such as automated process planning, generate consistent process route sheets, analyze product mixes and material flow, and generate machining time standards. These packages can aid in analyzing raw material needs, work cell capacities, machine tool requirements, and other aspects of manufacturing. They also have the potential for finding optimal solutions to machine cell problems.

There are many good GT software packages available today. In conjunction with the use of a coding and classification system, this software has a very high implementation success rate. Producers of these packages claim an 80 to 90% success rate when used for examining manufacturing systems and implementing short and long term planning.

A disadvantage to this approach is that, if the company does not already possess the GT software, it must research the available packages and implement the system. The company must first purchase and implement a coding and classification software package - the manufacturing and analysis packages cannot work without this. The costs and time to implement these systems are significant. To adequately handle the needs of a small to medium size manufacturing company, the system must be run on a mainframe computer - microcomputers can only handle very small applications. These software packages can cost from $25,000 to $225,000, with additional monthly fees.

Once the software is procured, the parts must be coded and entered into the system. Extensive training is required in order to operate the system, and it can take up to 18 months to enter the part data. (This is assuming that the company has thousands of parts and hundreds of processes to encode.)

After making these investments into this system, there is no guarantee that this method will produce a better machine cell configuration then the other methods, however there is the assurance that it is reflective of all data, and not the result of a narrow perspective.

The methods for identifying machine cells, that are presented in this chapter, are not necessarily all the methods available to industry today. They do however, represent three of the most popular and widely used approaches to the machine cell definition problem. Each method has its inherent advantages and disadvantages, and can be adequately applied to particular environments.

The Trial and Error approach is best suited for companies that produce a few part families, made up of large numbers of parts that vary only slightly. The Rank Order Clustering Algorithm, or heuristic approach, is better suited to companies that produce large varieties of part families. An example would be an airplane manufacturer. An airplane literally is made up of thousands of parts. The components assembled in an airplane differ greatly from one another, but very few are used more than once. The use of GT software can benefit the great majority of manufacturing companies, but the capital required to implement these systems may be too high for many.

PART III. ISSUES THAT AFFECT IMPLEMENTATION

CHAPTER 5.

SIMULATION

A simulation model is required in order to permit inferences to be drawn about a system without having to perform actual experiments on that system. In the context of establishing machine cells, simulation is an essential procedure for the analysis of such activities as possible procedural changes, a cell's performance, shop and cell scheduling, work-in-process (W.I.P.) control, operator and machine utilization, maintenance scheduling, and to determine the proper layout of the cells within the facility. Of primary concern is the scheduling of W.I.P. within the cell, operator/machine utilization, and cell capacity.

5.1 The Process of Simulation

The process of developing a successful simulation model, as outlined by Pritsker [26], consists of beginning with a simple model which can be made more complex as needed to solve unique problems. The first task is to construct a clear definition of the problem with explicit statements of the objectives sought in the analysis. Problem definition is a continuing process which evolves throughout the duration of the analysis. As more and more information becomes available, the definition of the problem changes.

The second task to be accomplished is to formulate a model of the system. In this step, the abstract system is defined in terms of mathematical-logical relationships. The model consists of both a static description and a dynamic description of the system's elements. The static description defines the elements of the system, while the dynamic description defines the way elements interact with each other. The process of formulating a system model is still largely an art. "The modeler must understand the structure and operating rules of the system and be able to extract the essence of the system without including unnecessary detail." The model should be easy enough to understand, yet contain enough detail to realistically represent the system.

When creating a model, it is important to build a "first cut" model. This preliminary model is used to discuss all assumptions made with the people most familiar with the system. This is required to minimize the impact of inaccurate and improper assumptions on the simulation process. The first cut model, as described by Serfass and Stadelman [28], is developed in order to gain a better understanding of the system and its problems. It will also form the basis for the development of a more complex simulation model which can be effectively applied to machine cell design.

The third step in the simulation process is the identification, specification and collection of data. This data consists of routing sequences, setup times, processing times, batch sizes, the number of machines in each cell, part reject rates, job types and lot sizes, the variation in types of jobs and arrival times, number of production shifts, amount of storage space, occurrence of machine breakdowns, and the frequency of job priority changes. Some of the data needed at this stage will be on hand and easy to collect, while other data requirements may involve considerable time and great costs to obtain. An analysis would have to be done to determine how critical the unknown data is, and how sensitive the model is to the accuracy of that data. In cases where the model is not very sensitive to such data, assumptions can be used based on past experiences.

The next task is to translate the model into a form acceptable for computer simulation. A computer program can be written using a general purpose language, or a simulation language can be used, such as GPSS, SLAM II or SIMON. The advantages of using a simulation language over a general purpose programming language are a savings in programming time, use of graphics, and it can assist in formation of the model by providing a set of concepts for articulating the system description.

The fifth step in this process is that of model verification. It is here that the modeler determines whether or not the computer program executes as intended. This is typically accomplished by manually checking the calculations.

The validation step is to be done next. This task consists of determining that the simulation model is a reasonable representation of the system. It is at this step that the sensitivity of the model is assessed to variations in data inputs.

The seventh task, "Strategic and Tactical Planning", is that of establishing the experimental conditions for the simulation runs. This consists of developing an efficient experimental design to either explain the relationships between the simulation responses and controllable variables, or to find the controllable variables that either minimize or maximize the simulation responses. This also involves determining how each simulation within the experiment is to be made to obtain the most information possible from the data.

The next two tasks in the simulation process involve experimentation and the analysis of the results. The experimentation step is the actual execution of the simulation model to obtain output values. The process of analyzing the output data is done to draw inferences and make recommendations for problem solutions. This is the interpretation of the simulation outputs. It is at this stage where such information as machine cell capacity, machine utilization, throughput, and manufacturing cycle times are determined.

The final stages of this process are the implementation of the solutions and the documentation of the simulation model and its use. The documentation of the model and the circumstances surrounding its implementation are needed to aid in future simulation projects.

5.2 Advantages

The process of simulating manufacturing systems is required in order to obtain valuable operating data without having to run actual experiments on those systems. Simulation models can supply such information as machine utilization, manpower utilization, work-in-process inventory (in quantity of parts and dollars), queue statistics for each machine or machine cell, and capacity information. Often, simulation is the only means of obtaining this information.

Simulation models have the advantage of being flexible enough to be applicable to almost any situation that may arise on the shop floor. This makes it possible to perform a "what if" analysis prior to making any system changes.

Simulation is a cost effective method of obtaining optimal solutions to manufacturing problems. While a simulation model can be used to analyze scheduling rules and machine layouts, it can also be used to help in the implementation of future machine cells.

5.3 Disadvantages

While there are many advantages to simulating manufacturing systems, there are also a few drawbacks. To begin with, extensive training is required to formulate an effective simulation model. The person, or persons, responsible for creating and evaluating the simulation model must be versed in the use of one of the computer simulation software packages. These simulation languages are often complex and require many hours of training for effective utilization.

Another problem is that these models are abstractions of real systems, which may be very complex. As stated earlier, the modeler must understand the structure and operating rules of the system and be able to extract only the pertinent information, excluding unnecessary detail, to make the simulation useful. A successful model depends on the experience of the modeler with the system as well as with the simulation process. Simulation models are only as good as the information and assumptions that are employed in those models.

The critical data needed for an appropriate model is often hard to obtain or is nonexistent. Often, heuristic assumptions about the system's operating parameters are required in the formulation of the model. A simulation project may involve false starts, erroneous assumptions, reformation of the problem objectives, and repeated criticism and redesign of the model because of the lack of good information or incorrect assumptions. If improperly handled, this may result in eventual abandonment of the project.

These are some of the risks inherent in simulating real manufacturing systems. Recognizing the risks of improperly modeling a system should help to eliminate potential simulation problems.

A benefit of simulation, as it relates to cell design, is the definition of problems areas within the machine cell. These problem areas include long queues, and over or under utilization of machine tools and operators. Long queues would indicate high work-in-process inventories and potential bottlenecks. Over or under utilization means suboptimal usage of the machine tools or the operators, which leads to higher than necessary production costs.

CHAPTER 6.

SUMMARY AND EXPERIENCES

In this thesis a review of automation strategy concepts and some existing machine cell grouping methodologies have been presented. Five characteristics of a strategy were outlined: activities associated with a time horizon; actions taken have an eventual impact on the company; concentration of effort; the pattern of decisions; pervasive through all levels of management. These characteristics, applied to manufacturing functions, and based on technology-dominated strategies, are shown to form the conceptual framework for the automation strategy. The automation strategy puts the small to medium size manufacturer in a position to exploit new manufacturing technologies that are relevant to their product lines and markets.

In outlining an automation strategy, it is shown that the development and implementation of machine cells offers many benefits to the small to medium size company. The benefits in creating an automation strategy include gaining a better understanding of the company's manufacturing processes, achieve reductions in direct and indirect labor costs, better utilization of existing resources, reducing workmanship errors, and increasing product turnaround time. These aid in reducing overall production costs and improving product quality, which are essential to assuring the competitiveness and ultimate survival of the company.

The constraints of an automation strategy were discussed. The strategy must be consistent with company policies, corporate strategies, and the associated manufacturing strategy. These strategies must support each other in order to meet the company's overall business objectives. It must also be implementable for the small batch manufacturer. The strategy must be economically feasible, utilize existing technologies, and provide adequate flexibility to manufacturing operations. It should allow companies to integrate the new technologies into the system one step at a time, taking advantage of existing resources. The automation strategy should be implemented quickly and be merged with longer range plans for advancement.

The alternatives to developing an automation strategy were found to be merely methods of either deferring the implementation to someone else, or ignoring this responsibility altogether.

The machine cell is determined to be one of the most important aspect of an automation strategy for the batch-type manufacturer. It is a grouping of general purpose machine tools dedicated to the production of a family of parts. The machine groupings are considered factories-within-factories, producing batches of parts at near the efficiencies of large scale production. The biggest advantages gained are the reduction in distances parts travel between machining operations, reduced labor costs, reduced workmanship defects, and better tracking and control of parts throughout manufacturing. Labor cost reductions are achieved by placing one or two operators on up to seven machine tools within a cell. Machining operations are similar across a part family, thus saving on setup and tool changeover costs. Machine cells are shown to be inexpensive to implement, and can be on line rather quickly. They offer many of the benefits of Flexible Manufacturing Systems, at far less cost. With all the advantages, there are several inherent problems associated with the introduction of machine cells. Balancing labor and machine tools can be a major task. Finding suitable supervisory personnel and cell operators is difficult, and present problems when dealing with unions.

Three methods for identifying machine cells were discussed in detail (trial and error, heuristics, and use of GT software). The trial and error approach, based on intuition and experience, is a quick and dirty method used most often in establishing a company's first cell. As shown in the example, it is ideally suited for manufacturing involving many parts having slight variations in a few basic part geometries. It runs into problems, however, where there are many variations in part geometries. The problem becomes too complex to solve without the use of analytical techniques. The identification of cells using heuristics (Rank Order Clustering Algorithm) have gained wide acceptance. These approaches are relatively simple, and take into consideration all components, machines and parts, of the system. The main disadvantage of these two systems, is that they can only be expected to improve upon the present system. They cannot be used determine the optimal solution to a company's cell problem. This disadvantage turns out to be the main advantage of the GT software approach. GT software, though it is very expensive to implement, can provide optimal solutions, in addition to, providing computer aided process planning. These software packages can also generate machine time standards, analyze product mixes and material flow, and compute work cell capacities.

Before machine cells can be implemented, these systems must be modelled and simulated. Simulation was determined necessary to perform such need tasks as analyzing the cell's performance and capacity, shop and cell scheduling, work-in-process control, determining operator and machine utilization, for maintenance scheduling, and much more.

The process of simulation was presented, followed by a discussion of the advantages and disadvantages of simulation. Simulation is a cost effective method for obtaining the critical data listed above, and it is flexible. The model can be applied to may situations to perform "what if" analyses. Simulation can run into problems, however, if the modeler is not adequately trained or if incorrect assumptions are used.

The work presented in this thesis is reflections of a literature search, interviews with various company executives, and experiences gained in participation in a team which developed an automation strategy for a small to medium size manufacturer. The author of the thesis was the principle architect of the machine cell-definition phase of the project.

Because the details of the specific cells and strategy developed were proprietary to the company, where the work was performed, no details of that strategy or cell design data are contained herein.

However, the ideas developed in this thesis, and the concluding comments, are based on actual work experiences involving the development of an automation strategy and cell design.

CHAPTER 7.

CONCLUSIONS

When the concepts of strategies in business were conceived in the United States, little attention was given to the role of manufacturing in advancing the competitiveness of companies. Now that there is a push to implement manufacturing strategies, to coincide with the marketing and finance strategies, companies must also formulate plans for implementing new, more advanced manufacturing technologies into their plants. The costs of automating are very high, and the costs of mistakes or even not automating, are even higher. Companies must formulate automation plans, as part of longer range strategies, for developing and phasing in new technologies, and phasing out old technologies.

The small to medium size component manufacturer is particularly challenged, in that the newer manufacturing innovations are getting more and more expensive. In addition, there is greater competition from Far East and Third World countries. Automation is the key to survival. A viable solution to this problem is the development of an automation strategy, with machine cells as the key component. Machine cells offer the economies of large scale production, while retaining the flexibility needed in batch-type production. This gives the smaller producer a unique advantage over the mass producers, who are heavily invested in hard automation and are less flexible to changes in the market.

The three methods of creating machine cells, outlined in this thesis, are widely used and have achieved promising results. These approaches provide a methodology for identifying cells. Using the proper approach, that best suites the system environment, can make the difference between a successful implementation and one that is abandoned. Through the experience gained in applying these methodologies, it is paramount that top management support be provided and maintained. Conversations with engineers responsible for cell development and implementation indicate that a great deal of commitment and support from upper management is essential to the ultimate success of cell projects.

A company may not see the desired results for up to 18 months after the initial cell production starts. There were also observations of questioning and frustrations during development, that without proper support would have resulted in the abandonment of the project. Implementation may also require organizational changes or changes in the way a company deals with its hourly workers. Cooperation and open communication is essential in order to ease the difficulties inherent in change on the manufacturing floor.

Keeping in mind the concepts discussed in this thesis, there are some areas that still require future research. The problems of automating machine cells need to be resolved. These include areas such as sensors, cell to mainframe communication for computerized (real time) scheduling and tracking, and communication from the cell to the company's Material Requirement Planning (MRP) system for WIP status reporting and prioritization. These are problems associated with shop floor integration. This involves integrating the various cells, automated material handling systems, and CAD/CAM systems, and the integration of robotics into the cell. More research needs to be done in the area of general purpose tooling. The development of general purpose, or standardize, tooling has been difficult in the past, because of the varieties of parts processed across machine tools. However, when considering families of parts of similar geometries, as in a cell's part family, standardized tooling is now more feasible. The use of part families also facilitates the introduction of robotics onto the factory floor. More research needs to be done analyzing the use of robot grippers as they apply to families of parts. These robots would deal with far fewer part variances, thus could use simpler gripper designs as compared to robots that would handle many different part geometries, from castings, to shafts, to gears.

Through the use of machine cells, many of these problems can be resolved and integrated into the system, with little disruptions to the rest of the manufacturing facility.

VITA

The author of this thesis, Joseph Allan is a Manufacturing Engineer at the Federal Systems Division of International Business Machines, Corporation in Manassa, Virginia. He presently specializes in manufacturing processes and assembly techniques used in producing computers.

A native of Miami Beach, Florida, Mr. Allan graduated from the Catholic University of America with a BME degree. Upon graduation from Catholic University, he took a position at IBM, where he was involved in manufacturing projects for government and industry.

REFERENCES

1. Albus, James S., et al., A Control System for an Automated Manufacturing Research Facility, June 4, 1984.

2. Anderson, Howard, Factory Networks with a Future, CIM Technology, Summer 1985, pp. 29.

3. Apple, James M., Jr., and Strahan, Bruce A., Designing Work-In-Process Handling Systems, CASA Technical Paper MS85- 315, 1985.

4. Appleton, Daniel S., Customizing Shops, CIM Review, Summer 1985, pp. 3-7.

5. Appleton, Daniel S., "The State of CIM", Datamation, December 15, 1984, vol. 30 no. 21, pp. 66-72.

6. Arn, E. A., Group Technology, Springer-Verlag, New York, 1975.

7. Bergstrom, Robin P., FMS: The Drive Toward Cells, Mechanical Engineering, August 1985, pp. 34-38.

8. Boucher, Thomas, and Muckstadt, John A., Cost Estimating Methods for Evaluating the Conversion from A Functional Manufacturing Layout to Group Technology, College of Engineering Cornell University Ithica, New York, Technical Report No. 603, August 1983.

9. Cook, Nathan H., Computer-Managed Parts Manufacture, Scientific American, February 1975, pp. 23-29.

10. Farnum, Gregory T., Ten Commandments for CIM, CIM Technology, Summer 1985, pp. 26.

11. Gerwin, Donald, Do's and Don'ts of Computerized Manufacturing, Harvard Business Review, March-April 1982, pp. 107-116.

12. Glazer, Sarah, The Automation Industry: Integrating for Success, High Technology, May 1985, p. 46.

13. Gold, Bela, Alternate Strategies for Advancing a Company's Technology, Research Management, July 1975, pp. 24-29.

14. Groover, Mikell P., Automation, Production Systems, and Computer-Aided Manufacturing, Prentice-Hall, Inc., New Jersey, 1980.

15. Group Technology at General Dynamics, Pomona Division, OIR Group Technology User Profile, Organization for Industrial Research, Waltham, Massachusetts, June 1985.

16. Ham, Inyoung, Introduction to Group Technology, SME Technical Report no. MMR76-03.

17. Ham, Inyoung, Hitomi, Katsundo, and Yoshida, Teruhiko, Group Technology -Applications to Production Management, Kluwer-Nijhoff Publishing, Boston, 1984.

18. Hayes, Robert H., and Wheelwright, Steven C., Restoring Our Competitive Edge, Competing Through Manufacturing, John Wiley & Sons, Inc., New York, 1984.

19. Hitomi, K., and Ham, Inyoung, Machine Loading and Product-Mix Analysis for Group Technology, ASME Publication no. 77-WA/PROD-21.

20. Hyer, Nancy L., and Wemmerlov, Urdan, Group Technology and Productivity, Harvard Business Review, July-August 1984, pp. 140-149.

21. Johnson, Jerry J., Flexible Manufacturing in Fabrication, CASA Technical Paper MS85-151, 1985.

22. Kantrow, Alan M., The Strategy-Technology Connection, Harvard Business Review, July-August 1980, pp. 6-21.

23. King, J.R., Machine-Component Grouping in Production Flow Analysis: An Approach Using a Rank Order Clustering Algorithm, International Journal of Production Research, vol. 18 no. 2, 1980, pp. 213-232.

24. McGinn, Terrance E., The Next Generation Assembly Automation POD (AAPOD) for Electronics FMS, Amiti, Inc., 1985.

25. Phillips, Edward J., FMS: Advantages, Problems, Opportunities, Mechanical Engineering, June 1985, pp. 30-39.

26. Pritsker, A. Alan B., Introduction to Simulation and SLAM II, 2nd ed., System Publishing Corporation, Indiana, 1984.

27. Roberts, Edward B., Technology Strategy for the Medium-Size Company, Research Management, July 1976, pp. 29-32.

28. Serfass, James F., and Stadelman, Joseph F., Simluation for Group Technology, Goodyear Aerospace Corporation, Ohio, pp. 138-153.

29. Waterbury, Robert, FMS Expands into Assembly, Assembly Engineering, October, 1985, pp. 34-37.

30. Welch, Arther, and Emang, John T., Group Technology the Heart of Flexible Manufacturing Systems, International Harvester, Hinsdale, Illinois.

31. Wheelwright, Steven C., Japan-Where Operations Really Are Strategic, Business Horizons, August 1981, pp. 67-74.

32. Wheelwright, Steven C., Reflecting Corporate Strategy in Manufacturing Decisions, Business Horizons, February 1978, pp. 57-66.