CONSIDERATIONS FOR GROUP TECHNOLOGY MANUFACTURING IN PRODUCTION PLANNING

By

GERALD ROBERT GRAVES

Bachelor of Science
in Industrial Engineering
University of Arkansas
Fayetteville, Arkansas
1973

Master of Science
in Industrial Engineering
University of Arkansas
Fayetteville, Arkansas
1980

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Thesis Approved:

Philip M. Wolfe
Thesis Adviser

K E Case

J Chandler

Carl B. Estes

M. P. Terrell

Norman N. Durham
Dean of the Graduate College

PREFACE

This study is concerned with production planning for group technology manufacturing. The primary objective is to extend the existing methodology associated with production planning and control systems to enhance the benefits of group technology. A planning cost model is developed and solved using aggregated planning techniques. Potential applications and benefits of using the model are presented.

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CHAPTER I

INTRODUCTION

Goal of the Research

The goal of this research is to extend the existing methodology associated with production planning and control systems to enhance the benefits of using group technology concepts in batch manufacturing. The rapid growth of manufacturing using group technology (GT) concepts and the extensive use of production planning and control systems (PPCS) designed for traditional manufacturing systems have lead to the selection of this topic for further research.

Scope and Assumptions of the Research

This work concentrates on the planning of production of a group of parts by a group of machines. It is assumed that the parts and machines have been previously identified and selected following the principles of GT manufacturing. The demand for these parts is generated by a material requirements planning (MRP) system and is, therefore, dependent upon and constrained by the requirements for subassemblies at a higher level in bills of materials. Of course, it is assumed that management is concerned with minimizing the costs associated with production while satisfying the demand for parts.

In order to further define and delimit the research the following assumptions will also be made:

1. Adequate supplies of raw materials and trained personnel are available.
2. Time and cost standards exist and are constant.
3. The parts to be produced by the group of machines, termed the cell, are divided into families based upon processing similarities.
4. The operation of the cell is not affected by machine breakdowns or activities elsewhere in the manufacturing facility.
5. The processing time for a part exclusive of machine setup and tooling changes is not affected by the processing of any other part within the group. Thus, the machine cell will be treated as if it were a single entity.
6. Scrap is accounted for with the MRP system and will be ignored in this work.
7. Part family composition may be modified through additions or deletions, but individual jobs of non-family parts are not allowed.

In addition to the stated assumptions, the sequencing of jobs through the cell is not considered in this report, nor is the process of identifying the parts or machines to be included.

Methods and Conclusions

The specific objective of the research was to develop and evaluate a hierarchical procedure for planning production using a GT cell. In striving for this objective, an extensive literature review has been conducted, in addition to telephone conversations with knowledgeable individuals and a plant tour. The data and descriptions employed in the research derive from a combination of these sources. Using accepted cost estimating and accounting procedures a cost model has been developed which represents production planning for the GT cell. The model is a mixed integer-linear programming one. Equations for calculating the problem statistics are developed and, coupled with execution statistics from a sample problem, indicate the need for simplifying the problem. A hierarchical procedure to accomplish this has been developed in this research.

The hierarchical procedure involves aggregating the data, thereby simplifying the model to a linear programming problem. The validity of the solution which results is determined by comparison with the original model's solution using sample data. Potential sources of error are found to derive from roundoff and from the aggregation procedure itself. Guidelines to minimize the effects of these errors are suggested. It may be said, then, that the development portion of the research objective has been achieved.

The aggregate production planning model has been evaluated in several ways. First, computer processing requirements are found to decrease substantially, due to the elimination of integer variables and the reduction of problem statistics. The MPSX software package and the IBM 3081 computer were used to determine these requirements.

Application of the model to the long-term capacity management problem of GT manufacturing is evaluated. This is a subobjective of the research. This evaluation concludes that the model is found to serve quite well in production planning associated with GT manufacturing. Specifically, through sensitivity analysis insight into the relationships between the cost parameters and their effects on the optimal aggregate production plan are provided, thus guiding management in their cost reduction efforts. The potential impact of changes in cost parameters or in demand is easily forseen with the model, as are modifications to the GT manufacturing system. The manner in which the model may be used to examine potential system modifications is developed and presented in detail.

Another subobjective of the research involved evaluating the application of the procedure for planning family and part production in conjunction with an MRP system. Initially, the application of a disaggregation technique to the aggregate planning solution was planned as a part of this research. However, during the performance of the work the importance of the aggregation technique was discovered. A decision was made to concentrate more on this facet of the problem and on the application of the aggregate planning model, leaving the question of disaggregation for future research. The use of the model as an aid to production scheduling is, however, discussed.

Although not a stated objective, an additional benefit of GT manufacturing is indicated by this research. In contrast to functional machine layouts, with GT cells one can identify exactly which machines will be involved in the production of an order. Further, at any point in time one can access the order control system and determine exactly which orders will require processing on a particular machine or piece of equipment. Management is no longer forced to rely on estimated queue time or machine loading. This knowledge opens the door to the use of operations research techniques in ways heretofore deemed impractical. This research is an example of this potential, with linear programming being applied to the production planning problem for the manufacturing of parts.

Content of the Report

The body of this report consists of four sections. In Chapter II a review of literature pertinent to this work is provided and includes discussion of relevant concepts.

Chapter III is concerned with the development of the cost model and presents a detailed description of the manufactuing environment which is being addressed. Chapter IV concentrates on the problem-solving approach and presents the aggregation procedure. The manner in which the model may be applied and some examples are shown in Chapter V.

Following the body of the report is a section which summarizes the report and recommends further areas for study. The report is then terminated with a bibliography and appendicies which are referenced within the body.

CHAPTER II

HISTORY AND RELATED CONCEPTS

Introduction

The concept of GT is relatively new in the United States. Thus, this chapter begins with a brief overview of the history and concepts of GT. Background material concerning the concepts applied in this research is then presented.

Definitions

GT is a system given many names and definitions. It is also known as part family manufacturing, group machining, and family grouping. V. B. Solaja (52) provides the well-defined concept:

> Group technology is the realization that many problems are similar, and that, by grouping similar problems, a single solution can be found to a set of problems, thus saving time and effort. (p. 33)

A refinement to this definition of GT-related to manufacturing is given by Kimbler and Agee (30):

> . . . the organizational philosophy of collecting

> components into groups based on component similarities to facilitate component production and effective use of manufacturing resources. (p.53)

Other definitions of GT which may be found are very similar to these, or are variations intended to encompass the specific application being discussed.

Historical Background and Current Trends

The use of GT concepts in manufacturing activities appeared as early as World War II in Europe. In the early 1950's the Russians took renewed interest in GT, and are generally credited with its development. In 1959 the concept of GT was first formalized by the Russian S. P. Mitrofanov in his book Scientific Principles of Group Technology. By 1963 the success of GT applications in manufacturing were such that the Russian Government promulgated a plan for increased implementation throughout Russian industry (47).

By early 1960 in West Germany and Great Britian, serious studies into GT techniques had begun. Other European contries quickly followed, becoming active in GT research and applications. By mid 1970, GT applications in Japan had begun under the sponsorship of the Japanese Government.

In the U.S., GT concepts have been practiced under different names in various forms to increase manufacturing efficiency. However, it has received little formal recognition, and is only now gaining momentum as a desirable manufacturing technique. As late as 1976 there were still only a handful of companies even interested in GT. Current trends in manufacturing, however, have set the stage for acceptance of GT. These trends, as cited by Ham (22), include:

1. A rapid proliferation of numbers and varieties of products, resulting in smaller lot sizes.
2. A growing demand for closer dimensional tolerances, resulting in a need for more economical means of working to higher accuracies.
3. A growing need for working increased varieties of materials, heightening the need for more economical means of manufacturing.
4. An increasing proportion of cost of materials to total product cost due to increasing labor efficiency, thereby lowering acceptable scrap rates.
5. Pressure from the above factors to increase communication across all manufacturing functions with a goal of minimizing production costs and maximizing production rates.

Estimates of parts to be produced on a small-lot basis run as high as 75% of all industrial parts by 1990. This will certainly increase the viability of GT manufacturing. In fact, researchers have predicted that between 50 and 70% of American manufacturing industries will be using some form of

GT by 1990 (29). It would appear that GT is no longer a fad, but a management strategy for the future (29,31,33,51).

Concept of GT

> Group technology is a manufacturing philosophy which identifies and exploits the underlying sameness of items and the processes used for their manufacture.
> I. Ham (20, p. 21)

The use of GT in the U.S. typically employs a systematic methodology which forms part families based on certain similar characteristics. Using these families, product design may be rationalized, process plans optimized, and groups of machines designated for processing one or more families. These aims comprise almost all current GT applications, though potential contributions exist in other areas.

Classification and Coding Systems

Identifying the "underlying sameness" of parts is commonly accomplished with a classification and coding (C&C) system. A number of commercial systems exist, each having its merits and drawbacks. Most applications involve a customized system to staisfy the peculiar needs of the client.

Modern C&C systems identify parts by their fundamental design and manufacturing attributes. Typically, these attributes are geometric shape, dimensions, processing requirements and sequence, tolerances, etc. These attributes are then related to a code for retrieval purposes. Codes vary both in length (typically 6 to 36 digits) and structure. Also, the software available for retrieval and analysis varies among vendors.

Once a C&C system has been introduced, part families may be established based upon attribute similarities. This is a critical and time-consuming task, and forms the basis for GT applications. The composition of each family is a function of the application (design or processing). Although some sophisticated techniques have been developed for this task, it is normally an iterative process and highly company-dependent.

Though expensive and time-consuming, the introduction of a C&C system is vital to GT applications. In addition, duplicate and outdated designs and process plans are revealed and may be eliminated. Further, an excellent survey of the parts and processes is provided.

GT Manufacturing

Manufacturing using GT principles provides a way of realizing the economies normally associated with large-scale production. These economies include reduced tooling costs, reduced setup time, increased throughput, and higher labor productivity (33).

Currently, three general methods of applying GT to manufacturing systems are suggested (1):

1. Single machine system;
2. Group layout system;
3. Group flowline system.

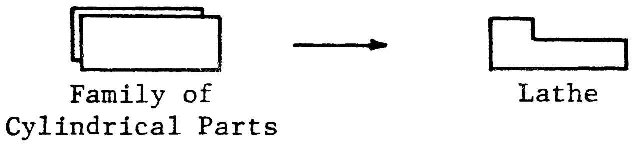
These are depicted in Figure 1.

In the single machine system, a machine is tailored to the processing of similarly shaped components. One or more part families may be sequenced through the machine in their operations routes. A reduction in setup time is achieved.

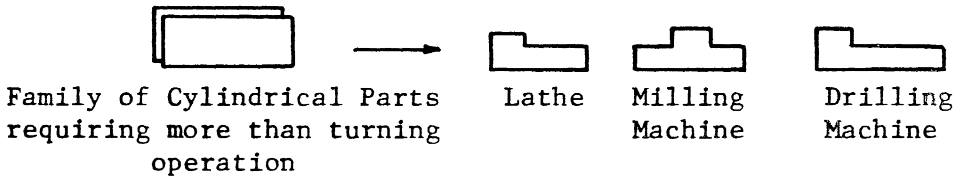
The group layout system, or manufacturing cell, consists of a set of machines devoted to the processing required by one or more families of parts. A manufacturing facility may include a number of these cells operating independently. In addition to reducing the setup changes required, the operator's productivity is improved by the reduction in the variety of parts processed. Material handling requirements are reduced and quality has been found to increase. These reductions result in the throughput time for a part being reduced.

The group flowline is a special case of the group layout. With this type of GT manufacturing system all jobs processed by a group of machines adhere to the same sequence of processing, resulting in a flow shop. Automated material handling within the cell is more easily incorporated, and the scheduling and controlling of jobs is simplified.

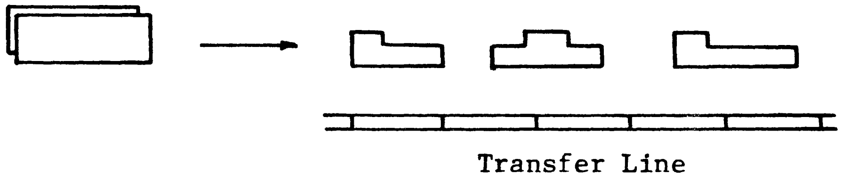
A number of techniques for the assignment of machines



a.) The Single Machine System



b.) The Group Layout System



c.) The Group Flow Line System

Source: Abou-Zeid (1,33).

Figure 1. Three Methods of Applying Group Technology to Machine Layout

and part families to cells have been proposed and applied (10,16,36,41,44,47,58). Most involve some type of mathematical programming technique, such as linear programming, goal programming, cluster analysis or combinatorial programming. In general, these methods are applied with consideration for machinery investment, system flexibility, and workload distribution. Oliva-Lopez and Purcheck (39) propose analyzing alternative systems using both static and dynamic stages. In the static stage the analysis is in terms of:

1. Investment in machinery;
2. Flexibility of cells to manufacture various components;
3. Balance of workload between cells;
4. Utilization of equipment due to static factors;
5. Scope of control through the number of cells and the number of machines in each cell.

In the dynamic stage simulation is employed to analyze the systems in terms of:

1. Capability to satisfy external requirements;
2. Efficient utilization of resources.

Regardless of the method used, proper development of part families and machine groups to process them is vital to a successful GT implementation.

Economics of GT Manufacturing

A number of benefits from GT manufacturing have been reported. Primary among these are:

1. Reduced setup time (up to 60%);
2. Reduced tooling expense (10 to 40%);
3. Reduced work-in-process (up to 50%);
4. Reduced throughput time (up to 60%);
5. Reduced scrap (up to 40%);
6. Reduced order lateness;
7. Increased worker satisfication.

Methods for economically analyzing proposed implementations, however, usually rely on a comparitive cost analysis with the current manufacturing method (14,18,20,36,50,51). Further, they fail to include potential savings which may result from the further application of GT in other areas (e.g., design or process planning). Edwards (14) states that:

> . . . companies have generally realized the futility of attempting to calculate cost savings simply because they know that the information available to them from costing sections is neither accurate nor appropriate for the changing circumstances of group technology. (p. 18)

Although the implementation costs may be accurately estimated, the resulting savings are difficult to quantify beforehand. Yet, the benefits others have experienced continues to encourage the adoption of GT.

Production Planning

Most of the literature concerning GT manufacturing pertains to the creation of part families and production cells. Few have dealt with the attendant issues of the associated production planning and control system. Of these, the period batch control system is usually suggested as the proper system to employ with GT manufacturing. However, in the U.S. material requirements planning systems are used extensively for production planning. Both of these systems, therefore, must be addressed. Also, as an aggregate planning technique is employed in this research this concept will also be discussed.

Period Batch Control

Although this system was developed in Great Britian, some of the Russian literature addressed the need for special considerations for GT manufacturing in production planning and control.

In his text Scientific Principles of Group Technology (36), Mitrofanov concentrates on the technological aspects of group machining. He does, however, recongize that GT manufacturing principles provide a method for realizing in small batch manufacturing the economies associated with mass production. In order to achieve these economies of scale the following general conditions are presented for a cell or flowline:

1. It must be highly productive, and based on the maximum utilization of equipment and technology.
2. The physical parameters, labor requirements, and operations duration should be stable.
3. Both the individual operations and the entire process should have a cyclic repeatability.
4. The operations should be synchronized.

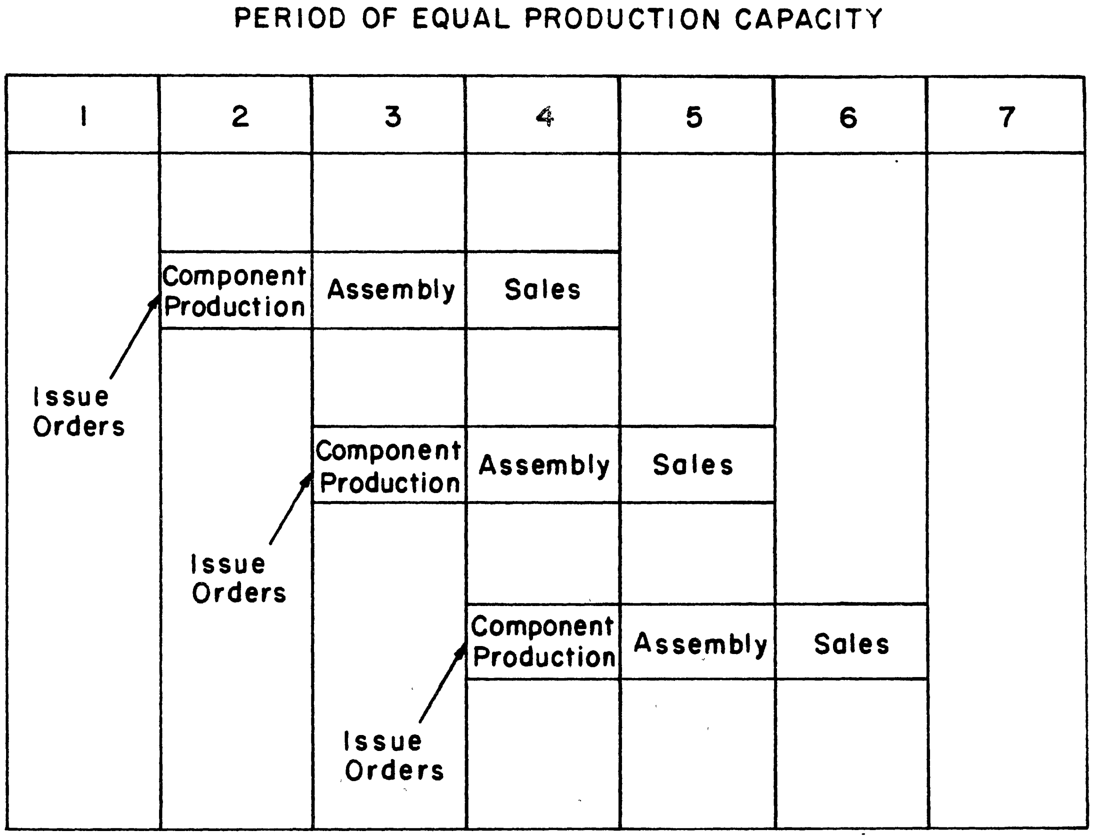
His suggestions laid the groundwork for further research by V. A. Petrov.

In 1966 Petrov published his text _Flowline Group Production Planning_ (44). This work was accomplished after an extensive survey of GT manufacturing applications in the USSR. In the text Petrov states that the production planning aspect is the least developed element of GT. He proposes establishing a standard batch size for each component within given limits. The limits are set to maximize machine utilization and minimize work in process. Also, the batch should be a multiple of assembly batch sizes and be within any space or handling limitaions. Once these standard batch sizes are established, a batch rhythm may be calculated for each part from the forecasted demand, and a production cycle calculated for the part family. Further, he proposes that the number of batch sizes and batch rhythms be kept to a minimum in order to maintain proportionality throughout the production process. This should lead to a smoothing out of the disturbing effects of a wide variety of factors. Primary among these factors is continued high utilization of GT manufacturing equipment.

In planning and control of a GT manufacturing process British industry relies primarily on the period batch control (PBC) approach (15,29,38). PBC was developed by Burbidge (10) and focuses on the use of short-term cycles. In using PBC the planning horizon is divided into cycles of equal length, and a production schedule of end items for a given cycle generated. This schedule is then exploded into requirements for parts to be produced in the preceding cycle.

In applying PBC to a GT manufacturing cell, New (38) suggests the use of a special form of PBC, termed unicycle PBC (UPBC). This system, illustrated in Figure 2, uses a single cycle across all products. The entire production process, then, is operating on the same cycle length. This should allow for a carefully planned loading sequence, thereby permitting jobs to be grouped for GT manufacturing.

Hyer and Wemmerlov (29) recognized several problems associated with a UPBC system. First, no clear guidelines exist for establishing cycle length. Further, capacity imbalances may exist as the time required to produce component parts for a cycle may be quite different from the



SOURCE: NEW (38, p. 58).

Figure 2. Unicycle Period Batch Control

time required to assemble those parts into end products. Another problem area noted is the use of a fixed loading sequence which assumes that a stable demand pattern exists. Considering the previously discussed trends, this is not a valid assumption for a large number of manufacturing enterprises.

Material Requirements Planning

In the U.S. the use of computer systems to perform the tasks of PPC is widespread. For the purposes of this study those systems which employ MRP are of interest. MRP is a process for converting product requirements into requirements for items on all levels of the product structure (bill of material) below the end product. The result of this process is a schedule of planned production and purchase orders, and recommended modifications of released orders for parts. Extensive literature exists addressing MRP in significant detail. Orlicky's text Material Requirements Planning is perhaps the best known and most widely quoted.

Initially, many perceived that the grouping of parts in GT applications and the individual treatment of parts in MRP systems made the two incompatible (27,29,34,38,54). However, without exception the literature relating to the subject contradicts this perception. Mahany and Tompkins (34) state:

GT and MRP are fully compatible, and in fact, the benefits of the two techniques are synergetic.(p. 48) They attribute this synergistic effect to the balance of efficient manufacturing, a result of GT, and effective manufacturing, a result of MRP.

The procedure recommended by most for combining GT and MRP is basically the same as that formalized by Sato, Ignizio, and Ham (49). Their proposed procedure is to simply group planned orders for the immediate period and apply a group scheduling algorithm (to be discussed later in this section). A lot-for-lot lotsizing rule is generally recommended (29,34,38,49,56). This is desirable in that it avoids having unbalanced sets of parts in inventory, and it is possible due to the rapid throughput time of GT cells. Mahany and Tompkins (34) suggest that the planned orders for at least two periods should be combined, and then a decision made by the production planner as to whether sufficient item volume exists to warrant a family release. Hyer and Wemmerlov (29) argue that since major setup times stem from changes in the production of families , lotsizing should be by families. No guidelines for accomplishing this are suggested, however. Spencer (53) details the use of an EOQ model which includes opportunity costs to determine the run quantity for a family of diesel engines. However, the engines were end items for the facility, and a very stable demand pattern existed.

An important aspect of MRP systems is the inherent assumption that adequate capacity exists to meet the schedule of planned orders. As a consequence, the work load placed on a machine or work center may vary drastically from period to period. Capacity requirements planning (CRP) techniques are usually applied to alleviate this problem. CRP involves exploding projected demands on capacity from the MRP planned orders. There are two approaches to performing CRP: infinite loading and finite loading.

Infinite capacity loading is appropriately named since this approach does not explicitly consider actual capacity limitations or processing sequence restrictions (9). The basic input to this procedure is a unit load profile for each part to be produced. The unit load profile indicates the time required to produce a part at each major processing step, and the number of periods after order issue that the requirement will occur. By summing the projected load from MRP planned orders and the load from previously released orders, the total projected load for a work center may be calculated. The resulting machine load reports indicate the need for subcontracting, rescheduling, or overtime.

Finite capacity loading is somewhat more detailed. In this approach actual queue times and loads are simulated based on available capacity. Consequently, the scheduling rule employed at work centers is taken into account. More sophisticated systems will shift jobs forward or backward to relieve simulated overloads. Finite loading systems ,then, are primarily useful for short-term scheduling with a fixed capacity. Although finite loading techniques yield more precise and detailed information concerning shop schedules and capacity, they are generally complicated and difficult to implement. Moreover, long-term simulations of capacity utilization usually contain substantial error (9). No literature has been found which discusses the use of either infinite or finite loading techniques in conjunction with GT manufacturing.

Once the planned orders from MRP are finalized they are released to shop floor control. This function includes order release, scheduling, and monitoring through work centers. GT manufacturing should have a significant impact on this function, as only the flow of jobs into and out of a cell need be monitored (29). Scheduling jobs should be greatly simplified since the scope of the problem is reduced from that of a large portion of the shop to a small group of machines. Hitomi and Ham (21) have termed the scheduling associated with GT "group scheduling." They propose applying branch and bound techniques to solve the problem. The scope of the problem is further reduced in that all jobs for parts belonging to a family must be scheduled together. Petrov (45) proposes a scheduling technique for GT flowlines based on Johnson's solution to the two machine flow shop problem. A further refinement to Petrov's technique is presented by Subramanian (55). What is apparent from these approaches is that existing scheduling techniques and objectives are appropriate with GT, as long as jobs are sequenced along part family lines. The benefits resulting from adhering to this restriction are significant and have been presented.

Aggregate Planning

Aggregate planning is the starting point for most manufacturing control systems (9) and is concerned with the aggregate production rate and work force size in a facility. Although aggregate planning is concerned with end products, one approach to solving the aggregate production planning problem deserves attention in this study. Use of a hierarchical decision process, as suggested by Hax and Meal (23), avoids the computational complexity inherent in other models by decomposing the production planning problem into an aggregate planning subproblem and a disaggregation subproblem. What makes this approach relevant to this study is the manner in which the model is formulated. For planning purposes, production items are aggregated into families, and families aggregated into types. The basis for the formation of product families is that, among other criteria, the items share a common setup. This is also an attribute of GT part families. Product types are composed of families with similar seasonal demand patterns and production rates. This is analogous to grouping GT part families which are processed on a single cell or flowline. Bitran, Haas, and Hax (8) use a linear programming formulation to represent the aggregate planning subproblem.

The model is reproduced in Figure 3. This problem is solved with a rolling horizon of length T, updating the parameters after each period. Fluctuations in demand are met by modifying the decision variables in a manner which minimizes the cost function.

The production quantities of each product type are disaggregated into family production quantities, which are then disaggregated into item production quantities. Disaggregation is generally accomplished by formulating the problem as a continuous knapsack problem (8). No literature has been found which proposed the use of this approach to production planning at the part level in conjuntion with GT manufacturing.

Remarks

As Petrov (44) noted, although there is no obligatory coordination between production planning and GT manufacturing, coordination is necesary to experience the full economic advantages of GT. The modifications proposed for MRP-based systems have been relatively simple. No attempt was found, in the literature search, to provide for maximum utilization of machine groups, or to establish a stable flow of work through them. These conditions were established early in GT development by Mitrofanov and Petrov. Further, long-term management of GT manufacturing systems has been totally ignored in literature. Considering

$$\text{Minimize} \quad \sum_{i=1}^{I} \sum_{t=1}^{T} (c_{it}X_{it} + I_{it}) + \sum_{t=1}^{T} (r_t R_t + o_t O_t)$$

$$\begin{array}{lll}
\text{Subject To} & T_{it-1} + X_{it} - I_{it} = d_{it} & i = 1, 2, \ldots I; \\
 & & t = 1, 2, \ldots T. \\
 & \sum_{i=1}^{I} m_i X_{it} \leq R_t + O_t & t = 1, 2, \ldots T. \\
 & R_t \leq (rm)_t & t = 1, 2, \ldots T. \\
 & O_t \leq (om)_t & t = 1, 2, \ldots T. \\
 & X_{it}, I_{it}, R_t, O_t \geq 0 & t = 1, 2, \ldots T.
\end{array}$$

I_{it-1}

The decision variables of the model are:

X_{it},	the number of units to be produced of type i during period t,
I_{it},	the number of units of inventory of type i at the end of period t,
R_t,	regular hours used in period t, and
O_t,	overtime hours used in period t.

The parameters are:

T,	the length of the planning horizon,
c_{it},	the unit production cost (excluding labor),
r_t, o_t,	the regular and overtime labor cost/man hour,
$(rm)_t$, $(om)_t$,	the availability of regular and overtime hours,
m_i,	the hours required to produce a unit of product type i, and
d_{it},	the effective demand for product type i in the period t.

Source: Bitran Et Al. (8, p. 720)

Figure 3. Linear Programming Formulation of Aggregate Planning Subproblem

the manufacturing trends of today, it is important that these problems are addressed.

CHAPTER III

COST MODEL DEVELOPMENT

Introduction

As is evident from the preceding chapters, group technology applications assume a variety of forms in a diversity of industries. To narrow the scope of this research a specific manufacturing environment has been chosen which is the target of many applications of GT. Prior to developing the cost model this environment will be described.

Description of the Facility

The manufacturing facility with which this research is concerned is depicted in Figure 4. The facility is involved in the production of a product which requires the fabrication of a large number of parts. Within the total parts population, families of parts have been identified for manufacture within a cell containing machines. Typical processes which might be performed within the cell are milling, drilling, grinding, finishing, etc. Raw material in some basic shape is introduced into the cell and a part

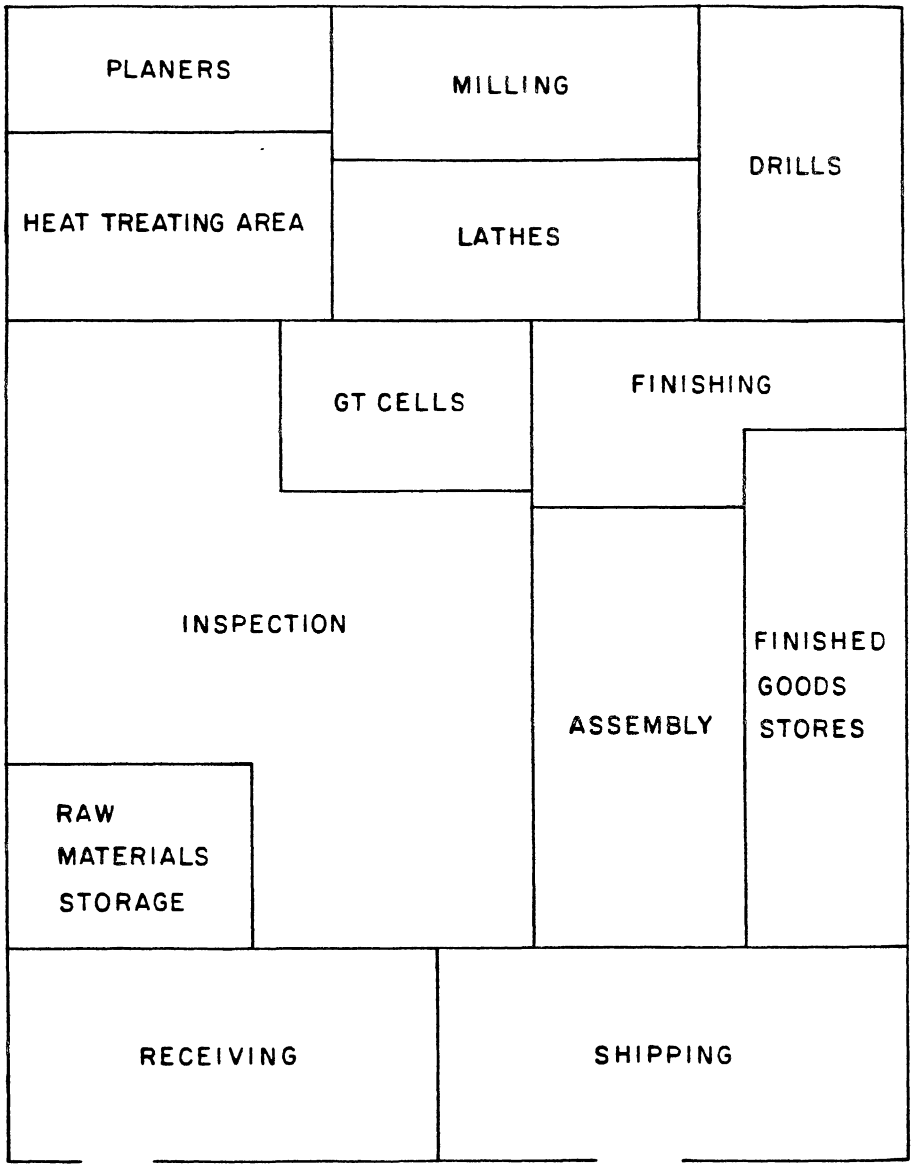


Figure 4. Typical Layout of a Facility with GT Cells

is produced for further processing or assembly elsewhere within the plant.

A family of parts may be defined as parts requiring similar processing within the cell. Further, the machine setup and tooling requirements for a part are significantly reduced when it is processed subsequent to any other part belonging to the same family. When parts from different families are manufactured in sequence within the cell, a major machine adjustment and tooling change is required. These major changes may be termed family setups. The operation performed within the cell are such that, for planning purposes, the cell may be treated as a single machine performing a single operation. This is analagous to having an identified bottleneck, or to production using a machining center or transfer machine.

As indicated in Figure 5 the parts assigned to families are a subset of the total population of parts manufactured within the plant. Thus, other parts exist which could be processed within the cell. Also, those parts currently processed within the cell could be processed elsewhere. The same may be stated for the processes performed within the cell. That is, they are also currently being performed elsewhere in the plant.

This type of environment occurs frequently in manufacturing with GT, especially in the early implementation stages. Even the most extensive applications maintain some portion of the manufacturing equipment in the

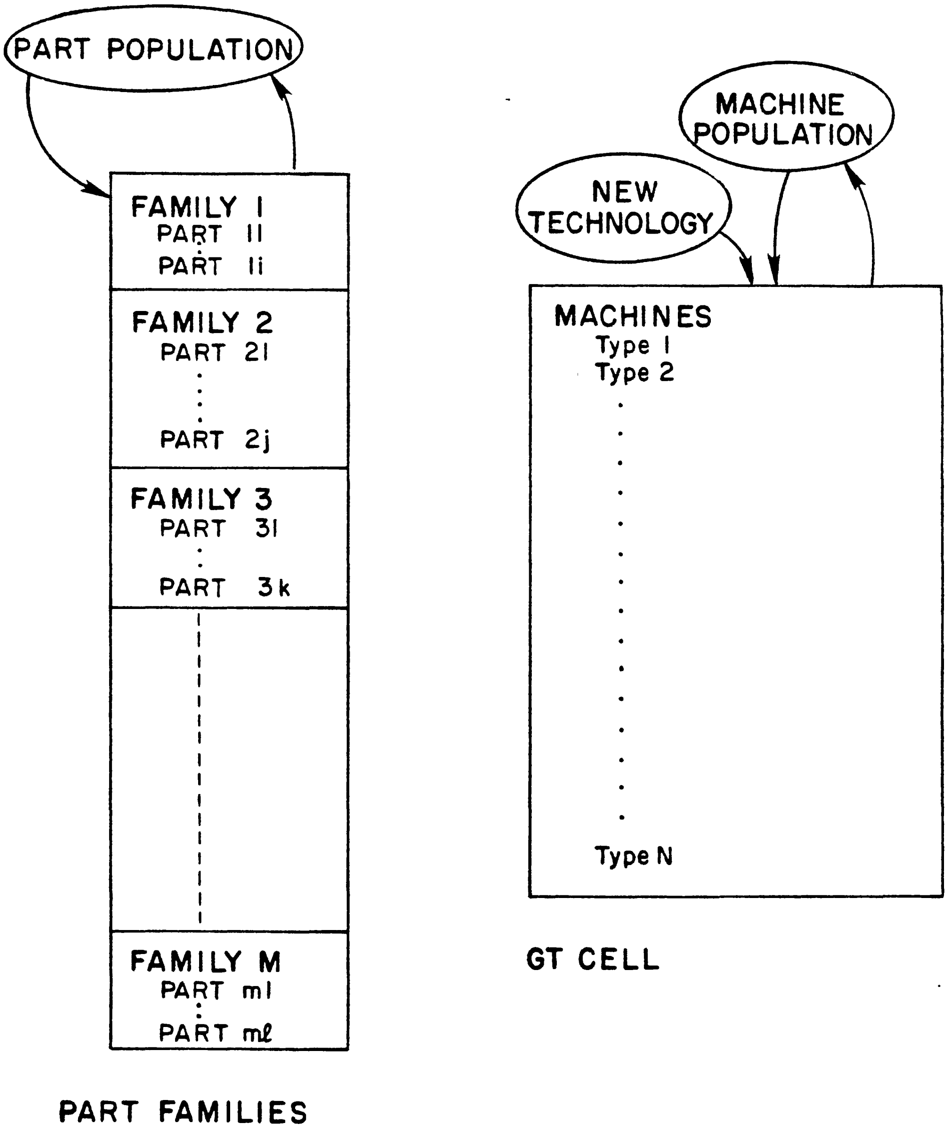


Figure 5. Relationship of GT Part Families and Machines to the Manufacturing Facility

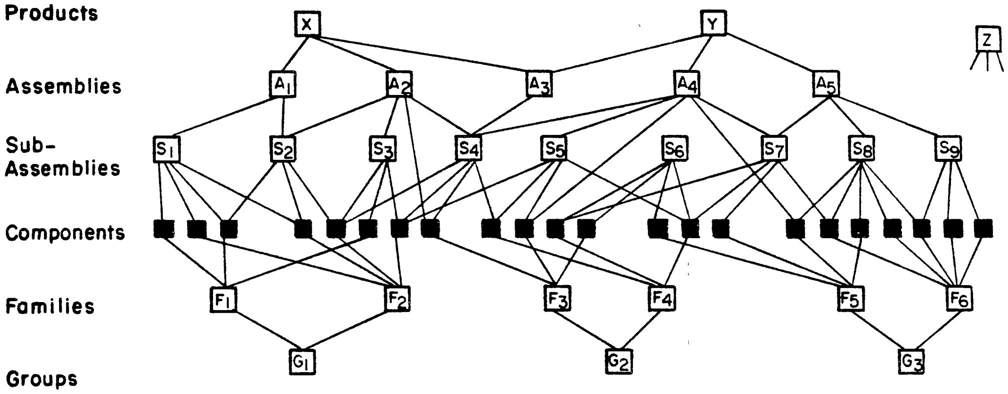
more traditional functional layout for processing those parts which cannot be combined with families.

Management of the Facility

In evaluating the performance of a group of operations a variety of measures are typically used. These include the average production rate, the efficiency of operations, demand satisfaction, the total cost of production, and the aggregate load on the cell. The first two of these measures are influenced primarily by the initial GT setup and the shop floor control system. The remaining measures, however, are significantly affected by the production planning system. Consequently, it is these measures with which this research is concerned.

The demand for parts produced in the cell is generated through the MRP system, and is dependent on the net requirements for higher level assemblies. This relationship is typified in Figure 6. Since numerous different parts may be required to produce a subassembly, a shortage or stockout of any single part can be very costly. Therefore, the assumption will be adopted that demand satisfaction is the overriding objective of cell management.

A number of feasible production plans may exist which satisfy the demand for parts. Selection from among these plans will be based on the total cost of production. These costs will be discussed in detail in the next section.



SOURCE: New (38, p. 61)

Figure 6. MRP Breakdown and Cellular Production

The aggregate load on the cell represents the direct labor hours required by a production plan in each period. Naturally, the proportion of available regular hours consumed by the aggregate load is a measure of capacity utilization. It is imperative that the aggregate load on the cell is comparable to the load placed on other areas of the facility. Otherwise, the potential for violating the "sanctity" of the cell is significantly increased. That is, jobs for non-family parts may be introduced into the cell. This violates a principle of GT manufacturing, the dedication of a group of machines to the processing of a specific group of parts. A consequence of the violation is the reduction in the advantages GT manufacturing achieves in reduced throughput time, setup time, NC programming costs, and the simplification of shop floor control. Further, once this situation is allowed to develop it is highly likely that it will continue to expand until the GT implementation, in effect, no longer exists.

In light of the above, management must strive to ensure an adequate load is planned for the cell from the families of parts. To accomplish this task, upper and lower bounds will be placed on the allowable deviation of the cell load.

When a production plan will result in the load limits being exceeded, management must take corrective action. Two courses of action are available. First, the load may be adjusted by modifying the part family composition. This entails the addition or deletion of parts from the families.

As previously mentioned, an assumption has been made that suitable parts exist which may be added to the families, and the necessary equipment exists for processing family parts elsewhere in the facility. The second course of corrective action is to modify the capacity of the cell. This could be accomplished through the addition or deletion of equipment, or replacement with more efficient equipment. The feasible methods available to modify capacity for a cell will be dependent on the type of equipment employed in the cell and the nature of the processes being performed. Thus, for the purposes of this research, the capability to modify capacity is of more importance than the method by which this may be accomplished.

Production Costs

Planning for production in a facility is normally accomplished by converting the factors to be considered into a common measure, the associated cost. This not only permits the use of operations research-type models, but also provides essential data to the financial planning and accounting departments. These costs, termed the manufacturing costs, will be examined in order to construct a cost model for production planning purposes.

Manufacturing costs can be divided into three basic cost elements (57): direct material cost, direct labor cost, and overhead cost. The derivation of these basic

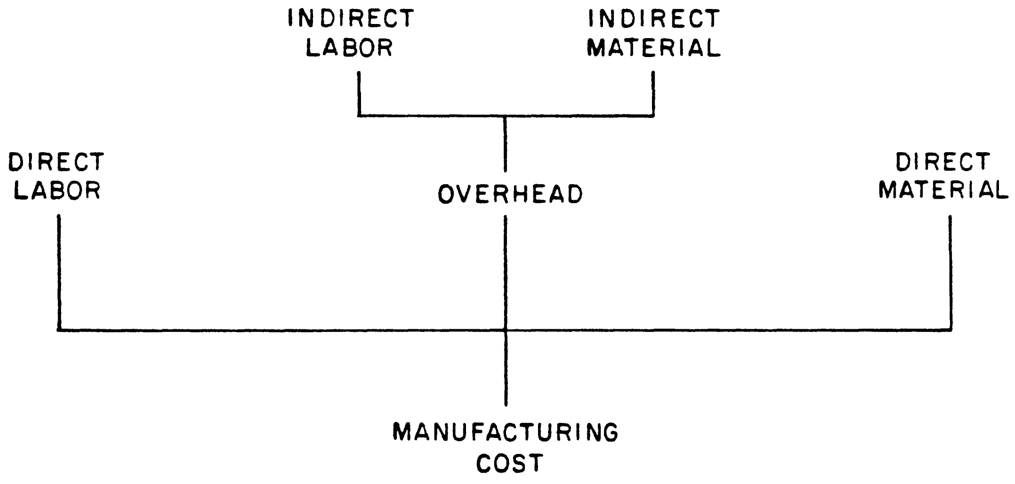


Figure 7. Basic Elements of Manufacturing Cost

the accounting department once a part or product has been completed. Standard costs, on the other hand, are predetermined and reflect what the manufacturing costs should be. These standard costs may be used for developing and evaluating production plans.

The elements of manufacturing cost may also be categorized as either a fixed cost or a variable cost. Fixed costs remain the same regardless of the volume of production, assuming certain upper and lower limits on production quantities exist. Specific examples of fixed costs are executive and administrative salaries, durable fixtures and tooling, and maintenance and custodian wages. Generally, if the production volume does not exceed certain limits, fixed costs will be constant regardless of the volume. Consequently, fixed costs will have no bearing on the evaluation of alternative production plans, and may be ignored in the selection of a plan.

Variable costs, conversely, rise as the production volume increases. The relationship between volume and a variable cost may assume any number of forms, such as a linear, quadratic, or a step function. Reagardless of the form, variable costs must be included in any analysis of alternative production plans. The three basic cost elements will now be analyzed to determine those cost factors which must be included in planning manufacturing using a GT cell.

Direct Material Cost

Since the assumption has been made that the cell is involved with the fabrication of parts, only the cost of raw materials need be considered in determining direct material costs. This cost will vary directly with the production volume. Thus, the direct material cost for a part will be treated as a linear function of production volume. The cost may be calculated by multiplying the planned number of units to be produced in a period times the standard cost. This standard cost for direct material for a part is based on the amount of raw material used in producing the part. Since the parts comprising a family are usually fabricated from the same raw material, any variation between standard costs within the family is directly attributable to differences in the amount of material required per unit.

Price breaks frequently are available for large quantity purchases of raw materials. However, assuming the raw material is used in the fabrication of a large number of different parts, price breaks need not be considered for planning purposes. Most companies prefer to include price break considerations in planning production of end-products (57).

The previously stated assumption of an unlimited supply of raw materials eliminates the need for an upper bound constraint on raw material availability. Incorporation of a constraint of this type would be straightforward if the situation required it.

With the restriction that demand must be satisfied, the total direct material cost over the planning horizon will not change with changes in the production plan. However, it is easily included in the model. This will leave fixed cost as the only cost element which must be added after adoption of a production plan in order to forcast the associated cash flows.

Direct Labor Costs

Direct labor costs are derived by applying labor cost rates to the time required for manufacturing operations. Manufacturing operations time can be separated into two components, productive and non-productive time. These times must be determined for each period in order to calculate the direct labor cost associated with a production plan.

The productive time component represents the time a laborer spends processing parts. Most companies have developed standard data for this time on a unit basis. These data contain allowances for such factors as part loading/unloading, operator fatigue, machine downtime, and maintenance. The productive time for a part produced in the cell is the sum of standard data for the operations performed within the the cell on the part, and will hereafter be referred to as the standard processing time. The total productive time requirements for a period is the summation of productive times over all parts.

The non-productive time component derives from machine setup and represents the time required for an operator to prepare a machine for processing a part. These preparations normally include setting the jig or fixture, loading the tool, and adjusting the machine. Using NC, DNC, or CNC machining would include computer tape or program preparation with tool loading and machine adjustment in the setup time. Through time studies standard setup times may be established for a part and will include these and any other ancilliary tasks which are necessary.

With group technology, however, the nature of machine setup is changed. Tooling for the operations within a part family should be arranged so that all parts may be processed with a single group jig or fixture and setup. These group jigs and fixtures are designed to accept every member of the family, using adapters to acccmodate minor variations in part geometry or processing (10). This accounts for one of the major savings experienced with the introduction of GT, the reduction in tooling costs.

The setup time for a cell, then, may be divided into a family setup time and a part setup time, both of which are independent of production quantity. For production planning purposes the total time associated with each type of setup for a period is a step function of the planned number of setups for the period.

The sum of the productive and non-productive times associated with a production plan will result in one of three situations occurring. The time required will either be less than (undertime), equal to, or greater than (overtime) the regular hours scheduled. In the first two cases the labor rate may be applied to the total manufacturing time to determine the direct labor cost. When overtime occurs a higher labor rate, the overtime rate, must be applied to those hours in excess of that regularly scheduled.

Since no additional cost is included for undertime, the assumption is being made that laborers may be used elsewhere in the facility. This labor cost will be included with the actual costs for other work centers. The labor rate will be treated as two constant values, one for regular time and one for overtime. This assumes that the skill level required for production of any of the parts produced within the cell does not vary, and should be a valid assumption for most GT cells.

Burden Cost

In planning production for the cell only those variable cost elements of burden need be considered, as the fixed elements continue regardless of production volume. Variable burden costs include such items as indirect labor, indirect materials, electricity for operating equipment, and tooling. As mentioned previously, the method of assigning burden varies among industries and among companies. For the purposes of this research the direct labor cost will be selected for estimating variable burden, as it is easily incorporated into the model. Once a production plan is selected the fixed burden estimate may be calculated and included to more accurately estimate total costs.

<u>Inventory Holding Costs</u>

Some costs vary directly with the size of inventories. There are handling costs associated with the storage and retrieval of parts, and costs associated with storing parts, such as insurance, taxes, and capital costs. Although these cost may be included in the burden for a part, they will be treated separately in this study in order to examine the effect various plans may have on them. To measure this, a holding cost will be applied to the ending inventory for each period in the production plan.

Cost Model Representation and Constraints

Figure 8 presents the mathematical formulation of a production planning cost model for GT manufacturing. Also in the figure are the constraints placed on the model and

$$Z = \sum_t [LR \left(\sum_i V_{it} P_i + W_{it} S_i \right) + \sum_j F_{jt} G_j + oO_t) \qquad \text{(labor)}$$

$$+ \sum_i V_{it} (M_i + B_i) \qquad \text{(material and burden)}$$

$$+ \sum_i h_i I_{it}] \qquad \text{(inventory holding)}$$

subject to:

$$V_{it} + I_{it-1} - I_{it} = d_{it} \qquad \forall i,\ t \qquad (1)$$

$$\sum_i V_{it} P_i + \sum_i W_{it} S_i + \sum_j F_{jt} G_j - O_t + U_t = R_t \qquad \forall t \qquad (2)$$

$$\sum_{i \in j} W_i \leq C\, F_{jt} \qquad \forall t,j \qquad (3)$$

$$V_{it} \leq C\, W_{it} \qquad \forall i,t \qquad (4)$$

$$F_{jt},\ W_{it} \geq 0 \qquad \forall i,j,t \qquad (5)$$

$$F_{jt},\ W_{it} \leq 1 \qquad \forall i,j,t \qquad (6)$$

$$F_{jt},\ W_{it} = 0 \text{ or } 1 \qquad \forall i,j,t \qquad (7)$$

$$O_t \leq E \qquad \forall t \qquad (8)$$

$$U_t \leq A \qquad \forall t \qquad (9)$$

$$V_{it},\ U_t,\ O_t,\ I_{it} \geq 0 \qquad \forall i,t \qquad (10)$$

where:

V_{it} = the production quantity of part i in period t,
I_{it} = the inventory of part i at the end of period t,
U_t = the undertime associated with the plan in period t,
O_t = the overtime associated with the plan in period t,
W_{it} = the number of setups for part i in period t,
F_{it} = the number of setups for family j in period t,
t = the period in the planning horizon,
LR = the labor rate,
P_i = the unit processing time for part i,
S_i = the standard setup time for part i,
G_j = the standard setup time for part family j,
o = the percent increase in the labor rate for overtime,
M_i = the standard material cost per unit for part i,
B_i = the burden cost per unit of part i,
h_i = the holding cost per unit for part i,
R_t = the regular hours scheduled for period t,
d_{it} = the demand for part i in period t,
C = an arbitrarily large constant,
E = maximum overtime permitted,
A = maximum undertime permitted.

Figure 8. Mathematical Formulation of Production Planning with GT Manufacturing

the variable definitions.

Constraint (1) is a demand constraint, and will ensure that the plan satisfies the demand for all parts in every period, either from inventory or by production. Constraint (2) relates to the manufacturing time required by a plan, and establishes the amount of overtime or undertime which will result. Constraint (3) ensures that a part setup is included in every period in which a part is to be manufactured, and constraint (4) accomplishes the same for family setups when any member parts are to be made. Constraints (5), (6), and (7) limit the number of part and family setups in a period to either 0 or 1. Constraints (8) and (9) limit the amount of overtime and undertime which may occur in a period, and constraint (10) ensures that the decision and measured variables will be non-negative.

Summary

This chapter has presented a description of the manufacturing facility and the typical GT cell which is being addressed by this research. The performance measures of concern to management are discussed. The measures addressed in this research include demand satisfaction, total production cost, and aggregate cell load. The basic cost elements of manufacturing are examined, and then analyzed to determine which factors to include in planning manufacturing for a GT cell. From this analysis, and in light of the performance measures a cost model is formulated which represents production planning for the GT cell.

CHAPTER IV

SOLVING THE MODEL

Introduction

The cost model developed in the previous chapter was formulated with a two-fold objective. First, it is intended that the model serve the production planning function of determining resource requirements to satisfy demand over a specified planning horizon. Second, the model should serve as a tool for evaluating alternative production schedules. These are typical of production planning and scheduling model objectives.

The model is a mixed-integer linear programming formulation, and is similar to previous models used for aggregate production planning at the end-product level. Two distinct approaches for solving models of this nature have appeared in the literature (17). The first of these, termed a monolithic approach, attempts to solve the problem with some type of procedure which will produce a good feasible solution. The second approach, termed hierarchical, partitions the problem into a hierarchy of subproblems. This approach is discussed in Chapter II, and is taken primarily to avoid the computational difficulties encountered with monolithic approaches. Although neither of these approaches has been taken with production planning for a GT cell, the similarities in model formulations encourage the use of previous aggregate planning research as a guide for the problem solving approach taken in this work.

Approach to the Problem

The procedure developed for solving this problem is shown in Figure 9. The part data is aggregated into data representing the average for all parts produced in the cell. It is hierarchical in nature in that at the highest level of aggregation decisions concerning capacity will be made. As indicated in the previous chapter, these decisions will be concerned with part family and machining capacity modifications. With disaggregation, decisions concerning the production time available for each part family and individual parts could be made. In order to demonstrate and evaluate this approach, sample data were developed. These data are presented in Table I. A portion of these data were taken from sample problem data presented by Ham (21).

As shown in the table there are 20 parts to be produced in the cell, with these belonging to 3 distinct part families. Although there are no figures available on the average or recommended number of parts in a family, a range of 10 to 100 parts is frequently quoted in literature

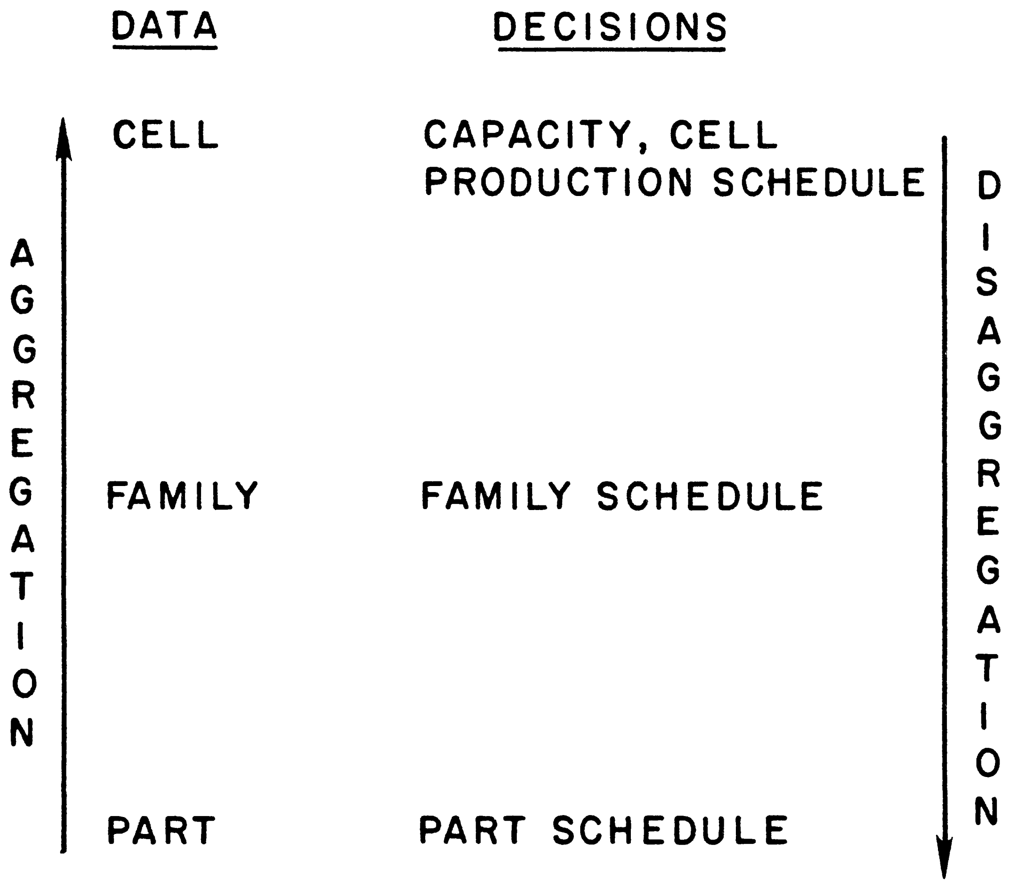


Figure 9. Illustration of Hierarchical Procedure for Cell Production Planning

TABLE I

SAMPLE PART AND FAMILY DATA

Part No.	Family No.	Process Time	Setup Time	Holding Cost	Material Cost	Burden Cost	Average 3 Period Demand
1	1	9	20	$ .75	$ .019	$ .02	115
2	1	12	15	2.20	.016	.02	30
3	1	10	15	8.00	.022	.02	10
4	1	9	15	16.00	.020	.02	5
5	1	14	23	12.25	.009	.02	10
6	1	8	15	1.05	.016	.02	61
7	1	12	23	5.75	.021	.02	18
8	1	10	23	3.90	.019	.02	25
9	2	5	13	1.00	.041	.02	55
10	2	8	15	6.00	.031	.02	10
11	2	6	13	1.75	.026	.02	35
12	2	10	12	4.80	.032	.02	10
13	2	6	10	10.50	.036	.02	5
14	3	14	33	1.40	.028	.02	105
15	3	15	15	5.50	.023	.02	12
16	3	8	30	16.00	.035	.02	10
17	3	17	15	25.00	.033	.02	4
18	3	10	23	7.50	.032	.02	24
19	3	11	30	3.00	.030	.02	46
20	3	9	20	1.40	.029	.02	61

(32,55,60). Consequently, this sample problem, though realistic, is probably at the small end of the spectrum in terms of the number of parts to produced in the cell. The parts are assumed to be similar in design and in processing operations requirements, such that they conform to the manufacturing environment presented in Chapter 3. The variety among processing times, demand quantities, and costs may not be representative of actual GT implementations. The GT manufacturing implementation is such that a 3 week cycle exists. That is, each part is expected to be produced once every three weeks in quantities which will satisfy demand over the three week period. Although the processing time requirements to meet this demand vary among parts and families, the total of these times is 7230 minutes for the 3 week period, or 30 minutes of overtime required with a 40 hour work week. With these data, then, the cell should operate at 100.42% capacity with 88.8% of the time required being productive time. The initial and final inventory quantities approximate the 3 period demand quantities. Again, it should be stressed that the initial GT implementation is assumed to be the result of a classification and coding program.

Solving the Sample Data Problem

Although a hierarchical procedure will be used, it was necessary to employ a monolithic approach also. This serves two purposes. First, by taking this approach with a sample problem of relatively small dimensions one can demonstrate the mathematical difficulties which will be encountered. Second, by comparing the optimum solution from a monolithic approach with the solution from a hierarchical procedure, one hopefully can evaluate the procedure.

To achieve an optimum production plan from the sample problem, the IBM computer software package Mathematical Programming System Extended (MPSX/370) was used. Although primarily used for solving linear programming problems, this package contains a feature for solving mixed-integer linear programming problems. This feature, called MIP/370, searches for a solution in two stages. First, the problem is solved as if it were a linear program to derive an optimal continuous solution. Next, the branch and bound technique is employed in the search for an optimal integer solution. This search starts from the optimal continuous solution and forces the designated integer variables to assume integral values. Thus, a series of integer solutions may be found which tend toward the optimal solution. When an integer solution is found, it is not known whether it is optimal. The search must continue until it is proven through bounding techniques that no better solution exists. When a variable is forced to an integral value, a subproblem is created and a solution to this subproblem calculated. In representing branch and bound searches, these subproblems are symbolized as nodes in a tree. The number of nodes in a tree, then, may be used as a measure of the size of a problem, since each represents a solution.

Since the inclusion of integrality constraints has a significant impact on the numerical difficulties of optimization problems, it is best to limit these as much as possible. Hence, the production quantities are not constrained to be integer in the model formulation. Rather, if non-integer quantities are included in the optimal solution it is assumed that these values may be rounded to the nearest integer. This rounding would require a very slight relaxing of either the overtime or undertime restrictions for a period. This leaves the number of part and family setups for each period as the only integer variables. Further, these quantities are restricted to be either 0 or 1. This speeds MIP execution and shortens the input data requirements. This action is logical, as the demand for and production of parts are modeled as occurring at discrete intervals of time.

Figure 10 presents the manner in which some of the problem statistics may be calculated prior to attempting to solve this model with MIP. Using the equations for calculating the total constraints, structural variables, and integer variables, one can determine what these statistics will be for any set of problem parameters. This is demonstrated in Figure 11. In this figure, each parameter of the problem is varied independently, and the resulting statistics printed. These graphs demonstrate the rapidity

VARIABLE DEFINITIONS

PH - NUMBER OF PERIODS IN THE PLANNING HORIZON
NP - NUMBER OF DIFFERENT PARTS PROCESSED IN THE CELL
NF - NUMBER OF DISTINCT PART FAMILIES PROCESSED IN THE CELL

CONSTRAINTS

DEMAND = NP * NH
LABOR: REGULAR = PH
UNDERTIME = PH
OVERTIME = PH
INVENTORY: INITIAL = NP
FINAL = NP
SETUPS: PART = NP*PH
FAMILY = NF*PH
TOTAL CONSTRAINTS = PH(2NP+NF+3)+2NP

STRUCTURAL VARIABLES

PRODUCTION QUANTITIES = NP*PH
INVENTORY LEVELS = (PH+1)*NP
SETUPS: PART = NP*PH
FAMILY = NF*PH
LABOR HOURS: UNDERTIME = PH
OVERTIME = PH
TOTAL STRUCTURAL VARIABLES = PH(3NP+NF+2)+NP

INTEGER VARIABLES

SETUPS = (NP+NF)*PH

Figure 10. Equations for Calculating Problem Statistics

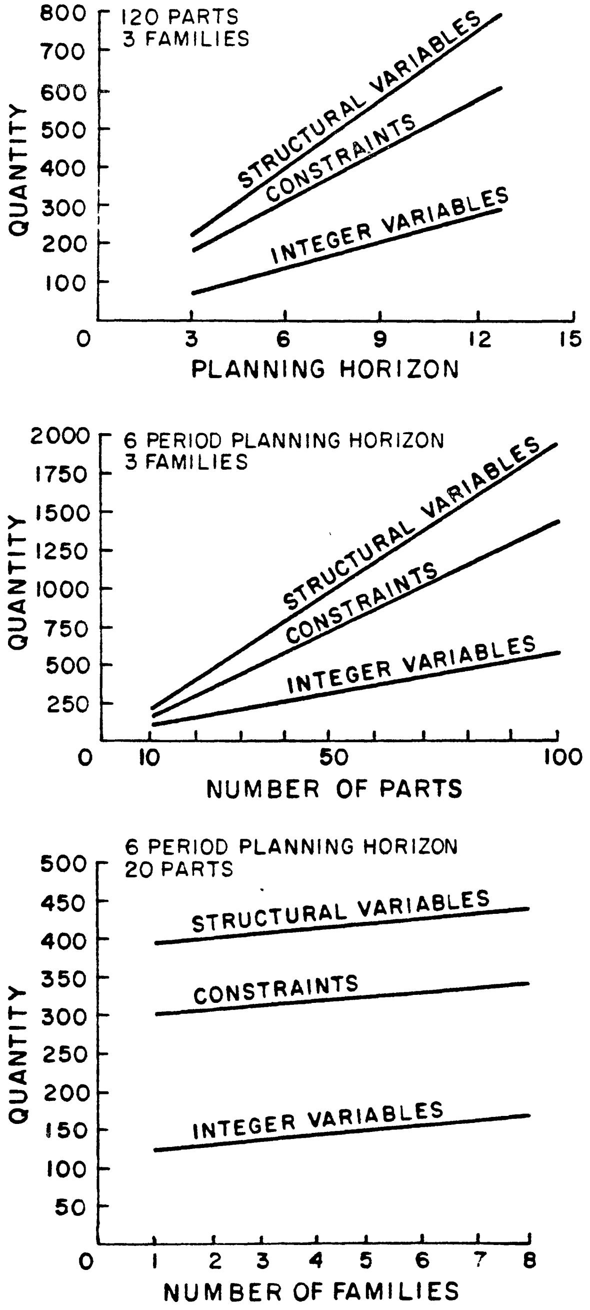


Figure 11. Graphical Representation of Statistic Equations

with which the problem statistics grow with even small changes in the parameters. For instance, in Figure 11(b) one can see that increasing the number of parts to be considered from 10 to 20, and with 3 families and a 6 period planning horizon the problem statistics almost double. To draw conclusions from graphs such as these, either equations for estimating computer time and space requirements must be available, or one must experiment. The latter approach was taken in this research.

Table II presents the execution statistics which resulted from solving the sample problem using MIP on an IBM 3081 computer. Merely encoding the data is quite a time-consuming task. Use of a matrix-generating computer program would certainly be justified if the model were to be exercised with a variety of data. The iterations performed in searching for the continuous optimum involve changing the basic solution by the revised simplex method. Each subsequent iteration indicates that a solution has been calculated for a node in the branch and bound tree. The iterations shown include those performed in searching for the continuous optimum.

As can been seen in the table, 3,019 iterations were required to arrive at the first integer solution. Considering the relative size of the problem (20 parts, 3 families, 3 periods) extensive calculations were required. Although the optimum integer solution was produced after 8,895 iterations the optimality of this solution was not

TABLE II

SAMPLE PROBLEM EXECUTION STATISTICS

Statistic	Value
Constraints	178
Structural Variables	215
Integer Variables	69
Input Data Records	770
Iterations to:	
Continuous Optimum	333
First Integer Solution	3019
Optimum Integer Solution	8895
Optimality Proven	42480
Execution:	
Time	8 min. 43.79 sec.
Space	569,344 bytes
Total Processor Cost	$236.21

(IBM 3081 COMPUTER REQUIREMENTS)

known until 42,480 iterations had been completed.

The computer time and space requirements and the resulting processor cost discourage the monolithic approach taken with the sample problem. Returning to Figure 11(a) one can see that the problem statistics rise substantiallly with an expanded planning horizon of 6 months. The processor costs could be expected to rise at an even faster rate. Further, changes in problem variables may significantly affect processor costs. As an example, the initial and final inventory levels of the sample problem were reduced to values approximating single-period demands. This change necessitated a program modification increasing the amount of space alloted for nodes awaiting processing. With this in mind one would expect the processing costs to rise, which did in fact occur. Although exact processing costs for solving the cost model with MIP cannot be predicted, the results from the sample problem strongly discourage this approach. The computer processing costs for using this approach with multiple GT cells and a longer planning horizon would be prohibitive.

It should be noted that the computer processing requirements are dependent upon the linear programming algorithm employed. The MPSX computer software used in this research, an IBM product, relies on the simplex algorithm and is generally considered to be the fastest program available. However, as new algorithmic and computer processors are developed it might become practical to use the part data with the cost model.

Aggregating the Data

Buffa and Miller (9) provide a definition of aggregate planning attributed to Holt, Modigliani, and Simon:

> . . . a measure of production per unit of time (per week or per month, for example.) Most factories produce many products rather than just one; hence, a common unit must be found by adding quantities of different products. For example, a unit of weight, volume, work required, or value might serve as a suitable common denominator. (p.219)

Although considerable research has been conducted on the subject of aggregate planning, rarely are the aggregation procedures presented or discussed. Most of these efforts, rather, are directed at solving the aggregate problem.

The aggregation procedure selected for this problem determines a weighted-average based primarily on forecast demand. The calculations are presented in Figure 12, and the computer program developed to perform them in Appendix A. These calculations are performed in order to represent all of the parts in a family as a single entity, thereby reducing the mathematical difficulties of finding a solution.

As shown in Figure 12 the aggregate material, holding, and burden costs are strictly weighted averages. The

VARIABLE DEFINITIONS

AB_j - aggregate burden cost per unit for family j
AD_{jk} - aggregate demand per period for family j in period k
AH_j - aggregate holding cost per unit for family j
AM_j - aggregate material cost per unit for family j
AP_j - aggregate processing time per unit for family j
AII_j - aggregate initial inventory for family j
AIF_j - aggregate final inventory for family j
b_i - burden cost per unit for part i
d_{ik} - demand for part i in period k
LI_i - initial inventory of part i
LF_i - final inventory of part i
p_i - processing time per unit for part i
s_i - setup time for part i
N - number of setups over planning horizon
h_i - holding cost per unit for part i
M_i - material cost per unit for part i
TD_i - total demand for part i over planning horizon

$$TD_i = \sum_{\text{all } k} d_{ik} \qquad \forall i \qquad \text{(part demand)}$$

$$AM_j = \frac{\sum_{i \in j} TD_i * M_i}{\sum_{i \in j} TD_i} \qquad \forall j \qquad \text{(material cost)}$$

$$AH_j = \frac{\sum_{i \in j} TD_i * h_i}{{}_{i \quad j} TD_i} \qquad \forall j \qquad \text{(holding cost)}$$

$$AB_j = \frac{\sum_{i \in j} TD_i * b_i}{\sum_{i \in j} TD_i} \qquad \forall j \qquad \text{(burden cost)}$$

Figure 12. Equations for Aggregating Data

$$AP_j = \frac{\sum_{i \varepsilon j} s_i * N + TD_i * p_i}{\sum_{i \varepsilon j} TD_i} \quad , \forall j \qquad \text{(processing time)}$$

$$AD_{jk} = \sum_{i \varepsilon j} d_{ik} \quad , \forall k, j \qquad \text{(family demand)}$$

$$AII_j = \sum_{i \varepsilon j} LI_i \quad , \forall j \qquad \text{(family initial inventory)}$$

$$AIF_j = \sum_{i \varepsilon j} LF_i \quad , \forall j \qquad \text{(family final inventory)}$$

Figure 12. (Continued)

aggregate processing time differs slightly in that the part setup time must be included. This is accomplished by estimating the frequency of setups for parts. For this problem a frequency of once every three periods was selected for all parts. The total processing time required to meet demand is calculated and divided by the total demand to determine the aggregate processing time per part. Finally, the aggregate initial and final inventories and demand per period are simple summations over the parts in a family. The aggregated part data for the sample problem is shown in Table III. The only modification to the cost model structure is the elimination of the integer variables representing part setups.

Through aggregation the original problem is now represented as if 3 parts belonging to a single family are to be produced within the cell. Viewing the aggregated data in this manner, it is quite natural to further reduce the problem by again applying aggregation. This was done to the data in Table III and the results are shown in Table IV. The problem is now represented as a single aggregate part to be produced in the cell. The processing time per unit now includes both part and family setup times. Thus, the cost model representation of this data is no longer a mixed-integer problem, but simply a linear one. Hereafter, the 3 sets of data will be referred to as the part data, the

TABLE III

AGGREGATED PART DATA FOR THE SAMPLE PROBLEM

Family Number	1	2	3
Setup Time	160	45	225
Processing Time/Unit	10.19	6.64	12.42
Demand/Period	92	39	88
Holding Cost/Unit	2.72	2.49	3.63
Material Cost/Unit	0.018	0.034	0.029
Burden Cost/Unit	0.20	0.20	0.20
Initial Inventory	274	115	262
Final Inventory	274	115	262

TABLE IV

AGGREGATED FAMILY DATA FOR THE SAMPLE PROBLEM

PARAMETER	DATA
Processing Time/Unit	11.11
Demand/Period	219
Holding Cost/Unit	3.04
Material Cost/Unit	.025
Burden Cost/Unit	.020
Initial Inventory	651
Final Inventory	651

family data, and the cell data.

Comparison of Execution Statistics

The problem and execution statistics of the part data problem are displayed again in Table V along with those from the family data and cell data problems. The difference in the statistics between part data and family data is obviously significant. Although the difference between family data and cell data statistics is not nearly as great, it would increase rapidly if the planning horizon is expanded to a more reasonable length or with the addition of another part family. Further, by reducing the problem to a linear programming one, the potential for model use is enhanced.

Comparison of Solutions

From the preceding discussion one can see that production planning with the family or cell data would be desireable from a computational standpoint. The question remains, however, as to the validity of a plan produced using aggregated data. This question will be approached by comparing the solutions which result from the three sets of data.

The production plans and associated inventory levels which represent the optimum solutions for the data are shown

TABLE V

PROBLEM AND EXECUTION STATISTICS

Model	Part Data	Family Data	Cell Data
Constraints	178	33	14
Structural Variables	215	36	13
Integer Variables	69	9	0
Input Data Records	770	154	48
Iterations	42,480	118	18
Execution Time (sec.)	523.79	1.70	0.74
Execution Space (bytes)	569,344	114,688	276
Total Processor Cost	236.21	1.25	1.25

(IBM 3081 COMPUTER REQUIREMENTS)

in Table VI. In the table the production and inventory quantities for the part data and the family data are presented by families in addition to the total for each period in the planning horizon.

To compare the plans the solutions must be examined on the basis of costs also. These are shown in Table VII. This table presents the overall cost as deriving from three sources: production, inventory, and overtime. This reflects the objective function of the cost model in which the material, burden, and regular labor cost coefficients are combined. This is possible as all of these costs are functions of the production volumes. The part data and family data production costs include costs for regular labor due to setups. The coefficient used in the model for calculating overtime reflects the increase in labor costs for overtime and is identical for the three sets of data. The sources of difference in the costs will now be discussed.

In aggregating data a certain amount of roundoff error will occur. The effects of this can be seen in the third period inventory costs. The model constrains the ending inventory values which should result in identical third period inventory costs. The differences are an indication of the roundoff error which results from aggregating the inventory holding costs per unit. It may be concluded that a small portion of the differences found are due to roundoff error.

TABLE VI

PRODUCTION PLANS

MODEL	Production			Inventory			
	Period			Period			
	1	2	3	0	1	2	3
Cell Data	194	225	238	651	626	632	651
Family Data							
Family 1	113	0	163	274	295	203	274
2	0	0	117	262	244	350	115
3	70	194	0	262	244	350	262
Total	183	194	280	651	615	590	651
Part Data							
Family 1	0	204	72	274	182	294	274
2	0	90	27	115	76	127	115
3	181	0	83	262	355	267	262
Total	181	294	182	651	613	688	651

TABLE VII

OPTIMUM SOLUTION PRODUCTION COSTS

COST SOURCE	Part Data	Family Data	Cell Data
Production			
Period 1	372.74	361.48	330.96
2	416.67	395.69	383.85
3	393.40	415.30	406.03
Total	1182.81	1172.47	1120.84
Inventory			
Period 1	1469.75	1752.81	1784.10
2	1134.25	1779.32	1801.20
3	1852.95	1853.55	1855.35
Total	4456.95	5385.68	5440.65
Overtime			
Period 1	17.40	0.64	0.00
2	46.60	48.00	19.85
3	48.00	48.00	48.00
Total	112.00	96.64	67.85
TOTAL	5751.76	6654.79	6629.34

Both production and overtime total costs decrease with the aggregated data, indicating a decrease in the time required to meet the plan. This casts suspicion on the aggregation procedure. The most obvious source of the difference would be the incorporation of setup times in the aggregated processing time per unit. The optimum plan from the part data calls for a single setup for all parts over the planning horizon with only a single exception (part number 19). This would account for only a small portion of the difference between the production costs of the part data plan and the family data plan, as only 30 minutes are required for this extra setup. The differences in family setup time requirements are more significant. From the production plans in Table VI one can see that a total of 6 family setups were included in the part data plan and 5 in the family data plan. Only 3 were included in calculating the aggregate processing time per unit for the cell data plan. Examining this facet of the problem reveals a shortcoming of the mixed-integer formulation of the model. Considering the part data production plan it is apparent that the setup for either family 1 or 2 would not be necessary in period 3, as both of these are to be produced in period 2. The same would be true of family 3 in period 2 of the family data plan if it were also scheduled last in period 1. If one removes the cost of these setup times the totals of the production and overtime costs become:

part data------ $1241.48

family data---- 1194.11

cell data------ 1188.69

These figures indicate that the cell data provides a close approximation of the production costs associated with the optimum part data plan for the sample data.

The greatest difference in total costs derive from inventory holding costs. With the part data the model is able to select for production early in the planning horizon those parts with smaller per unit holding cost. This depletes the inventories of parts with higher per unit holding cost as much as possible. With aggregation this distinction is lost. The reason for the magnitude of the differences is the variety of holding costs in the sample data. Since the formation of part families is normally based on similarities in raw material, design, and processing the inventory holding cost per unit will likely have much less variety than that of the sample data.

Summary and Conclusions

Solving the cost model for the GT cell is the topic of this chapter. Equations are developed which calculate problem statistics for any set of data to be used in the model. It is concluded from graphs of these equations and from the execution statistics using sample data that computer requirements using current MIP techniques discourage a monolithic approach.

An aggregation procedure is developed which allows the parts in a part family to be represented as a single part. Additional aggregation reduces the problem to a single representative part for the cell. This allows the model to be solved with linear programming. The changes in the execution statistics which result are dramatic.

To validate the aggregation procedure the production plan total costs before and after aggergation are compared, using the sample data. A small portion of the cost differences are the result of roundoff error. Another source of difference in costs derives from the aggregation procedure. The manner in which setup time is included during aggregation is concluded to be important. The majority of the differences in total costs are traced to the variety present in inventory holding costs for parts. It is concluded, however, that this variety will usually not be present in GT cells, and that the aggregated data provides a close approximation of the production costs.

In using the aggregate planning approach developed in this research, the following guidelines are recommended:

1. A weighted-average based upon planned orders from MRP should be used for aggregating the data.
2. The accuracy of the aggregate planning solution is improved when the ranges of values for the parameters are relatively small.
3. Reasonably accurate estimates of the number of part and family setups which will be required over the

planning horizon are necessary for calculating the aggregate processing times.

4. If the aggregate planning model does not accurately reflect the unaggregated data, then the aggregation technique should be examined for possible modification.

Adhering to these guidelines and requirements should not pose a difficult problem. Uses of the aggregate planning model will be discussed in the next chapter.

CHAPTER V

APPLICATIONS OF THE MODEL

Introduction

In the preceding chapter it was demonstrated that the aggregate model, termed the cell data model, provides a close approximation to the cost of production with a GT cell. In this chapter the manner in which this model may be used will be presented.

Four ways in which the model may be of value to management will be discussed and demonstrated in this chapter. First, the solution will be analyzed to examine the relationships of the variables and constraints in hopes of gaining insight into the costs of the manufacturing system. Second, the solution will be analyzed to examine the impact of a changing external environment. The models use in possible system modifications to adapt to these changes will then be discussed. Lastly, the use of the solution in the scheduling function of production planning and scheduling will be examined. Prior to performing these analyses the model was expanded to 12 periods which is considered to be a more realistic planning horizon.

Analysis to Examine Underlying Relationships

The optimum solution from the cell model with a 12 period horizon is contained in Appendix B. The production plan associated with this solution is shown in Table VIII. One can see that the plan calls for minimum production in the first five periods, an increase in production in period 6, and maximum production in periods 7 through 12. The undertime in periods 1 through 5 is at a maximum, as is the overtime in periods 7 through 12. Furthermore, through use of the range feature of MPSX it was found that an increase in demand in any of the first four periods of the horizon would actually decrease the overall cost associated with the plan. For instance, the computer output indicates that the current objective function value would decrease $10.32 for each unit increase in demand in period 1 from the current value of 219 up to 226 units. At this point the limit on overtime in period 6 would become an active constraint as the inventory level at the beginning of period 6 would be lower. This would require more production in period 6 to meet demand and the final inventory constraint. In fact, modification of any of the active constraints (all periods demand, regular hours available, undertime in periods 1-5, overtime in periods 7-12, and initial and final inventory

TABLE VIII

AGGREGATE PRODUCTION PLAN FROM CELL MODEL SOLUTION

PERIOD	PRODUCTION QUANTITY	ENDING INVENTORY	LABOR HOURS
0		651	
1	194	626	2160
2	194	601	2160
3	194	576	2160
4	194	551	2160
5	194	526	2160
6	230	537	2557
7	238	556	2640
8	238	575	2640
9	238	594	2640
10	238	613	2640
11	238	632	2640
12	238	651	2640

values) will result in the overtime constraint for period 6 becoming active. Thus, the cost structure of the sample problem is such that the optimum solution delays production as long as possible, thereby depleting the initial inventory.

All of the above aspects of the solution to the model may be attributed to the relatively high inventory holding cost. Although this insight could have been attained by other methods, it is a by-product of this production planning procedure which is available at litte cost.

To further investigate the effects of the inventory parameters a sensitivity analysis of these parameters was conducted. The parameter variations studied are shown in Table IX. The following discussion relates to this table.

In case 1 the initial inventory value was varied from 0 to 295 while the final inventory value and holding cost remained constant. The optimum solution obtained with zero initial and final inventory values maintains a level production rate which matches the demand. Thus, the overtime is a constant 33.09 minutes per period and the undertime 0 minutes per period. As the initial inventory level is increased the objective function value decreases initially. This is a result of the elimination of the overtime in period 1 which was required to meet demand. This decreasing trend ceases once the undertime constraint forces inventory to be carried from period one to two. Afterwards, the objective function value strictly increases

TABLE IX

INVENTORY PARAMETER VARIATIONS STUDIED

CASE NUMBER	INITIAL INVENTORY	FINAL INVENTORY	INVENTORY HOLDING COST
1.	0 to 295	0	2.85
2.	0	0 to 223	2.85
3.	0 to 651	0 to 651	2.85
4.	651	651	285 to 0.00

with increasing initial inventory. The effect of increasing initial inventory on the production plan is a decrease in production volume in the earliest period until the undertime constraint is encountered, at which time the decrease will continue into the next earlier period. This pattern continues until the initial inventory reaches a value of 295, at which point a feasible solution no longer exists.

Case number 2 from Table VIII involves varying the final inventory. As one would suspect, the objective function value strictly increases as the final value is increased from 0. The optimum production plan accounts for increasing final inventory values by increasing the amount of production in the latest period possible, subject to the overtime constraint. With an initial inventory of 0 the maximum possible final inventory is 223.

Cases 1 and 2 demonstrate that, given the cost model parameters, initial and final inventory values other than 0 will result in a production plan which delays production as long as possible. By varying these values simultaneously (case number 3) this conclusion was reinforced. With this problem data, then, minimum inventory levels are desireable. However, this would be true for any manufacturing situation if the demand were stable, accurate forecasts available, and the production facilities highly reliable. Management policy will normally exist for establishing these minimum values.

Case number 4 involves the sensitivity analysis of a cost coefficient, the inventory holding cost. Beginning with a cost of 2.85 dollars per unit this parameter is gradually decreased, resulting in a corresponding decrease in the objective function value. The optimum solution production plan does not change until a holding cost of 2.22 is reached. After this point the overtime cost incurred per unit of production is greater. Consequently, subsequent solutions have reduced overtime in the later periods, offset by reduced undertime in earlier periods. When the holding cost per unit is eventually reduced to 0.0 the resulting production plan requires exactly 2400 minutes of production time per period for the first 10 periods. The initial inventory is used to absorb the excess demand. In periods 11 and 12 overtime is used to meet the final inventory requirement. From this one can conclude that the inventory holding cost per unit has a significant effect on the optimum production plan, especially if it exceeds the cost of overtime to produce a unit.

The results of these analyses indicate the importance of the inventory parameters, quantity on hand and holding cost, to production planning for the cell. Management will be able to satisfy the planned orders from MRP, and should examine the inventory policies and concentrate cost reduction efforts on the holding costs, given the current problem parameters.

Analysis of the Impact of a Changing External Environment

An important yet frequently overlooked feature of many linear programming software packages is that through sensitivity analysis one can determine the effects of variations in the data without completely rerunning the entire program. The most obvious source of potential external variation with this cost model is the forecasted demand. To examine the impact of a non-constant demand a series of computer runs were made. These are summarized in Table X. Each of the six demand streams employed is drawn from a uniform distribution. The parameters of the distributions were arbitrarily selected, but constitute both increasing and decreasing mean values, and an increase in the range about a mean. The use of these varying demand streams with the model is intended to examine the impact of fluctuating demand on the resulting production plan, as well as demonstrate the value of the model in evaluating the impact of a changing external demand. Consequently, with each stream the initial and final inventory levels were varied from 650 to 0.

The first two demand streams shown in the table are distributed about a mean value approximately equal to 219, the constant demand used with the original model. With demand stream number 1 the demand lies in a range which extends 10% either side of the mean. The demand is allowed

TABLE X

SUMMARY OF VARYING DEMAND STREAMS USED IN ANALYSIS

DEMAND STREAM NO.	DISTRIBUTION	MEAN	Bounds UPPER	Bounds LOWER
1	Uniform	219	197	241
2	Uniform	219	175	263
3	Uniform	241	217	265
4	Uniform	263	237	289
5	Uniform	197	177	217
6	Uniform	175	158	193

to vary up to 20% of the mean in demand stream number 2. The production plans which resulted from these demand streams and varying initial and final inventory values produced no surprises. The optimum cost plans with zero initial and final inventory values cost less than those produced with higher inventory values. As with previous analyses the inventory level is minimized by matching the demand stream as much as possible. Using demand stream 1 the production plan does not vary as the inventory values are increased above 100. The same is true above 150 with demand stream number 2. Above these values, the production plan calls for maximum undertime early in the planning horizon and maximum overtime in the later periods. One may conclude, then, that moderate fluctuations in the demand will have minimal impact on the optimum production plan for this problem. One point of interest does occur with demand stream 2. Below a final inventory value of 16 no feasible solution exists, as the undertime constraint forces production in period 12 to exceed the sum of the demand in that period and the final inventory value. Thus, either this overtime constraint would have to be relaxed, or the final inventory value increased.

To examine the impact of increasing demand, streams 3 and 4 were employed. These are based on increases in the demand mean of 10% and 20%. With the 10% increase the cell is capable of meeting demand within the constraints, as long as the initial inventory value is greater 18. The resulting production plans use maximum overtime in periods 2-12, regardless of the initial and final inventory values. As the inventory values are reduced from 650 to 50, in steps of 100, the production plans change only in inventory levels and objective function values, both of which decrease. At and below an initial inventory value of 18 no feasible solution exists, as the demand in period 9 can no longer be met within the overtime constraint.

With demand stream 4 the results are more dramatic, as no feasible solution exists with inventory values of 650. Although the demand in each period is satisfied, only 367 aggregate units remain at the end of the planning horizon. This is not suprising, however, as the lower value of the demand range equals the maximum capacity of the cell within the overtime constraint. The total demand over the planning horizon is such that the initial inventory will be depleted unless the overtime constraint is relaxed or a modification is made to the manufacturing system or part families.

With an increase in the mean demand one can see the value of maintaining a certain amount of inventory as safety stock. This enables the cell to meet high fluctuations in demand without violating constraints. The model's detection of potential problems with increased demand is clearly evident. As a tool in the examination of possible remedies to this problem, the model will be demonstrated later in this chapter.

Demand streams 5 and 6 are drawn from distributions with mean values 10% and 20% below the initial constant value of 219. In the former case, the model is able to handle the reduced demand within the constraints. With initial and final inventory values other than 0, the undertime in periods 1-11 is at a maximum with overtime being used in period 12 to meet the final inventory value. Using demand stream 6 no feasible solution exists, as the total demand over the planning horizon is less than the production volume using maximum undertime. Consequently, some increase in the inventory level must occur in order to remain within the undertime constraints. The decision must be made either to relax the undertime constraint or accept an excess of inventory at the end of the planning period. These choices assume that modification of the manufacturing system or part families is not possible, an alternative which will be considered in the next section of this chapter.

Analysis of GT System Modifications

The establishment of part families and selection of machines to process these families are tasks normally accomplished by a project team for GT implementation. Once families and machine cells are established, however, it generally becomes the responsibility of the production planning and control department to monitor the performance of these cells. Yet, no literature has been found which suggests methods for accomplishing this task.

Modification of the GT system may occur in two ways. The composition of the part families may be modified or the processing capability of the cell may be changed. These modifications may be accomplished in different ways and in response to different external factors. However the modifications are accomplished, the cell model may be used to analyze the impact.

Part Family Modifications

In the previous section it was demonstrated how the cell model detects potential problems in over- or underloading the cell with work over the planning horizon. The problems were presented as deriving from changes in the aggregate demand. These demand changes could come from a number of sources, including demand changes for end-products, introduction of new products, or product design changes. Regardless of the source of the change, some action must be taken to ensure the continued viability of the GT system.

Several actions were suggested to combat underor overloading of the cell, primarily through relaxation of a constraint. Another option which exists and should be considered is modification of the part families being produced in the cell. In the case of an overloaded cell the number of parts might be reduced. This would be accomplished either through subcontracting or by routing the jobs to other machines in the facility. To rectify an underloading condition, additional parts may be included in the families. This possibility is realistic, as no actual implementation has ever processed the entire parts population. Furthermore, new part designs are frequently being introduced for production.

The cell model may be used to analyze the impact of proposed part family modifications. One way to accomplish this is to simply aggregate the data again, including data for the new part or excluding data for a part to be removed. If a part is to be added one could include it in the model by introducing new variables and constraint rows to the model. However, this would entail the inclusion of 12 new row vectors and 26 new column vectors. Consequently, reaggregating the data is recommended.

Consider demand stream number 6 of Table IX which resulted in an infeasible solution, as the undertime constraints could not be satisfied. If a part exists which technologically could be added to one of the part families, one may wish to consider the impact of this addition on the production plan. As an example, consider the data for part number 21 presented in Table XI. The revised aggregate cost coefficient and processing time per unit may be calculated as shown in Figure 13, rather than reaggregating the data. The initial and final inventory values and demand per period for the new part may be included by simple addition.

TABLE XI

CANDIDATE PART DATA

Part No.	Process Time	Setup Time	Cost Per Unit		
			Holding	Material	Burden
21	11.0	15.0	5.0	0.02	0.02

Forecast Demand By Period											
1	2	3	4	5	6	7	8	9	10	11	12
41	20	19	36	42	45	33	5	47	70	34	18

Previous Aggregate Data

Processing Time Per Unit = 11.11
Total Demand = 2628
Total Processing Time = 2628 * 11.11 = 29197.08
Cost Coefficient = 1.706

New Part Data

Cost Coefficient = 1.687
Total Processing time = 4020
Demand = 360

Revised Aggregate Data

Processing Time Per Unit = (29197.08+4020) / (2628+360)
= 11.12
Cost Coefficient = (1.706*2628+1.687*360) / (2628+360)
= 1.704

Figure 13. Calculations for Modifying the Aggregate Data

Further, reconstructing the data for the linear programming model is easily accomplished with an editing program.

The model has been solved successfully using the revised aggregate data, and the results reveal that, with the modified GT part families, the cell will operate within the constraints for the forcasted demand. If additional candidate parts exist they might also be considered, as the optimum production plan will use maximum undertime in the first 8 periods.

To consider the effects of the deletion of a part from a family one would follow the same procedure, subtracting times, costs, and demand as opposed to adding. This action might be required due to part obsolescence or to relieve an overloaded cell. In the latter case, another alternative would be the modification of the GT system machines.

Machine Group Modifications

A number of external factors may affect the processing capabilities of the GT system. Machines may be modified to increase their production rate, such as by adding automated tool changers or by switching from NC to CNC. Newer machines may be purchased as replacements or as an addition to existing machines, or identical machines may be added to the cell. Regardless of the manner of change, the effect on the production plan may be significant and should be examined.

A change of this nature will affect parameters of every part processed in the cell. The burden cost may be affected through new requirements for indirect labor, indirect materials, or other burden component cost. Direct material costs may be decreased if the amount of scrap is reduced. The setup and processing time for a part and setup time for a family may be changed. This would directly affect the processing capabilities of the cell. An example will be used to demonstrate use of the model to examine the impacts of processing capability modifications.

In Section 5.3 demand stream number 4 from Table X was used to demonstrate the reaction of the model when the demand mean was increased by 20%. The result was an infeasible solution. Since the demand for parts must be satisfied some action must be taken. One option available to management might be to add an additional machine. Assuming that the only parameter which would change is the aggregate processing time, reaggregation of the data is not necessary. Rather, the new aggregate processing time, 9.95, may be substituted easily with an editing program. This change has been made in the data with the result being a feasible solution.

Analysis of Alternatives

The aggregate cost model, then, serves quite well as a tool in examining the impact of GT system modifications, whether the change is for improvement or to avoid a potential problem. Furthermore, since the model is based on production costs, alternative proposals may be analysed. If the proposed change is the addition or deletion of a part, or a change which will affect the parameters of all parts equally, then the existing data for the model may be edited quite easily. Even if the aggregation procedure must be performed again, a matrix-generating program for the LP computer package would make this task a minor effort.

Two topics not mentioned in the preceding discussion should be noted. First, the effect on the balance of work within the cell must be considered prior to implementing any GT system change. This could be a major consideration, depending on the composition of the cell. Balancing techniques are an entire study in themselves and will not be addressed here. Second, it was assumed that a candidate part existed which could technologically be processed along with one of the existing part families. This implies that the inclusion of this part would not affect the processing of any existing parts.

The Solution as a Scheduling Aid

The result of the cell data model is a solution to the aggregate problem which enables managers to make decisions related to workforce requirements, machining capacity, and part family composition. The next step normally taken in aggregate planning is the disaggregation of this solution to a production plan, allocating part and family production to distinct periods in time. However, since the demand for the model was generated through MRP, the timing and quantity of the requirements for parts is already known. Furthermore, these are constrained by the demand for subassemblies at a higher level in the bill of material. Thus, the only changes which could be made would involve moving orders forward in hopes of eliminating a family or part setup. The solution to the aggregate model indicates production activity in terms of labor hours per period. This may be used as a goal in the analysis of possible changes to the proposed order release from MRP. However, as discussed earlier in this chapter, if low initial and final inventory values exist the optimum plan matches demand as closely as is possible. With higher inventory values production is delayed. Thus, with this sample data few changes would be anticipated. Rather, a "cut-and-fit" approach might be applied to avoid excessive deviations from the labor hours associated with the aggregate solution. The potential for future work related to this topic will be addressed in the next chapter.

Summary

This chapter has been directed to the examination of ways in which the aggregate planning model can be utilized.

Sensitivity analysis is the primary tool used in this examination.

The solution was closely examined using the range feature of MPSX. This indicated that the inventory parameters had the strongest impact on the solution within the given constraints. A sensitivity analysis of the inventory levels and holding cost parameters was performed and indicated that production will be delayed as long as possible within the constraints in order to deplete the inventory. This results in maximum overtime in the later periods and undertime in the earlier periods. Varying the initial and final inventory values only affects the magnitude of this unbalanced plan. Sensitivity analysis of the holding cost reveals that the production plan will not be affected by changes in this value until it is reduced to a point at which the overtime cost parameter becomes dominant. Through these analyses the value of the model as a tool in understanding the cost structure of the GT cell is demonstrated.

Sensitivity analysis of the aggregate demand has been performed to examine fluctuations, increases and decreases in demand. Through this analysis the cell's capability to handle high fluctuations in demand is shown. Also, the need for maintaining some inventory to absorb these fluctuations becomes apparent. The ability of the model to detect potential problems which might arise from changes in demand is demonstrated.

The model is found to serve quite well in evaluating GT system modifications in response to increased or decreased demand. Modifications of the part family and the machine group are examined, and examples presented. Methods for incorporating these changes were developed and are presented. Finally, the manner in which the model's solution may be used in production scheduling are discussed. It is concluded that the solution may be used as a guide when considering possible changes to the MRP planned orders.

CHAPTER VI

SUMMARY AND PROSPECTS

The goal of the research has been achieved. An aggregate planning technique is used to solve a cost model which represents the production of parts by a GT cell. The cost model and the aggregate planning technique were developed in this research. The manner in which the model may be used for planning purposes has been thoroughly examined. By applying the technique in a hierarchical planning procedure as recommended in this thesis one may enhance the benefits of using group technology concepts in manufacturing. The proposed procedure is practical, flexible, and easily incorporated into existing production planning and control systems.

The costs associated with a production plan for a GT cell have been identified and categorized as direct labor and materials, burden, and inventory costs. These costs are translated into a cost model. The management and operational aspects of the cell have been examined and relevant modeling constraints developed for the model. The resulting model and constraints comprise a mixed-integer linear programming problem.

The problem has been solved using MPSX. Equations were developed for calculating the problem statistics with changes in the planning horizon, the number of parts, or the number of part families. An examination of the graphs of these equations and the execution statistics which resulted when a small problem was solved led to the development of another problem-solving approach. Aggregate planning techniques are applied and a linear programming problem results. The validity and advantages of using an aggregate approach are analyzed using sample data. Guidelines for applying the aggregation approach are presented. These are intended to be general and to ensure a reasonably accurate solution will result when aggregate data is used.

Ways in which the model may be of benefit are demonstrated. The solution is analyzed to provide insight into the costs associated with a GT manufacturing system. The impact of changes external to the system were examined, and potential modifications evaluated. These modifications represent changes in both machining capacity and part family composition. The manner in which the model may be modified to represent these changes has been developed and demonstrated. The use of the solution as an aid to the scheduling function of production planning and control is discussed.

Several potential areas exist for future research related to this topic. In reviewing the literature the lack of definitive methods for economically analyzing the initial

GT implementation was revealed. Other aspects of establishing a GT manufacturing system appear to be well-researched. However, another absence in the literature is the lack of documented studies of the performance of GT manufacturing systems over a long period of time, especially in the presence of major economic fluctuations or technological change.

The procedure developed in this research might be extended to include the scheduling function. This would entail disaggregation of the solution into a schedule of part family and part production. Although a cut-and-fit method has been suggested, other methods might prove worthwhile.

Lastly, it is felt that additional study into data aggregation procedures is needed. The impact of this calculation upon the results of an aggregation procedure was found significant in this research. Since aggregate planning is typically applied at the manufacturing facility and the product levels, the potential worth of such a study is deemed significant.

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APPENDIX A

AGGREGATION COMPUTER PROGRAM LISTING

```
      DIMENSION JSET(3)
C
C
C   THIS PROGRAM AGGREGATES PART FAMILY DATA
C   AND STORES THE RESULTS IN A PART FAMILY FILE.
C
C   FOR ADDITIONAL DETAILS SEE THE DISSERTATION
C   ENTITLED "CONSIDERATIONS FOR GROUP TECHNOLOGY
C   MANUFACTURING IN PRODUCTION PLANNING" BY
C   GERALD R. GRAVES.
C
      JSET(1)=160
      JSET(2)=45
      JSET(3)=225
      WRITE(6,100)
 100  FORMAT(' ',////' ','ENTER THE NUMBER OF ',
     1        'PERIODS IN THE PLAN',/' ')
      READ(9,*) IPERS
C
C
      IPSETS=IPERS/3
      IFSETS=2*IPSETS
      DO 10 I=1,3
          TL=0.
          DT=0.
          AP=0.
          AH=0.
          AM=0.
          AB=0.
          DO 20 J=1,50
               READ(11,101,END=21) IPN,IGN,LOT,
     +            ISET,IPT,HC,IDEM,BURD,DMC
  101          FORMAT(2I2,I4,2I3,F5.2,I4,2F5.3)
               IF(IGN.NE.I) GO TO 20
               DT=DT+IDEM
               AP=AP+IPSETS*ISET+IDEM*IPT
               AH=AH+HC*IDEM
               AM=AM+DMC*IDEM
               AB=AB+BURD*IDEM
  20       CONTINUE
      WRITE(6,103)
 103  FORMAT(' ','******  ERROR, > 50 PARTS IN FILE  ******')
      STOP 9
   21     AP=AP/DT
          AH=AH/DT
          AD=DT/FLOAT(IPERS)
          AM=AM/DT
          AB=AB/DT
          WRITE(12,104) I,JSET(I),AP,IAD,AH,AM,AB
  104     FORMAT(I1,I3,F5.2,I4,F5.2,2F5.3)
          WRITE(6,107) I,JSET(I),AP,IAD,AH,AM,AB
  107     FORMAT(' ',//' ',T3,'GRPI[',T10,'SETUP',
     +         T17,'PROC.',T25,'DEMAND',T32,'HOLD',
     +         T40,'MATL.',T47,'BURDEN',/' ',T5,I1,
```

```
   +         T11,I3,T17,F5.2,T26,I4,T32,F5.2,T40,
   +         F5.3,T48,F5.3)
        REWIND 11
 10 CONTINUE
    WRITE(6,120)
120 FORMAT(' ','AGGREGATE PROCESSING ENDED',///' ')
    STOP 1
    END
```

APPENDIX B

PART DATA PRODUCTION PLAN

PART NO.	PERIOD 1	PERIOD 2	PERIOD 3
1	0	114	0
2	0	30	0
3	0	0	12
4	0	0	6
5	0	0	12
6	0	60	0
7	0	0	18
8	0	0	24
9	0	54	0
10	0	0	9
11	0	36	0
12	0	0	12
13	0	0	6
14	102	0	0
15	0	0	12
16	0	0	12
17	0	0	6
18	0	0	24
19	19	0	29
20	60	0	0
TOTAL	181	294	182

VITA 2

Gerald Robert Graves

Candidate for the Degree of

Doctor of Philosophy

Thesis: CONSIDERATIONS FOR GROUP TECHNOLOGY MANUFACTURING IN PRODUCTION PLANNING

Major Field: Industrial Engineering

Biographical:

Personal Data: Born in Nashville, Arkansas, August 6, 1950, the son of Louis F. and Wilton C. Graves,Jr.

Education: Graduated from Nashville High School, Nashville, Arkansas, in May, 1968; received Bachelor of Science degree in Industrial Engineering from The University of Arkansas in 1973; received Master of Science in Industrial Engineering from The University of Arkansas in August, 1980; enrolled in doctoral program at Oklahoma State University, 1980-1983; completed requirements for the Doctor of Philosophy degree in July, 1985.

Professional Experience: Lieutenant, Naval Flight Officer, United States Navy, 1973-1978; graduate teaching assistant, Department of Industrial Engineering, University of Arkansas, 1978-1979; graduate research associate, School of Industrial Engineering and Management, Oklahoma State University, 1980-1983; Visiting Assistant Professor, Department of Industrial Engineering and Computer Science, University of Arkansas, 1983-1984; Assistant Professor, Industrial Engineering Department, Louisiana State University, 1984.

Professional Affiliations: Institute of Industrial Engineers; Computer and Automated Systems Association of the Society of Manufacturing Engineers; Society for Computer Simulation.

manufacturing cost elements is depicted in Figure 7.

Direct material cost is relatively easily identified, and represents the value of the raw material required to produce a unit of product. Usually included in this cost is an allowance for wasted or scrapped material.

Direct labor cost consists of wages and other labor-related costs for production workers who are engaged directly in specific manufacturing operations to convert raw materials into finished products. The direct labor workers are those who operate production machines or processing equipment, assemble parts into a finished product, or work on the product with tools.

Overhead, or burden, cost consists of those costs that cannot be specifically attributed to a product. Typical of the costs included in overhead are rent, taxes, utilities, depreciation, and insurance. Also, indirect material costs, such as tools and cleaning gear, and indirect labor, such as material handlers and maintenance personnel, are added into overhead cost.

Overhead costs are allocated to individual products on a percentage basis. A common base is used to determine this percentage, such as the number of employees involved, direct labor hours or cost, direct material hours or cost, or machine hours. The overhead cost is then determined for a product on a per unit basis.

Manufacturing costs are also classified as being either actual or standard costs. Actual costs are determined by